Data and Information Committee

Meeting is held in the Council Chamber, Level 2, Philip Laing House
144 Rattray Street, Dunedin

Members:

Hon Cr Marian Hobbs, Co-Chair	Cr Michael Laws
Cr Alexa Forbes, Co-Chair	Cr Kevin Malcolm
Cr Hilary Calvert	Cr Andrew Noone
Cr Michael Deaker	Cr Gretchen Robertson
Cr Carmen Hope	Cr Bryan Scott
Cr Gary Kelliher	Cr Kate Wilson

Senior Officer: Sarah Gardner, Chief Executive

Meeting Support: Liz Spector, Committee Secretary

10 March 2021 02:00 PM

Agenda Topic — Page

1. APOLOGIES

No apologies were received prior to publication of the agenda.

2. PUBLIC FORUM

No requests to address the Committee under Public Forum were received prior to publication of the agenda.

3. CONFIRMATION OF AGENDA

Note: Any additions must be approved by resolution with an explanation as to why they cannot be delayed until a future meeting.

4. CONFLICT OF INTEREST

Members are reminded of the need to stand aside from decision-making when a conflict arises between their role as an elected representative and any private or other external interest they might have.

Minutes of previous meetings will be considered true and accurate records, with or without changes.

Outstanding actions from resolutions of the Committee will be reviewed.

Minutes of a meeting of the Data and Information Committee held in the Council Chamber on Wednesday 14 October 2020 at 1:00 pm

Membership

Hon Cr Marian Hobbs	*(Co-Chair)*
Cr Alexa Forbes	*(Co-Chair)*
Cr Hilary Calvert	
Cr Michael Deaker	
Cr Carmen Hope	
Cr Gary Kelliher	
Cr Michael Laws	
Cr Kevin Malcolm	
Cr Andrew Noone	
Cr Gretchen Robertson	
Cr Bryan Scott	
Cr Kate Wilson	

Welcome

Co-Chair Cr Alexa Forbes welcomed Councillors, members of the public and staff to the meeting at 10:15 am.

Staff present: Sarah Gardner (Chief Executive Officer), Nick Donnelly (GM Corporate Services), Gwyneth Elsum (GM Strategy, Policy and Science), Gavin Palmer (GM Operations), Richard Saunders (GM Regulatory), Amanda Vercoe (Executive Advisor), Liz Spector (Committee Secretary), Rachael Brown (Sr Analyst Freshwater and Land), Rachel Ozanne (Environmental Scientist), Jean-Luc Payan (Manager Natural Hazards), Sharon Hornblow (Natural Hazards Analyst), Sam Thomas (Coastal Scientist), Julie Everett-Hincks (Manager Science), Hugo Borges (Environmental Resource Scientist), Eleanor Ross (Manager Communications Channels), Ryan Tippet (Media Communications Lead).

1. APOLOGIES

Resolution

That the apologies for Cr Laws be accepted.

Moved: Cr Hope
Seconded: Cr Wilson
CARRIED

2. CONFIRMATION OF AGENDA

The agenda was confirmed as published. Cr Forbes noted that the Update on Biodiversity Mapping Project paper would be considered first.

3. CONFLICT OF INTEREST

No conflicts of interest were advised.

4. PUBLIC FORUM

No requests to address the Committee were made.

5. CONFIRMATION OF MINUTES

There are no previous minutes of the Data and Information Committee.

6. ACTIONS

There are no outstanding actions of the Data and Information Committee.

7. MATTERS FOR NOTING

7.1. Update on Biodiversity Mapping Project

Action 3.1 of Council's Biodiversity Action Plan is to complete biodiversity mapping and ecological prioritisation of potential sites for active management. This report provides an update on the Biodiversity Mapping and Ecological Prioritisation Project, which is on track to be completed by 30 October 2020. Rachael Brown (Senior Strategic Analyst Freshwater and Land) and Gwyneth Elsum (GM Strategy, Policy and Science) were present to speak to the report and respond to questions.

Several Councillors had questions about the use of the term "priorities" in relation to the project. Ms Elsum noted the word was used in a technical sense and reflected ecological values based on scientific data. After further discussions, Cr Robertson moved:

Resolution

That the Committee:

1) ***Receives** this report.*
2) ***Notes** that Phase 1 (mapping) of the Biodiversity Mapping and Ecological Prioritisation Project is complete and Phase 2 (zonation analysis) is on track to be complete by 30 October 2020.*

Moved: Cr Robertson
Seconded: Cr Hobbs
CARRIED

Cr Calvert left the meeting at 01:17 pm.

7.2. Update on the Geology and Ground Conditions of South Dunedin and Harbourside

The paper summarised recent South Dunedin geological and seismic hazard work undertaken by ORC and external scientific research programmes and proposed next steps for continued development of a work programme focusing on improving understanding of ground conditions in South Dunedin and Harbourside.

Sharon Hornblow (Natural Hazards Analyst), Jean-Luc Payan (Manager Natural Hazards) and Gavin Palmer (GM Operations) were present to speak to the report and respond to questions. After a discussion of the report, Cr Hobbs moved:

Resolution

That the Committee:

1) ***Receives*** *this report.*
2) ***Notes*** *the current state of knowledge of the geology and ground conditions of South Dunedin and Harbourside.*
3) ***Makes*** *this information publicly available through the National Geotechnical Database and ORC's Otago Natural Hazards Database.*
4) ***Provides*** *this information to Dunedin City Council for incorporation into building control, utility infrastructure and land use planning decisions.*

Moved: Cr Hobbs
Seconded: Cr Hope
CARRIED

Cr Kelliher left the meeting at 01:27 pm.
Cr Kelliher returned to the meeting at 01:36 pm.

7.3. State of the Environment (SOE) Report Card

As of July 2020, the ORC monitors 114 river, stream and lake sites across the Otago region as part of its long-term State of the Environment monitoring programme. Values are measured monthly at each site and include: water temperature, dissolved oxygen, conductivity, pH, turbidity, total suspended solids (TSS), soluble and total nitrogen and phosphorus, and E. coli. This report is generated annually and published to the ORC website. The work informs the Comprehensive State of the Environment report that is compiled every five years which provides a detailed review of water reporting on regional state and trends in river and lake health and performance against the National Policy Statement for Freshwater Management (NPSFM), and the effectiveness of the Water Plan. The next 5-year report will cover the period to June 2022.

Rachael Ozanne (Environmental Resource Scientist) and Gwyneth Elsum (GM Strategy, Policy and Science) were present to speak to the report and respond to questions. Ms Ozanne noted this was the first time the annual report had been formally presented to Councillors. A discussion was conducted about ways to make the report easier to comprehend for a layperson. Chief Executive Gardner said this was a difficult report to put into an easier-to-read format, but that staff was working towards this.

Cr Deaker noted a function of the Data and Information Committee was to receive information. He said the committee potentially also played a role in distribution of that information to interested stakeholders. He suggested the report would be pertinent for the Otago Catchment Group and suggested it be forwarded directly to them.

After further questions and discussion, a motion was made.

Resolution

That the Committee:

1) ***Forwards*** *a copy of the report to the Otago Catchments Group.*

Moved: Cr Deaker
Seconded: Cr Hope
CARRIED

Cr Hobbs further moved:

Resolution

That the Committee:

1) ***Notes*** *the report.*

Moved: Cr Hobbs
Seconded: Cr Hope
CARRIED

7.4. Proposed Estuary Monitoring Programme

The Otago Regional Council has regulatory obligations under the New Zealand Coastal Policy Statement and the Resource Management Act 1991 (RMA) to monitor estuaries in its region. The National Policy Statement for Freshwater Management (NPS-FM) requires an integrated approach to managing freshwater systems, with the lowest sensitive receiving environment such as estuaries used for limit setting in the river systems; therefore, an improved estuary monitoring network is needed to provide data to inform this process. This report was provided to note the staff proposal to expand the estuary monitoring programme to create a representative State of the Environment monitoring network for estuaries.

Sam Thomas (Coastal Scientist) and Gwyneth Elsum (GM Strategy, Policy and Science) were present to speak to the report and respond to questions. After discussion of the report, a motion was made.

Resolution

That the Committee:

1) ***Receives*** *this report.*

2) ***Notes*** *the proposal to expand ORC's estuary monitoring programme to create a representative SoE monitoring network for estuaries.*

Moved: Cr Wilson
Seconded: Cr Hobbs
CARRIED

Cr Deaker left the meeting at 02:42 pm.
Cr Deaker returned to the meeting at 02:48 pm.

8. CLOSURE

There was no further business and Co-Chair Forbes closed the meeting at 02:49 pm.

___________________________ _______________
Chairperson Date

Action Register – Outstanding Actions of the Data and Implementation Committee 2021.03.10

Meeting Date	Item	Status	Action Required	Assignee/s	Action Taken	Due Date	Completed (Overdue)
14/10/2020	OPS1020 Update on the Geology and Ground Conditions of South Dunedin and Harbourside	Assigned	Make [geological and seismic hazard report from 14 Oct 2020 Data and Information Committee agenda] publicly available through the National Geotechnical Database and ORC's Otago Natural Hazards Database and provide same information to DCC for incorporation into building control, utility infrastructure and land-use planning decisions.	General Manager Operations, Manager Natural Hazards		11/03/2021	

7.1. Otago Climate Change Risk Assessment

Prepared for:	Data and Information Committee
Report No.	HAZ2101
Activity:	Safety & Hazards: Natural Hazards
Author:	Ellyse Gore, Natural Hazard Analyst Jean-Luc Payan, Manager Natural Hazards
Endorsed by:	Gavin Palmer, General Manager Operations
Date:	1 March 2021

PURPOSE

[1] To present the first Otago Climate Change Risk Assessment (OCCRA) dataset and report for Otago and information on Otago's climate over the next century.

EXECUTIVE SUMMARY

[2] Climate change in Otago will exacerbate existing risks, result in new risks and challenges but also provide opportunities. These challenges and opportunities will be widespread, influencing the natural and built environments, the economy, governance, and society.

[3] Since mid-2019, ORC has been working with Aukaha and Kā Rūnaka, all the district and city councils in the region and sector leads and experts from both within and outside of the region to undertake the first Otago Climate Change Risk Assessment.

[4] The purpose of the Otago-wide risk assessment is to better understand the impacts of climate change and associated risks and opportunities for the region.

[5] This report presents the key findings of the climate change projections NIWA report and the now completed risk assessment discussion report and risk dataset.

RECOMMENDATION

That the Committee:

1) ***Receives*** *this report.*

2) ***Notes*** *the data set and information the first Otago Climate Change Risk Assessment provides for the region for building understanding, further investigation, and preparation for adaptation.*

3) ***Notes*** *the changes expected to occur in Otago's climate.*

4) ***Endorses*** *the data set and report and the pro-active presentation and dissemination of this information to the public and stakeholders.*

BACKGROUND

[6] Changes in the world's climate have been observed over an extended period of time, both through natural variability and as a result of human activity. These changes are

likely to continue into the foreseeable future. Human influence on the climate system is clear, as concluded by the Intergovernmental Panel on Climate Change (IPCC)[1].

[7] Climate change in Otago will exacerbate existing risks, result in new risks and challenges but may also provide opportunities. These challenges and opportunities will be widespread, influencing the natural and built environments, the economy, governance, and society.

[8] Two complementary pathways exist for responding to the risks and challenges related to climate change, these are: mitigation and adaptation. As defined by the IPCC, 'mitigation' of climate change is a human intervention to reduce the source or enhance the sinks of greenhouse gases (GHG) while adaptation to climate change, is the process of adjustment to actual or expected climate and its effects. In human systems, adaptation seeks to moderate or avoid harm or exploit opportunities. In some natural systems, human intervention may facilitate adjustment to expected climate and its effects.

[9] As preparation for enabling future prioritisation of risks for adaptation planning, ORC has undertaken the Otago Climate Change Risk Assessment (OCCRA). This builds on our understanding of climate change related risks and vulnerabilities within the region.

[10] The OCCRA relates primarily to impacts. It complements three projects commissioned by ORC that are focusing on mitigation: the analysis of ORC's greenhouse gas emissions which was presented to Council in November 2020, the Otago Regional Greenhouse Gas Inventory, and an investigation on the feasibility of ORC's lower emissions public transport.

ISSUE

[11] The work associated with the OCCRA started in mid-2019 following the Climate Change Adaptation Technical Working Group (CCATWG) recommendations report[2] released in May 2018 in which the need for a national climate change risk assessment was highlighted (Action 4).

[12] ORC initiated the risk assessment as it acknowledged that the CCATWG recommendation is also pertinent at a regional scale in order to anticipate and to prepare the region for the likely effects of climate change. It is the first risk assessment for Otago and one of first regional assessments for New Zealand[3].

[1] IPCC, 2013: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535 pp.

[2] Adapting to Climate Change in New Zealand - Recommendations from the Climate Change Adaptation Technical Working Group (2018). Climate Change Adaptation Technical Working Group. https://www.mfe.govt.nz/sites/default/files/media/Climate%20Change/ccatwg-report-web.pdf

[3] An informal survey presented by the Ministry for the Environment in January 2021 indicates that, among the survey respondents, 7 regional, district or city councils have completed or partially completed a climate change risk assessment and risk assessments are currently in progress for 13 regional, district or city councils.

[13] The risk assessment is a foundation step to enabling adaptation to the effects of climate change in Otago. It allows ORC to better understand the impacts of climate change and associated risks and opportunities for the region.

[14] One of the objectives of the risk assessment was to develop the first regional dataset of climate change related risks and opportunities in order to inform the public and various stakeholders (e.g., territorial authorities, industry sectors, infrastructure managers, etc.) about these risks and opportunities. It is anticipated that this information will provide the evidence base to support adaptation programmes and initiatives in the region.

[15] There are no statutory requirements to develop a regional climate change risk assessment. However, in the ORC 2019-204 Annual Plan, the need to focus on climate change impacts across all of Otago and to inform planning for climate change was identified. This has proven to be a prudent approach given central government initiatives and directions in the last 12-18 months, summarised as follows:

- In November 2019, the Climate Change Response (Zero Carbon) Amendment Act was adopted. The Act provides a framework by which New Zealand can develop and implement clear and stable climate change policies that contribute to the global effort under the Paris Agreement to limit the global average temperature increase to 1.5° Celsius above pre-industrial levels and allow New Zealand to prepare for, and adapt to, the effects of climate change. The Act requires the Government to develop and implement policies for climate change adaptation and mitigation and to establish a new, independent Climate Change Commission (established in December 2019) to provide expert advice and monitoring to help keep successive governments on track to meeting long-term goals.

- In July 2020, the recommendations[5] of the resource management system review Panel were released. The need to address the effects of climate change has been a particular focus of the Panel's work. One of the Panel's conclusions is that the resource management system needs to enable adaptation to the impacts of climate change and reduction of risk from natural hazards. One of its recommendation is the introduction of the Climate Change Adaptation Act to address complex issues associated with adaptation in a co-ordinated way (including addressing the complex legal and technical issues associated with managed retreat and funding and financing adaptation).

- In August 2020, the first National Climate Change Risk Assessment (NCCRA)[6] was released by the Ministry for the Environment. The risk assessment gives the first national picture of the risks New Zealand faces from climate change. The risks are grouped according to five value domains: natural environment, human, economy, built environment, and governance. The NCCRA lays the foundation for a National Adaptation Plan (NAP) which will outline the Government's response to these risks. The NAP[7] is expected to be released by 2022 as required by the Climate Change Response (Zero Carbon) Amendment Act.

[4] https://www.orc.govt.nz/media/7001/annual-plan-2019-20.pdf
[5] https://www.mfe.govt.nz/rmreview
[6] https://www.mfe.govt.nz/climate-change/assessing-climate-change-risk
[7] https://www.mfe.govt.nz/climate-change/climate-change-and-government/adapting-climate-change/adaptation-and-central

- In January 2021, He Pou a Rangi – New Zealand's Climate Change Commission released its draft advice on the direction of policy necessary to reduce greenhouse gas emissions[8]. The advice mentions the need to coordinate efforts to address climate change across government and consider the mitigation-adaptation link.

[16] Although the initiatives and directions from central government have not yet been translated into statutory adaptation requirements for local authorities and other stakeholders, the OCCRA will assist being prepared for such changes.

[17] Recognising that a consistent approach to local risk assessments is needed to support local government decision-making on climate change adaptation and to maintain links to the national system, the Ministry for the Environment is developing a standard local climate change risk assessment framework. The framework will build on the practices already being applied by regional councils and ORC is collaborating with the Ministry and other councils to support the development of the framework. This is particularly important as local risk assessments will also inform the next national climate change risk assessment due in 2026.

DISCUSSION

Methodology

[18] The approach developed for the OCCRA was based off the IPCC conceptual risk framework (**Figure** *1*) in which climate change impacts arise from the interaction between a hazard (event or trend related to climate change), vulnerability (susceptibility to harm) and exposure (people, assets or ecosystems at risk). The risk equation utilised in the OCCRA considered scorings for both exposure[9] and vulnerability[10] (sensitivity and adaptive capacity) combined for a final risk score.

[8] https://ccc-production-media.s3.ap-southeast-2.amazonaws.com/public/evidence/advice-report-DRAFT-1ST-FEB/ADVICE/CCC-ADVICE-TO-GOVT-31-JAN-2021-pdf.pdf

[9] 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).

[10] 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).

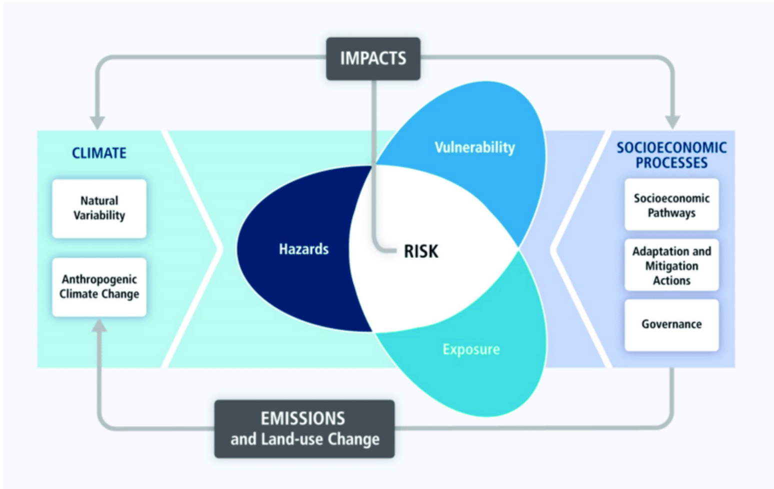

Figure 1. The Intergovernmental Panel on Climate Change (IPCC) AR5 conceptual risk framework. Risk of climate-related impacts results from the interaction of climate-related hazards (including hazardous events and trends) with the vulnerability and exposure of human and natural systems (IPCC Technical summary, Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change)

[19] It was important to achieve methodological alignment with the NCCRA. The approach used for the OCCRA is aligned with the approach used for the NCCRA although not completely identical.

[20] The OCCRA methodology assesses risk under the same 5 domains (Human, Natural, Economy, Built and Governance) as the NCCRA.

[21] The OCCRA utilised the climate change projections for the Otago Region report (2019)[11] prepared for ORC by NIWA as the climate basis for the risk assessment.

[22] The results for the RCP8.5[12] scenario were utilised due to this scenario being considered the 'business as usual' scenario. Risks were then assessed under three timeframes present day, mid-century and end of century, under RCP 8.5.

[11] Climate change projections for the Otago Region (2019). NIWA. https://www.orc.govt.nz/media/7591/niwa_climatechangereport_2019_final.pdf

[12] RCP: Representative Concentration Pathways.

IPCC Glossary: Scenarios that include time series of emissions and concentrations of the full suite of greenhouse gases (GHGs) and aerosols and chemically active gases, as well as land use/land cover (Moss et al., 2008). The word representative signifies that each RCP provides only one of many possible scenarios that would lead to the specific radiative forcing characteristics. The term pathway emphasises that not only the long-term concentration levels are of interest, but also the trajectory taken over time to reach that outcome (Moss et al., 2010). RCP8.5 One high pathway for which radiative forcing reaches greater than 8.5 W m-2 by 2100 and continues to rise for some amount of time (the corresponding ECP assuming constant emissions after 2100 and constant concentrations after 2250).

Key Findings - climate change projections

[23] The following bullet points outline some key findings from the climate change projections for the Otago Region report and **Figure** *2:* is an example of regional projections maps provided by NIWA (annual mean temperature projections).

1. The projected Otago temperature changes increase with time and emission scenario. Future annual average warming spans a wide range: 0.5-1.5°C by 2040, and 0.5-3.5°C by 2090. Diurnal temperature range (i.e., difference between minimum and maximum temperature of a given day) is expected to increase with time and emission scenarios.
2. The average number of extreme hot days (days >30°C) is expected to increase with time and emission scenario, with considerable variability between coastal and southernmost parts of Otago compared to Central Otago. The number of extreme hot days in Central Otago are projected to increase by 30-40 days by 2090 under RCP8.5. The number of frost days (days <0°C) is expected to decrease throughout the region. Largest decreases are expected in inland areas; 10-15 fewer frost days per year by 2040, and 20-40 fewer frost days per year by 2090.
3. Annual rainfall in Otago is expected to increase slightly by mid-century (0-10%), while the increase spans 10-20% (with a larger increase in the western part of the region) at the end of the century. Seasonally the largest increases are projected during winter, with 20-40% increases expected by 2090 under RCP8.5.
4. Extreme, rare rainfall events are projected to become more severe in the future under all four climate change scenarios. The depth of a current 1:100-year 1-hour duration rainfall event is projected to increase by approximately 35% by 2090 under RCP8.5.
5. By the end of the century, a decrease in annual dry days of 2-6 days is 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.
6. The future magnitude of the 99th percentile[13] 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 6-12% by 2090 under RCP8.5.
7. By the end of the century and with increased emissions, average annual flows are expected to increase across the region. Floods (characterised by the Mean Annual Flood) are expected to become larger everywhere, with increases up to 100% in some locations by the end of the century.

[13] This equates to the top 1% of daily mean winds recorded, i.e. about the top three windiest days each year.

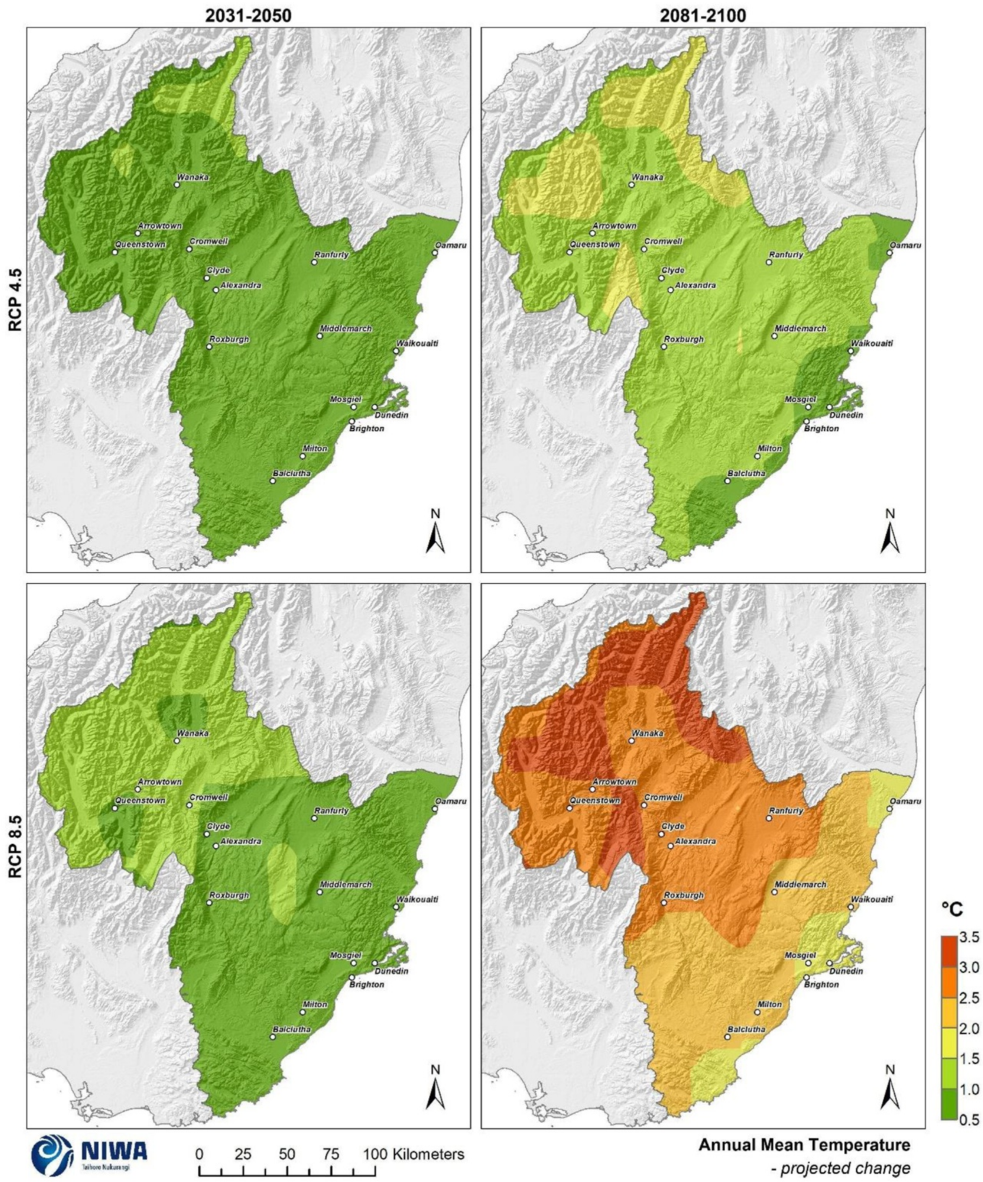

Figure *2:* **Otago will be warmer everywhere: Projected annual mean temperature changes by 2040 and 2090, under RCP4.5 and RCP8.5. Climate change scenarios: RCP4.5 (top panels) and RCP8.5 (bottom panels). Time periods: mid-century (2031- 2050; "2040" – panels on left) and end-century (2081-2100; "2090" – panels on right). Changes relative to 1986-2005 average, based on the average of six global climate models. Results are based on dynamical downscaled projections using NIWA's Regional Climate Model. Resolution of projection is 5km x 5km (from Climate change projections for the Otago Region, NIWA, October 2019).**

Engagement

[24] The risk assessment was based on readily-available data and studies and on domain and sector expert's opinion and advice. The assessment was undertaken through a workshop and extensive targeted elicitation engagement sessions.

[25] Aukaha and Kā Rūnaka were approached early, and we have worked with them to identify limitations of the risk assessment and improve the report. Rūnaka have had the chance to provide feedback on the draft OCCRA report and, on the basis that more work is to be undertaken to develop a Kāi Tahu approach to climate change risk assessment, rūnaka are comfortable with the methodology and direction of travel outlined in the OCCRA report. Staff will continue to work with Aukaha and Kā Rūnaka on these matters.

[26] All of the district and city councils in the region were consulted and sector leads and experts from both within and outside of the region had input into the assessment. Over 70 groups and specialists were provided the opportunity to contribute to the risk assessment (Appendix 1) including, for example, the Department of Conservation, Heritage New Zealand, New Zealand Insurance Council, Otago Chamber of Commerce, various groups from the primary industry sector, Dunedin and Queenstown airports, etc. Discussion and consensus with these groups led to the basis of the risk assessment and assigning the risk ratings.

Risk Relativity

[27] Ultimately the OCCRA provides a summary of relative understanding of risk across the region through a qualitative detailed risk assessment with risk ratings of low, medium, high and extreme provided for the built, natural and economy domains and key risks highlighted for the human and governance domains.

[28] No ranking was provided for the human or governance domains due to the complexity and difficulty in comparing these types of risks, instead key risks were identified which should be considered alongside all other risks due to their interconnectivity.

[29] Full risk tables are provided within the report and detailed discussion for each of these risks is provided. Risks are also grouped to display the highest risks for each domain (these are provided in Appendix 2).

[30] The risk assessment has produced the first regional, collective summary of relative risks to Otago from climate change and a comprehensive dataset which can be interrogated based on interest or perspective. It forms a key platform for building understanding of relative risks and furthermore detailed or localised investigations. It also provides a basis for connecting stakeholders with responsibilities for climate change issues.

[31] It was also important through this process to identify opportunities that climate change may bring for the region and some of these have also been highlighted.

[32] Research and knowledge gaps have been identified which can be filled in the future to better understand the risks.

CONSIDERATIONS

Policy Considerations

[33] Consideration will need to be given to implications of the National Adaptation Plan (under development by the Ministry for the Environment) and to the changes to the resource management system.

[34] The draft Regional Policy Statement requires that the risks of climate change be considered as part of integrated management and that a clear path for regional adaptation be developed by 2030. The OCCRA provides the initial information platform necessary to commence discussion and development of that path.

[35] As part of its Strategic Directions, ORC has committed to an effective climate change response, including a leadership role in regional collaboration, consideration of climate change in all ORC's decisions and community engagement about climate change as part of achieving healthy ecosystems and resilient and sustainable communities. The development of the OCCRA is an essential component of work to enable ORC to achieve Strategic Directions.

Financial Considerations

[36] Provision is being made in the Draft 2021/31 Long Term Plan to complete the repeat risk assessment in the 2026/27 financial year.

Significance and Engagement

[37] This paper does not trigger ORC's policy on Significance and Engagement.

Legislative Considerations

[38] As set out in paper.

Risk Considerations

[39] Providing the information presented in this paper helps the community and interested stakeholders and organisations understand and manage the risks associated with climate change.

NEXT STEPS

[40] It is expected this report and its findings will have widespread usage across the region by district and city councils and multiple sectors, especially those involved throughout the risk assessment.

[41] The work will be shared in accordance with the communications plan designed to appropriately reach a wide range of audiences in the region.

[42] Examples of these communication initiatives include:

a. Website page with online feedback channels, FAQs
b. Direct communications to relevant stakeholders with invitation to feed back/ask questions
c. Public engagement events e.g. Wanaka Show and South Dunedin Street Festival
d. Existing channels e.g. Facebook, On-Stream, Waterlines
e. Interactive & engaging education
f. Interactive map, videos, physical exhibits, games, utilise Enviroschools, community events
g. User-friendly online risk database

[43] This work will support decision makers in developing understanding and work towards adaptation decisions through considering the highlighted risks, areas that require further research and defining priorities for adaptation planning.

[44] It is recognised through the limitations highlighted within the risk assessment improvements can be made to the methodology, furthermore ongoing and future research will improve knowledge in this space and the risk assessment will require updating. It is recommended this follow a similar 6-yearly timeframe to the NCCRA to ensure alignment.

[45] As part of the Draft 2021/31 long term plan, the OCCRA and the Otago Regional Greenhouse Gas Inventory will provide an information platform which ORC Strategy Team will use to commence both consideration of internal policy requirements and progress regional discussions about collaboration on climate change adaptation and mitigation.

ATTACHMENTS

1. Appendix 1: Stakeholder engagement list [**7.1.1** - 4 pages]
2. Appendix 2: Grouped highest risks for each domain [**7.1.2** - 3 pages]
3. NIWA Climate Change Report 2019 [**7.1.3** - 136 pages]

Appendix 1: Stakeholder engagement list

Domain	Organisation	Engagement details
General	Otago Regional Council	Review and commentary provided by multiple teams within ORC.
	Waitaki 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.
	Clutha District Council	Risk list and draft report was disseminated, and comments provided.
	Central Otago District 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.
	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.

Human/Culture	Heritage New Zealand	Risk list and workshop report was disseminated to the stakeholder, and a consultation was undertaken.
	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.
Governance	Local Government New Zealand	Risk list and workshop report was disseminated, but no response was provided by the stakeholder.
	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.
Natural Environment	Department of Conservation	Risk list and workshop report was disseminated, and commentary was provided by the stakeholder.
	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 2: Grouped highest risks for each domain

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.

Table 8-1: Summary of risk ratings in the governance domain

Risks	Local vs central government influence
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
Risk of local authorities lacking capacity to effectively respond to climate change.	Local direct influence
Risk that the national, regional and local governance/institutional structures for managing climate change are inadequate.	Combination of local and central influence
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
Risk that climate change will result in increasing damage costs, with insufficient financing for adaptation and risk reduction.	Combination of local and central influence
Risk that public services will be impacted by climate change.	Combination of local and central influence

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

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.

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, 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. Refer individual risk discussions for detailed ratings

Climate change projections for the Otago Region

Prepared for Otago Regional Council

October 2019

NIWA – enhancing the benefits of New Zealand's natural resources www.niwa.co.nz

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Quality Assurance Statement		
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Executive summary

Otago's climate is changing, and these changes will continue for the foreseeable future. It is internationally accepted that human greenhouse gas emissions are the dominant cause of recent global climate change, and that further changes will result from increasing amounts of greenhouse gases in the atmosphere. The rate of future climate change depends on how fast greenhouse gas concentrations increase.

Otago Regional Council commissioned NIWA to analyse projected climate changes for the Otago Region. This report addresses expected changes for various climate variables out to 2100, drawing heavily on climate model simulations from the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report. In addition, hydrological impacts of climate change were assessed. The following bullet points outline some key findings of this report:

- The projected Otago temperature changes increase with time and emission scenario. Future annual average warming spans a wide range: 0.5-1.5°C by 2040, and 0.5-3.5°C by 2090. Diurnal temperature range (i.e., difference between minimum and maximum temperature of a given day) is expected to increase with time and emission scenarios.

- The average number of extreme hot days (days >30°C) is expected to increase with time and emission scenario, with considerable variability between coastal and southernmost parts of Otago compared to Central Otago. The number of extreme hot days in Central Otago are projected to increase by 30-40 days by 2090 under RCP8.5. The number of frost days (days <0°C) is expected to decrease throughout the region. Largest decreases are expected in inland areas; 10-15 fewer frost days per year by 2040, and 20-40 fewer frost days per year by 2090.

- Annual rainfall in Otago is expected to increase slightly by mid-century (0-10%), while the increase spans 10-20% (with a larger increase in the western part of the region) at the end of the century. Seasonally the largest increases are projected during winter, with 20-40% increases expected by 2090 under RCP8.5.

- Extreme, rare rainfall events are projected to become more severe in the future under all four climate change scenarios. The depth of a current 1:100-year 1-hour duration rainfall event is projected to increase by approximately 35% by 2090 under RCP8.5.

- By the end of the century, a decrease in annual dry days of 2-6 days is 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.

- By the end of the century and with increased emissions, average annual flows are expected to increase across the region (above 50% across all Freshwater Management Units except headwaters of Taieri and North Otago). Floods (characterised by the Mean Annual Flood) are expected to become larger everywhere, with increases up to 100% in some locations by the end of the century.

1 Introduction

Climate change is already affecting New Zealand and Otago with downstream effects on our natural environment, the economy, and communities. In the coming decades, climate change is highly likely to increasingly pose challenges to New Zealanders' way of life.

Otago Regional Council commissioned the National Institute of Water and Atmospheric Research (NIWA) to undertake a review of climate change projections for the Otago region (Figure 1-1; following page). This work follows the publication of the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report in 2013 and 2014, and the New Zealand climate change projections report published by the Ministry for the Environment; updated 2018 (Ministry for the Environment, 2018a). The contents of this technical report include analysis of climate projections for the Otago region in greater detail than the national-scale analysis. Regional-scale climate projection maps have been provided for various climate variables, and GIS data files have been provided to the Council.

This technical report describes changes which may occur over the 21st century to the climate of the Otago region. Consideration about future change incorporates knowledge of both natural variations in the climate and changes that may result from increasing global concentrations of greenhouse gases that are contributed to by human activities. Climatic variables discussed in this report include temperature, precipitation (rainfall, snow days and dry days), and wind. Projections for hydrological variables are also discussed.

Some of the information that underpins portions of this report resulted from academic studies based on the latest assessments of the Intergovernmental Panel on Climate Change (IPCC, 2013; 2014a; 2014b; 2014c). Details specific to Otago were based on scenarios for New Zealand that were generated by NIWA from downscaling of global climate model simulations. This effort utilised several IPCC representative concentration pathways for the future and this was achieved through NIWA's core-funded Regional Modelling Programme. The atmospheric climate change information presented in this report is consistent with recently-updated national-scale climate change guidance produced for the Ministry for the Environment (2018a), and the hydrological projections are consistent with similar reports produced by NIWA for the Ministry for the Environment (Ministry for the Environment, 2018b) and the Ministry for Primary Industries (Collins and Zammit, 2016).

The remainder of this chapter includes a brief introduction of global and New Zealand climate change, based on the IPCC Fifth Assessment Report. It includes an introduction to the climate change scenarios used in this report, and the methodology that explains the modelling approach for the climate change projections that are presented for Otago.

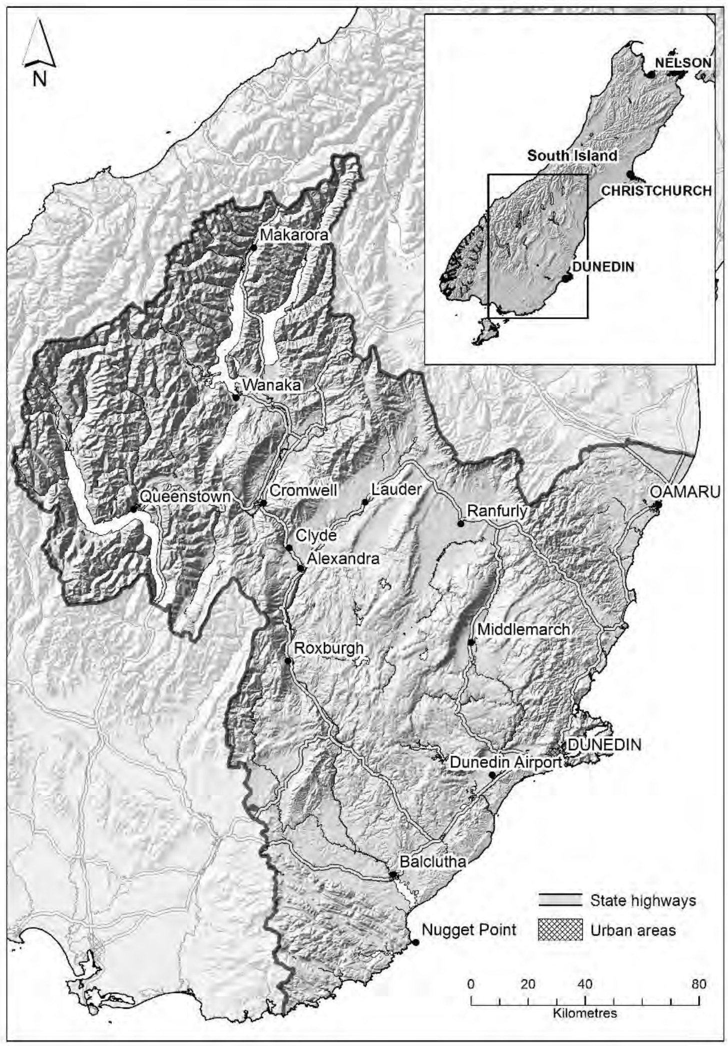

Figure 1-1: The Otago Region administered by the Otago Regional Council.

1.1 Global and New Zealand climate change

Key messages

- The global climate system is warming and many of the recently observed climate changes are unprecedented.
- Global mean sea level has risen over the past century at a rate of about 1.7 mm/year, and has very likely accelerated to 3.2 mm/year since 1993.
- Human activities (and associated greenhouse gas emissions) are estimated to have caused approximately 1.0°C of global warming above pre-industrial levels.
- Estimated human-induced global warming is currently increasing at 0.2°C per decade due to past and ongoing emissions.
- Continued increases in greenhouse gas emissions will cause further warming and impacts on all parts of the global climate system.

Warming of the global climate system is unequivocal, and since the 1950s, many of the observed climate changes are unprecedented over short and long timescales (decades to millennia) (IPCC, 2013). These changes include warming of the atmosphere and ocean, diminishing of ice and snow, sea-level rise, and increases in the concentration of greenhouse gases in the atmosphere. Climate change is likely influencing the intensity and frequency of many extreme weather and climate events globally. The Earth's atmosphere has warmed by 0.85°C on average over the period 1880-2012. The rate of sea-level rise since the mid-19th century has been larger than the mean rate of change during the previous two millennia. Over the period 1901-2010, global mean sea level rose by 0.19 m.

The atmospheric concentrations of carbon dioxide have increased to levels unprecedented in at least the last 3 million years (Willeit et al., 2019). Carbon dioxide concentrations have increased by at least 40% since pre-industrial times, primarily from fossil fuel emissions and secondarily from net land use change emissions (IPCC, 2013). In May 2019, the carbon dioxide concentration of the atmosphere reached 415 parts per million. The ocean has absorbed about 30% of the emitted anthropogenic carbon dioxide, causing ocean acidification. Due to the influence of greenhouse gases on the global climate system, it is extremely likely that human influence has been the dominant cause of the observed warming since the mid-20th century (IPCC, 2013, IPCC, 2018).

As global temperatures increase, it is virtually certain that there will be more hot and fewer cold temperature extremes over most land areas. It is very likely that heat waves will occur with a higher frequency and duration. Furthermore, the contrast in rainfall between wet and dry regions and wet and dry seasons will increase. Along with increases in global mean temperature, mid-latitude and wet tropical regions will experience more intense and more frequent extreme rainfall events by the end of the 21st century. The global ocean will continue to warm during the 21st century, influencing ocean circulation and sea ice extent.

Published information about the expected impacts of climate change on New Zealand is summarised and assessed in the Australasia chapter of the IPCC Working Group II assessment report (Reisinger et al., 2014) as well as a report published by the Royal Society of New Zealand (Royal Society of New Zealand, 2016). Key findings from these publications include:

The regional climate is changing. The Australasia region continues to demonstrate long-term trends toward higher surface air and sea surface temperatures, more hot extremes and fewer cold extremes, and changed rainfall patterns. Over the past 50 years, increasing greenhouse gas concentrations have contributed to rising average temperatures in New Zealand. Changing precipitation patterns have resulted in increases in rainfall for the south and west of the South Island and west of the North Island and decreases in the northeast of the South Island and the east and north of the North Island. Some heavy rainfall events already carry the fingerprint of a changed climate, in that they have become more intense due to higher temperatures allowing the atmosphere to carry more moisture (Dean et al., 2013). Cold extremes have become rarer and hot extremes have become more common.

The region has exhibited warming to the present and is virtually certain to continue to do so. New Zealand's mean annual temperature has increased, on average, by 1.00°C (± 0.25°C) per century since 1909 (Figure 1-2).

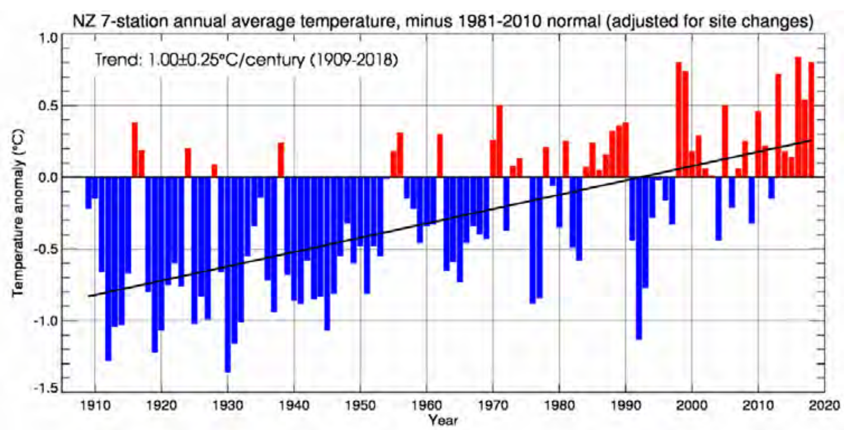

Figure 1-2: New Zealand national temperature series, 1909-2018. More information about the New Zealand seven-station temperature series can be found at https://www.niwa.co.nz/our-science/climate/information-and-resources/nz-temp-record/seven-station-series-temperature-data

Warming is projected to continue through the 21st century along with other changes in climate. Warming is expected to be associated with rising snow lines, more frequent hot extremes, less frequent cold extremes, and increasing extreme rainfall. Annual average rainfall is expected to decrease in the northeast South Island and north and east of the North Island, and to increase in other parts of New Zealand. Fire hazard is projected to increase in many parts of New Zealand. Regional sea level rise will very likely exceed the historical rate, consistent with global mean trends.

Impacts and vulnerability: Without adaptation, further climate-related changes are projected to have substantial impacts on water resources, coastal ecosystems, infrastructure, health, agriculture, and biodiversity. However, uncertainty in projected rainfall changes and other climate-related changes remains large for many parts of New Zealand, which creates significant challenges for adaptation.

Additional information about recent New Zealand climate change can be found in Ministry for the Environment (2018a).

1.2 Representative Concentration Pathways

Key messages

- Future climate change projections are considered under four emission scenarios, called Representative Concentration Pathways (RCPs) by the IPCC.
- The four RCPs project different climate futures based on future greenhouse gas concentrations, determined by economic, political and social developments during the 21st century.
- RCP2.6 is a mitigation scenario requiring significant reduction in greenhouse gas emissions, RCP4.5 and RCP6.0 are mid-range scenarios where greenhouse gas concentrations stabilise by 2100, and RCP8.5 is a 'business as usual' scenario with greenhouse gas emissions continuing at current rates.
- Projections for the future climate in Otago are presented for RCP4.5 and RCP8.5 in this report.

Assessing possible changes for our future climate due to human activity is difficult because climate projections depend strongly on estimates for future greenhouse gas concentrations. Those concentrations depend on global greenhouse gas emissions that are driven by factors such as economic activity, population changes, technological advances and policies for sustainable resource use. In addition, for a specific future trajectory of global greenhouse gas emissions, different climate model simulations produced somewhat different results for future climate change.

This range of uncertainty has been dealt with by the IPCC through consideration of 'scenarios' that describe concentrations of greenhouse gases in the atmosphere. The wide range of scenarios are associated with possible economic, political, and social developments during the 21st century, and via consideration of results from several different climate models for any given scenario. In the 2013 IPCC Fifth Assessment Report, the atmospheric greenhouse gas concentration components of these scenarios are called Representative Concentrations Pathways (RCPs). These are abbreviated as RCP2.6, RCP4.5, RP6.0, and RCP8.5, in order of increasing radiative forcing by greenhouse gases (i.e. the change in energy in the atmosphere due to greenhouse gas emissions). RCP2.6 leads to low anthropogenic greenhouse gas concentrations (requiring removal of CO_2 from the atmosphere, also called the 'mitigation' scenario), RCP4.5 and RCP6.0 are two 'stabilisation' scenarios (where greenhouse gas emissions and therefore radiative forcing stabilises by 2100) and RCP8.5 has very high greenhouse gas concentrations (the 'business as usual' scenario). Therefore, the RCPs represent a range of 21st century climate policies. Table 1-1 shows the projected global mean surface air temperature for each RCP.

Table 1-1: Projected change in global mean surface air temperature for the mid- and late- 21st century relative to the reference period of 1986-2005 for different RCPs. After IPCC (2013).

Scenario	Alternative name	2046-2065 (mid-century)		2081-2100 (end-century)	
		Mean	Likely range	Mean	Likely range
RCP2.6	Mitigation scenario	1.0	0.4 to 1.6	1.0	0.3 to 1.7
RCP4.5	Stabilisation scenario	1.4	0.9 to 2.0	1.8	1.1 to 2.6
RCP6.0	Stabilisation scenario	1.3	0.8 to 1.8	2.2	1.4 to 3.1
RCP8.5	Business as usual scenario	2.0	1.4 to 2.6	3.7	2.6 to 4.8

The full range of projected globally-averaged temperature increases for all scenarios for 2081-2100 (relative to 1986-2005) is 0.3 to 4.8°C (Figure 1-3). Warming will continue beyond 2100 under all RCP scenarios except RCP2.6. Warming will continue to exhibit inter-annual-to-decadal variability and will not be regionally uniform.

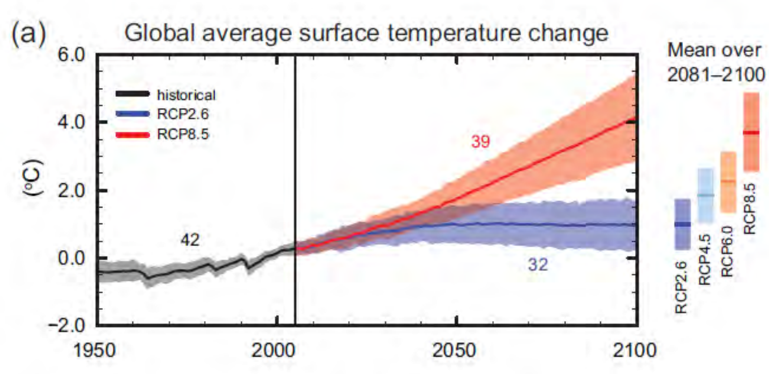

Figure 1-3: CMIP5 multi-model simulated time series from 1950-2100 for change in global annual mean surface temperature relative to 1986-2005. Time series of projections and a measure of uncertainty (shading) are shown for scenarios RCP2.6 (blue) and RCP8.5 (red). Black (grey shading) is the modelled historical evolution using historical reconstructed forcings. The mean and associated uncertainties averaged over 2081–2100 are given for all RCP scenarios as coloured vertical bars to the right of the graph (the mean projection is the solid line in the middle of the bars). The numbers of CMIP5 models used to calculate the multi-model mean is indicated on the graph. From IPCC (2013).

Cumulative CO_2 emissions will largely determine global mean surface warming by the late 21st century and beyond. Even if emissions are stopped, the inertia of many global climate changes will continue for many centuries to come. This represents a substantial multi-century climate change commitment created by past, present, and future emissions of CO_2.

In this report, global climate model outputs based on two RCPs (RCP4.5 and RCP8.5) have been downscaled by NIWA to produce future climate projections for the Otago Region. The rationale for choosing these two scenarios was to present a ‘business-as-usual’ scenario if greenhouse gas emissions continue at current rates (RCP8.5) and a scenario which could be realistic if global action is taken towards mitigating climate change, for example the Paris climate change agreement (RCP4.5). In addition, the global model outputs based on all RCPs (RCP2.6, RCP4.5, RCP6.0 and RCP8.5) have been utilised for the hydrological modelling component of this report.

1.3 Year to year climate variability and climate change

Key messages

- Natural variability is an important consideration in addition to the underlying climate change signal.
- El Niño-Southern Oscillation is the most dominant mode of inter-annual climate variability and it impacts New Zealand primarily through changing wind, temperature and rainfall patterns.
- The Interdecadal Pacific Oscillation affects New Zealand through drier conditions in the east and wetter conditions in the west during the positive phase, the opposite in the negative phase.
- The Southern Annular Mode affects New Zealand through higher temperatures and settled weather during the positive phase and lower temperatures and unsettled weather during the negative phase.
- Natural variability will continue to affect the year-to-year climate of New Zealand into the future, and thus introduce some uncertainty in the 20-year averages presented.

Much of the material in this report focuses on the projected impact on the climate of Otago over the coming century due to increases in global anthropogenic greenhouse gas concentrations. However, natural variations will also continue to occur. Much of the variation in New Zealand's climate is random and lasts for only a short period, but longer term, quasi-cyclic variations in climate can be attributed to different factors. Three large-scale oscillations that influence climate in New Zealand are the El Niño-Southern Oscillation, the Interdecadal Pacific Oscillation, and the Southern Annular Mode (Ministry for the Environment, 2008). Those involved in (or planning for) climate-sensitive activities in the Otago region will need to cope with the sum of both anthropogenic change and natural variability.

1.3.1 The effect of El Niño and La Niña

El Niño-Southern Oscillation (ENSO) is a natural mode of climate variability that has wide-ranging impacts around the Pacific Basin (Ministry for the Environment, 2008). ENSO involves a movement of warm ocean water from one side of the equatorial Pacific to the other, changing atmospheric circulation patterns in the tropics and subtropics, with corresponding shifts for rainfall across the Pacific.

During El Niño, easterly trade winds weaken and warm water 'spills' eastward across the equatorial Pacific, accompanied by higher rainfall than normal in the central-east Pacific. La Niña produces opposite effects and is typified by an intensification of easterly trade winds, and retention of warm ocean waters over the western Pacific. ENSO events occur on average three to seven years apart, typically becoming established in April or May and persisting for about a year thereafter.

During El Niño events, the weakened trade winds cause New Zealand to experience a stronger than normal south-westerly airflow. This generally brings lower seasonal temperatures to the country and drier than normal conditions to the north and east of New Zealand (Salinger and Mullan, 1999). During La Niña conditions, the strengthened trade winds cause New Zealand to experience more north-easterly airflow than normal, higher-than-normal temperatures (especially during summer), and generally drier conditions in the west and south of the South Island, including Otago (Figure 1-4).

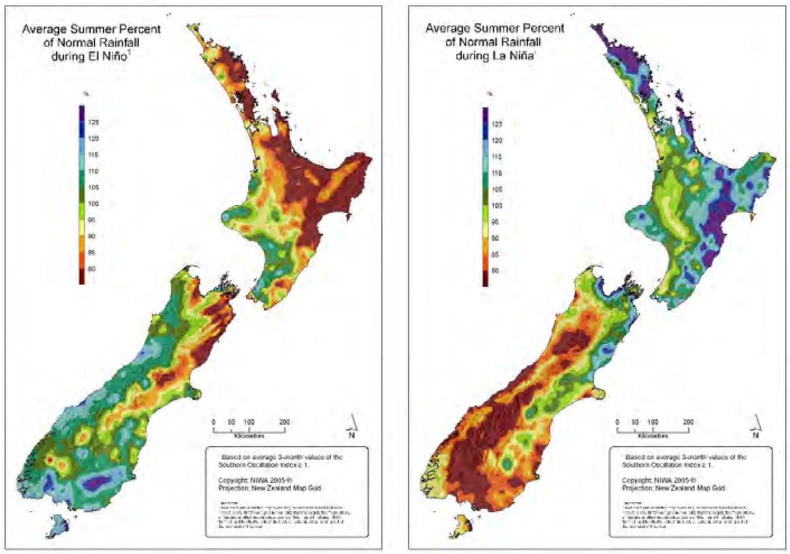

Figure 1-4: Average summer percentage of normal rainfall during El Niño (left) and La Niña (right). El Niño composite uses the following summers: 1963/64, 1965/66, 1968/69, 1969/70, 1972/73, 1976/77, 1977/78, 1982/83, 1986/87, 1987/88, 1991/92, 1994/95, 1997/98, 2002/03. La Niña composite uses the following summers: 1964/65, 1970/71, 1973/74, 1975/76, 1983/84, 1984/85, 1988/89, 1995/96, 1998/99, 1999/2000, 2000/01. This figure was last updated in 2005. © NIWA.

According to IPCC (2013), ENSO is highly likely to remain the dominant mode of natural climate variability in the 21st century, and that rainfall variability relating to ENSO is likely to increase. However, there is uncertainty about future changes to the amplitude and spatial pattern of ENSO.

1.3.2 The effect of the Interdecadal Pacific Oscillation

The Interdecadal Pacific Oscillation (IPO) is a large-scale, long-period oscillation that influences climate variability over the Pacific Basin including New Zealand (Salinger et al., 2001). The IPO operates at a multi-decadal scale, with phases lasting around 20 to 30 years. During the positive phase of the IPO, sea surface temperatures around New Zealand tend to be lower, and westerly winds stronger, resulting in drier conditions for eastern areas of both North and South Islands. The opposite occurs in the negative phase. The IPO can modify New Zealand's connection to ENSO, and it also positively reinforces the impacts of El Niño (during IPO+ phases) and La Niña (during IPO- phases).

1.3.3 The effect of the Southern Annular Mode

The Southern Annular Mode (SAM) represents the variability of circumpolar atmospheric jets that encircle the Southern Hemisphere that extend out to the latitudes of New Zealand. The SAM is often coupled with ENSO, and both phenomena affect New Zealand's climate in terms of westerly wind strength and storm occurrence (Renwick and Thompson, 2006). In its positive phase, the SAM is associated with relatively light winds and more settled weather over New Zealand, with stronger westerly winds further south towards Antarctica. In contrast, the negative phase of the SAM is associated with unsettled weather and stronger westerly winds over New Zealand, whereas wind and storms decrease towards Antarctica.

The phase and strength of the SAM is influenced by the size of the ozone hole, giving rise to positive trends in the past during spring and summer. In the future other drivers are likely to have an impact on SAM behaviour, for example changing temperature gradients between the equator and the high southern latitudes would have an impact on westerly wind strength in the mid-high latitudes.

1.3.4 The influence of natural variability on climate change projections

It is important to consider human-induced climate change in the context of natural climate variability. An example of this for temperature is shown in Figure 1-5. The solid black line on the left-hand side represents the observed annual average temperature for New Zealand[1], and the dashed black line represents the 1909-2014 trend of 0.92 °C/century extrapolated to 2100. All the other line plots and shading refer to the modelled air temperature averaged over the New Zealand region. Post-2014, the two line plots show the annual temperature changes for the New Zealand region under RCP8.5 (orange) and RCP2.6 (blue); a single model is selected to illustrate the inter-annual variability. The shading shows the range across <u>all</u> IPCC AR5 models for both historical and future periods.

Over the 1900-2014 historical period, the New Zealand observed temperature curve lies within the simulations of all models (purple shading). For the future 2015-2100 period, the RCP2.6 models (blue shading) show very little warming trend after about 2030, whereas the RCP8.5 models (orange shading) 'take off' to be anywhere between +2°C and +5°C by 2100.

Figure 1-5 should not be interpreted as a set of specific predictions for individual years. However, it illustrates that although we expect a long term overall upward trend in temperatures (at least for RCP8.5), there will still be some relatively cool years. For this example, a year which is unusually warm under our present climate could become the norm by about 2050, and an "unusually warm" year in 30-50 years' time (under the higher emission scenarios) is likely to be warmer than anything we currently experience.

[1] https://www.niwa.co.nz/our-science/climate/information-and-resources/nz-temp-record/seven-station-series-temperature-data

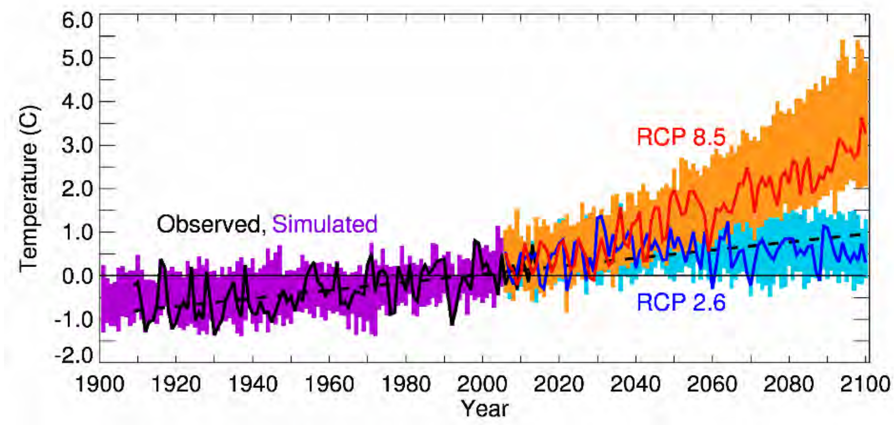

Figure 1-5: New Zealand Temperature - historical record and an illustrative schematic projection illustrating future year-to-year variability. (See text for full explanation). From Ministry for the Environment (2018).

For rainfall, multi-decadal variability associated with the IPO can enhance or counter the impacts of anthropogenic climate change. This influence may generate either slightly above normal or below normal rainfall for parts of New Zealand during summer. For the present period, IPO-negative conditions coupled with more frequent La Niña episodes could increase rainfall during spring and summer, essentially in the opposite direction as expected from anthropogenic factors (i.e. a potential reduction in spring and summer rainfall). A subsequent further reversal of the IPO in 10-20 years' time could have the opposite effect, enhancing part of the anthropogenic (drying) trend in rainfall for a few decades.

The message from this section is *not* that anthropogenic trends in climate can be ignored because of natural variability. In the projections, we have discussed these anthropogenic trends because they become the dominant factor locally as the century progresses. Nevertheless, we need to bear in mind that at some times natural variability will be adding to the human-induced trends, while at others it may be offsetting part of the anthropogenic effect.

1.4 Climate modelling methodology

Key messages

- Climate model simulation data from the IPCC Fifth Assessment has been used to produce climate projections for New Zealand.
- Six climate models were chosen by NIWA for dynamical downscaling. These models were chosen because they produced the most accurate results when compared to historical climate and circulation patterns in the New Zealand and southwest Pacific region.
- Downscaled climate change projections are at a 5 km x 5 km resolution over New Zealand.
- Climate projection and historic baseline maps and tables present the average of the six downscaled models.
- Climate projections are presented as a 20-year average for two future periods: 2031-2050 (termed '2040') and 2081-2100 (termed '2090'). All maps show changes relative to the baseline climate of 1986-2005 (termed '1995').
- More details about the methods used in climate change modelling are found in Appendix A.

1.5 Hydrological modelling methodology

Key messages

- NIWA's TopNet model has been used in this study. TopNet is a spatially semi-distributed, time-stepping model of water balance. The model is driven by time-series of precipitation and temperature, and additional weather elements (e.g. wind) where available.
- TopNet was run continuously from 1971 to 2100, with the spin-up period 1971 excluded from the analysis. The climate inputs were stochastically disaggregated from daily to hourly time steps.
- The simulation results comprise time-series of modelled river flow for each computational sub-catchment, and for each of the six GCMs and four RCPs considered.
- Hydrological projections are presented as the average for two future periods: 2036-2056 (termed 'mid-century') and 2086-2099 (termed 'late-century'). All maps show changes relative to the baseline climate (1986-2005 average).
- More details about the methods used in hydrological modelling are found in Appendix B.

2 Current and future climate of the Otago Region

The topography of the South Island has a profound effect on the weather of the Otago Region. The Southern Alps act as a barrier to the prevailing westerly winds over the region, separating New Zealand's wettest region (the West Coast) from Central Otago - New Zealand's driest region. As a result, a steep precipitation gradient exists eastward from the western ranges. In Central Otago, hot dry summers and cold dry winters approximate a semi-arid 'continental' climate. In coastal areas of eastern Otago, conditions are tempered by relatively cool sea surface temperatures nearby, and by the absence of shelter from airflows moving over the area from the south and southwest. More information about the present climate of Otago, outside of the information in this report, can be found in Chappell (2013).

The following sections (3-6) present climate change projections for the Otago Region.

3 Temperature

3.1 Mean temperature

Key messages

- Projected Otago temperature changes increase with time and emission scenario. Future annual average warming spans a wide range: 0.5-1.5°C by 2040, and 0.5-3.5°C by 2090.
- Seasonal mean temperatures are projected to increase by 0.5-1.0°C across much of Otago (by 2040 under RCP4.5,). By 2090 under RCP8.5, projected increases of 1.5-2.5°C in coastal areas of Otago, with increases of 2.0-3.5°C for inland parts of the region.

Present-day (average over 1986-2005) and future (average over 2031-2050 and 2081-2100) maps for mean temperature are shown in this section. The present-day maps show annual and seasonal mean temperature in units of degrees Celsius (°C) and the future projection maps show the change in mean temperature compared with the present day, in units of °C. Note that the present-day maps are on a different colour scale to the future projection maps.

At present, annual mean temperatures range between 8-12°C for most coastal and inland low-elevation locations of Otago (Figure 3-1). Seasonal mean temperatures are influenced by a proximity to the sea, such that coastal locations are typically cooler in summer and warmer in winter compared to inland parts of the region (Figure 3-3). For coastal areas of Otago including Dunedin, summer mean temperatures range between 12-16°C, and winter mean temperatures range between 6-8°C. For inland low-elevation locations, summer mean temperatures range between 16-18°C, and winter mean temperatures range between 2-6°C. Mean temperatures at high-elevation mountainous areas of Otago remain several degrees Celsius colder than the remainder of the region throughout the year.

Annual mean temperature is projected to increase by 0.5-1.5°C by 2040 under RCP4.5 and RCP8.5 (Figure 3-2). By 2090, annual mean temperature increases of 0.5-2.0°C (RCP4.5) and 1.5-3.5°C (RCP8.5) are projected. Seasonal projections of mean temperature change are shown for RCP4.5 by 2040 (Figure 3-4) and 2090 (Figure 3-6), and RCP8.5 by 2040 (Figure 3-5) and 2090 (Figure 3-7). Seasonal mean temperatures are projected to increase by 0.5-1.0°C across much of Otago by 2040 under RCP4.5, and by 0.5-1.5°C under RCP8.5. By 2090 under RCP4.5, seasonal mean temperatures are projected to increase by 0.5-1.5°C for most of Otago and 1.5-2.5°C for western high elevations areas. Under RCP8.5, seasonal mean temperatures are projected to increase by 1.5-2.5°C in coastal areas of Otago, with increases of 2.0-3.5°C projected for inland parts of the region.

Modelled seasonal and annual mean temperature data have been generated for 16 Otago locations, and these are presented in Table 3-1.

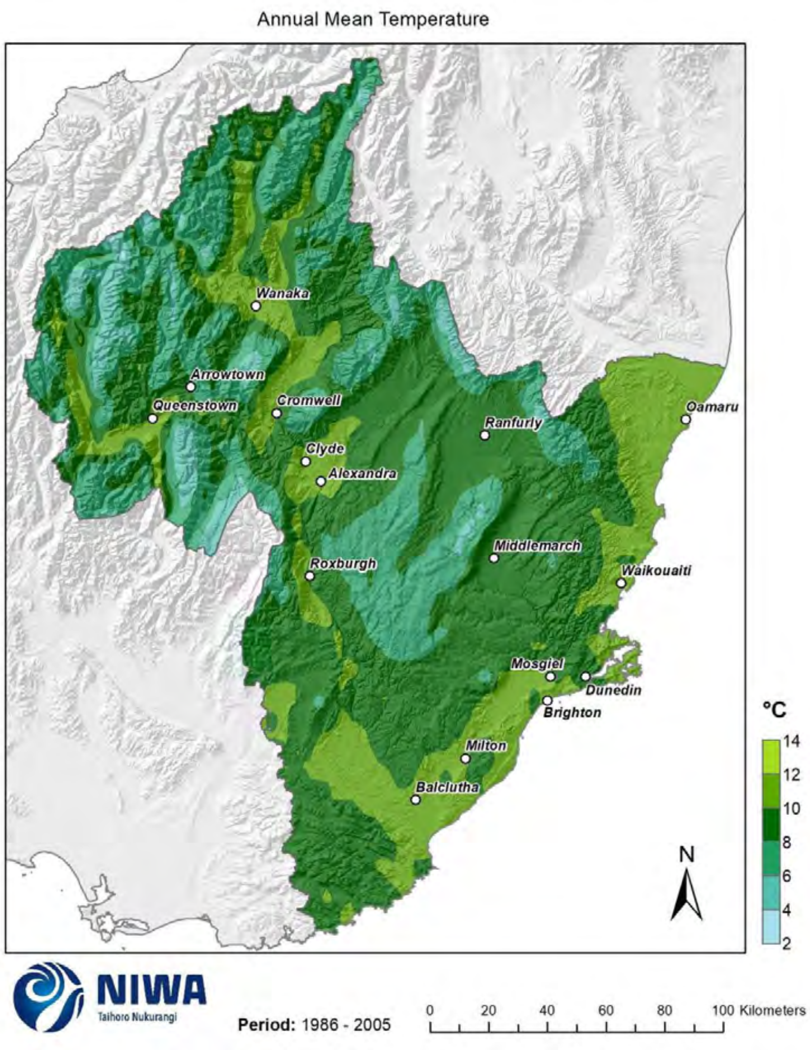

Figure 3-1: Modelled annual mean temperature, average over 1986-2005. Results are based on dynamical downscaled projections using NIWA's Regional Climate Model. Resolution of projection is 5km x 5km.

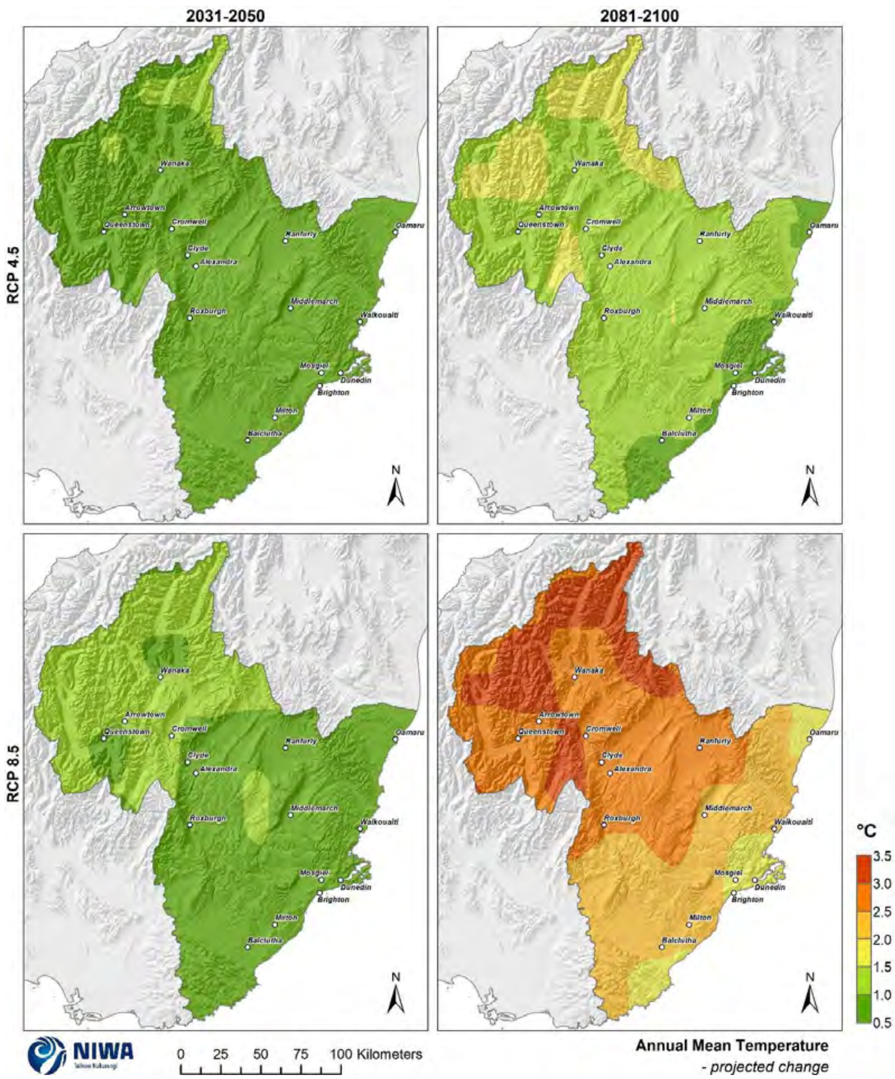

Figure 3-2: Projected annual mean temperature changes by 2040 and 2090, under RCP4.5 and RCP8.5. Climate change scenarios: RCP4.5 (top panels) and RCP8.5 (bottom panels). Time periods: mid-century (2031-2050; "2040" – panels on left) and end-century (2081-2100; "2090" – panels on right). Changes relative to 1986-2005 average, based on the average of six global climate models. Results are based on dynamical downscaled projections using NIWA's Regional Climate Model. Resolution of projection is 5km x 5km.

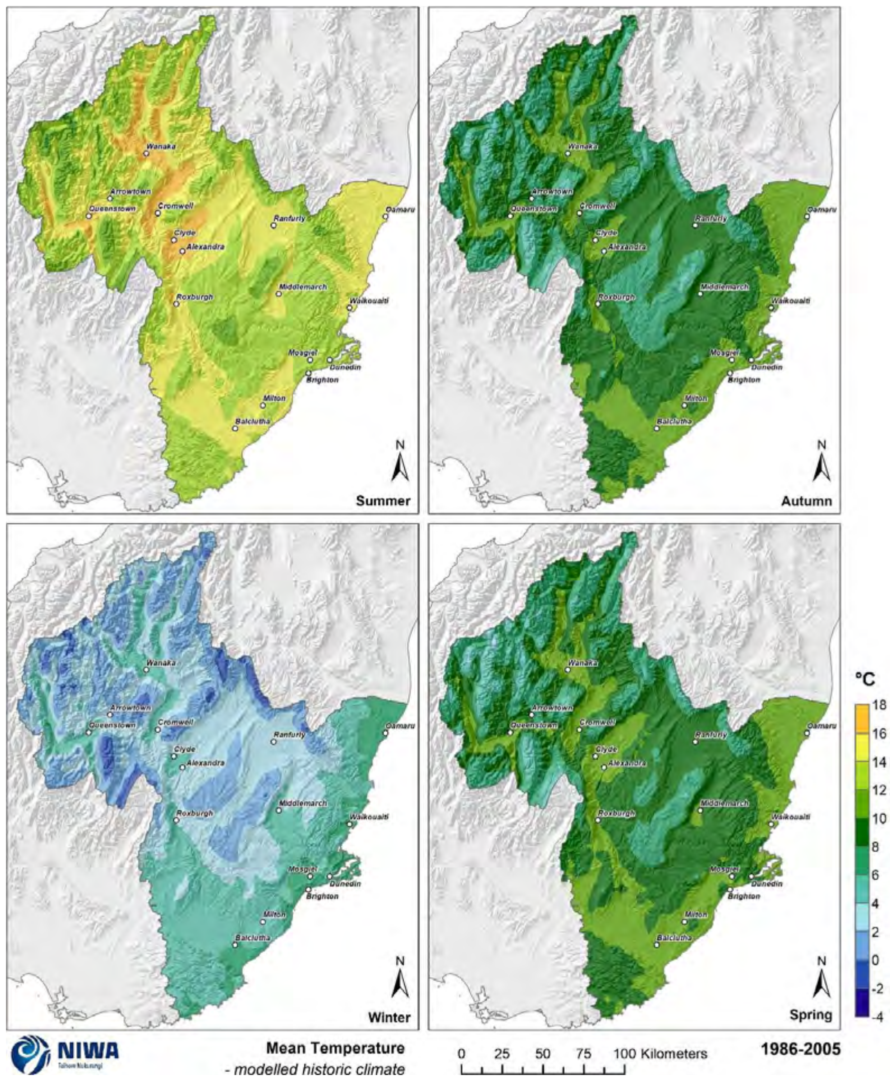

Figure 3-3: Modelled seasonal mean temperature, average over 1986-2005. Results are based on dynamical downscaled projections using NIWA's Regional Climate Model. Resolution of projection is 5km x 5km.

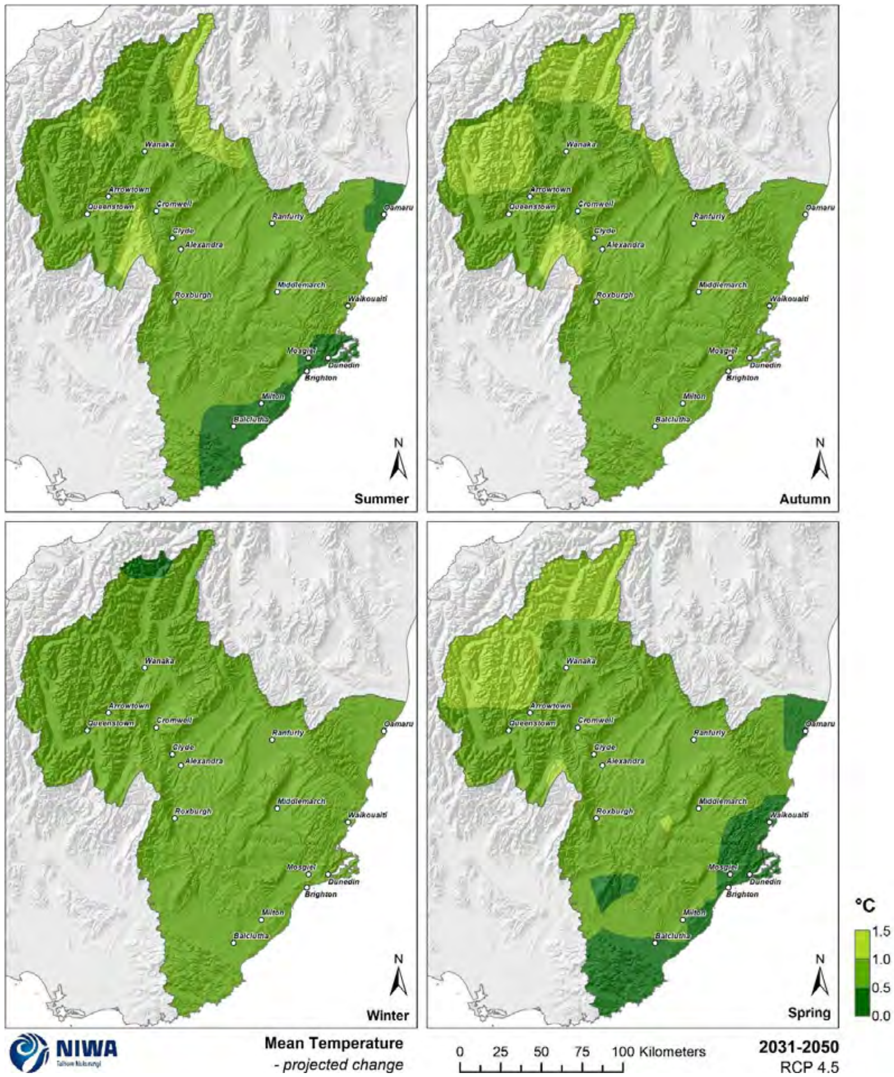

Figure 3-4: Projected seasonal mean temperature changes by 2040 for RCP4.5. Relative to 1986-2005 average, based on the average of six global climate models. Results are based on dynamical downscaled projections using NIWA's Regional Climate Model. Resolution of projection is 5km x 5km.

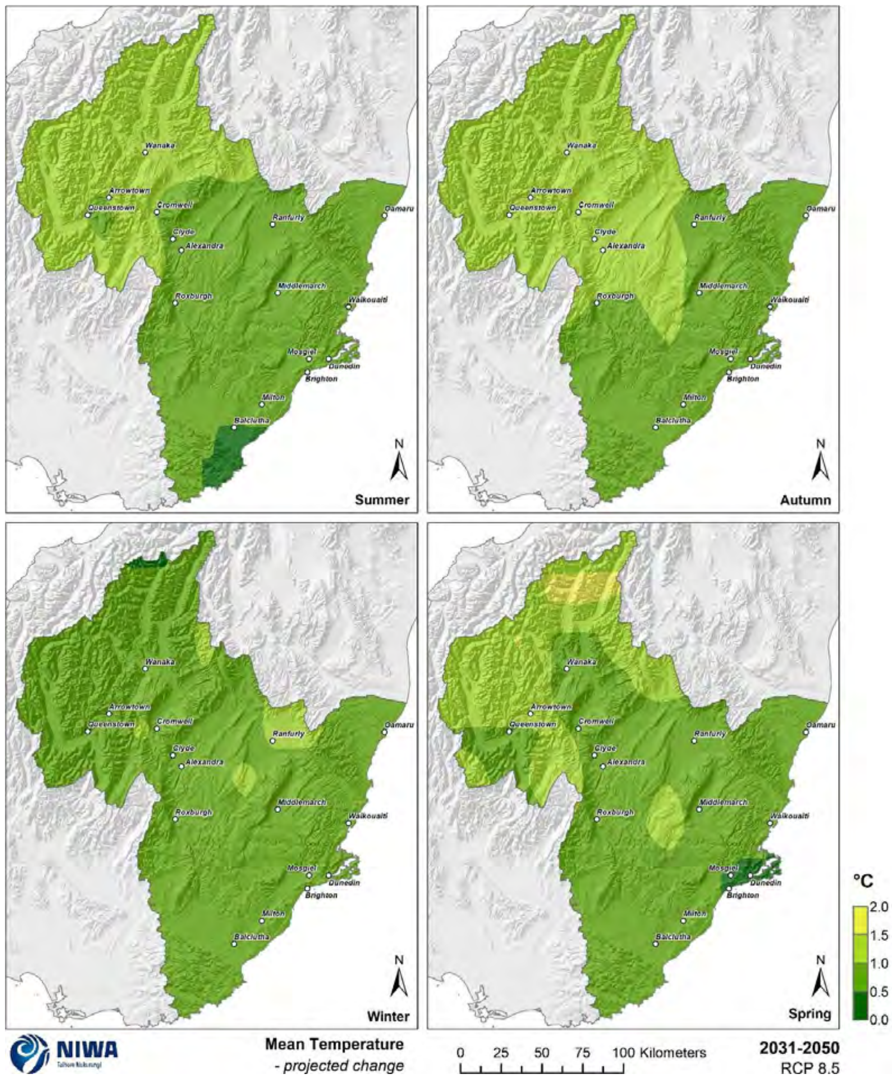

Figure 3-5: Projected seasonal mean temperature changes by 2040 for RCP8.5. Relative to 1986-2005 average, based on the average of six global climate models. Results are based on dynamical downscaled projections using NIWA's Regional Climate Model. Resolution of projection is 5km x 5km.

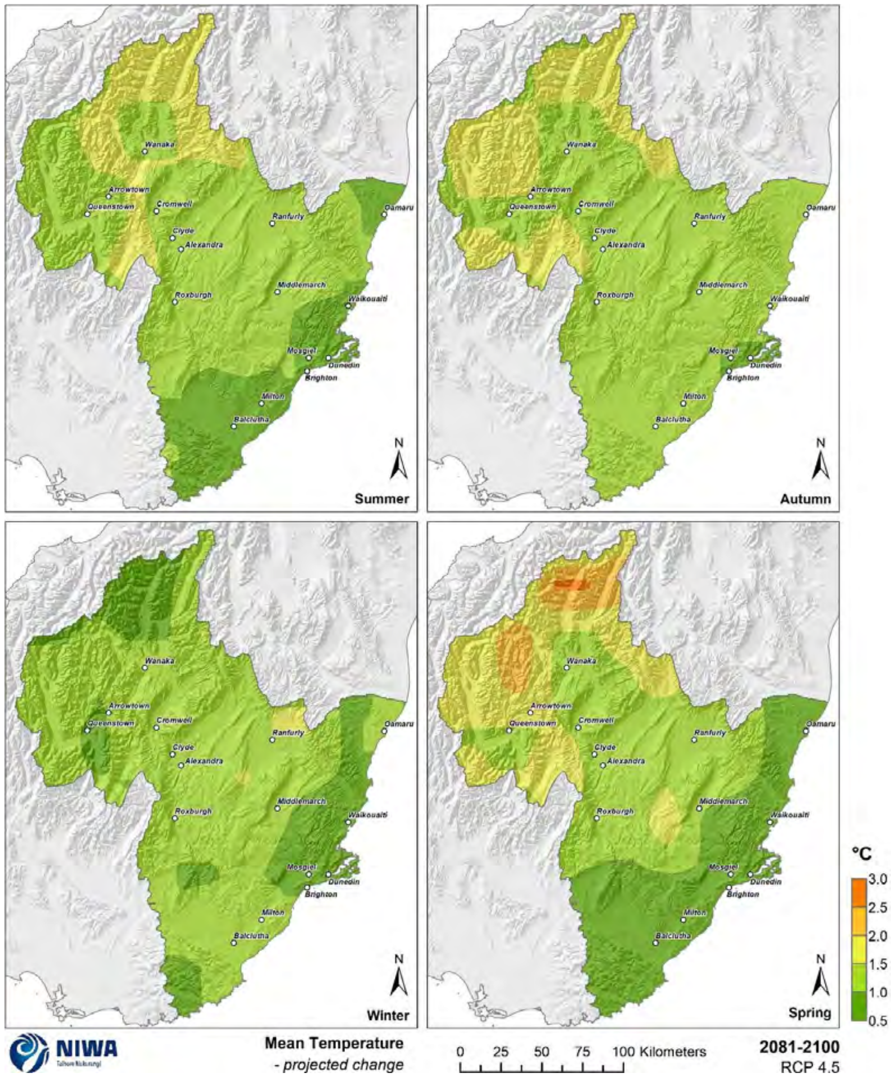

Figure 3-6: Projected seasonal mean temperature changes by 2090 for RCP4.5. Relative to 1986-2005 average, based on the average of six global climate models. Results are based on dynamical downscaled projections using NIWA's Regional Climate Model. Resolution of projection is 5km x 5km.

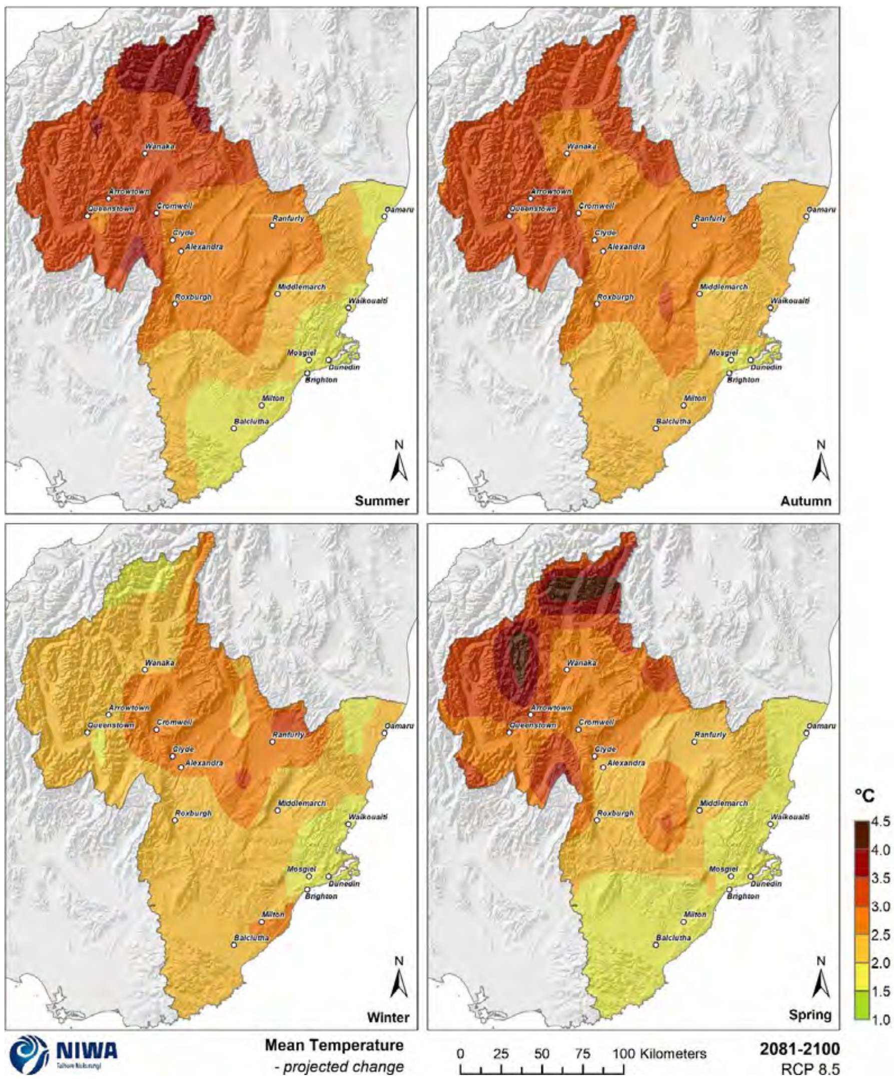

Figure 3-7: Projected seasonal mean temperature changes by 2090 for RCP8.5. Relative to 1986-2005 average, based on the average of six global climate models. Results are based on dynamical downscaled projections using NIWA's Regional Climate Model. Resolution of projection is 5km x 5km.

Table 3-1: Modelled seasonal and annual mean temperature for present and two climate change scenarios (RCP4.5 and RCP8.5) at two future time periods. Time periods: present (1986-2005), mid-century (2031-2050; "2040") and end-century (2081-2100; "2090"); based on the average of six global climate models. Annual ("Ann"); Seasons: summer ("Sum"), autumn ("Aut"), winter ("Win") and spring ("Spr").

	PRESENT				
	Sum	Aut	Win	Spr	Ann
Alexandra	16.9	10.7	4.4	11.4	10.8
Arrowtown	15.0	9.3	3.2	9.1	9.1
Balclutha	14.2	10.3	5.8	10.4	10.2
Brighton	13.1	10.2	6.2	9.6	9.7
Clyde	16.7	10.5	4.1	11.2	10.6
Cromwell	17.5	11.3	4.7	11.8	11.3
Dunedin	13.6	10.6	6.6	10.0	10.2
Middlemarch	14.7	9.8	4.7	10.2	9.8
Milton	14.5	10.5	6.0	10.6	10.4
Mosgiel	14.0	11.1	7.0	10.5	10.6
Oamaru	15.0	10.9	6.3	10.8	10.7
Queenstown	14.8	9.5	3.7	9.4	9.3
Ranfurly	14.7	9.3	3.2	9.7	9.2
Roxburgh	16.3	10.8	5.1	11.3	10.8
Waikouaiti	14.1	10.3	6.0	10.3	10.2
Wanaka	16.9	11.0	4.6	10.9	10.8

		2040					**2090**				
		Sum	Aut	Win	Spr	Ann	Sum	Aut	Win	Spr	Ann
Alexandra	RCP4.5	+0.9	+1.0	+0.7	+0.7	+0.8	+1.3	+1.4	+1.2	+1.2	+1.3
	RCP8.5	+0.9	+1.1	+0.8	+0.8	+0.9	+2.7	+2.9	+2.6	+2.5	+2.7
Arrowtown	RCP4.5	+0.9	+1.0	+0.6	+1.0	+0.9	+1.4	+1.5	+1.0	+1.7	+1.5
	RCP8.5	+1.0	+1.2	+0.7	+1.1	+1.0	+3.2	+3.1	+2.2	+3.3	+3.0
Balclutha	RCP4.5	+0.5	+0.7	+0.6	+0.5	+0.6	+0.8	+1.1	+1.1	+0.9	+1.0
	RCP8.5	+0.5	+0.8	+0.7	+0.6	+0.7	+1.7	+2.2	+2.4	+1.9	+2.1
Brighton	RCP4.5	+0.5	+0.6	+0.6	+0.4	+0.5	+0.8	+0.9	+0.9	+0.7	+0.9
	RCP8.5	+0.5	+0.7	+0.6	+0.5	+0.6	+1.6	+1.9	+1.9	+1.6	+1.8
Clyde	RCP4.5	+0.9	+1.0	+0.7	+0.7	+0.8	+1.3	+1.4	+1.2	+1.2	+1.3
	RCP8.5	+0.9	+1.1	+0.8	+0.8	+0.9	+2.8	+2.9	+2.7	+2.5	+2.7
Cromwell	RCP4.5	+0.9	+1.0	+0.9	+0.8	+0.9	+1.4	+1.4	+1.4	+1.4	+1.4
	RCP8.5	+1.0	+1.1	+1.0	+0.9	+1.0	+3.0	+3.0	+2.8	+2.8	+2.9
Dunedin	RCP4.5	+0.5	+0.6	+0.6	+0.4	+0.5	+0.8	+0.9	+0.9	+0.7	+0.9
	RCP8.5	+0.5	+0.7	+0.6	+0.5	+0.6	+1.6	+1.9	+1.9	+1.6	+1.8
Middlemarch	RCP4.5	+0.7	+0.8	+0.6	+0.6	+0.7	+1.1	+1.2	+1.0	+1.0	+1.1
	RCP8.5	+0.8	+0.9	+0.7	+0.7	+0.8	+2.3	+2.4	+2.2	+2.1	+2.3
Milton	RCP4.5	+0.5	+0.7	+0.7	+0.5	+0.6	+0.8	+1.1	+1.1	+0.9	+1.0
	RCP8.5	+0.5	+0.8	+0.8	+0.6	+0.7	+1.7	+2.3	+2.5	+1.9	+2.1
Mosgiel	RCP4.5	+0.5	+0.6	+0.6	+0.4	+0.5	+0.8	+0.9	+0.9	+0.7	+0.9
	RCP8.5	+0.5	+0.7	+0.6	+0.5	+0.6	+1.6	+1.9	+1.9	+1.6	+1.8
Oamaru	RCP4.5	+0.4	+0.7	+0.7	+0.5	+0.6	+0.8	+1.2	+1.1	+0.8	+1.0
	RCP8.5	+0.5	+0.8	+0.7	+0.6	+0.7	+1.5	+2.2	+2.0	+1.7	+1.9
Queenstown	RCP4.5	+0.9	+1.0	+0.6	+0.8	+0.9	+1.4	+1.5	+1.0	+1.5	+1.4
	RCP8.5	+1.0	+1.1	+0.7	+1.0	+1.0	+3.0	+3.0	+2.1	+2.9	+2.8
Ranfurly	RCP4.5	+0.8	+0.8	+0.9	+0.7	+0.8	+1.2	+1.3	+1.4	+1.2	+1.3
	RCP8.5	+0.8	+1.0	+1.0	+0.8	+0.9	+2.6	+2.6	+2.9	+2.3	+2.6
Roxburgh	RCP4.5	+0.8	+0.9	+0.6	+0.6	+0.8	+1.2	+1.3	+1.1	+1.2	+1.2
	RCP8.5	+0.9	+1.0	+0.8	+0.8	+0.9	+2.7	+2.7	+2.3	+2.4	+2.5
Waikouaiti	RCP4.5	+0.6	+0.8	+0.6	+0.5	+0.6	+1.0	+1.2	+0.9	+0.8	+1.0
	RCP8.5	+0.6	+0.8	+0.6	+0.5	+0.7	+2.0	+2.4	+1.9	+1.8	+2.0
Wanaka	RCP4.5	+1.0	+0.9	+0.7	+0.8	+0.9	+1.5	+1.4	+1.2	+1.4	+1.4
	RCP8.5	+1.1	+1.1	+0.8	+0.9	+1.0	+3.2	+2.9	+2.5	+2.8	+2.9

3.1.1 Model confidence

Key message

- The complete range of model projections (as shown in this section) demonstrate the difference with season and RCP, allowing interpretation of the range of model uncertainty.
- For mean temperature, all models at 2040 project warming, so this direction of change has high certainty.
- By 2090, the model spread is quite large within the scenarios, so the actual value of temperature change is less certain. However, all models for RCP4.5, 6.0 and 8.5 project warming, with higher greenhouse gas concentrations generally projecting more warming.

The climate change projections in other sections of this report show the average of six dynamically downscaled climate models. This is useful as the average is the 'best estimate' of future conditions, but these results taken alone do not allow for communication of uncertainty or range in potential future outcomes within the different scenarios and time periods. This section presents the full range of model results for mean temperature, to help the reader understand that there is no 'single answer' in terms of future projections.

Projected changes in seasonal and annual mean temperature are shown for the Otago region overall in Table 3-2 (i.e. the average of all grid points within Otago). Note that data in this table was derived from additional IPCC Fifth Assessment Report models than are presented in the maps in this report (the maps are the average of six dynamically downscaled models, whereas the data here are from ~40 statistically downscaled models), in order to enable an assessment of the range of temperature change projected for Otago by 2040 and 2090 under RCP4.5 and RCP8.5. The difference between dynamical and statistical downscaling is explained in Appendix A.

Figure 3-8 and Figure 3-9 illustrate the seasonal and annual temperature projections for each RCP, for the two time periods of 2040 and 2090, respectively. The temperature changes are averaged over all grid-points within the Otago region. The coloured vertical bars, and inset stars, show all the individual models, so the complete range is displayed (unlike Table 3-2 where the 5th to 95th percentile range has been calculated). These figures are an excellent way of not only demonstrating the difference between the models for each season and RCP, but also the range of model sensitivity (i.e. how the different models predict future conditions under the same scenarios/greenhouse gas concentrations). The closer together the model outcomes are, it can be inferred that these projections have more certainty. The black stars within each vertical bar represent the results of the six RCM simulations selected for presentation in this report.

For 2040 projections (Figure 3-8 and Table 3-2), the average of all the models is similar between the different scenarios, indicated in the table and by the horizontal black line on each bar in the figure (averages between 0.7 and 1.0°C). The average projection for RCP8.5 is higher than the other RCPs. However, the range of model results for each scenario is quite different as seen by the size of the coloured bars and the numbers inside the parentheses in the table – some models project close to 0°C change under RCP2.6 and others over 2°C increase under RCP8.5. Although the models project a range of different outcomes, all the projections are for increases in temperature (i.e. >0°C) so there is high confidence that ongoing warming will be observed to the mid-century period.

For 2090 projections (Figure 3-9 and Table 3-2), there is a much larger range of model results within and between scenarios, indicated by the length of the coloured bars in the figure and the numbers in parentheses in the table. The average mean temperature of all the models (seasonal and annual), indicated by the horizontal black line, is also quite different between the scenarios (around 0.5°C for RCP2.6 for all seasons and annual, and around 2.5-3°C for RCP8.5 for all seasons and annual). This is a response of the models to the different greenhouse gas concentrations under each scenario by 2090 compared with similar concentrations between scenarios at 2040. The differences between the model results in the same scenario by 2090 indicates that there is less certainty about the actual value of projected temperatures by this time period. However, for RCP4.5, 6.0 and 8.5, all models project warming, so there is a high degree of certainty that warming will continue under those scenarios, and that higher greenhouse gas concentrations will result in more warming. For RCP2.6, one or two models project cooling by 2090, indicating that 2090 temperatures under this scenario are less certain whether it will be warmer or cooler than present, or about the same.

Table 3-2: Projected changes in seasonal and annual mean temperature (°C) between 1986-2005 and two climate change scenarios (RCP4.5 and RCP8.5) at two future time periods for Otago. Time periods: mid-century (2031-2050; "2040") and end-century (2081-2100; "2090"). The values in each column represent the ensemble average, taken over 41 models (RCP8.5) and 37 models (RCP4.5). Bracketed values represent the range (5th percentile to 95th percentile) over all models within that ensemble. Changes averaged over the Otago region.

		Summer	Autumn	Winter	Spring	Annual
2040	RCP8.5	0.9 (0.3, 1.7)	1.0 (0.6, 1.5)	1.1 (0.7, 1.5)	0.8 (0.3, 1.3)	0.9 (0.6, 1.5)
	RCP4.5	0.8 (0.2, 1.4)	0.8 (0.3, 1.3)	0.9 (0.6, 1.4)	0.7 (0.3, 1.1)	0.8 (0.4, 1.2)
2090	RCP8.5	2.9 (1.8, 4.6)	2.9 (2.0, 4.3)	3.1 (2.3, 4.2)	2.5 (1.7, 3.4)	2.8 (2.1, 4.0)
	RCP4.5	1.2 (0.6, 2.6)	1.3 (0.8, 2.1)	1.5 (0.8, 2.2)	1.1 (0.6, 1.8)	1.3 (0.8, 2.1)

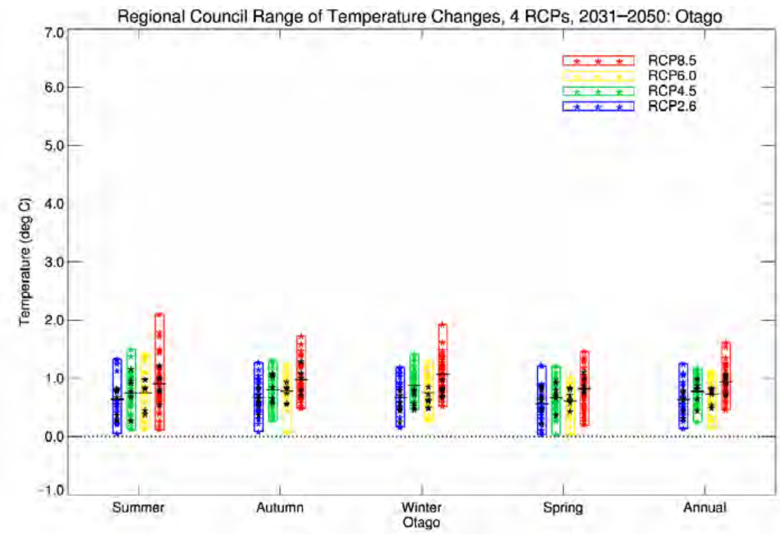

Figure 3-8: Projected seasonal and annual mean temperature change for Otago by 2040 (2031-2050). Coloured stars represent all models as derived by statistical downscaling. Black stars correspond to the six-model RCM-downscaling, and the horizontal bars are the average over all downscaled results (statistical and RCM).

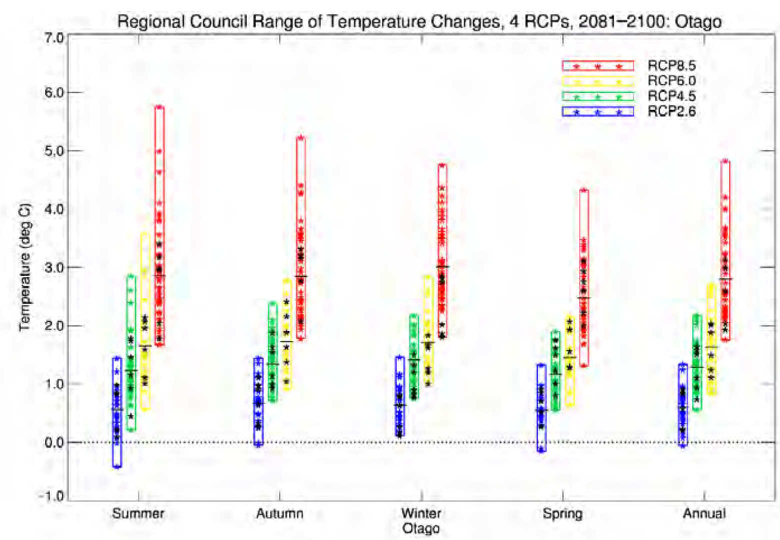

Figure 3-9: Projected seasonal and annual mean temperature change for Otago by 2090 (2081-2100). Coloured stars represent all models as derived by statistical downscaling. Black stars correspond to the six-model RCM-downscaling, and the horizontal bars are the average over all downscaled results (statistical and RCM).

3.2 Maximum temperature

Key messages

- Annual mean maximum temperature is projected to increase by 0.5-1.5°C by 2040 under RCP4.5 and RCP8.5.
- By 2090, annual mean maximum temperature increases of 1.0-2.0°C (RCP4.5) and 2.0-4.0°C (RCP8.5) are projected.
- Central and western parts of Otago are projected to observe a 4.0-5.0°C increase in summer mean maximum temperatures by 2090 under RCP8.5.

Maximum temperatures are generally recorded in the afternoon, and therefore are known as daytime temperatures. Present-day (average over 1986-2005) and future (average over 2031-2050 and 2081-2100) maps for mean maximum temperature are shown in this section. The present-day maps show annual and seasonal mean maximum temperature in units of degrees Celsius (°C) and the future projection maps show the change in mean temperature compared with the present day, in units of °C. Note that the present-day maps are on a different colour scale to the future projection maps.

Annual mean maximum temperatures range between 14-16°C for most coastal locations of Otago, compared to 16-18°C for much of the inland basins of Central and western Otago (Figure 3-10). For coastal areas of Otago, summer mean maximum temperatures range between 18-20°C, and winter mean maximum temperatures range between 10-12°C (Figure 3-12). For inland low-elevation locations, summer mean maximum temperatures range between 22-24°C, and winter mean maximum temperatures range between 8-10°C.

Annual mean maximum temperature is projected to increase by 0.5-1.5°C by 2040 under RCP4.5 and RCP8.5 (Figure 3-11). By 2090, annual mean maximum temperature increases of 1.0-2.0°C (RCP4.5) and 2.0-4.0°C (RCP8.5) are projected. Seasonal projections of mean maximum temperature change are shown for RCP4.5 by 2040 (Figure 3-13) and 2090 (Figure 3-15), and RCP8.5 by 2040 (Figure 3-14) and 2090 (Figure 3-16). By 2040 under RCP4.5, seasonal mean maximum temperatures are projected to increase by 0.5-1.5°C across much of Otago, and by 0.5-2.5°C under RCP8.5. By 2090 under RCP4.5, seasonal mean maximum temperatures are projected to increase by 1.0-3.0°C for most of Otago. Under RCP8.5 by 2090, seasonal mean maximum temperatures are projected to increase by 2.0-4.0°C for much of Otago. Notably, central and western parts of the region are projected to observe a 4.0-5.0°C increase in summer mean maximum temperatures by 2090 under RCP8.5.

Modelled seasonal and annual mean maximum temperature data have been generated for 16 Otago locations, and these are presented in Table 3-3.

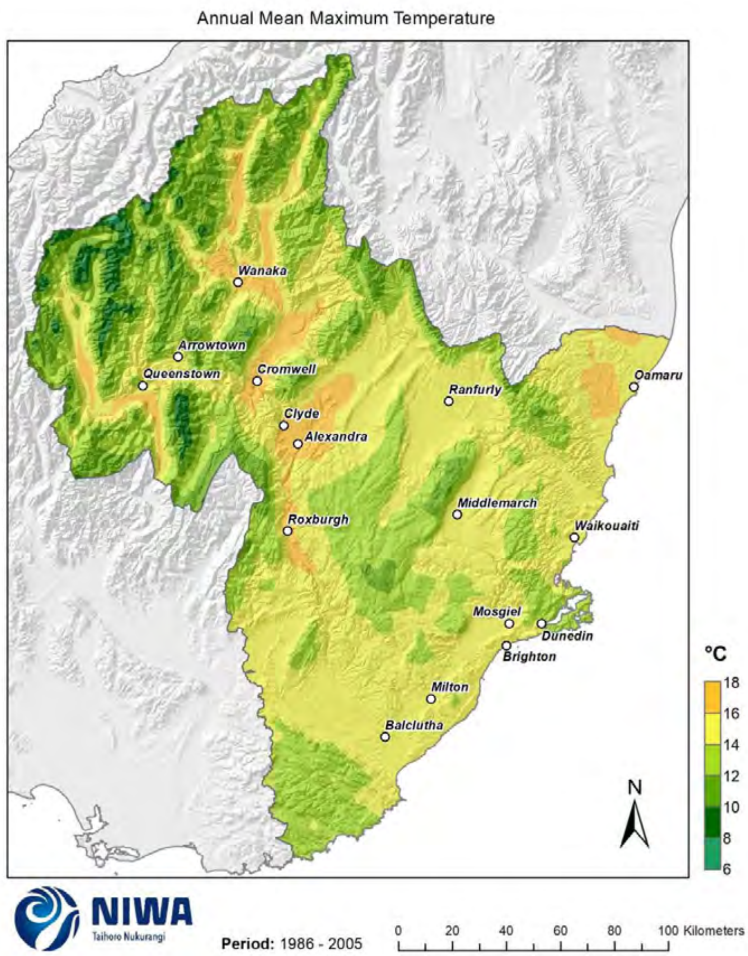

Figure 3-10: Modelled annual mean maximum temperature, average over 1986-2005. Results are based on dynamical downscaled projections using NIWA's Regional Climate Model. Resolution of projection is 5km x 5km.

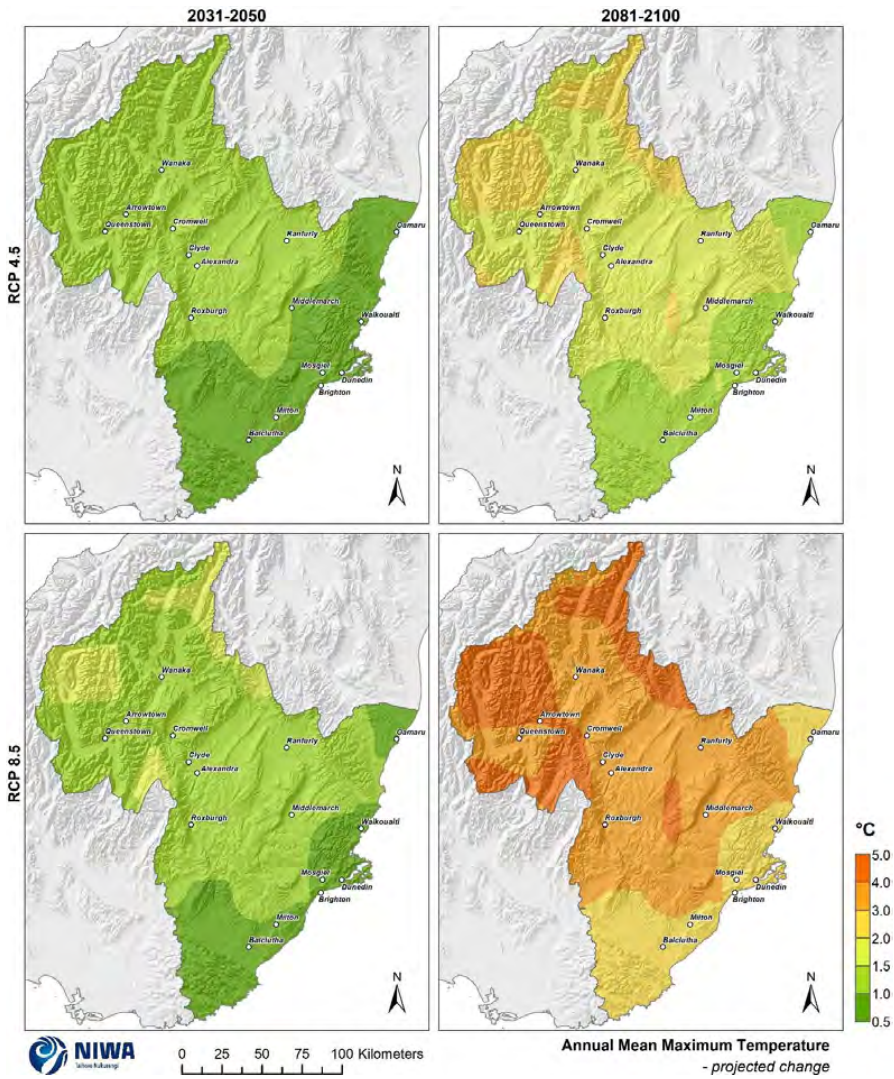

Figure 3-11: Projected annual mean maximum temperature changes by 2040 and 2090, under RCP4.5 and RCP8.5. Climate change scenarios: RCP4.5 (top panels) and RCP8.5 (bottom panels). Time periods: mid-century (2031-2050; "2040" – panels on left) and end-century (2081-2100; "2090" – panels on right). Changes relative to 1986-2005 average, based on the average of six global climate models. Results are based on dynamical downscaled projections using NIWA's Regional Climate Model. Resolution of projection is 5km x 5km.

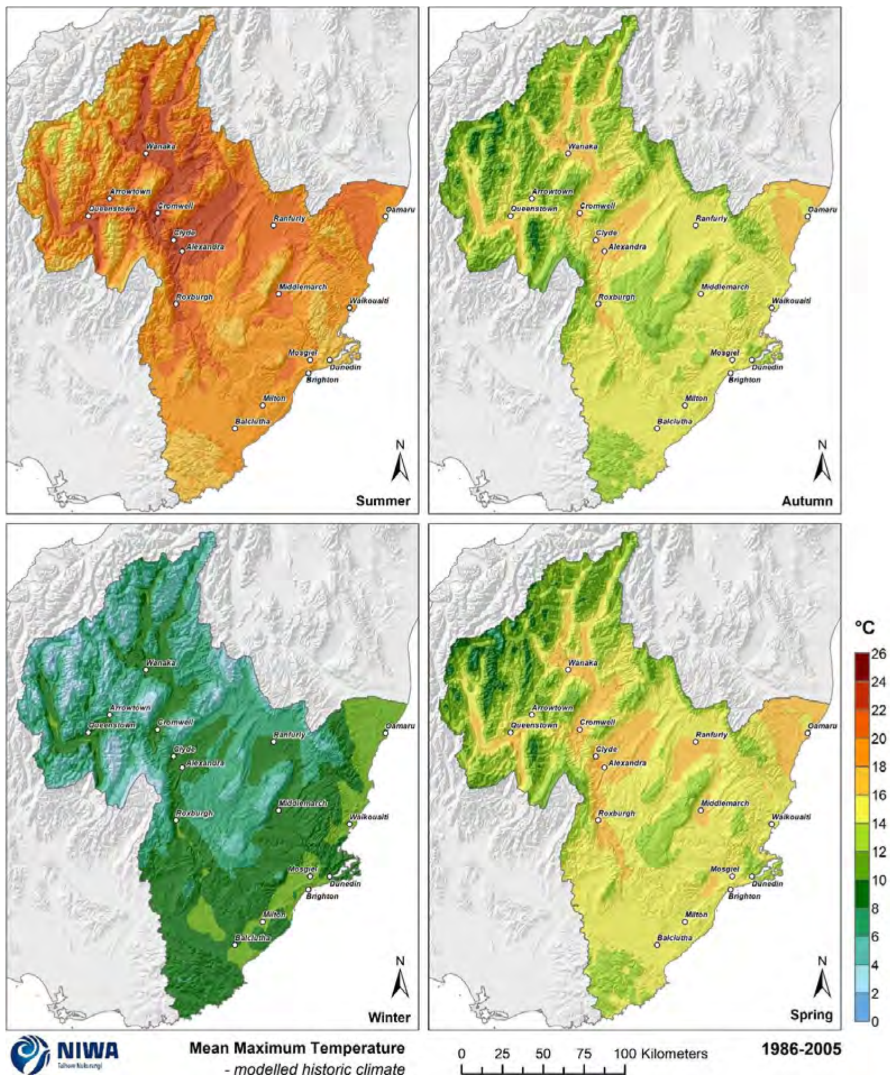

Figure 3-12: Modelled seasonal mean maximum temperature, average over 1986-2005. Results are based on dynamical downscaled projections using NIWA's Regional Climate Model. Resolution of projection is 5km x 5km.

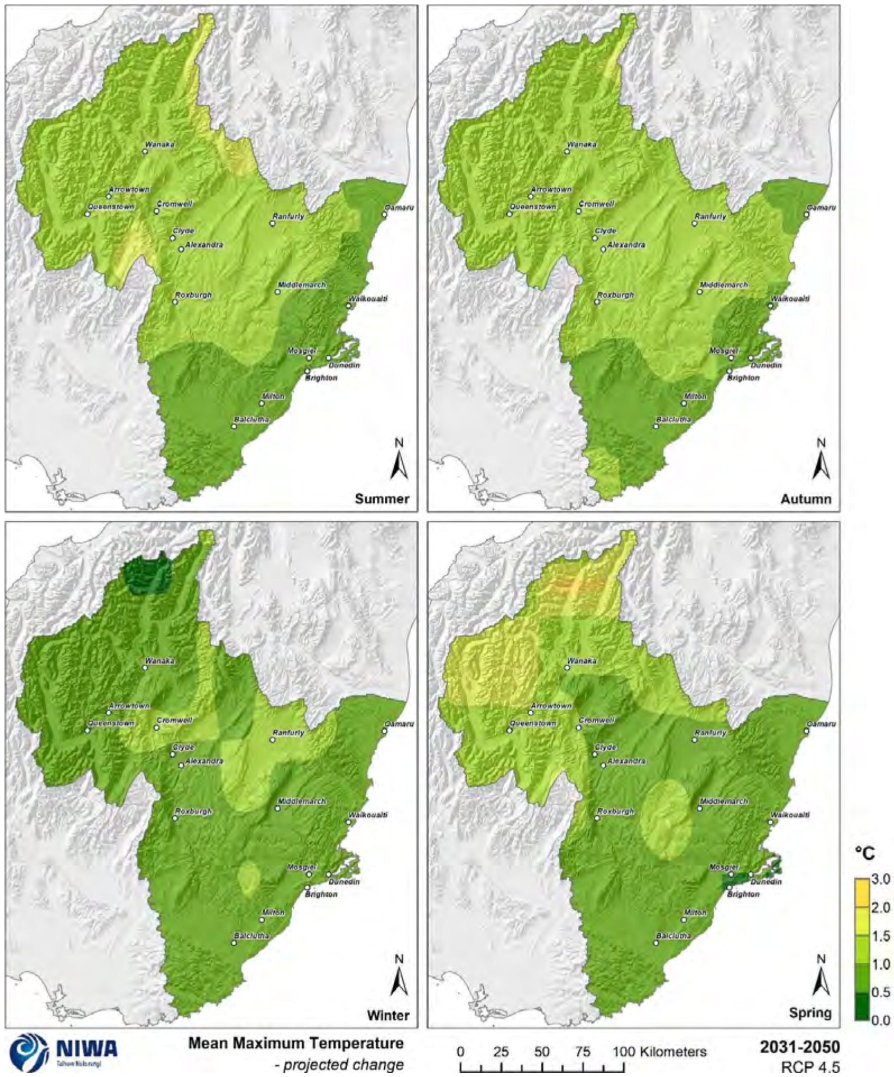

Figure 3-13: Projected seasonal mean maximum temperature changes by 2040 for RCP4.5. Relative to 1986-2005 average, based on the average of six global climate models. Results are based on dynamical downscaled projections using NIWA's Regional Climate Model. Resolution of projection is 5km x 5km.

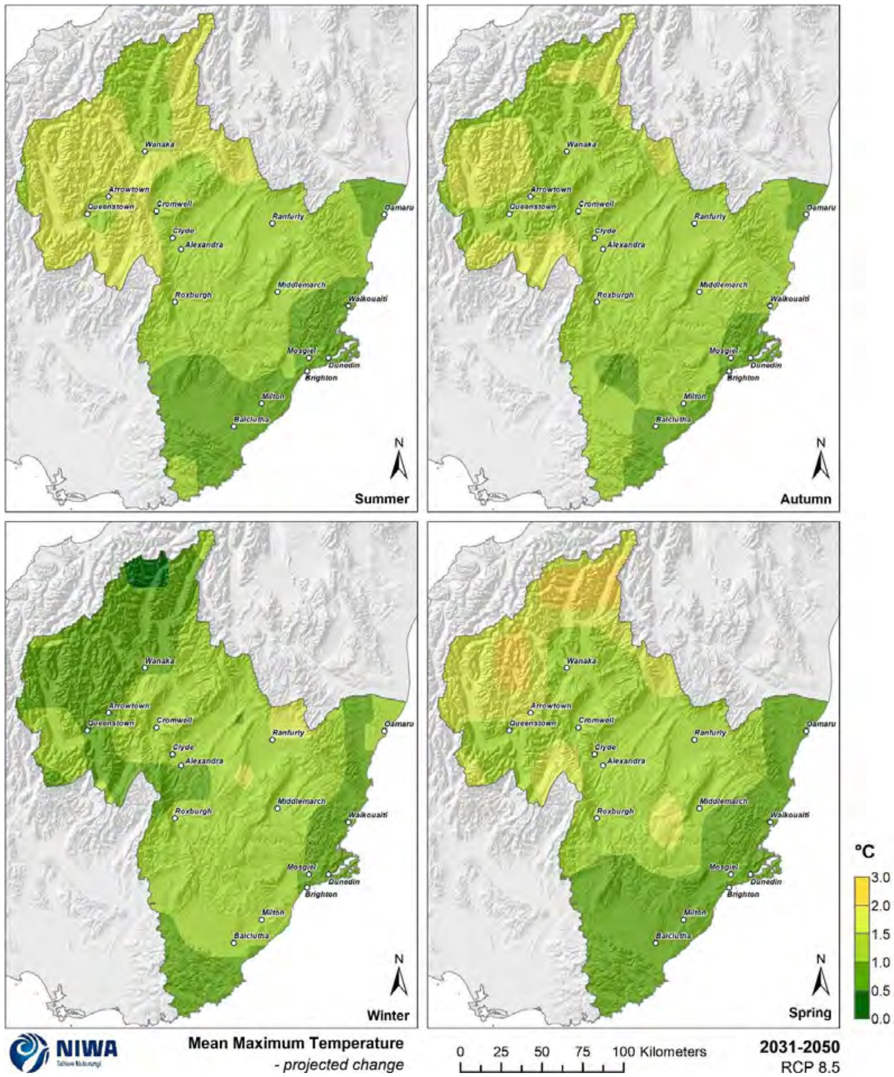

Figure 3-14: Projected seasonal mean maximum temperature changes by 2040 for RCP8.5. Relative to 1986-2005 average, based on the average of six global climate models. Results are based on dynamical downscaled projections using NIWA's Regional Climate Model. Resolution of projection is 5km x 5km.

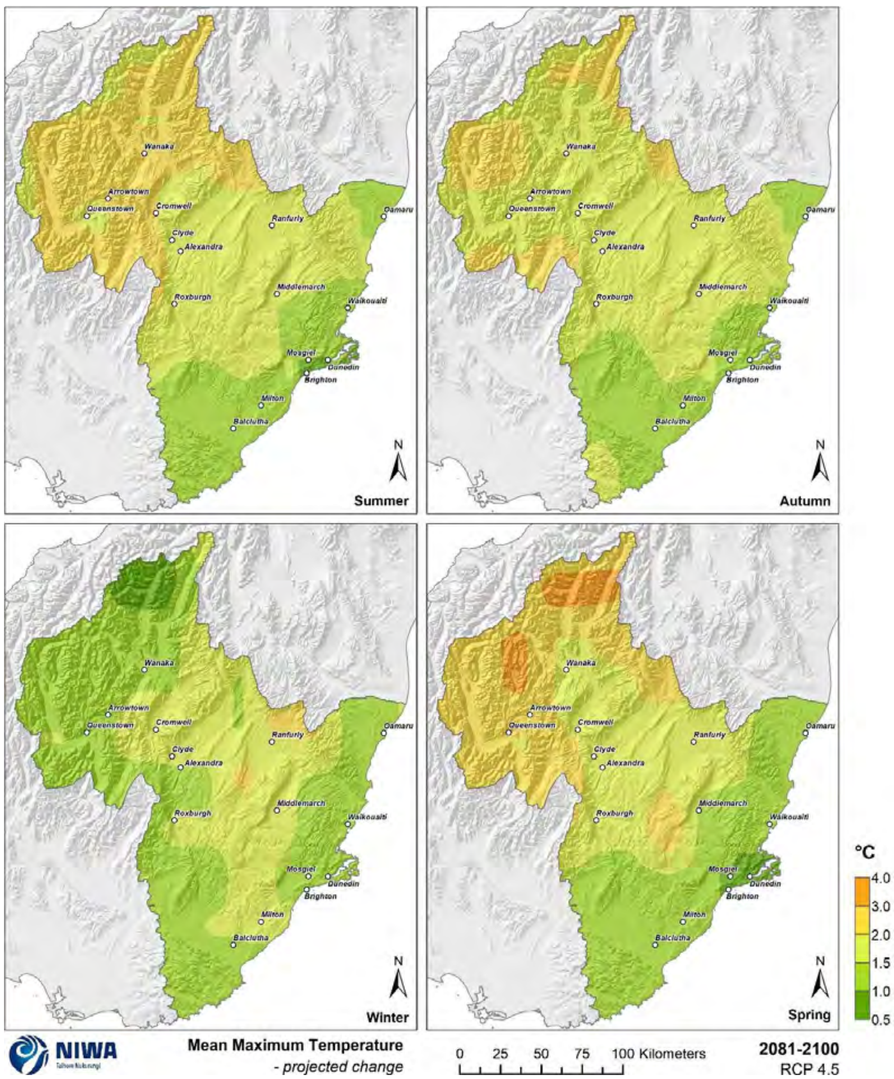

Figure 3-15: Projected seasonal mean maximum temperature changes by 2090 for RCP4.5. Relative to 1986-2005 average, based on the average of six global climate models. Results are based on dynamical downscaled projections using NIWA's Regional Climate Model. Resolution of projection is 5km x 5km.

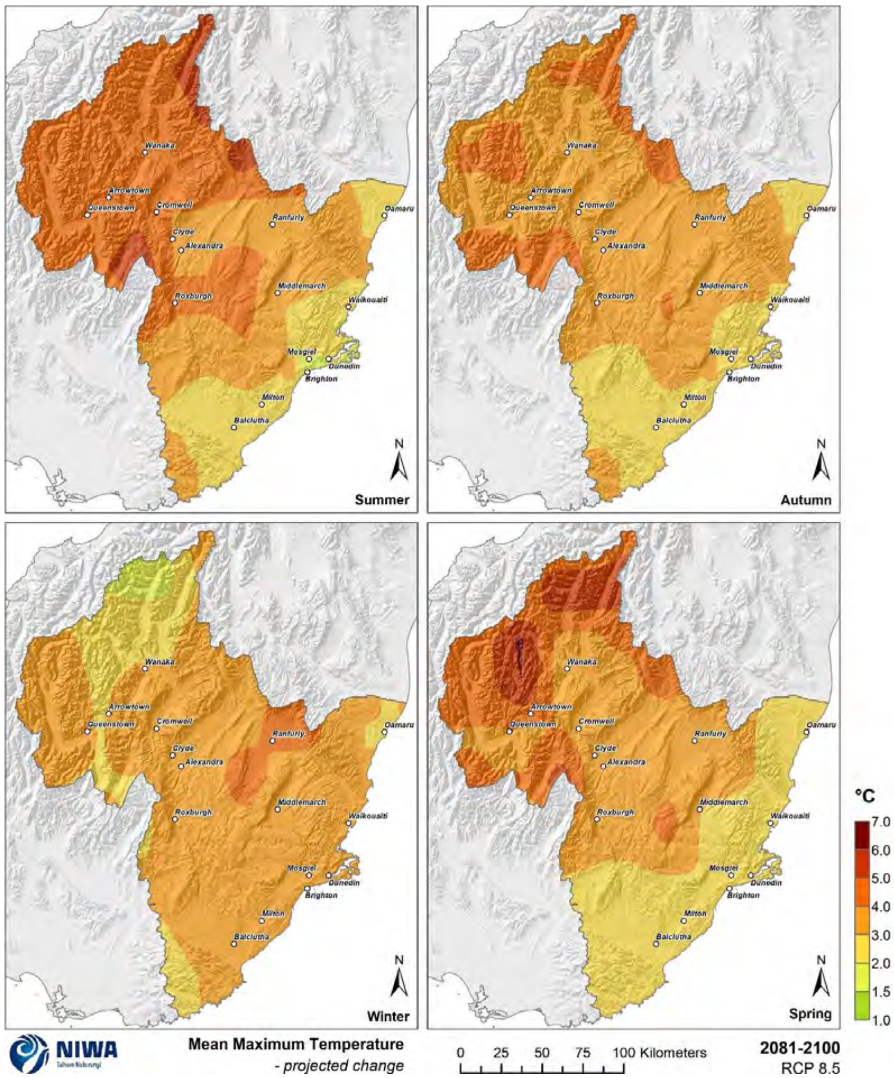

Figure 3-16: Projected seasonal mean maximum temperature changes by 2090 for RCP8.5. Relative to 1986-2005 average, based on the average of six global climate models. Results are based on dynamical downscaled projections using NIWA's Regional Climate Model. Resolution of projection is 5km x 5km.

Table 3-3: Modelled seasonal and annual mean maximum temperature for present and two climate change scenarios (RCP4.5 and RCP8.5) at two future time periods. Time periods: present (1986-2005), mid-century (2031-2050; "2040") and end-century (2081-2100; "2090"); based on the average of six global climate models. Annual ("Ann"); Seasons: summer ("Sum"), autumn ("Aut"), winter ("Win") and spring ("Spr").

	PRESENT				
	Sum	Aut	Win	Spr	Ann
Alexandra	23.9	17.2	9.5	17.9	17.1
Arrowtown	21.0	14.5	7.4	14.2	14.2
Balclutha	19.2	15.1	9.9	15.3	14.9
Brighton	17.8	14.8	10.2	14.3	14.3
Clyde	23.6	16.9	9.1	17.5	16.7
Cromwell	24.4	17.6	9.5	18.0	17.3
Dunedin	17.7	14.7	10.2	14.3	14.2
Middlemarch	21.3	15.9	9.9	16.4	15.8
Milton	19.6	15.5	10.3	15.7	15.3
Mosgiel	18.9	16.0	11.4	15.5	15.4
Oamaru	19.7	15.9	11.3	15.9	15.7
Queenstown	20.8	14.6	7.7	14.6	14.4
Ranfurly	21.6	15.5	8.3	16.1	15.3
Roxburgh	22.9	16.9	10.1	17.8	16.9
Waikouaiti	18.7	15.1	10.4	15.1	14.8
Wanaka	23.2	16.4	9.0	16.5	16.3

		2040					2090				
		Sum	Aut	Win	Spr	Ann	Sum	Aut	Win	Spr	Ann
Alexandra	RCP4.5	+1.3	+1.2	+0.9	+0.9	+1.1	+1.9	+1.7	+1.5	+1.6	+1.7
	RCP8.5	+1.3	+1.3	+1.0	+1.1	+1.2	+4.0	+3.5	+3.6	+3.3	+3.6
Arrowtown	RCP4.5	+1.3	+1.3	+0.7	+1.4	+1.2	+2.0	+1.9	+1.3	+2.5	+2.0
	RCP8.5	+1.5	+1.5	+0.8	+1.7	+1.4	+4.6	+3.9	+3.0	+4.7	+4.1
Balclutha	RCP4.5	+0.7	+0.9	+0.9	+0.6	+0.8	+1.2	+1.4	+1.5	+1.2	+1.3
	RCP8.5	+0.8	+1.0	+1.1	+0.8	+0.9	+2.5	+2.7	+3.3	+2.5	+2.8
Brighton	RCP4.5	+0.6	+0.7	+0.9	+0.5	+0.7	+1.0	+1.1	+1.4	+0.9	+1.1
	RCP8.5	+0.7	+0.8	+1.0	+0.7	+0.8	+2.0	+2.2	+3.1	+2.1	+2.4
Clyde	RCP4.5	+1.3	+1.2	+0.9	+0.9	+1.1	+1.8	+1.7	+1.6	+1.7	+1.7
	RCP8.5	+1.3	+1.3	+1.1	+1.1	+1.2	+4.0	+3.5	+3.7	+3.4	+3.7
Cromwell	RCP4.5	+1.4	+1.2	+1.1	+1.0	+1.2	+2.0	+1.8	+1.8	+1.9	+1.9
	RCP8.5	+1.4	+1.4	+1.2	+1.3	+1.4	+4.3	+3.6	+3.9	+3.7	+3.9
Dunedin	RCP4.5	+0.6	+0.7	+0.9	+0.5	+0.7	+1.0	+1.1	+1.4	+0.9	+1.1
	RCP8.5	+0.7	+0.8	+1.0	+0.7	+0.8	+2.0	+2.2	+3.1	+2.1	+2.4
Middlemarch	RCP4.5	+1.1	+1.0	+0.9	+0.8	+1.0	+1.6	+1.6	+1.6	+1.4	+1.6
	RCP8.5	+1.1	+1.2	+1.1	+1.1	+1.1	+3.3	+3.2	+3.5	+3.0	+3.3
Milton	RCP4.5	+0.7	+0.9	+0.9	+0.7	+0.8	+1.2	+1.4	+1.5	+1.2	+1.3
	RCP8.5	+0.8	+1.0	+1.1	+0.9	+1.0	+2.5	+2.8	+3.4	+2.6	+2.9
Mosgiel	RCP4.5	+0.6	+0.7	+0.9	+0.5	+0.7	+1.0	+1.1	+1.4	+0.9	+1.1
	RCP8.5	+0.7	+0.8	+1.0	+0.7	+0.8	+2.0	+2.2	+3.1	+2.1	+2.4
Oamaru	RCP4.5	+0.6	+0.9	+0.9	+0.6	+0.8	+1.1	+1.3	+1.5	+1.0	+1.2
	RCP8.5	+0.7	+1.0	+1.0	+0.8	+0.9	+2.1	+2.6	+3.0	+2.1	+2.5
Queenstown	RCP4.5	+1.3	+1.2	+0.9	+1.2	+1.2	+2.0	+1.9	+1.4	+2.1	+1.9
	RCP8.5	+1.5	+1.5	+0.9	+1.4	+1.3	+4.4	+3.9	+3.1	+4.0	+3.9
Ranfurly	RCP4.5	+1.2	+1.1	+1.2	+0.9	+1.1	+1.8	+1.7	+1.9	+1.7	+1.8
	RCP8.5	+1.3	+1.2	+1.4	+1.2	+1.3	+3.8	+3.5	+4.1	+3.3	+3.7
Roxburgh	RCP4.5	+1.2	+1.1	+0.9	+0.9	+1.1	+1.9	+1.6	+1.5	+1.6	+1.7
	RCP8.5	+1.3	+1.2	+1.1	+1.1	+1.2	+4.1	+3.4	+3.4	+3.3	+3.6
Waikouaiti	RCP4.5	+0.8	+1.0	+0.9	+0.7	+0.8	+1.3	+1.5	+1.4	+1.1	+1.4
	RCP8.5	+0.9	+1.0	+1.0	+0.8	+0.9	+2.7	+3.0	+3.1	+2.5	+2.8
Wanaka	RCP4.5	+1.4	+1.1	+0.8	+1.0	+1.1	+2.0	+1.7	+1.4	+1.9	+1.8
	RCP8.5	+1.5	+1.3	+1.0	+1.3	+1.3	+4.5	+3.5	+3.1	+3.7	+3.7

3.3 Minimum temperature

Key messages

- Annual mean minimum temperature is projected to increase by between 0-1.0°C by 2040 under RCP4.5 and RCP8.5.
- By 2090, annual mean minimum temperature increases of 0.5-1.0°C (RCP4.5) and 1.0-2.0°C (RCP8.5) are projected.
- Seasonal mean minimum temperatures are projected to increase by 0.5-2.5°C for much of Otago (by 2090 under RCP8.5).
- Projected increases in mean minimum temperatures are not as high as increases in mean maximum temperatures, leading to a projected increase in the diurnal temperature range.

Minimum temperatures are generally recorded in the early hours of the morning, and therefore are known as night time temperatures. Present-day (average over 1986-2005) and future (average over 2031-2050 and 2081-2100) maps for mean minimum temperature are shown in this section. The present-day maps show annual and seasonal mean minimum temperature in units of degrees Celsius (°C) and the future projection maps show the change in mean minimum temperature compared with the present day, in units of °C. Note that the present-day maps are on a different colour scale to the future projection maps.

Annual mean minimum temperatures range between 2-6°C for most low-elevation locations of Otago, with lowest annual mean minimum temperatures observed in mountainous terrain (Figure 3-17). For coastal areas of Otago, summer mean minimum temperatures range between 8-10°C, and winter mean minimum temperatures range between 0-4°C (Figure 3-19). For inland low-elevation locations, summer mean minimum temperatures range between 6-10°C, and winter mean minimum temperatures range from just below freezing (-2°C) to just above freezing (2°C).

Annual mean minimum temperature is projected to increase by between 0-1.0°C by 2040 under RCP4.5 and RCP8.5 (Figure 3-18). By 2090, annual mean minimum temperature increases of 0.5-1.0°C (RCP4.5) and 1.0-2.0°C (RCP8.5) are projected. Seasonal projections of mean minimum temperature change are shown for RCP4.5 by 2040 (Figure 3-20) and 2090 (Figure 3-22), and RCP8.5 by 2040 (Figure 3-21) and 2090 (Figure 3-23). By 2040 under RCP4.5 and RCP8.5, seasonal mean minimum temperatures are projected to increase by between 0-1.0°C across Otago, with the larger increases expected inland. By 2090 under RCP4.5, seasonal mean minimum temperatures are projected to increase by 0.5-1.0°C for most of Otago, and up to 1.5°C inland. Under RCP8.5, seasonal mean minimum temperatures are projected to increase by 0.5-2.5°C for much of Otago, with larger increases up to 3°C at high elevations. Notably, increases in mean minimum temperatures are not projected to be as high as increases in mean maximum temperatures, leading to a projected increase in the diurnal temperature range (i.e. the difference in temperature between daytime and night time temperature).

Modelled seasonal and annual mean minimum temperature data have been generated for 16 Otago locations, and these are presented in Table 3-4.

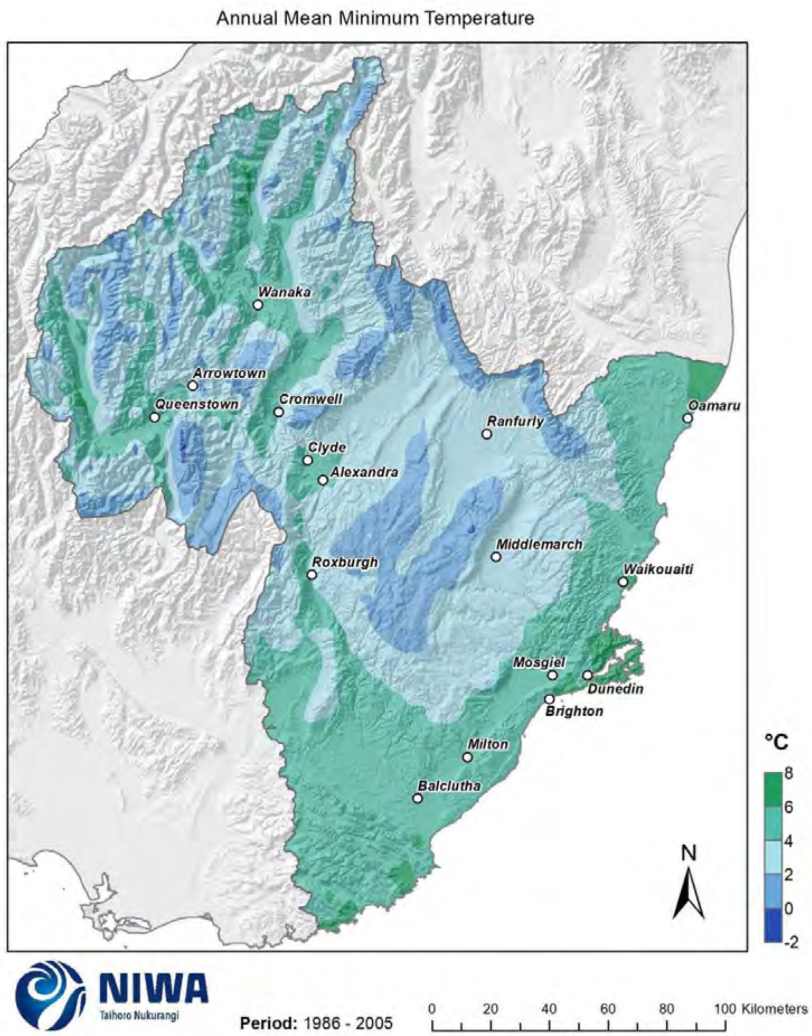

Figure 3-17: Modelled annual mean minimum temperature, average over 1986-2005. Results are based on dynamical downscaled projections using NIWA's Regional Climate Model. Resolution of projection is 5km x 5km.

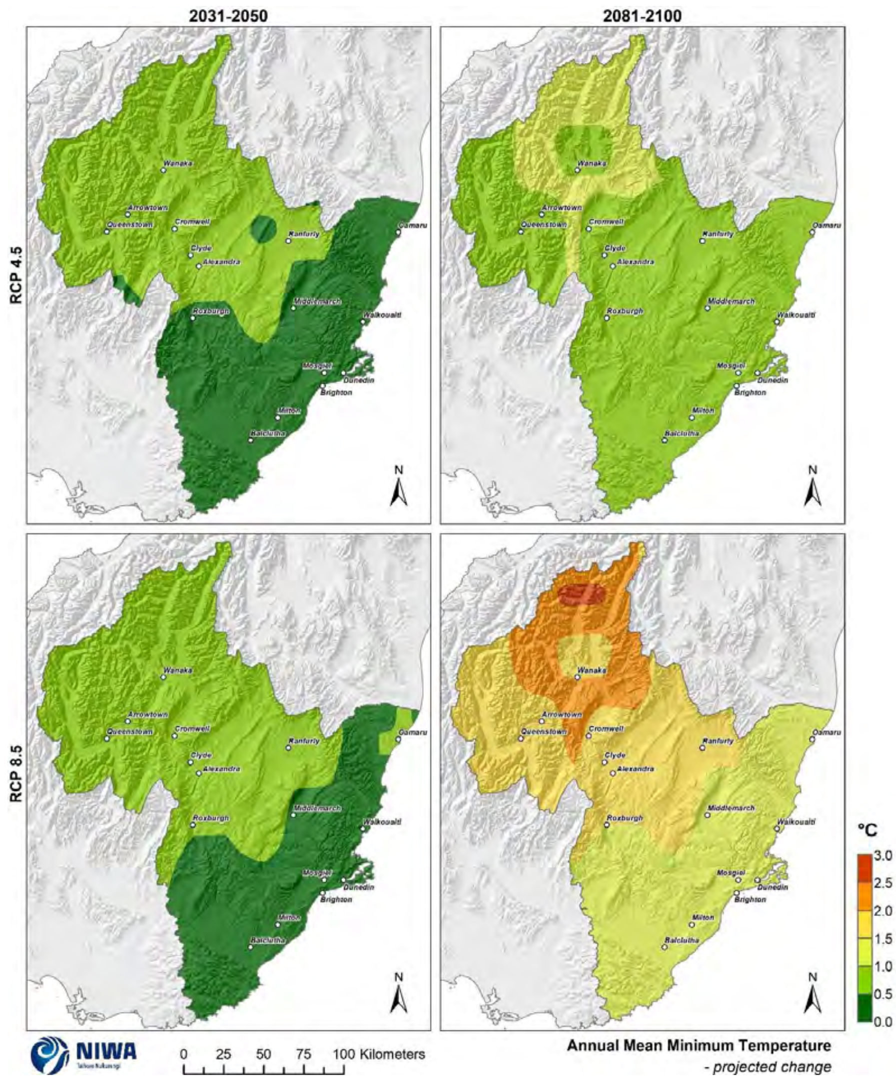

Figure 3-18: Projected annual mean minimum temperature changes by 2040 and 2090, under RCP4.5 and RCP8.5. Climate change scenarios: RCP4.5 (top panels) and RCP8.5 (bottom panels). Time periods: mid-century (2031-2050; "2040" – panels on left) and end-century (2081-2100; "2090" – panels on right). Changes relative to 1986-2005 average, based on the average of six global climate models. Results are based on dynamical downscaled projections using NIWA's Regional Climate Model. Resolution of projection is 5km x 5km.

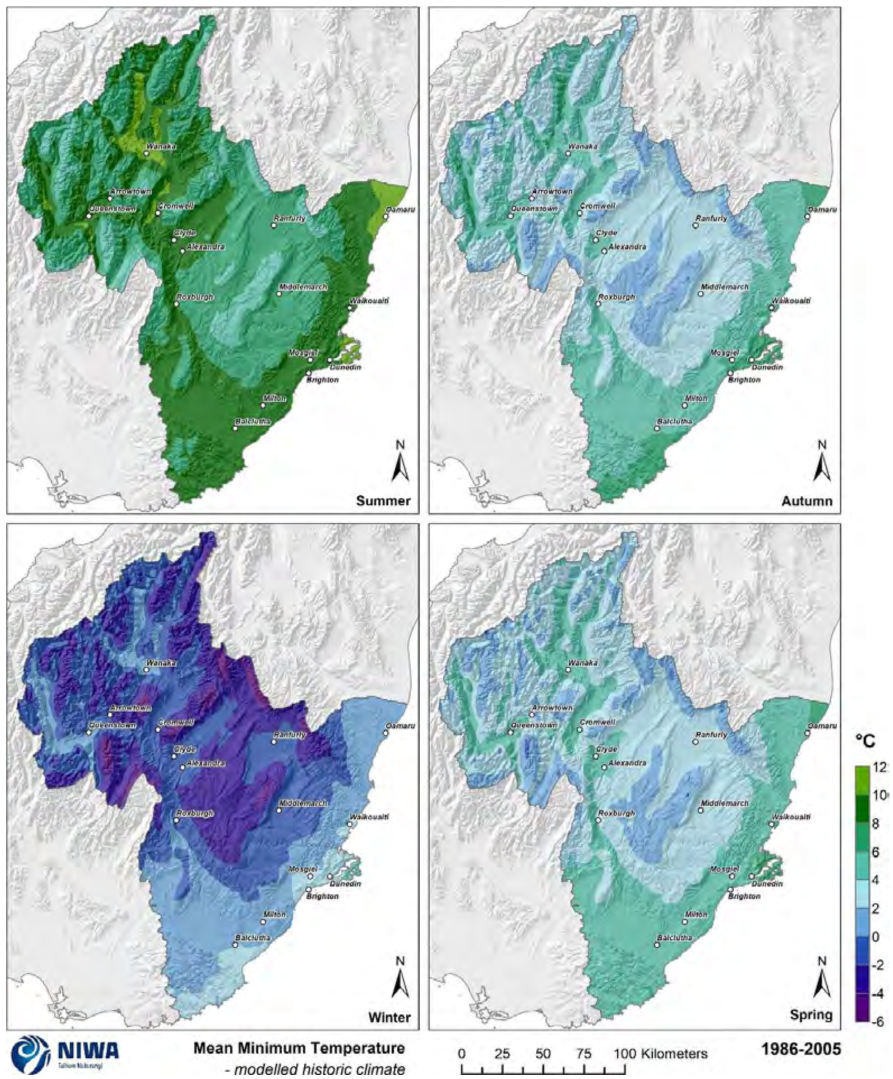

Figure 3-19: Modelled seasonal mean minimum temperature, average over 1986-2005. Results are based on dynamical downscaled projections using NIWA's Regional Climate Model. Resolution of projection is 5km x 5km.

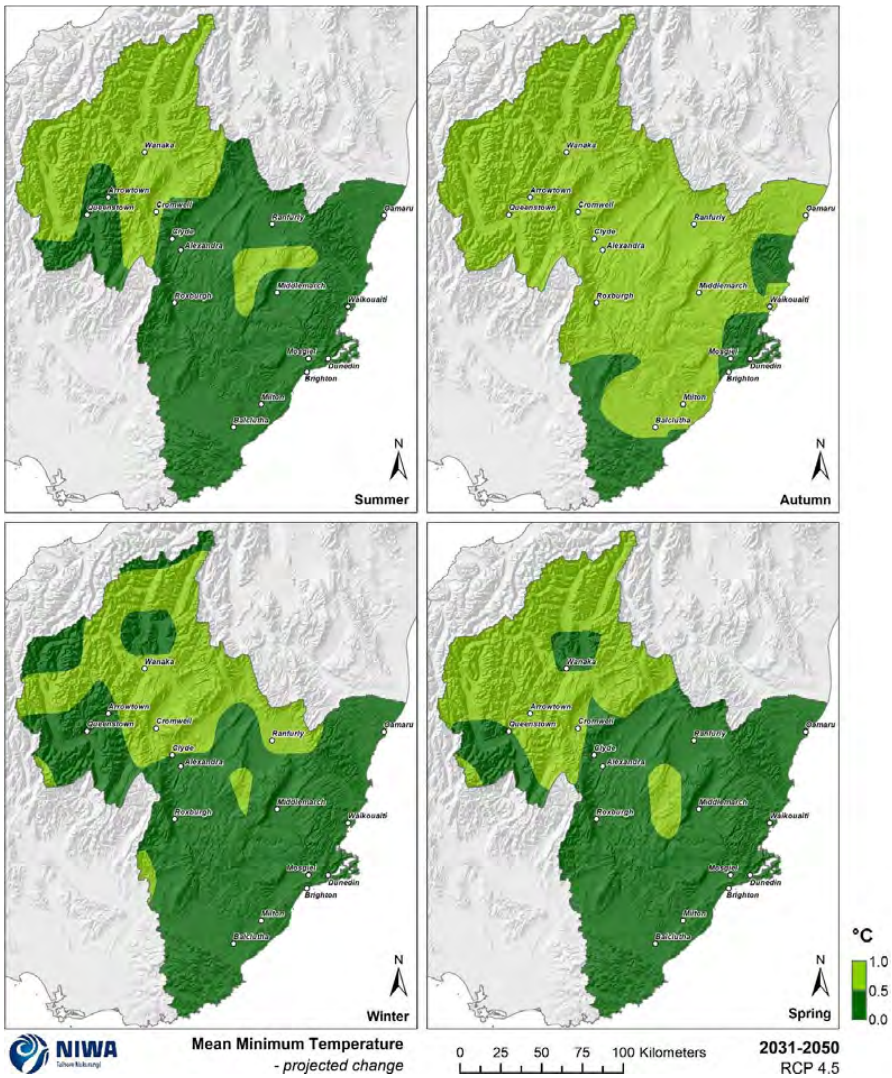

Figure 3-20: Projected seasonal mean minimum temperature changes by 2040 for RCP4.5. Relative to 1986-2005 average, based on the average of six global climate models. Results are based on dynamical downscaled projections using NIWA's Regional Climate Model. Resolution of projection is 5km x 5km.

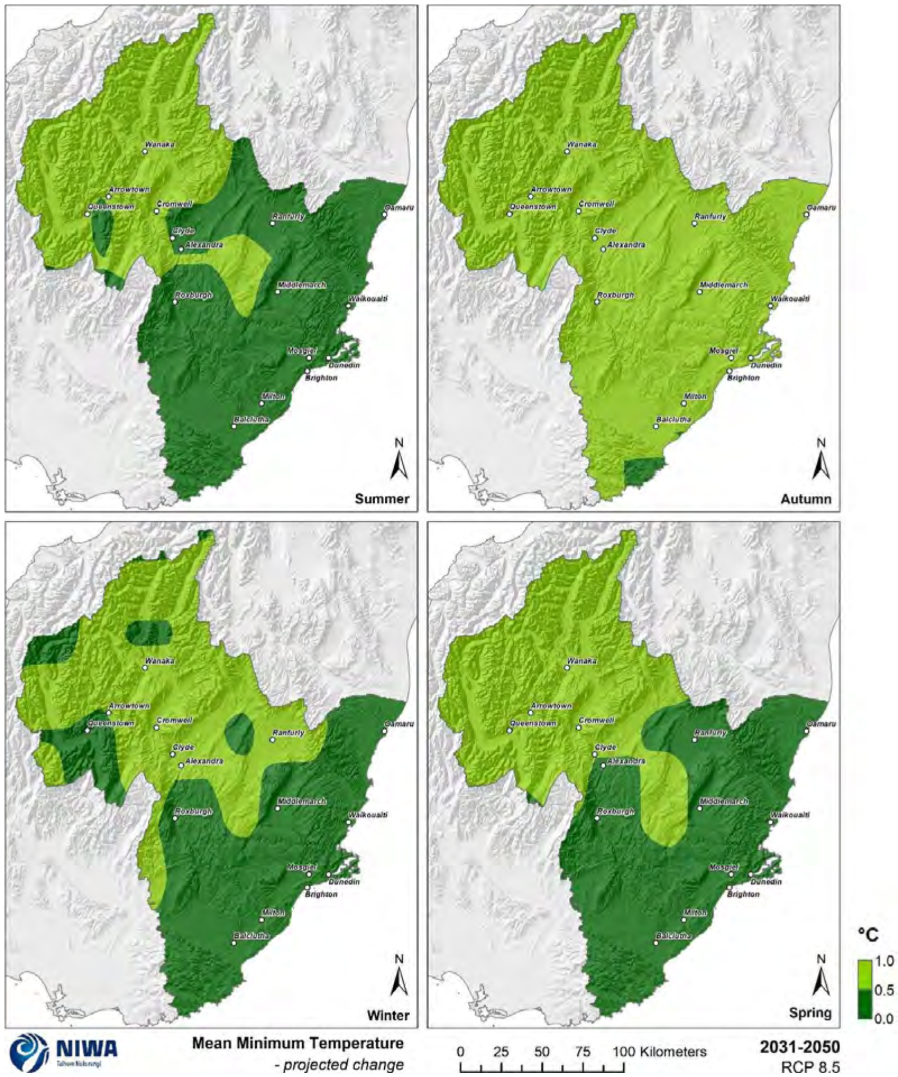

Figure 3-21: Projected seasonal mean minimum temperature changes by 2040 for RCP8.5. Relative to 1986-2005 average, based on the average of six global climate models. Results are based on dynamical downscaled projections using NIWA's Regional Climate Model. Resolution of projection is 5km x 5km.

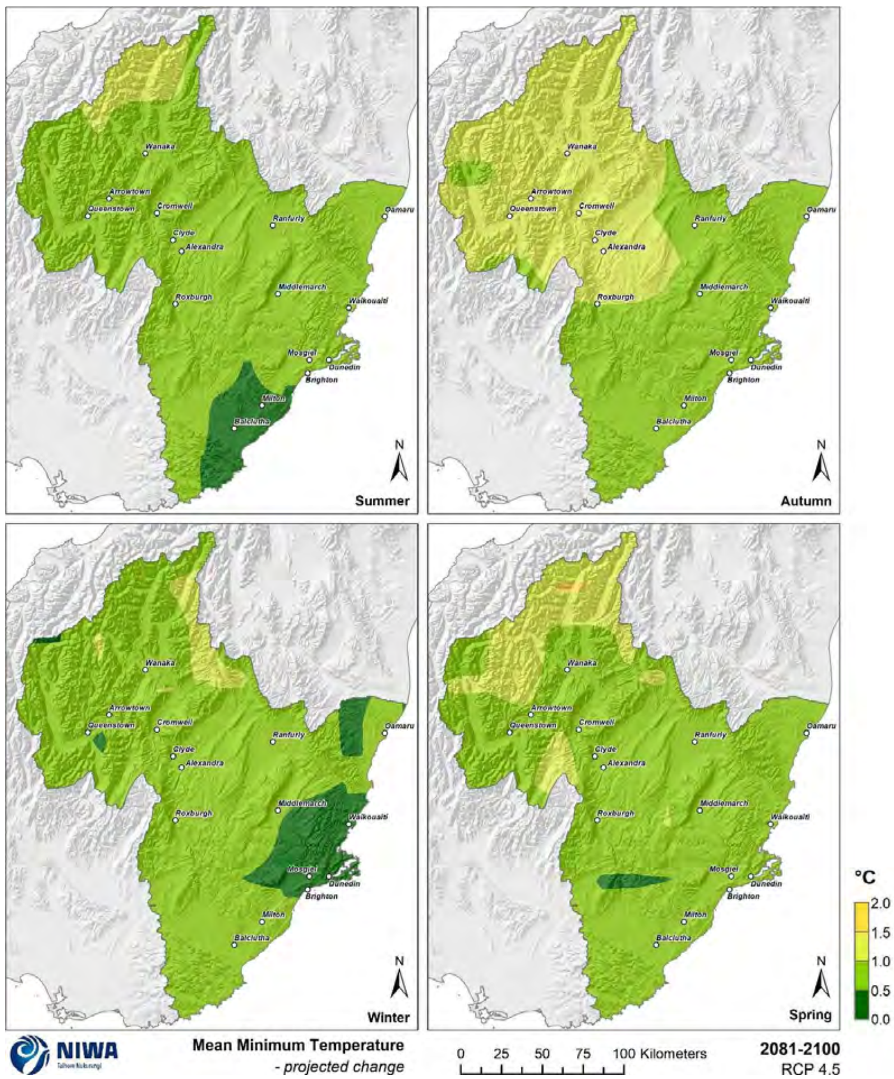

Figure 3-22: Projected seasonal mean minimum temperature changes by 2090 for RCP4.5. Relative to 1986-2005 average, based on the average of six global climate models. Results are based on dynamical downscaled projections using NIWA's Regional Climate Model. Resolution of projection is 5km x 5km.

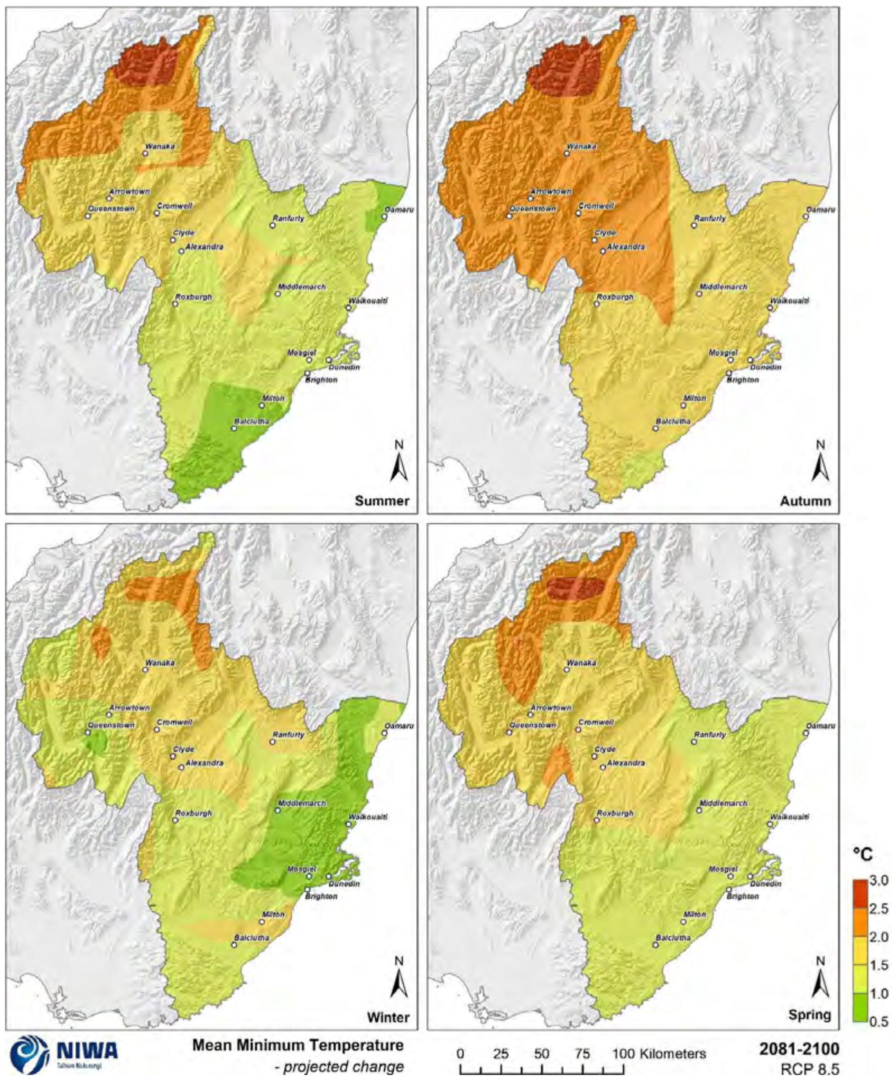

Figure 3-23: Projected seasonal mean minimum temperature changes by 2090 for RCP8.5. Relative to 1986-2005 average, based on the average of six global climate models. Results are based on dynamical downscaled projections using NIWA's Regional Climate Model. Resolution of projection is 5km x 5km.

Table 3-4: Modelled seasonal and annual mean minimum temperature for present and two climate change scenarios (RCP4.5 and RCP8.5) at two future time periods. Time periods: present (1986-2005), mid-century (2031-2050; “2040”) and end-century (2081-2100; “2090”); based on the average of six global climate models. Annual (“Ann”); Seasons: summer (“Sum”), autumn (“Aut”), winter (“Win”) and spring (“Spr”).

	PRESENT				
	Sum	Aut	Win	Spr	Ann
Alexandra	9.7	4.4	-0.7	4.8	4.5
Arrowtown	8.8	4.3	-0.9	3.8	4.0
Balclutha	9.1	5.6	1.8	5.4	5.4
Brighton	8.3	5.6	2.0	4.8	5.2
Clyde	9.6	4.3	-0.8	4.7	4.4
Cromwell	10.4	5.2	-0.1	5.3	5.2
Dunedin	9.3	6.6	3.0	5.7	6.1
Middlemarch	8.0	3.7	-0.5	3.8	3.7
Milton	9.2	5.6	1.7	5.4	5.4
Mosgiel	8.9	6.2	2.6	5.3	5.7
Oamaru	10.1	5.9	1.2	5.6	5.7
Queenstown	8.6	4.5	-0.4	3.9	4.2
Ranfurly	7.6	3.3	-1.8	3.2	3.0
Roxburgh	9.4	4.8	0.2	4.7	4.8
Waikouaiti	9.3	5.6	1.6	5.5	5.5
Wanaka	10.4	5.6	0.1	5.1	5.3

		2040					**2090**				
		Sum	Aut	Win	Spr	Ann	Sum	Aut	Win	Spr	Ann
Alexandra	RCP4.5	+0.5	+0.8	+0.5	+0.4	+0.6	+0.7	+1.2	+0.8	+0.8	+0.9
	RCP8.5	+0.5	+0.9	+0.6	+0.5	+0.6	+1.5	+2.3	+1.6	+1.6	+1.8
Arrowtown	RCP4.5	+0.5	+0.7	+0.4	+0.5	+0.6	+0.8	+1.1	+0.7	+1.0	+0.9
	RCP8.5	+0.5	+0.8	+0.5	+0.6	+0.7	+1.7	+2.2	+1.4	+2.0	+1.8
Balclutha	RCP4.5	+0.3	+0.5	+0.4	+0.4	+0.4	+0.5	+0.9	+0.7	+0.6	+0.7
	RCP8.5	+0.2	+0.6	+0.4	+0.4	+0.4	+0.9	+1.7	+1.5	+1.2	+1.3
Brighton	RCP4.5	+0.3	+0.4	+0.2	+0.3	+0.3	+0.6	+0.8	+0.4	+0.6	+0.6
	RCP8.5	+0.3	+0.5	+0.2	+0.3	+0.3	+1.2	+1.6	+0.8	+1.1	+1.2
Clyde	RCP4.5	+0.5	+0.8	+0.5	+0.5	+0.6	+0.7	+1.1	+0.9	+0.8	+0.9
	RCP8.5	+0.5	+0.9	+0.6	+0.5	+0.6	+1.6	+2.3	+1.7	+1.7	+1.8
Cromwell	RCP4.5	+0.5	+0.8	+0.6	+0.5	+0.6	+0.8	+1.1	+1.0	+0.9	+1.0
	RCP8.5	+0.5	+0.9	+0.7	+0.6	+0.7	+1.8	+2.3	+1.8	+1.9	+2.0
Dunedin	RCP4.5	+0.3	+0.4	+0.2	+0.3	+0.3	+0.6	+0.8	+0.4	+0.6	+0.6
	RCP8.5	+0.3	+0.5	+0.2	+0.3	+0.3	+1.2	+1.6	+0.8	+1.1	+1.2
Middlemarch	RCP4.5	+0.4	+0.5	+0.3	+0.4	+0.4	+0.7	+0.8	+0.5	+0.6	+0.7
	RCP8.5	+0.4	+0.6	+0.4	+0.4	+0.4	+1.3	+1.6	+0.9	+1.2	+1.3
Milton	RCP4.5	+0.3	+0.5	+0.4	+0.4	+0.4	+0.5	+0.9	+0.7	+0.6	+0.7
	RCP8.5	+0.3	+0.6	+0.4	+0.4	+0.4	+0.9	+1.8	+1.6	+1.2	+1.4
Mosgiel	RCP4.5	+0.3	+0.4	+0.2	+0.3	+0.3	+0.6	+0.8	+0.4	+0.6	+0.6
	RCP8.5	+0.3	+0.5	+0.2	+0.3	+0.3	+1.2	+1.6	+0.8	+1.1	+1.2
Oamaru	RCP4.5	+0.3	+0.6	+0.4	+0.3	+0.4	+0.6	+1.0	+0.7	+0.6	+0.7
	RCP8.5	+0.3	+0.7	+0.5	+0.4	+0.5	+1.0	+1.8	+1.1	+1.3	+1.3
Queenstown	RCP4.5	+0.5	+0.7	+0.4	+0.5	+0.5	+0.8	+1.1	+0.6	+0.9	+0.8
	RCP8.5	+0.5	+0.8	+0.4	+0.6	+0.6	+1.7	+2.2	+1.0	+1.8	+1.7
Ranfurly	RCP4.5	+0.4	+0.6	+0.5	+0.4	+0.5	+0.7	+0.9	+0.8	+0.7	+0.8
	RCP8.5	+0.4	+0.7	+0.6	+0.4	+0.6	+1.3	+1.8	+1.6	+1.3	+1.6
Roxburgh	RCP4.5	+0.4	+0.7	+0.4	+0.4	+0.5	+0.6	+1.0	+0.6	+0.8	+0.8
	RCP8.5	+0.4	+0.7	+0.5	+0.4	+0.5	+1.4	+1.9	+1.2	+1.5	+1.5
Waikouaiti	RCP4.5	+0.4	+0.5	+0.2	+0.3	+0.4	+0.6	+0.9	+0.4	+0.6	+0.6
	RCP8.5	+0.4	+0.6	+0.2	+0.3	+0.4	+1.2	+1.8	+0.7	+1.1	+1.2
Wanaka	RCP4.5	+0.6	+0.7	+0.6	+0.5	+0.6	+1.0	+1.1	+0.9	+0.9	+1.0
	RCP8.5	+0.6	+0.9	+0.7	+0.6	+0.7	+2.0	+2.3	+1.9	+1.8	+2.0

3.4 Extreme hot days

Key messages

- Parts of Central Otago are projected to observe a considerable increase in annual extreme hot days of 30-40 days per year (by 2090 under RCP8.5).
- Most remaining inland areas of Otago are projected to observe an increase of 10-30 hot days per year (by 2090 under RCP8.5).
- Extreme hot days are projected to remain a relatively infrequent occurrence for coastal and southernmost parts of Otago, with increases of between 0.1-4 days.

In this report, an extreme hot day is considered to occur when the maximum temperature is above 30°C. Present-day (average over 1986-2005) and future (average over 2031-2050 and 2081-2100) maps for extreme hot days are shown in this section. The present-day maps show annual average numbers of extreme hot days and the future projection maps show the change in the annual number of extreme hot days compared with present. Note that the present-day maps are on a different colour scale to the future projection maps.

At present, extreme hot days occur most regularly in parts of Central Otago about Alexandra, Cromwell and Clyde. Here, the annual number of extreme hot days averages 8-10 days per year (Figure 3-24). For the remainder of Otago, extreme hot days are relatively infrequent, with an average annual occurrence of between 0.1-4 days.

In the future, extreme hot days are projected to remain a relatively infrequent occurrence for coastal and southernmost parts of Otago, with increases of between 0.1-4 days under both time periods and scenarios (Figure 3-25). However, this is in stark contrast to inland parts of Otago, which are projected to observe a considerable increase in the future number of extreme hot days, particularly by 2090. By 2040, 6-10 more extreme hot days are projected for parts of Central Otago under RCP4.5 and RCP8.5. By 2090 under RCP4.5, 10-20 more extreme hot days per year are projected for parts of Central Otago, and 30-40 more extreme hot days per year under RCP8.5. Most remaining inland areas of Otago are projected to observe an increase of 6-10 extreme hot days under RCP4.5 by 2090 and 10-30 extreme hot days per year under RCP8.5 by 2090.

Modelled annual extreme hot days data have been generated for 16 Otago locations, and these are presented in Table 3-5. At present, Dunedin observes an average of 0.2 extreme hot days per year (i.e. on average, one extreme hot day every five years). By 2040 under RCP4.5 Dunedin is projected to observe 0.5 extreme hot days (i.e. on average, one extreme hot day every two years). By 2090 under RCP8.5, the city is projected to observe an average of 1.8 extreme hot days per year. In Cromwell, the town presently observes an average of 9.8 extreme hot days per year. This is projected to increase to between an average of 18.6 extreme hot days per year (by 2040 under RCP4.5) and 47.1 extreme hot days per year (by 2090 under RCP8.5).

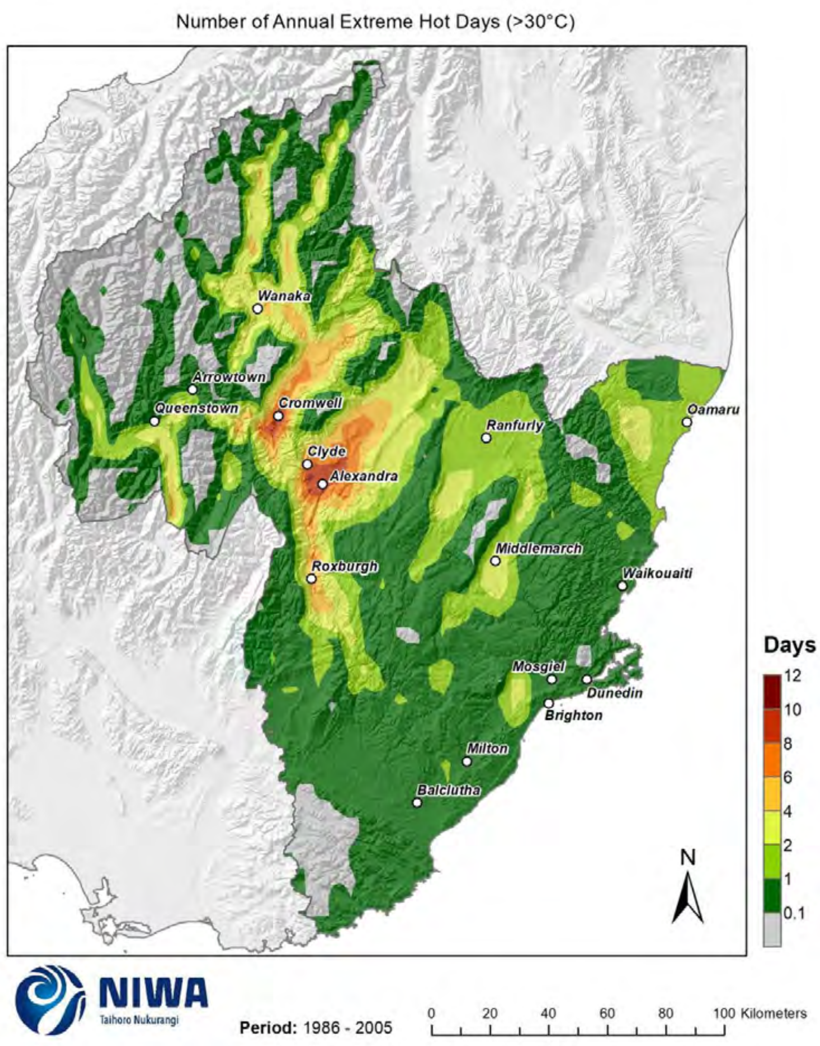

Figure 3-24: Modelled annual number of extreme hot days (days with maximum temperature >30°C), average over 1986-2005. Results are based on dynamical downscaled projections using NIWA's Regional Climate Model. Resolution of projection is 5km x 5km.

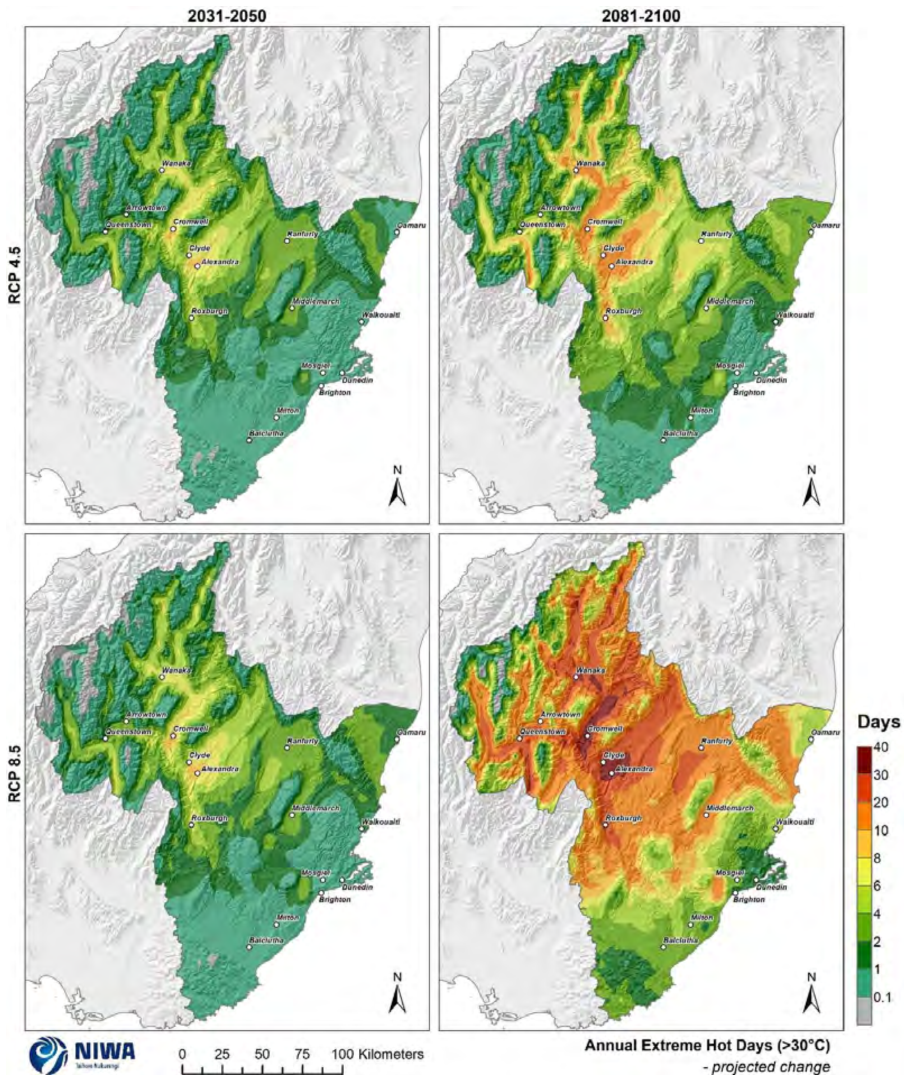

Figure 3-25: Projected annual extreme hot day (maximum temperature >30°C) changes by 2040 and 2090, under RCP4.5 and RCP8.5. Climate change scenarios: RCP4.5 (top panels) and RCP8.5 (bottom panels). Time periods: mid-century (2031-2050; "2040" – panels on left) and end-century (2081-2100; "2090" – panels on right). Changes relative to 1986-2005 average, based on the average of six global climate models. Results are based on dynamical downscaled projections using NIWA's Regional Climate Model. Resolution of projection is 5km x 5km.

Table 3-5: Modelled annual average number of extreme hot days (maximum temperature >30°C) for present and two climate change scenarios (RCP4.5 and RCP8.5) at two future time periods. Future projections are shown as the total future projected number of extreme hot days outside the parentheses, and future change inside the parentheses (the top table shows the change in days, and the bottom table shows the change in per cent). Time periods: present (1986-2005), mid-century (2031-2050; "2040") and end-century (2081-2100; "2090"); based on the average of six global climate models.

		2040 (days change)		2090 (days change)	
	PRESENT	RCP4.5	RCP8.5	RCP4.5	RCP8.5
Alexandra	9.1	17.2 (+8.1)	17.3 (+8.2)	21.7 (+12.6)	42.4 (+33.3)
Arrowtown	0.5	2.3 (+1.8)	2.6 (+2.1)	4.4 (+3.9)	15.7 (+15.2)
Balclutha	0.5	1.0 (+0.5)	1.0 (+0.5)	1.3 (+0.8)	3.4 (+2.9)
Brighton	0.2	0.5 (+0.3)	0.6 (+0.4)	0.8 (+0.6)	1.8 (+1.6)
Clyde	7.4	14.6 (+7.2)	14.8 (+7.4)	18.5 (+11.1)	38.6 (+31.2)
Cromwell	9.8	18.6 (+8.8)	19.1 (+9.3)	23.8 (+14.0)	47.1 (+37.3)
Dunedin	0.2	0.5 (+0.3)	0.6 (+0.4)	0.8 (+0.6)	1.8 (+1.6)
Middlemarch	2.9	5.4 (+2.5)	5.8 (+2.9)	7.6 (+4.7)	16.6 (+13.7)
Milton	0.5	0.9 (+0.4)	1.1 (+0.6)	1.5 (+1.0)	3.7 (+3.2)
Mosgiel	0.5	0.9 (+0.4)	1.1 (+0.6)	1.5 (+1.0)	3.1 (+2.6)
Oamaru	1.3	2.2 (+0.9)	2.9 (+1.6)	3.4 (+2.1)	6.6 (+5.3)
Queenstown	0.3	1.5 (+1.2)	1.9 (+1.6)	3.3 (+3.0)	12.5 (+12.2)
Ranfurly	1.7	4.7 (+3.0)	5.2 (+3.5)	7.5 (+5.8)	20.6 (+18.9)
Roxburgh	6.4	12.5 (+6.1)	12.8 (+6.4)	17.1 (+10.7)	35.0 (+28.6)
Waikouaiti	0.4	1.0 (+0.6)	1.3 (+0.9)	1.9 (+1.5)	4.9 (+4.5)
Wanaka	3.7	9.6 (+5.9)	10.0 (+6.3)	14.0 (+10.3)	33.1 (+29.4)

		2040 (% change)		2090 (% change)	
	PRESENT	RCP4.5	RCP8.5	RCP4.5	RCP8.5
Alexandra	9.1	17.2 (+89)	17.3 (+90)	21.7 (+138)	42.4 (+366)
Arrowtown	0.5	2.3 (+360)	2.6 (+420)	4.4 (+780)	15.7 (+3040)
Balclutha	0.5	1 (+100)	1 (+100)	1.3 (+160)	3.4 (+580)
Brighton	0.2	0.5 (+150)	0.6 (+200)	0.8 (+300)	1.8 (+800)
Clyde	7.4	14.6 (+97)	14.8 (+100)	18.5 (+150)	38.6 (+422)
Cromwell	9.8	18.6 (+90)	19.1 (+95)	23.8 (+143)	47.1 (+381)
Dunedin	0.2	0.5 (+150)	0.6 (+200)	0.8 (+300)	1.8 (+800)
Middlemarch	2.9	5.4 (+86)	5.8 (+100)	7.6 (+162)	16.6 (+472)
Milton	0.5	0.9 (+80)	1.1 (+120)	1.5 (+200)	3.7 (+640)
Mosgiel	0.5	0.9 (+80)	1.1 (+120)	1.5 (+200)	3.1 (+520)
Oamaru	1.3	2.2 (+69)	2.9 (+123)	3.4 (+162)	6.6 (+408)
Queenstown	0.3	1.5 (+400)	1.9 (+533)	3.3 (+1000)	12.5 (+4067)
Ranfurly	1.7	4.7 (+176)	5.2 (+206)	7.5 (+341)	20.6 (+1112)
Roxburgh	6.4	12.5 (+95)	12.8 (+100)	17.1 (+167)	35 (+447)
Waikouaiti	0.4	1 (+150)	1.3 (+225)	1.9 (+375)	4.9 (+1125)
Wanaka	3.7	9.6 (+159)	10 (+170)	14 (+278)	33.1 (+795)

3.5 Frost days

Key messages

- Future number of frost days per year is projected to decline throughout the region; larger reductions in frost days are projected further inland (due to more frosts currently being experienced there).
- By 2040, reductions of 10-15 frost days per year are projected for inland parts of the region
- By 2090, considerable reductions in frost days are projected for inland areas, with around 20-40 fewer frost days for those areas (under RCP8.5).
- It is likely that future frost season length will reduce (i.e. the time between the first and last frost in a given year).

A frost day is defined in this report when the modelled daily minimum temperature falls below 0°C. This is purely a temperature-derived metric for assessing the potential for frosts over the 5 km x 5 km climate model grid. Frost conditions are influenced at the local scale (i.e. finer scale than 5 km x 5 km) by temperature, topography, wind, and humidity, so the results presented in this section can be considered as the large-scale *temperature* conditions conducive to frosts.

Present-day (average over 1986-2005) and future (average over 2031-2050 and 2081-2100) maps for frost days are shown in this section. The present-day maps show annual average numbers of frost days and the future projection maps show the change in the annual number of frost days compared with present. Note that the present-day maps are on a different colour scale to the future projection maps. Table 3-6 shows the present and future projected numbers of frost days for the model grid point closest to specific locations in the Otago region.

At present, the fewest number of frost days per year occurs about the Otago Peninsula, with 1-5 frost days per year (Figure 3-26). The annual number of frost days increases considerably for inland and high-elevation parts of the region. For example, many low-elevation parts of Central Otago typically observe 75-100 days of frost per year. For coastal parts of North Otago, 25-50 frost days per year are experienced.

In the future, the number of frost days per year is projected to decline throughout the region. Larger reductions in frost days are projected further inland, due to more frosts currently being experienced there (Figure 3-27). By 2040, reductions of 10-15 frost days per year are possible for low-elevation inland parts of the region under both RCP4.5 and RCP8.5, with the reductions getting smaller towards the east coast. By 2090, considerable reductions in frost days are projected for inland areas, with around 15-20 fewer frost days for those areas under RCP4.5 and 20-40 fewer frost days under RCP8.5. Larger reductions are projected for high elevations (i.e. decrease of >40 days under RCP8.5 at 2090). In addition, it is likely that future frost season length (i.e. the time between the first and last frost in a given year) will reduce.

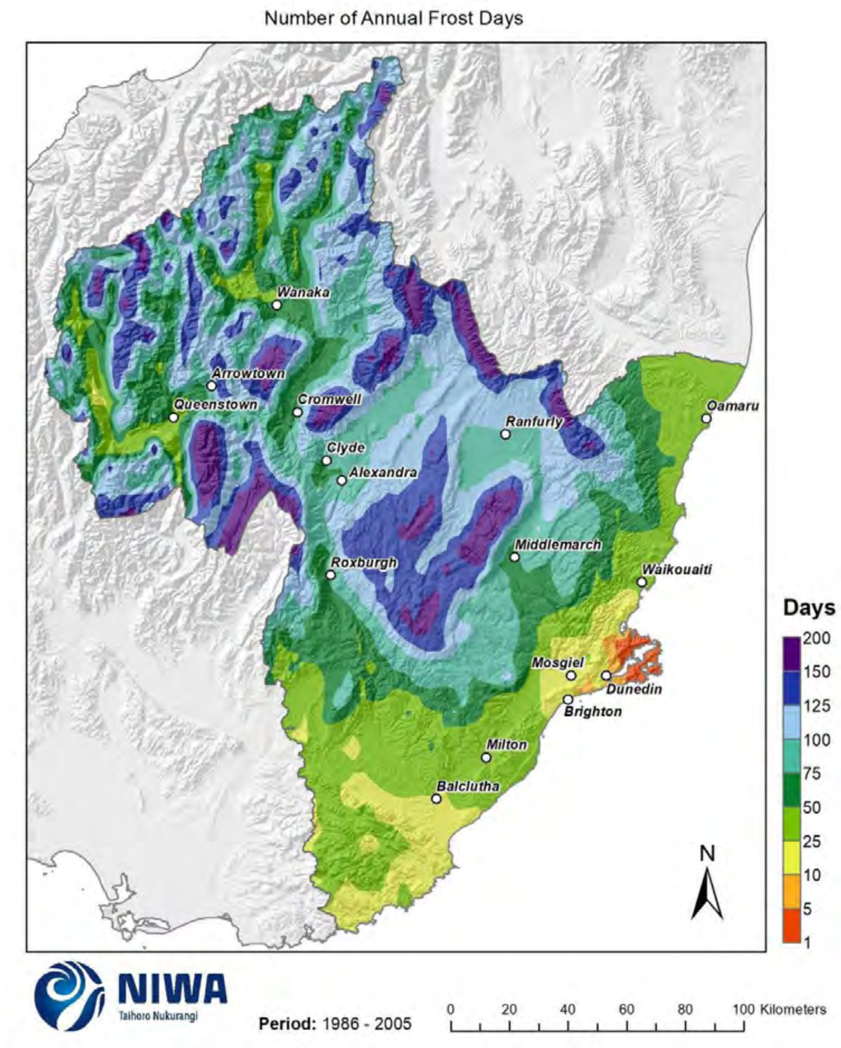

Figure 3-26: Modelled annual number of frost days (daily minimum temperature <0°C), average over 1986-2005. Results are based on dynamical downscaled projections using NIWA's Regional Climate Model. Resolution of projection is 5km x 5km.

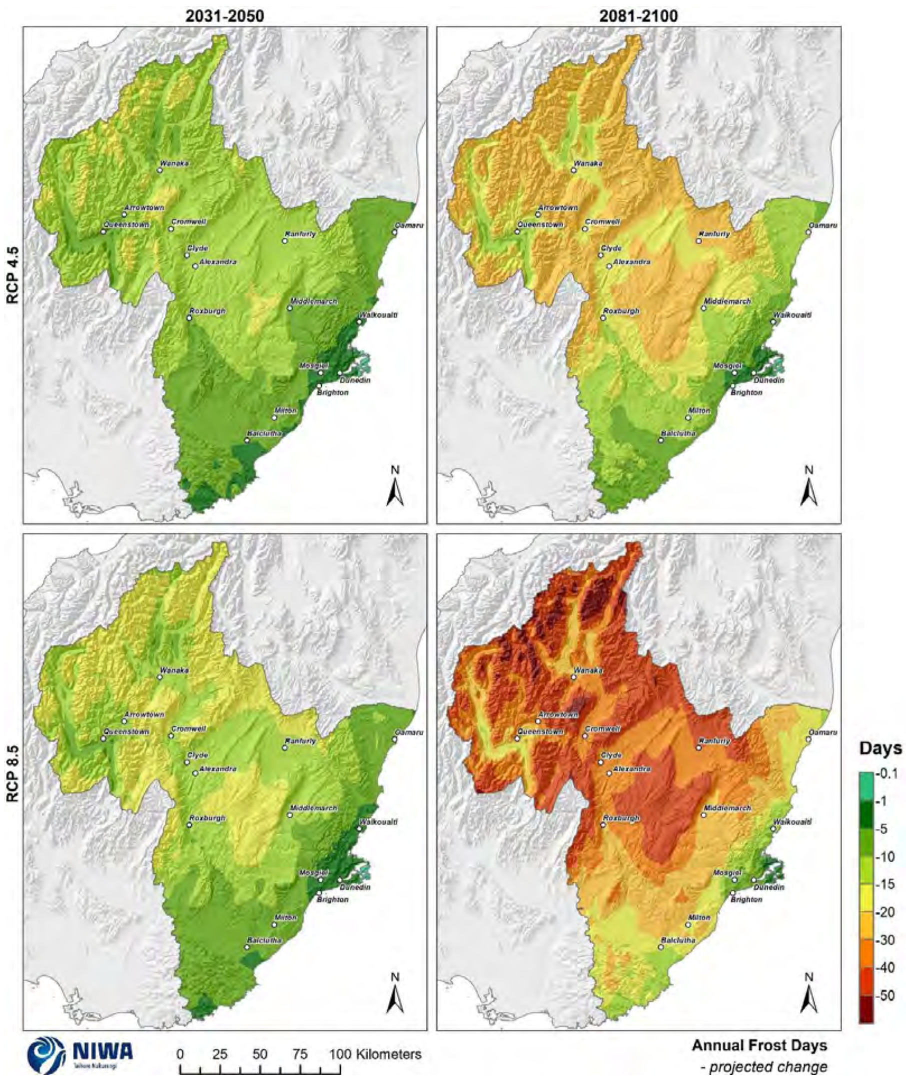

Figure 3-27: Projected annual frost day (minimum temperature <0°C) changes by 2040 and 2090, under RCP4.5 and RCP8.5. Climate change scenarios: RCP4.5 (top panels) and RCP8.5 (bottom panels). Time periods: mid-century (2031-2050; "2040" – panels on left) and end-century (2081-2100; "2090" – panels on right). Changes relative to 1986-2005 average, based on the average of six global climate models. Results are based on dynamical downscaled projections using NIWA's Regional Climate Model. Resolution of projection is 5km x 5km.

Table 3-6: Modelled annual average number of frost days (minimum temperature <0°C) for present and two climate change scenarios (RCP4.5 and RCP8.5) at two future time periods. Future projections are shown as the total future projected number of frost days outside the parentheses, and future change inside the parentheses (the top table shows the change in days, and the bottom table shows the change in per cent). Time periods: present (1986-2005), mid-century (2031-2050; "2040") and end-century (2081-2100; "2090"); based on the average of six global climate models.

		2040 (days change)		2090 (days change)	
	PRESENT	RCP4.5	RCP8.5	RCP4.5	RCP8.5
Alexandra	74.3	62.8 (-11.5)	61.1 (-13.2)	55.5 (-18.8)	39.1 (-35.2)
Arrowtown	74.2	63.7 (-10.5)	62.3 (-11.9)	56.0 (-18.2)	39.3 (-34.9)
Balclutha	25.4	20.0 (-5.4)	19.7 (-5.7)	16.2 (-9.2)	8.5 (-16.9)
Brighton	23.0	20.0 (-3.0)	19.9 (-3.1)	17.7 (-5.3)	12.4 (-10.6)
Clyde	75.7	64.0 (-11.7)	62.9 (-12.8)	56.6 (-19.1)	40.5 (-35.2)
Cromwell	57.8	46.2 (-11.6)	44.5 (-13.3)	39.4 (-18.4)	25.7 (-32.1)
Dunedin	9.3	7.5 (-1.8)	7.4 (-1.9)	6.4 (-2.9)	3.3 (-6.0)
Middlemarch	73.0	64.0 (-9.0)	62.5 (-10.5)	59.1 (-13.9)	49.5 (-23.5)
Milton	26.9	21.0 (-5.9)	20.4 (-6.5)	17.1 (-9.8)	9.1 (-17.8)
Mosgiel	14.2	12.0 (-2.2)	11.8 (-2.4)	10.3 (-3.9)	6.3 (-7.9)
Oamaru	43.1	36.1 (-7.0)	34.0 (-9.1)	31.6 (-11.5)	25.2 (-17.9)
Queenstown	63.5	53.4 (-10.1)	51.8 (-11.7)	48.3 (-15.2)	35.8 (-27.7)
Ranfurly	97.5	85.0 (-12.5)	82.5 (-15.0)	76.9 (-20.6)	56.9 (-40.6)
Roxburgh	57.5	48.9 (-8.6)	47.3 (-10.2)	43.5 (-14.0)	31.4 (-26.1)
Waikouaiti	35.4	30.6 (-4.8)	31.4 (-4.0)	29.1 (-6.3)	23.6 (-11.8)
Wanaka	54.7	44.0 (-10.7)	42.5 (-12.2)	37.9 (-16.8)	24.2 (-30.5)

		2040 (% change)		2090 (% change)	
	PRESENT	RCP4.5	RCP8.5	RCP4.5	RCP8.5
Alexandra	74.3	62.8 (-15)	61.1 (-18)	55.5 (-25)	39.1 (-47)
Arrowtown	74.2	63.7 (-14)	62.3 (-16)	56 (-25)	39.3 (-47)
Balclutha	25.4	20 (-21)	19.7 (-22)	16.2 (-36)	8.5 (-67)
Brighton	23.0	20 (-13)	19.9 (-13)	17.7 (-23)	12.4 (-46)
Clyde	75.7	64 (-15)	62.9 (-17)	56.6 (-25)	40.5 (-46)
Cromwell	57.8	46.2 (-20)	44.5 (-23)	39.4 (-32)	25.7 (-56)
Dunedin	9.3	7.5 (-19)	7.4 (-20)	6.4 (-31)	3.3 (-65)
Middlemarch	73.0	64 (-12)	62.5 (-14)	59.1 (-19)	49.5 (-32)
Milton	26.9	21 (-22)	20.4 (-24)	17.1 (-36)	9.1 (-66)
Mosgiel	14.2	12 (-15)	11.8 (-17)	10.3 (-27)	6.3 (-56)
Oamaru	43.1	36.1 (-16)	34 (-21)	31.6 (-27)	25.2 (-42)
Queenstown	63.5	53.4 (-16)	51.8 (-18)	48.3 (-24)	35.8 (-44)
Ranfurly	97.5	85 (-13)	82.5 (-15)	76.9 (-21)	56.9 (-42)
Roxburgh	57.5	48.9 (-15)	47.3 (-18)	43.5 (-24)	31.4 (-45)
Waikouaiti	35.4	30.6 (-14)	31.4 (-11)	29.1 (-18)	23.6 (-33)
Wanaka	54.7	44 (-20)	42.5 (-22)	37.9 (-31)	24.2 (-56)

4 Precipitation

4.1 Rainfall

Key messages

- Annual rainfall is projected to increase by between 0-10% for most of the region by 2040.
- Increases in winter and spring rainfall of between 5-20% are projected for many western and inland parts of Otago by 2040.
- 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%).
- Winter rainfall is projected to increase considerably by 2090 under RCP8.5, with 20-40% more rainfall projected for many parts of the region.
- Decreases in summer rainfall of 5-10% are projected around Ranfurly and Middlemarch by 2090 under RCP8.5

This section contains maps showing present-day total rainfall and the future projected change in total rainfall. Present-day rainfall maps are in units of mm per year or season (average over 1986-2005) and future (average over 2031-2050 and 2081-2100) maps show the percentage change in rainfall compared with the present-day total. Note that the present-day maps are on a different colour scale to the future projection maps.

At present, the highest annual rainfall totals are recorded in the high elevations of the western ranges (>2000 mm), with lowest annual rainfall totals about Central Otago (350-400 mm) (Figure 4-1). Alexandra is frequently the driest location in New Zealand, with around 350-400 mm of annual rainfall. Winter is typically the driest season of the year for much of Otago (Figure 4-3), although the inter-seasonal variability of average rainfall totals isn't considerable.

Otago is generally projected to observe an increase in future annual rainfall (Figure 4-2). By 2040 under RCP4.5 and RCP8.5, annual rainfall is projected to increase by between 0-10% for most of the region. The exception is an area about Ranfurly, where annual rainfall is projected to decrease by between 0-5%. By 2090 under RCP4.5, annual rainfall is projected to increase by 5-10% for western areas and 0-5% for eastern and coastal areas. Under RCP8.5, annual rainfall increases of 10-20% are projected for the majority of Otago, with smallest increases expected near Ranfurly (0-5%).

At the seasonal scale, increases in winter and spring rainfall of between 5-20% are projected for many western and inland parts of Otago by 2040 under RCP4.5 (Figure 4-4) and RCP8.5 (Figure 4-5). For summer by 2040 under RCP4.5 and RCP8.5, increases in rainfall (generally 0-10%) are projected for western areas, and decreases in rainfall (generally 0-10%) are projected for central and coastal areas. Autumn rainfall is projected to slightly increase (0-5%) in western parts and decrease (0-5%) in eastern and coastal areas.

By 2090 under RCP4.5 (Figure 4-6), winter rainfall in western and central areas is projected to increase by 5-25% (the larger increases in the western ranges), and increase by 0-10% in most other parts of the region. Summer rainfall is also projected to increase by 0-20% for western and central areas. Most locations expect an increase of 0-10% in autumn rainfall, and spring rainfall projections suggest ±5% change for most of the region (except for 5-10% increase in Central Otago). By 2090 under RCP8.5, seasonal rainfall changes are larger (Figure 4-7). Winter rainfall is projected to increase considerably under RCP8.5, with 20-40% more rainfall projected for many parts of the region and >50% increase for the western ranges. Rainfall increases for the area around Alexandra are projected for summer and spring as well, with 15-25% more rainfall expected there. Decreases in summer rainfall of 5-10% are projected around Ranfurly and Middlemarch by 2090 under RCP8.5. Autumn rainfall is projected to increase by 5-15% across most of the region, with decreases (0-10% near Wanaka).

Table 4-1 shows the present and future projected rainfall for the model grid point closest to specific locations in the Otago region.

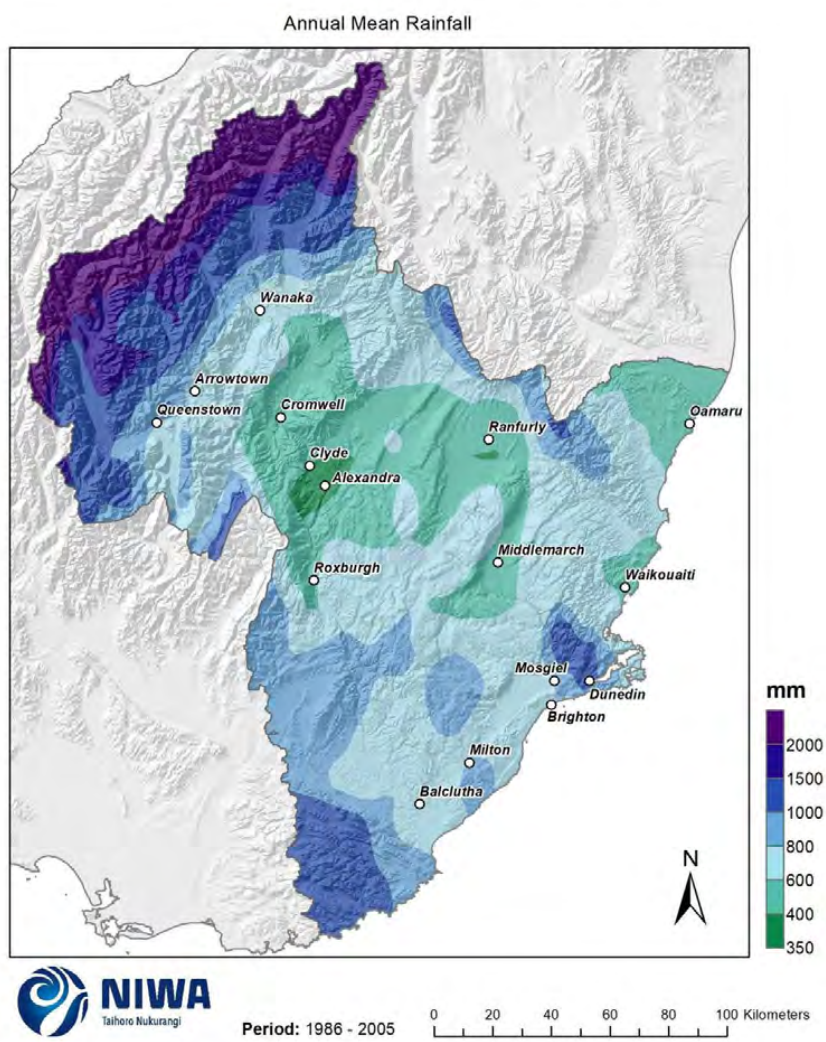

Figure 4-1: Modelled annual mean rainfall (mm), average over 1986-2005. Results are based on dynamical downscaled projections using NIWA's Regional Climate Model. Resolution of projection is 5km x 5km.

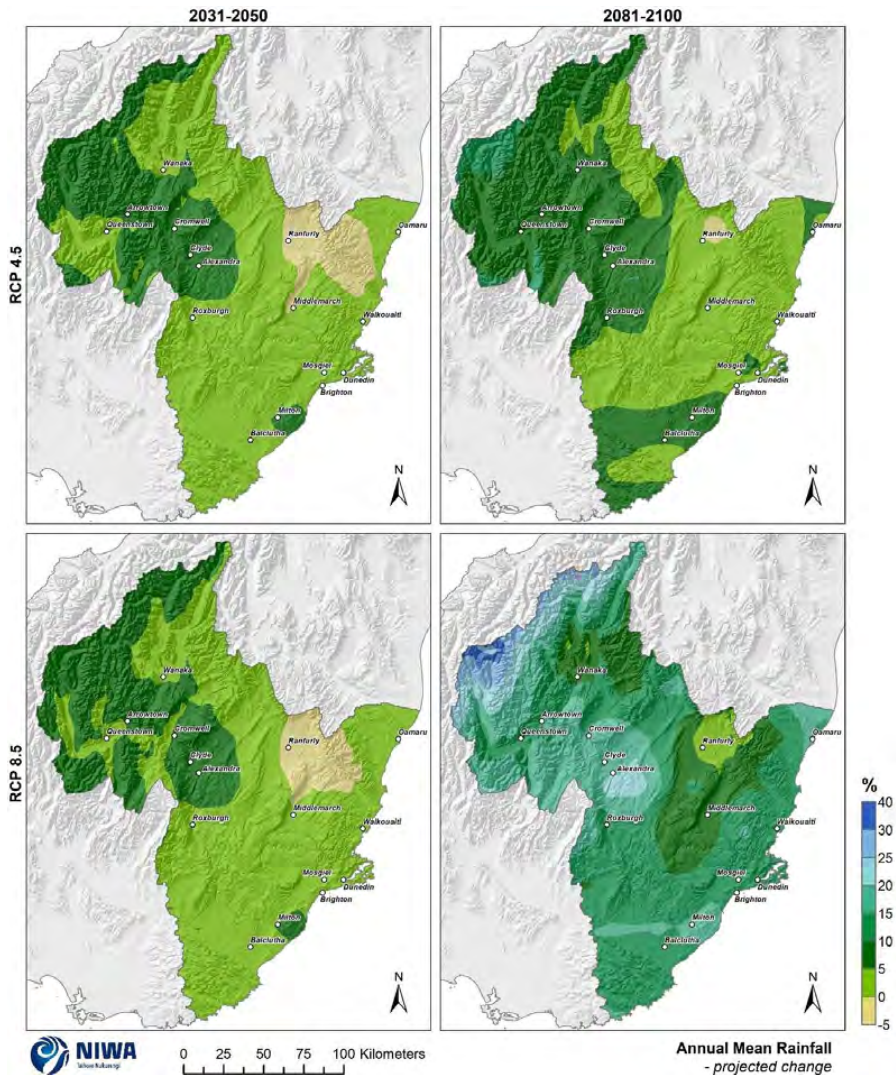

Figure 4-2: Projected annual mean rainfall changes by 2040 and 2090, under RCP4.5 and RCP8.5. Climate change scenarios: RCP4.5 (top panels) and RCP8.5 (bottom panels). Time periods: mid-century (2031-2050; "2040" – panels on left) and end-century (2081-2100; "2090" – panels on right). Changes relative to 1986-2005 average, based on the average of six global climate models. Results are based on dynamical downscaled projections using NIWA's Regional Climate Model. Resolution of projection is 5km x 5km.

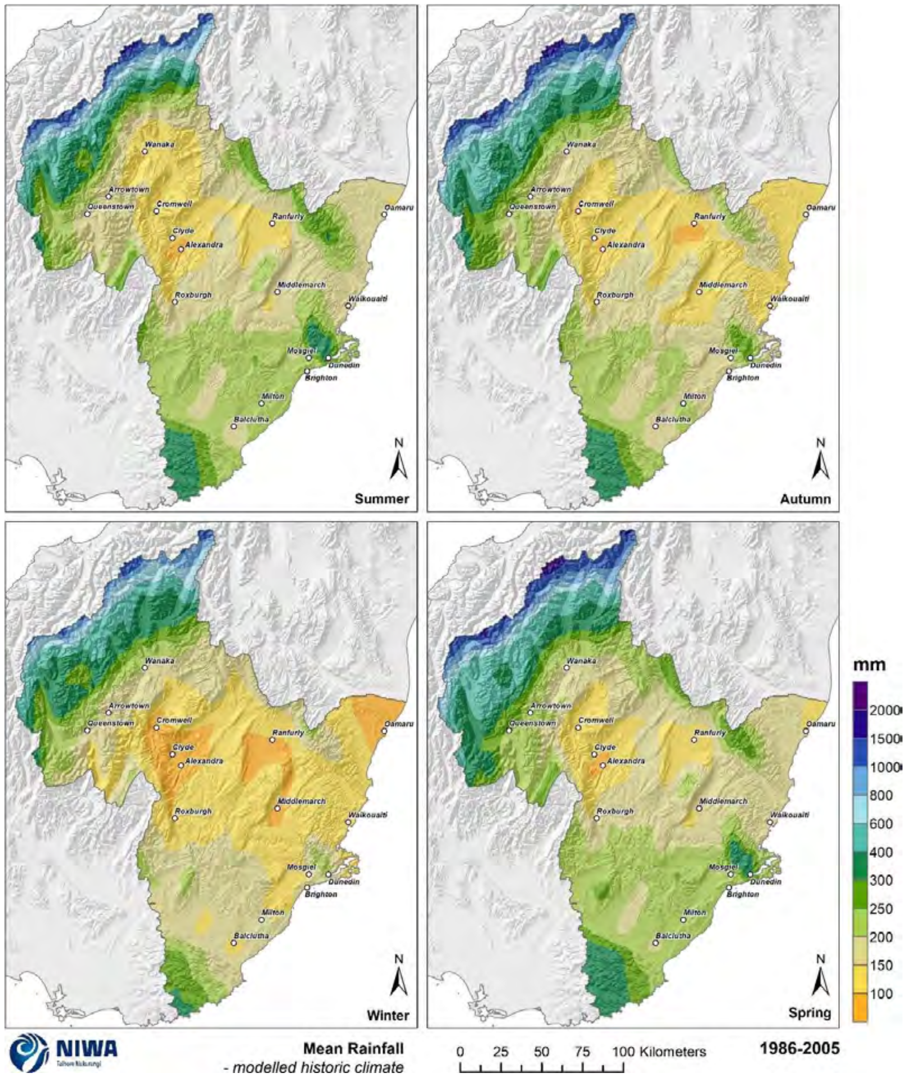

Figure 4-3: Modelled seasonal mean rainfall, average over 1986-2005. Results are based on dynamical downscaled projections using NIWA's Regional Climate Model. Resolution of projection is 5km x 5km.

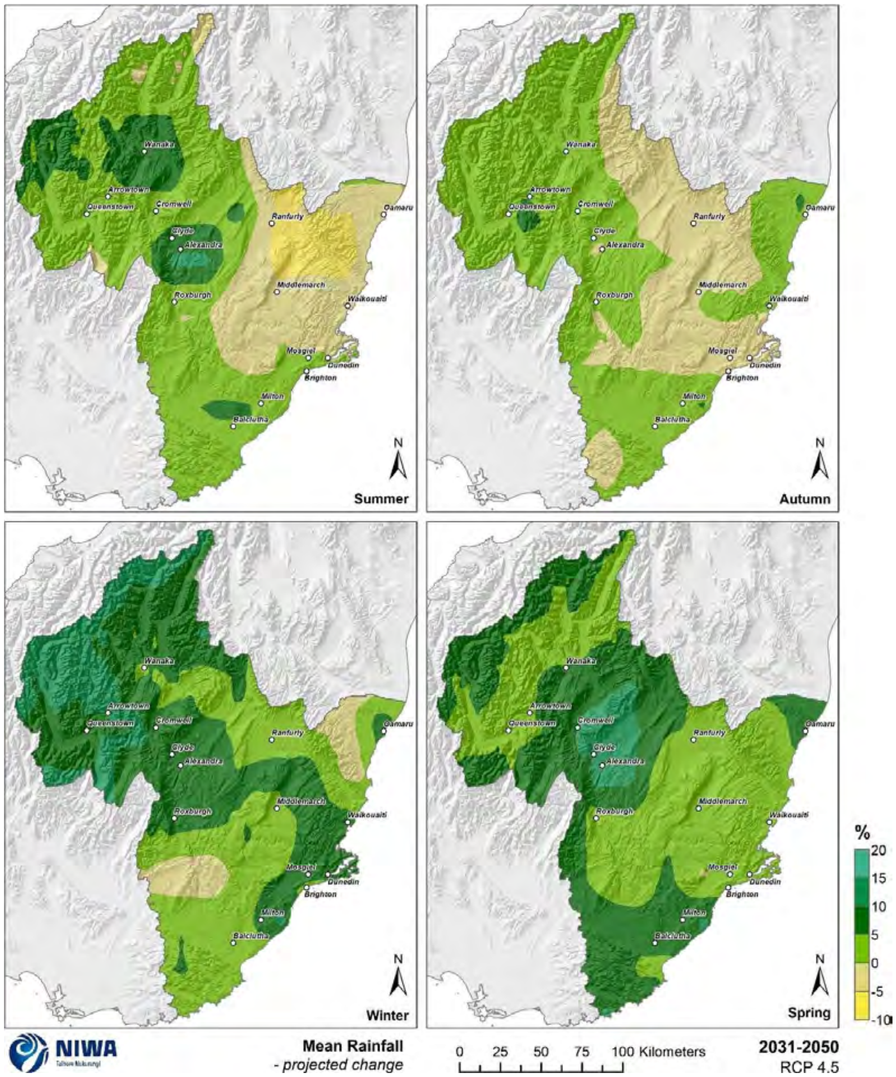

Figure 4-4: Projected seasonal mean rainfall changes by 2040 for RCP4.5. Relative to 1986-2005 average, based on the average of six global climate models. Results are based on dynamical downscaled projections using NIWA's Regional Climate Model. Resolution of projection is 5km x 5km.

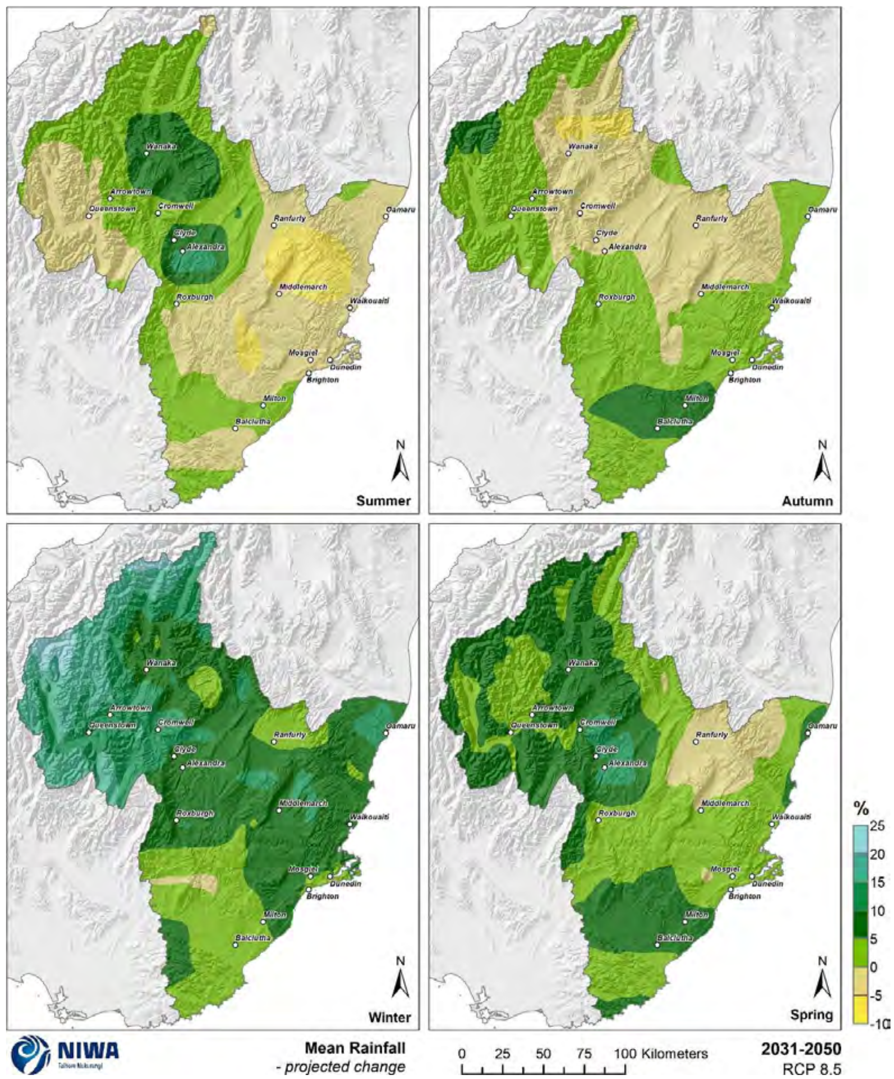

Figure 4-5: Projected seasonal mean rainfall changes by 2040 for RCP8.5. Relative to 1986-2005 average, based on the average of six global climate models. Results are based on dynamical downscaled projections using NIWA's Regional Climate Model. Resolution of projection is 5km x 5km.

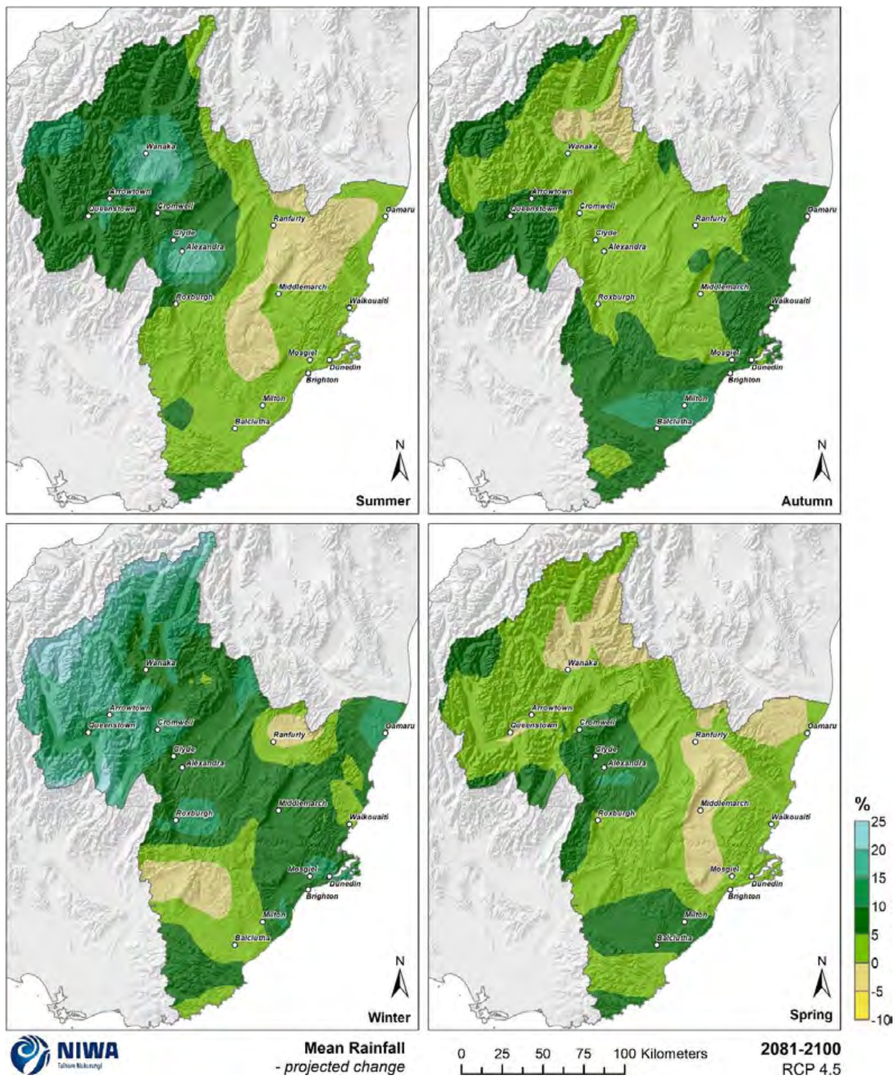

Figure 4-6: Projected seasonal mean rainfall changes by 2090 for RCP4.5. Relative to 1986-2005 average, based on the average of six global climate models. Results are based on dynamical downscaled projections using NIWA's Regional Climate Model. Resolution of projection is 5km x 5km.

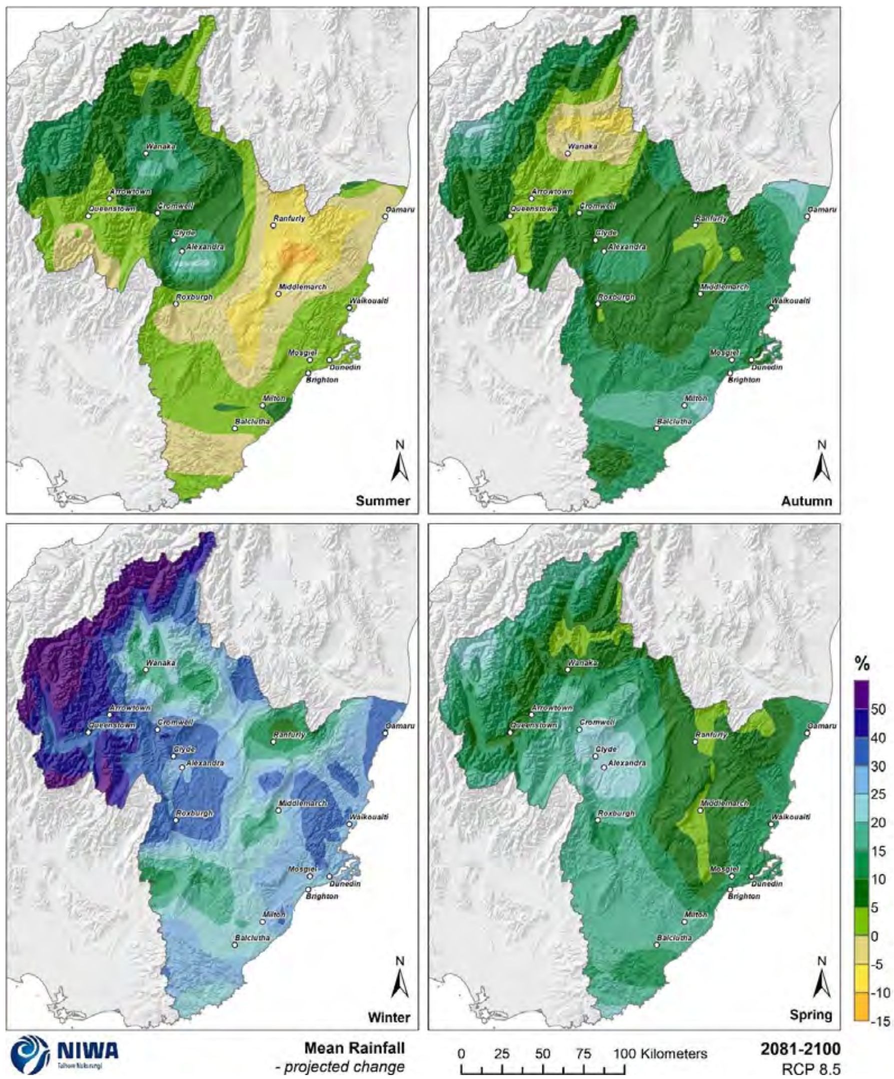

Figure 4-7: Projected seasonal mean rainfall changes by 2090 for RCP8.5. Relative to 1986-2005 average, based on the average of six global climate models. Results are based on dynamical downscaled projections using NIWA's Regional Climate Model. Resolution of projection is 5km x 5km.

Table 4-1: Modelled seasonal and annual average rainfall for present and two climate change scenarios (RCP4.5 and RCP8.5) at two future time periods. Time periods: present (1986-2005), mid-century (2031-2050; “2040”) and end-century (2081-2100; “2090”); based on the average of six global climate models. Annual (“Ann); Seasons: summer (“Sum”), autumn (“Aut”), winter (“Win”) and spring (“Spr”). Note that present rainfall is in millimetres and future rainfall change is in per cent.

	PRESENT (mm)				
	Sum	Aut	Win	Spr	Ann
Alexandra	99	100	78	97	374
Arrowtown	175	216	183	241	815
Balclutha	196	189	150	202	738
Brighton	219	187	151	216	773
Clyde	119	118	90	117	444
Cromwell	105	108	81	113	407
Dunedin	259	216	174	255	904
Middlemarch	146	117	93	144	500
Milton	220	201	154	213	788
Mosgiel	198	166	132	198	694
Oamaru	160	124	88	151	523
Queenstown	191	235	204	263	893
Ranfurly	123	102	92	121	438
Roxburgh	140	133	97	147	516
Waikouaiti	179	134	107	165	585
Wanaka	125	187	203	188	703

		2040 (% change)					**2090 (% change)**				
		Sum	Aut	Win	Spr	Ann	Sum	Aut	Win	Spr	Ann
Alexandra	RCP4.5	+8	0	+7	+11	+7	+14	+2	+6	+8	+8
	RCP8.5	+9	0	+7	+10	+6	+14	+9	+29	+21	+18
Arrowtown	RCP4.5	+4	+5	+11	+4	+6	+10	+5	+15	+1	+8
	RCP8.5	+1	+2	+14	+4	+5	+4	+3	+39	+9	+14
Balclutha	RCP4.5	+5	+3	+4	+6	+4	+2	+10	+3	+7	+5
	RCP8.5	+0	+7	+2	+6	+4	+2	+15	+23	+16	+14
Brighton	RCP4.5	+1	-1	+5	+4	+2	+1	+6	+8	+2	+5
	RCP8.5	-1	+4	+5	+3	+3	+3	+12	+24	+12	+13
Clyde	RCP4.5	+7	0	+7	+12	+6	+12	+2	+8	+7	+7
	RCP8.5	+7	0	+9	+10	+6	+12	+9	+31	+21	+18
Cromwell	RCP4.5	+3	+2	+9	+11	+6	+7	+4	+13	+6	+8
	RCP8.5	+3	-2	+13	+8	+6	+6	+6	+37	+21	+17
Dunedin	RCP4.5	0	-1	+6	+4	+2	+1	+5	+10	+3	+5
	RCP8.5	-2	+3	+4	+4	+2	+2	+9	+26	+14	+13
Middlemarch	RCP4.5	-3	0	+3	+2	0	+1	+2	+8	-2	+2
	RCP8.5	-4	0	+8	+1	+1	-6	+7	+22	+4	+7
Milton	RCP4.5	+3	+4	+7	+8	+6	+2	+13	+5	+8	+7
	RCP8.5	+1	+8	+5	+8	+5	+5	+19	+25	+18	+17
Mosgiel	RCP4.5	0	-2	+6	+3	+2	0	+5	+10	+1	+4
	RCP8.5	-1	+3	+5	+2	+2	+2	+10	+27	+11	+12
Oamaru	RCP4.5	-3	+5	+7	+7	+4	+1	+5	+14	0	+5
	RCP8.5	-2	+4	+12	+6	+5	-3	+19	+31	+13	+15
Queenstown	RCP4.5	+2	+4	+7	+3	+4	+9	+6	+11	0	+6
	RCP8.5	-2	+2	+12	+5	+4	+1	+4	+35	+9	+12
Ranfurly	RCP4.5	-4	-3	+2	+4	0	0	+2	0	0	+1
	RCP8.5	-3	-2	+4	-2	-1	-6	+5	+12	+6	+4
Roxburgh	RCP4.5	+2	+1	+6	+5	+3	+5	+4	+12	+5	+6
	RCP8.5	0	+2	+10	+3	+4	+1	+7	+35	+16	+14
Waikouaiti	RCP4.5	-3	+1	+7	+3	+2	+1	+7	+4	+3	+4
	RCP8.5	-5	+2	+9	+4	+3	+3	+13	+30	+11	+14
Wanaka	RCP4.5	+7	+1	+4	+6	+4	+17	+2	+6	0	+6
	RCP8.5	+8	-3	+6	+6	+4	+14	-1	+14	+8	+9

4.1.1 Model confidence

Key message

- The complete range of model projections (as shown in this section) demonstrate the difference with season and RCP, allowing interpretation of the range of model uncertainty.
- The direction of change for rainfall is less certain than for temperature, owing to models projecting both increases and decreases of rainfall within the same scenario.
- However, confidence is higher for winter increases in rainfall compared with changes for other seasons.

The climate change projections in other sections this report show the average of six dynamically downscaled climate models. This is useful as the average is the 'best estimate' of future conditions, but these results taken alone do not allow for communication of uncertainty or range in potential future outcomes within the different scenarios and time periods. This section presents the full range of model results for rainfall, to help the reader understand that there is no 'single answer' in terms of future projections.

Projected changes in seasonal and annual rainfall are shown for Dunedin and Queenstown in Table 4-2. Note that data in this table was derived from additional IPCC Fifth Assessment Report models than are presented in the maps in this report (the maps are the average of six dynamically downscaled models, whereas the data here are from ~40 statistically downscaled models), in order to enable an assessment of the range of rainfall change for Dunedin and Queenstown by 2040 and 2090 under RCP4.5 and RCP8.5. The difference between dynamical and statistical downscaling is explained in Appendix A.

Figure 4-8 and Figure 4-9 illustrate the seasonal and annual rainfall projections for each RCP, for the two time periods of 2040 and 2090, respectively. The projections for Dunedin are shown in this example. The coloured vertical bars, and inset stars, show all the individual models, so the complete range is displayed (unlike Table 4-2 where the 5th to 95th percentile range has been calculated). These figures are an excellent way of not only demonstrating the difference between models for each season and RCP, but also the range of model sensitivity (i.e. how the different models predict future conditions under the same scenarios/greenhouse gas concentrations). The closer together the model outcomes are, it can be inferred that these projections have more certainty. The black stars within each vertical bar represent the results of the six RCM simulations selected for presentation in this report.

For 2040 projections (Figure 4-8 and Table 4-2), the average of all the models is similar between the different scenarios, indicated in the table and by the horizontal black line on each bar in the figure (averages between 0 and 5% increase). There is a range of model results, as seen by the size of the coloured bars and the numbers inside the parentheses in the table, and the model results span 0% change under all scenarios. Most models project an increase in rainfall, but overall the direction of change is less certain than, say, for temperature (Section 3.1.1) where all models project warming.

For 2090 projections (Figure 4-9 and Table 4-2), the range of model results is much larger within the scenarios than at 2040. Most models are clustered within -5% to +10% change, but some individual models project up to a 55% increase (winter under RCP8.5) and a 25% decrease (spring under RCP4.5). The model average results show a stronger seasonal signal, with wetter winters and springs expected (not much change is expected for summer and autumn on average). With the average model results for winter and spring showing increases in seasonal and annual rainfall, increases are expected but decreases should not be 'ruled out' as some models project decreases in rainfall.

Table 4-2: Projected changes in seasonal and annual rainfall (%) between 1986-2005 and two climate change scenarios (RCP4.5 and RCP8.5) at two future time periods. Time periods: mid-century (2031-2050; "2040") and end-century (2081-2100; "2090"). The values in each column represent the ensemble average, taken over 41 models (RCP8.5) and 37 models (RCP4.5). Bracketed values represent the range (5th percentile to 95th percentile) over all models within that ensemble.

			Summer	Autumn	Winter	Spring	Annual
2040	Dunedin						
		RCP8.5	2 (-6, 11)	0 (-5, 7)	4 (-4, 13)	3 (-4, 11)	2 (-3, 6)
		RCP4.5	2 (-5, 12)	0 (-7, 6)	4 (-5, 10)	4 (-5, 12)	3 (-2, 7)
	Queenstown						
		RCP8.5	3 (-10, 17)	2 (-10, 11)	16 (-4, 36)	16 (-4, 36)	7 (-1, 19)
		RCP4.5	3 (-10, 15)	1 (-8, 11)	13 (-12, 28)	13 (-12, 28)	6 (0, 14)
2090	Dunedin						
		RCP8.5	3 (-13, 16)	2 (-7, 11)	10 (-5, 22)	9 (-2, 21)	6 (1, 14)
		RCP4.5	4 (-6, 12)	1 (-5, 12)	5 (-7, 16)	5 (-3, 13)	4 (-1, 9)
	Queenstown						
		RCP8.5	4 (-20, 20)	1 (-11, 14)	4 (-3, 14)	17 (-9, 40)	16 (-1, 28)
		RCP4.5	4 (-10, 20)	3 (-8, 12)	19 (-10, 52)	8 (-6, 28)	9 (-4, 21)

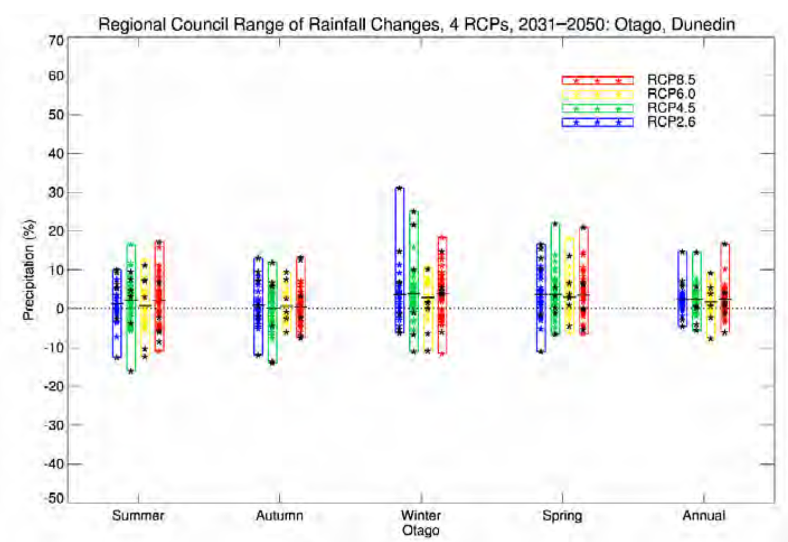

Figure 4-8: Projected seasonal and annual rainfall change for Dunedin by 2040 (2031-2050). Coloured stars represent all models as derived by statistical downscaling. Black stars correspond to the six-model RCM-downscaling, and the horizontal bars are the average over all downscaled results (statistical and RCM).

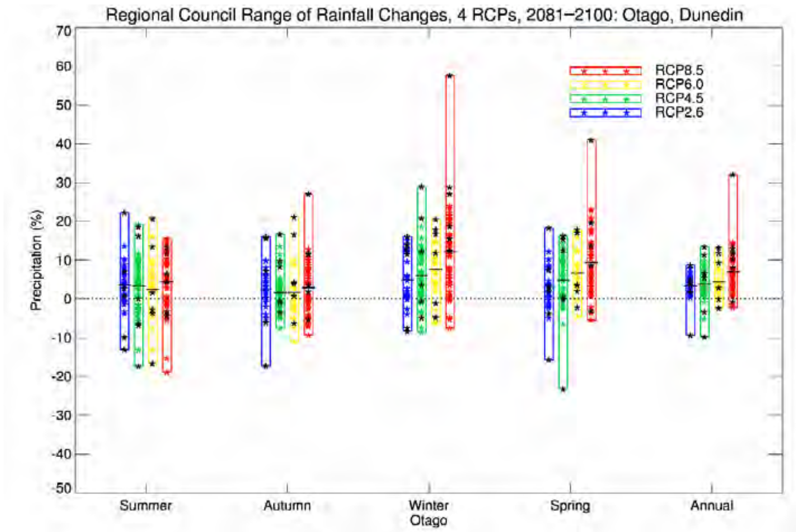

Figure 4-9: Projected seasonal and annual rainfall change for Dunedin by 2090 (2081-2100). Coloured stars represent all models as derived by statistical downscaling. Black stars correspond to the six-model RCM-downscaling, and the horizontal bars are the average over all downscaled results (statistical and RCM).

4.2 Heavy rain days

Key messages

- Relatively small change in future annual number of heavy rain days projected for most of Otago (±0-1 day per year for RCP4.5 and RCP8.5 by 2040 and 2090).
- For far western Otago, the number of heavy rain days is projected to increase by 5-15 days per year (by 2090 under RCP8.5).
- At the seasonal scale, relatively small changes of ±0-1 heavy rain days are projected for most parts of Otago.

A heavy rain day considered here is a daily rainfall total above 25 mm. Present-day (average over 1986-2005) and future (average over 2031-2050 and 2081-2100) maps for heavy rain days are shown in this section. The present-day maps show annual and seasonal average numbers of heavy rain days and the future projection maps show the change in the number of heavy rain days compared with present. Note that the present-day maps are on a different colour scale to the future projection maps.

At present, the area with the highest number of heavy rain days is the highest elevations of the mountain ranges in the west of the Otago region, where there is an average of at least 20 heavy rain days per year (Figure 4-10). Parts of Central Otago have the lowest number of heavy rain days per year (0.1-1 days per year). Heavy rain days are evenly distributed throughout the year, with perhaps a seasonal minimum occurring in winter (Figure 4-12).

In the future, the annual number of heavy rain days are not projected to change much for most of Otago; changes of ±0-1 day per year are projected for RCP4.5 and RCP8.5 by 2040 and 2090 (Figure 4-11). However, western parts of the region may see a considerable increase in heavy rain days. For example, by 2090 under RCP8.5, the number of heavy rain days is projected to increase in the far west of Otago by 5-15 days per year. Seasonal projections of change in heavy rain days are shown for RCP4.5 by 2040 (Figure 4-13) and 2090 (Figure 4-15), and RCP8.5 by 2040 (Figure 4-14) and 2090 (Figure 4-16). At the seasonal scale, for both time periods and scenarios, relatively small changes of ±0-1 heavy rain days are projected for most parts of Otago.

Table 4-3 shows the present and future projected heavy rain days for the model grid point closest to specific locations in the Otago region. Dunedin currently receives 4.9 heavy rain days per year, which is the highest of the 16 Otago locations presented. In future, Dunedin is projected to experience up to one more heavy rain day per year (by 2090 under RCP8.5). Alexandra and Arrowtown are projected to experience two more heavy rain days per year by 2090 under RCP8.5.

Note that although the number of heavy rain days per year/season is not expected to change much, the severity of these heavy rain events (i.e. the amount of rain that falls during these events) is likely to increase (Section 4.3).

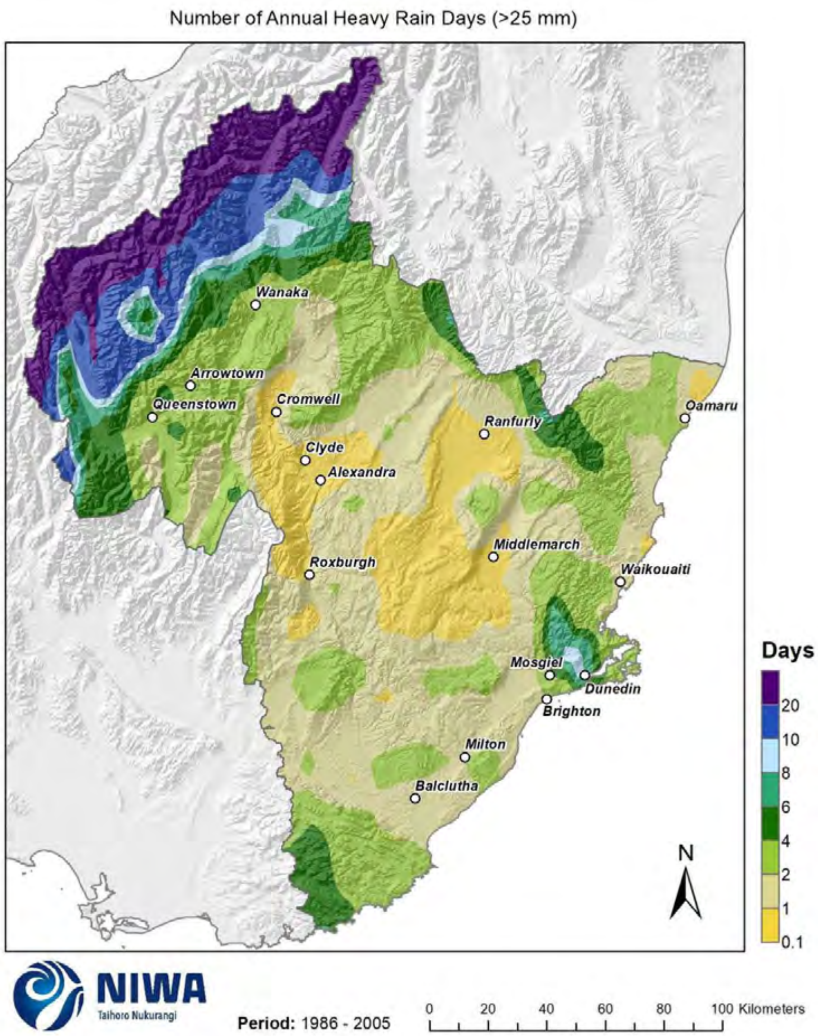

Figure 4-10: Modelled annual number of heavy rain days (daily rainfall >25mm), average over 1986-2005. Results are based on dynamical downscaled projections using NIWA's Regional Climate Model. Resolution of projection is 5km x 5km.

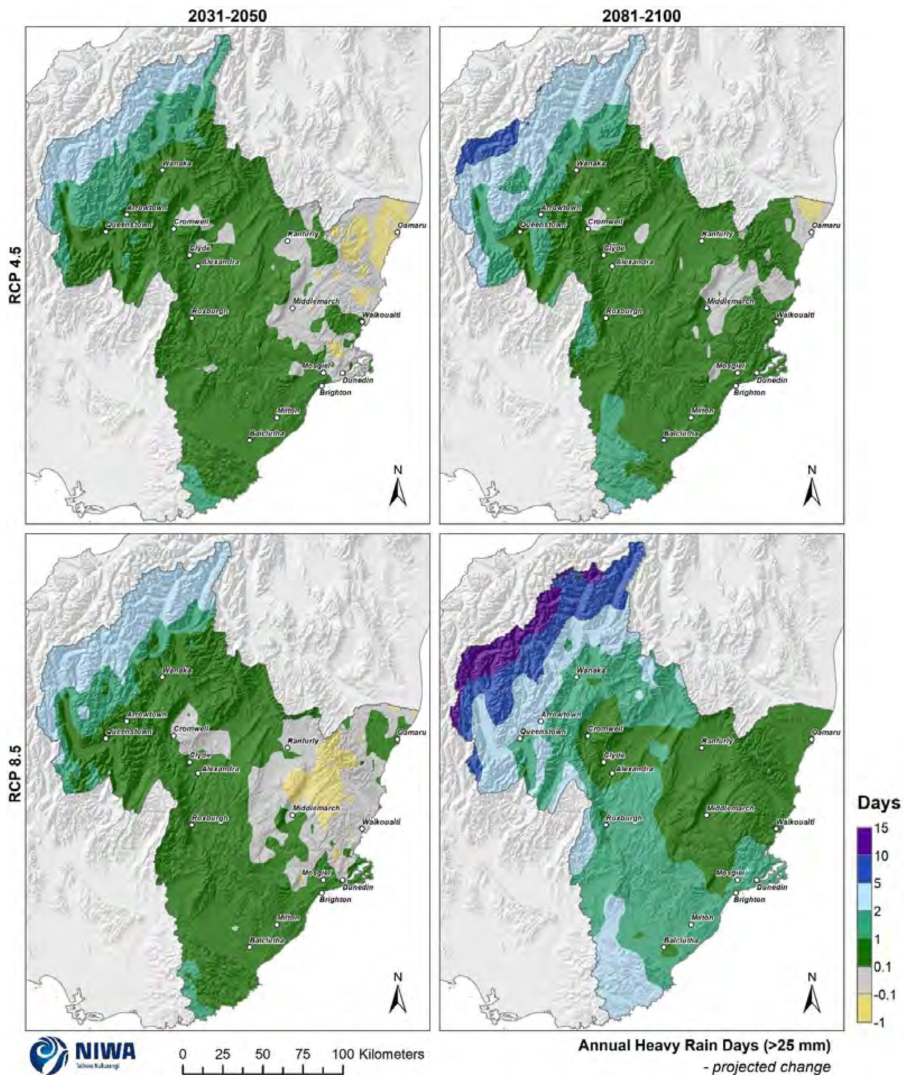

Figure 4-11: Projected annual number of heavy rain day (>25mm) changes by 2040 and 2090, under RCP4.5 and RCP8.5. Climate change scenarios: RCP4.5 (top panels) and RCP8.5 (bottom panels). Time periods: mid-century (2031-2050; "2040" – panels on left) and end-century (2081-2100; "2090" – panels on right). Changes relative to 1986-2005 average, based on the average of six global climate models. Results are based on dynamical downscaled projections using NIWA's Regional Climate Model. Resolution of projection is 5km x 5km.

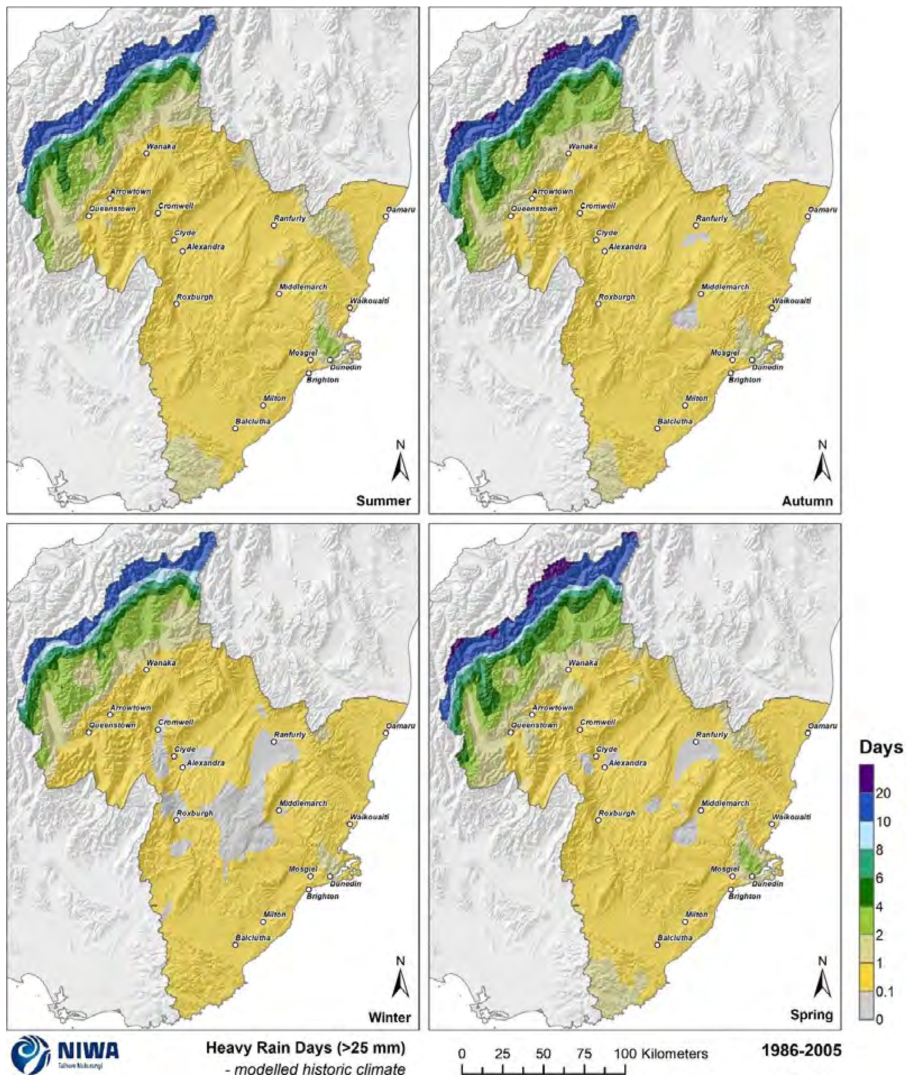

Figure 4-12: Modelled seasonal number of heavy rain days (daily rainfall >25mm), average over 1986-2005. Results are based on dynamical downscaled projections using NIWA's Regional Climate Model. Resolution of projection is 5km x 5km.

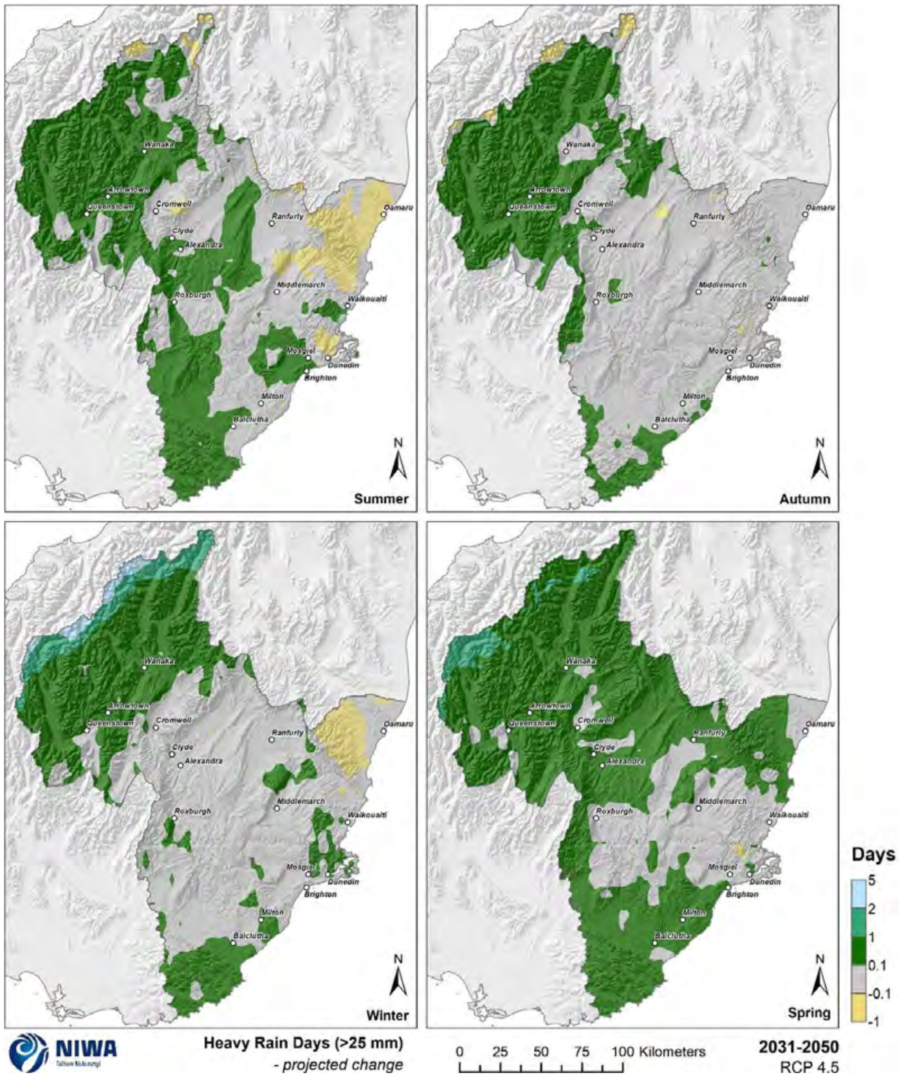

Figure 4-13: Projected seasonal number of heavy rain day (>25mm) changes by 2040 for RCP4.5. Relative to 1986-2005 average, based on the average of six global climate models. Results are based on dynamical downscaled projections using NIWA's Regional Climate Model. Resolution of projection is 5km x 5km.

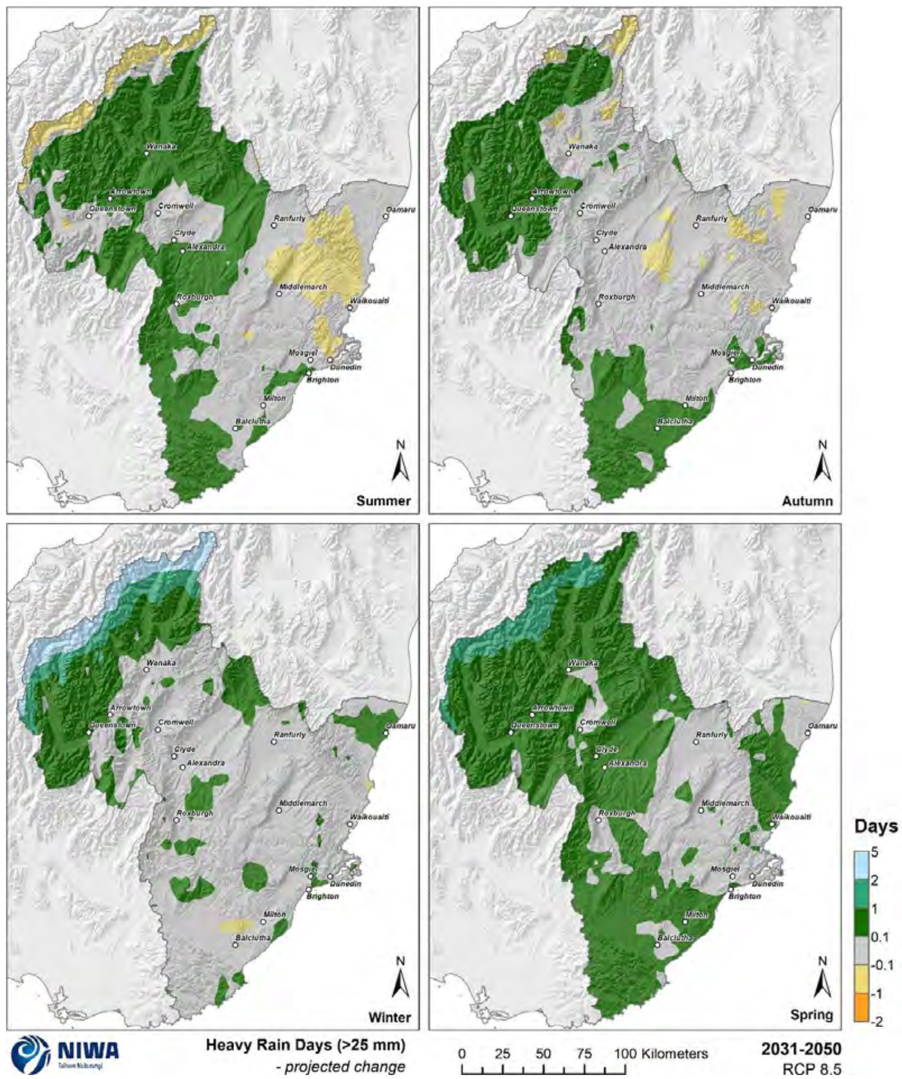

Figure 4-14: Projected seasonal number of heavy rain day (>25mm) changes by 2040 for RCP8.5. Relative to 1986-2005 average, based on the average of six global climate models. Results are based on dynamical downscaled projections using NIWA's Regional Climate Model. Resolution of projection is 5km x 5km.

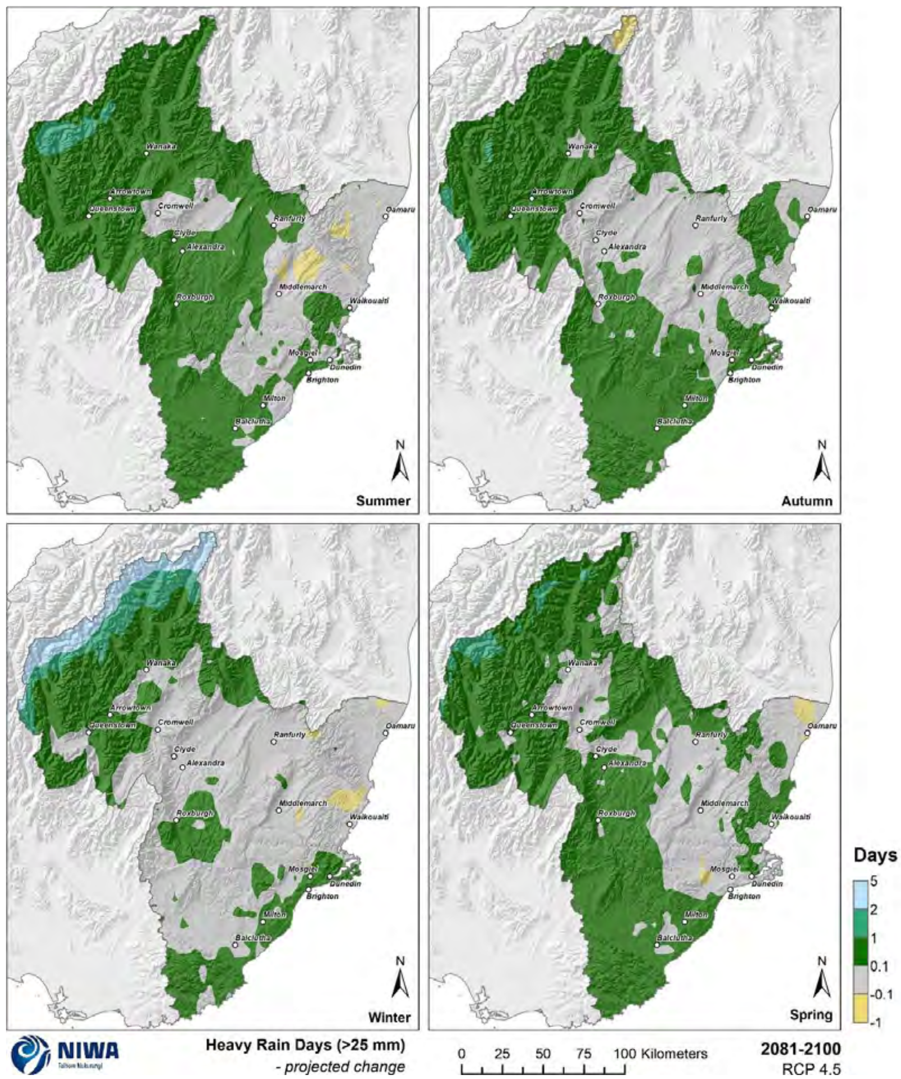

Figure 4-15: Projected seasonal number of heavy rain day (>25mm) changes by 2090 for RCP4.5. Relative to 1986-2005 average, based on the average of six global climate models. Results are based on dynamical downscaled projections using NIWA's Regional Climate Model. Resolution of projection is 5km x 5km.

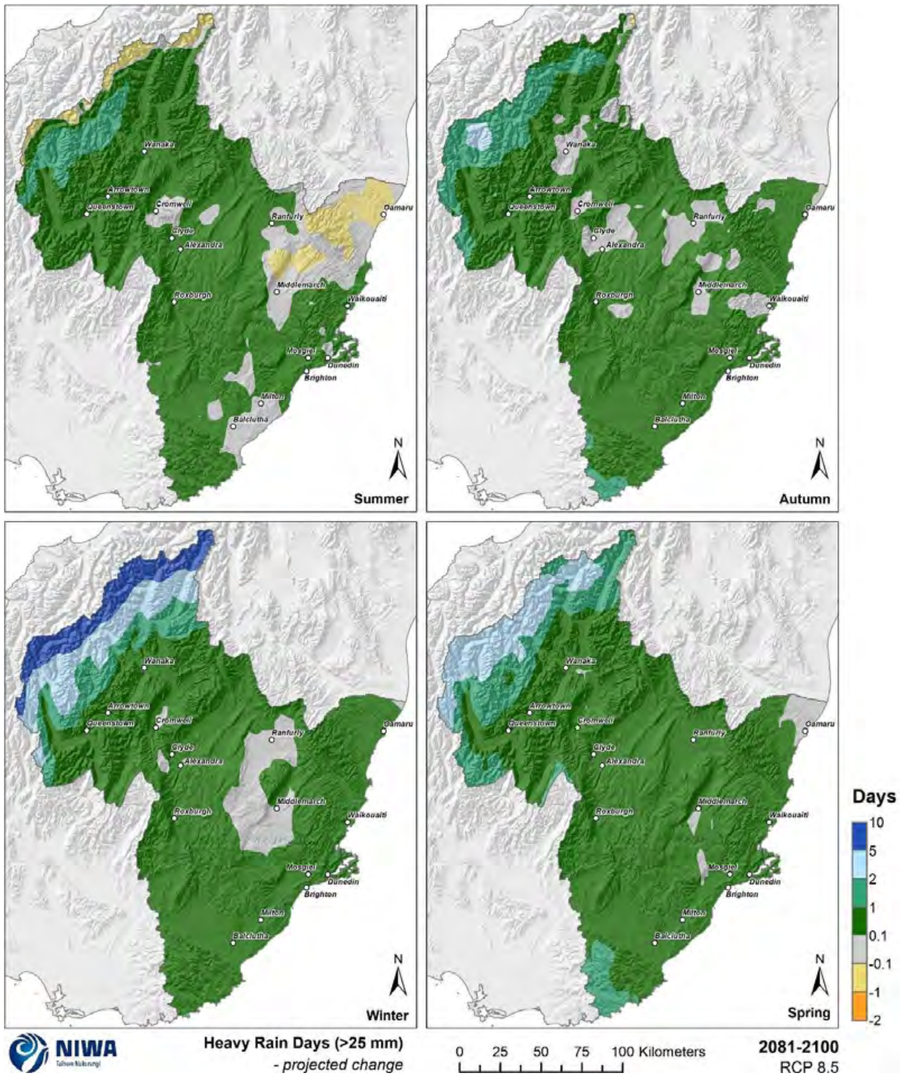

Figure 4-16: Projected seasonal number of heavy rain day (>25mm) changes by 2090 for RCP8.5. Relative to 1986-2005 average, based on the average of six global climate models. Results are based on dynamical downscaled projections using NIWA's Regional Climate Model. Resolution of projection is 5km x 5km.

Table 4-3: Modelled seasonal and annual average number of heavy rain days (>25 mm) for present and two climate change scenarios (RCP4.5 and RCP8.5) at two future time periods. Time periods: present (1986-2005), mid-century (2031-2050; "2040") and end-century (2081-2100; "2090"); based on the average of six global climate models. Annual ("Ann"); Seasons: summer ("Sum"), autumn ("Aut"), winter ("Win") and spring ("Spr"). Note that present values are *total* days whereas future values are the *change* in days.

	PRESENT				
	Sum	Aut	Win	Spr	Ann
Alexandra	0.1	0.2	0.1	0.1	0.5
Arrowtown	0.7	0.8	0.5	0.8	2.8
Balclutha	0.5	0.3	0.2	0.4	1.4
Brighton	0.5	0.4	0.2	0.5	1.6
Clyde	0.2	0.3	0.1	0.2	0.8
Cromwell	0.2	0.1	0.1	0.2	0.5
Dunedin	1.5	1.1	0.8	1.5	4.9
Middlemarch	0.2	0.1	0.1	0.1	0.5
Milton	0.7	0.4	0.2	0.5	1.9
Mosgiel	0.5	0.4	0.2	0.5	1.6
Oamaru	0.7	0.5	0.3	0.6	2.1
Queenstown	0.8	0.8	0.6	0.9	3.0
Ranfurly	0.2	0.2	0.1	0.1	0.5
Roxburgh	0.2	0.2	0.0	0.1	0.6
Waikouaiti	0.7	0.5	0.5	0.5	2.1
Wanaka	0.5	0.9	0.7	1.0	3.1

		2040					**2090**				
		Sum	Aut	Win	Spr	Ann	Sum	Aut	Win	Spr	Ann
Alexandra	RCP4.5	+0.2	+0.4	+0.1	+0.2	+0.9	+0.2	+0.4	+0.1	+0.2	+0.9
	RCP8.5	-0.1	+0.3	+0.2	+0.2	+0.7	+0.3	+0.5	+0.6	+0.6	+2.0
Arrowtown	RCP4.5	+0.2	+0.3	+0.2	+0.2	+0.9	+0.3	+0.4	+0.2	+0.2	+1.0
	RCP8.5	+0.2	+0.2	+0.1	+0.3	+0.7	+0.5	+0.3	+0.6	+0.6	+2.0
Balclutha	RCP4.5	+0.2	-0.1	+0.1	+0.1	+0.4	+0.3	+0.1	0	-0.1	+0.3
	RCP8.5	+0.2	-0.1	0	+0.1	+0.2	+0.4	+0.1	+0.5	+0.2	+1.1
Brighton	RCP4.5	0	+0.1	0	0	+0.1	0	0	0	0	+0.1
	RCP8.5	0	0	0	0	0	+0.1	+0.1	+0.1	+0.2	+0.3
Clyde	RCP4.5	+0.1	+0.1	0	+0.1	+0.3	+0.2	0	0	+0.1	+0.3
	RCP8.5	+0.1	0	+0.1	+0.2	+0.3	+0.3	+0.1	+0.2	+0.3	+0.9
Cromwell	RCP4.5	+0.1	0	0	+0.2	+0.3	+0.2	0	0	+0.1	+0.3
	RCP8.5	+0.1	-0.1	0	+0.1	+0.2	+0.2	+0.1	+0.1	+0.3	+0.7
Dunedin	RCP4.5	+0.1	0	0	+0.1	+0.2	+0.2	+0.1	+0.1	+0.1	+0.5
	RCP8.5	+0.1	0	0	+0.1	+0.2	+0.3	+0.2	+0.2	+0.4	+1.0
Middlemarch	RCP4.5	0	0	0	+0.1	+0.1	+0.1	0	0	+0.1	+0.2
	RCP8.5	0	0	0	+0.1	+0.1	+0.1	+0.1	+0.1	+0.3	+0.6
Milton	RCP4.5	0	0	0	0	0	0	+0.1	0	+0.1	+0.1
	RCP8.5	0	0	+0.1	0	+0.1	+0.1	+0.1	+0.1	+0.1	+0.3
Mosgiel	RCP4.5	-0.2	0	0	0	-0.2	0	+0.1	0	-0.1	0
	RCP8.5	0	0	+0.2	0	+0.2	-0.2	+0.1	+0.1	+0.1	+0.1
Oamaru	RCP4.5	0	0	+0.1	0	+0.1	+0.1	+0.1	0	+0.1	+0.3
	RCP8.5	-0.1	0	0	+0.2	0	+0.2	+0.1	+0.2	+0.3	+0.7
Queenstown	RCP4.5	0	0	+0.1	-0.1	0	+0.1	+0.3	+0.2	0	+0.6
	RCP8.5	0	+0.1	+0.1	-0.1	+0.1	+0.2	+0.4	+0.5	+0.5	+1.6
Ranfurly	RCP4.5	+0.2	0	+0.1	+0.1	+0.3	+0.2	+0.1	+0.1	0	+0.5
	RCP8.5	+0.1	+0.1	+0.1	+0.1	+0.4	+0.2	+0.2	+0.3	+0.3	+1.0
Roxburgh	RCP4.5	+0.2	0	+0.1	+0.1	+0.5	+0.3	+0.1	+0.2	+0.1	+0.7
	RCP8.5	+0.1	+0.1	+0.1	+0.1	+0.4	+0.3	+0.3	+0.4	+0.4	+1.3
Waikouaiti	RCP4.5	-0.1	+0.1	+0.1	+0.3	+0.4	+0.2	+0.2	+0.2	+0.2	+0.7
	RCP8.5	+0.1	+0.1	+0.1	+0.2	+0.5	+0.1	+0.6	+0.3	+0.5	+1.4
Wanaka	RCP4.5	+0.1	0	+0.1	+0.2	+0.4	+0.1	+0.3	+0.1	+0.1	+0.5
	RCP8.5	+0.1	+0.1	0	+0.1	+0.3	+0.1	+0.4	+0.2	+0.4	+1.1

4.3 Extreme, rare rainfall events (HIRDS v4)

Key messages

- Extreme, rare rainfall events are likely to increase in intensity in Otago because a warmer atmosphere can hold more moisture.
- Rainfall depth increases are projected at both future periods (2040 and 2090) under all four climate change scenarios; greatest increases are projected by 2090 under RCP8.5 (up to 35% higher for a 1:100 year 1-hour duration rainfall event).
- Short duration rainfall events have the largest relative increases.
- Extreme rainfall projections for any New Zealand location can be viewed at https://hirds.niwa.co.nz/
- Increases in extreme rainfall events may cause more flooding (see Section 6).

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

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

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

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

NIWA's High Intensity Rainfall Design System (HIRDS version 4) allows rainfall event totals (depth; measured in mm) at various recurrence intervals to be calculated for any location in New Zealand (Carey-Smith et al., 2018). The rainfall event durations presented in HIRDS range from 10 minutes to 120 hours. HIRDS calculates historic rainfall event totals for given recurrence intervals as well as future potential rainfall event totals for given recurrence intervals based on climate change scenarios. HIRDS v4 can be freely accessed at https://hirds.niwa.co.nz/, and more background information to the HIRDS methodology can be found at https://www.niwa.co.nz/information-services/hirds/help. HIRDS rainfall projections for locations in Otago are presented in Sections 4.3.1 to 4.3.5. Each section contains two tables; the first table presents data for 1:50 year rainfall events, and the second table presents data for 1:100 year rainfall events.

The depth of historic 1:50 and 1:100-year rainfall events are projected to increase in the future under all four climate change scenarios. The most considerable increases are projected at the end of the century (i.e. 2090) under RCP8.5. Short duration rainfall events have the largest relative increases compared with longer duration rainfall events. For example, the depth of a current 1:100-year 1-hour duration rainfall event is projected to increase by approximately 35% by 2090 under RCP8.5 for locations throughout Otago. In contrast, the depth of a current 1:100-year 48-hour duration rainfall event is projected to increase by approximately 20% by 2090 under RCP8.5 for Otago locations.

4.3.1 1-hour duration rainfall

Table 4-4 (50-year ARI) and Table 4-5 (100-year ARI) show modelled historic and projected rainfall depths for a 1-hour rain event. Rainfall depths are projected to increase across both future periods and for all climate change scenarios. Projected rainfall depth increases range from 8% (by 2040 and 2090 under RCP2.6) to 35% (by 2090 under RCP8.5).

Table 4-4: Modelled historic and projected rainfall depths (mm) for a 1-hour rain event with a 50-year ARI. Time periods: mid-century (2031-2050; "2040") and end-century (2081-2100; "2090"); based on the average of six global climate models under four climate change scenarios (RCP2.6, RCP4.5, RCP6.0 and RCP8.5).

	Historic depth (mm)	2040				2090			
		RCP2.6	RCP4.5	RCP6.0	RCP8.5	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Alexandra	27.1	29.2	29.8	29.5	30.2	29.2	31.5	33.0	36.5
Arrowtown	23.1	24.9	25.4	25.2	25.7	24.9	26.9	28.2	31.1
Balclutha	25.6	27.7	28.2	28.0	28.6	27.7	29.8	31.3	34.6
Brighton	26.3	28.4	28.9	28.7	29.3	28.4	30.6	32.1	35.4
Clyde	23.0	24.9	25.3	25.1	25.7	24.9	26.8	28.1	31.1
Cromwell	22.8	24.6	25.1	24.9	25.4	24.6	26.5	27.8	30.8
Dunedin	27.1	29.2	29.8	29.6	30.2	29.2	31.5	33.0	36.5
Middlemarch	25.8	27.9	28.4	28.2	28.8	27.9	30.0	31.5	34.8
Milton	28.0	30.3	30.8	30.6	31.2	30.3	32.6	34.2	37.8
Mosgiel	27.4	29.6	30.1	29.9	30.5	29.6	31.9	33.4	36.9
Oamaru	26.5	28.6	29.1	28.9	29.5	28.6	30.8	32.3	35.7
Queenstown	22.9	24.8	25.2	25.0	25.6	24.8	26.7	28.0	30.9
Ranfurly	30.8	33.2	33.9	33.6	34.3	33.2	35.8	37.6	41.5
Roxburgh	27.9	30.1	30.7	30.4	31.1	30.1	32.4	34.0	37.6
Waikouaiti	27.6	29.8	30.4	30.2	30.8	29.8	32.2	33.7	37.3
Wanaka	20.2	21.8	22.2	22.0	22.5	21.8	23.5	24.6	27.2

Table 4-5: Modelled historic and projected rainfall depths (mm) for a 1-hour rain event with a 100-year ARI. Time periods: mid-century (2031-2050; "2040") and end-century (2081-2100; "2090"); based on the average of six global climate models under four climate change scenarios (RCP2.6, RCP4.5, RCP6.0 and RCP8.5).

	Historic depth (mm)	2040				2090			
		RCP2.6	RCP4.5	RCP6.0	RCP8.5	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Alexandra	32.3	34.9	35.5	35.3	36.0	34.9	37.6	39.4	43.6
Arrowtown	26.8	28.9	29.5	29.2	29.9	28.9	31.2	32.7	36.2
Balclutha	30.3	32.7	33.3	33.1	33.8	32.7	35.3	37.0	40.9
Brighton	31.0	33.5	34.1	33.9	34.6	33.5	36.1	37.9	41.9
Clyde	27.1	29.3	29.8	29.6	30.2	29.3	31.6	33.1	36.6
Cromwell	26.8	28.9	29.5	29.2	29.9	28.9	31.2	32.7	36.2
Dunedin	32.0	34.5	35.2	34.9	35.7	34.5	37.2	39.0	43.2
Middlemarch	30.6	33.0	33.7	33.4	34.1	33.0	35.6	37.4	41.3
Milton	32.8	35.5	36.1	35.9	36.6	35.5	38.2	40.1	44.4
Mosgiel	32.3	34.9	35.5	35.3	36.0	34.9	37.6	39.5	43.6
Oamaru	30.9	33.4	34.0	33.8	34.5	33.4	36.0	37.8	41.8
Queenstown	26.7	28.8	29.3	29.1	29.7	28.8	31.0	32.6	36.0
Ranfurly	36.3	39.2	40.0	39.7	40.5	39.2	42.3	44.3	49.0
Roxburgh	33.0	35.7	36.4	36.1	36.8	35.7	38.5	40.4	44.6
Waikouaiti	32.5	35.1	35.8	35.5	36.3	35.1	37.9	39.7	43.9
Wanaka	23.1	25.0	25.5	25.3	25.8	25.0	27.0	28.3	31.3

4.3.2 6-hour duration rainfall

Table 4-6 (50-year ARI) and Table 4-7 (100-year ARI) show modelled historic and projected rainfall depths for a 6-hour rain event. Rainfall depths are projected to increase across both future periods and for all climate change scenarios. Projected rainfall depth increases range from 7% (by 2040 and 2090 under RCP2.6) to 30% (by 2090 under RCP8.5).

Table 4-6: Modelled historic and projected rainfall depths (mm) for a 6-hour rain event with a 50-year ARI. Time periods: mid-century (2031-2050; "2040") and end-century (2081-2100; "2090"); based on the average of six global climate models under four climate change scenarios (RCP2.6, RCP4.5, RCP6.0 and RCP8.5).

	Historic depth (mm)	2040				2090			
		RCP2.6	RCP4.5	RCP6.0	RCP8.5	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Alexandra	52.9	56.4	57.3	57.0	58.0	56.4	60.1	62.7	68.3
Arrowtown	57.2	61.0	62.0	61.6	62.7	61.0	65.0	67.8	73.9
Balclutha	53.6	57.2	58.1	57.8	58.8	57.2	61.0	63.5	69.3
Brighton	61.5	65.6	66.6	66.2	67.4	65.6	69.9	72.8	79.4
Clyde	46.7	49.8	50.6	50.3	51.2	49.8	53.1	55.3	60.3
Cromwell	50.9	54.3	55.2	54.8	55.8	54.3	57.9	60.3	65.7
Dunedin	65.1	69.4	70.5	70.1	71.3	69.4	74.0	77.0	84.0
Middlemarch	54.5	58.1	59.1	58.7	59.7	58.1	61.9	64.5	70.4
Milton	62.5	66.7	67.8	67.3	68.5	66.7	71.1	74.1	80.8
Mosgiel	67.3	71.7	72.9	72.4	73.7	71.7	76.5	79.7	86.9
Oamaru	66.2	70.6	71.8	71.3	72.6	70.6	75.3	78.4	85.5
Queenstown	56.4	60.1	61.1	60.7	61.8	60.1	64.1	66.7	72.8
Ranfurly	56.0	59.7	60.7	60.3	61.4	59.7	63.7	66.3	72.3
Roxburgh	52.9	56.4	57.3	56.9	58.0	56.4	60.1	62.6	68.3
Waikouaiti	69.6	74.2	75.4	74.9	76.3	74.2	79.1	82.4	89.9
Wanaka	57.7	61.6	62.6	62.2	63.3	61.6	65.6	68.4	74.6

Table 4-7: Modelled historic and projected rainfall depths (mm) for a 6-hour rain event with a 100-year ARI. Time periods: mid-century (2031-2050; "2040") and end-century (2081-2100; "2090"); based on the average of six global climate models under four climate change scenarios (RCP2.6, RCP4.5, RCP6.0 and RCP8.5).

	Historic depth (mm)	2040				2090			
		RCP2.6	RCP4.5	RCP6.0	RCP8.5	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Alexandra	61.4	65.6	66.6	66.2	67.4	65.6	69.9	72.9	79.6
Arrowtown	65.3	69.8	70.9	70.5	71.7	69.8	74.4	77.6	84.7
Balclutha	62.5	66.7	67.8	67.3	68.6	66.7	71.2	74.2	81.0
Brighton	71.9	76.8	78.1	77.6	79.0	76.8	81.9	85.4	93.3
Clyde	53.8	57.5	58.4	58.0	59.1	57.5	61.3	63.9	69.8
Cromwell	58.5	62.5	63.5	63.1	64.2	62.5	66.7	69.5	75.9
Dunedin	76.2	81.4	82.7	82.1	83.6	81.4	86.8	90.5	98.8
Middlemarch	63.4	67.7	68.8	68.4	69.6	67.7	72.2	75.3	82.2
Milton	72.7	77.6	78.9	78.4	79.8	77.6	82.8	86.3	94.2
Mosgiel	78.6	84.0	85.3	84.8	86.3	84.0	89.6	93.4	102.0
Oamaru	77.0	82.3	83.6	83.1	84.6	82.3	87.8	91.5	99.9
Queenstown	64.4	68.7	69.9	69.4	70.7	68.7	73.3	76.4	83.5
Ranfurly	64.8	69.2	70.3	69.8	71.1	69.2	73.8	76.9	84.0
Roxburgh	61.3	65.5	66.5	66.1	67.3	65.5	69.8	72.8	79.5
Waikouaiti	81.3	86.8	88.2	87.6	89.2	86.8	92.6	96.5	105.0
Wanaka	65.4	69.9	71.0	70.6	71.8	69.9	74.5	77.7	84.8

4.3.3 12-hour duration rainfall

Table 4-8 (50-year ARI) and Table 4-9 (100-year ARI) show modelled historic and projected rainfall depths for a 12-hour rain event. Rainfall depths are projected to increase across both future periods and for all climate change scenarios. Projected rainfall depth increases range from 6% (by 2040 and 2090 under RCP2.6) to 26% (by 2090 under RCP8.5).

Table 4-8: Modelled historic and projected rainfall depths (mm) for a 12-hour rain event with a 50-year ARI. Time periods: mid-century (2031-2050; "2040") and end-century (2081-2100; "2090"); based on the average of six global climate models under four climate change scenarios (RCP2.6, RCP4.5, RCP6.0 and RCP8.5).

	Historic	2040				2090			
	depth (mm)	RCP2.6	RCP4.5	RCP6.0	RCP8.5	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Alexandra	65.0	68.7	69.7	69.3	70.4	68.7	72.7	75.4	81.5
Arrowtown	77.5	82.0	83.2	82.7	84.0	82.0	86.8	90.0	97.3
Balclutha	71.2	75.4	76.5	76.0	77.2	75.4	79.8	82.7	89.4
Brighton	85.2	90.2	91.4	90.9	92.4	90.2	95.4	98.9	107.0
Clyde	59.5	62.9	63.8	63.5	64.5	62.9	66.6	69.1	74.7
Cromwell	66.0	69.9	70.8	70.5	71.6	69.9	73.9	76.7	82.9
Dunedin	89.9	95.2	96.5	96.0	97.5	95.2	101.0	104.0	113.0
Middlemarch	71.7	75.9	76.9	76.5	77.7	75.9	80.3	83.2	90.0
Milton	83.3	88.2	89.4	88.9	90.3	88.2	93.3	96.8	105.0
Mosgiel	93.2	98.6	100.0	99.5	101.0	98.6	104.0	108.0	117.0
Oamaru	91.2	96.6	97.9	97.4	98.9	96.6	102.0	106.0	115.0
Queenstown	76.9	81.4	82.6	82.1	83.4	81.4	86.2	89.4	96.6
Ranfurly	67.3	71.3	72.3	71.9	73.0	71.3	75.4	78.2	84.5
Roxburgh	66.1	70.0	71.0	70.6	71.7	70.0	74.1	76.8	83.0
Waikouaiti	94.8	100.0	102.0	101.0	103.0	100.0	106.0	110.0	119.0
Wanaka	81.0	85.7	86.9	86.4	87.8	85.7	90.7	94.1	102.0

Table 4-9: Modelled historic and projected rainfall depths (mm) for a 12-hour rain event with a 100-year ARI. Time periods: mid-century (2031-2050; "2040") and end-century (2081-2100; "2090"); based on the average of six global climate models under four climate change scenarios (RCP2.6, RCP4.5, RCP6.0 and RCP8.5).

	Historic	2040				2090			
	depth (mm)	RCP2.6	RCP4.5	RCP6.0	RCP8.5	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Alexandra	74.6	79.0	80.1	79.7	81.0	79.0	83.7	86.8	94.0
Arrowtown	88.0	93.3	94.6	94.1	95.6	93.3	98.8	103.0	111.0
Balclutha	82.5	87.4	88.7	88.2	89.6	87.4	92.6	96.1	104.0
Brighton	99.4	105.0	107.0	106.0	108.0	105.0	112.0	116.0	125.0
Clyde	67.9	72.0	73.0	72.6	73.8	72.0	76.2	79.1	85.6
Cromwell	75.3	79.8	80.9	80.5	81.8	79.8	84.5	87.7	94.9
Dunedin	105.0	111.0	113.0	112.0	114.0	111.0	118.0	122.0	132.0
Middlemarch	82.8	87.7	89.0	88.5	89.9	87.7	92.9	96.4	104.0
Milton	96.6	102.0	104.0	103.0	105.0	102.0	108.0	112.0	122.0
Mosgiel	109.0	115.0	117.0	116.0	118.0	115.0	122.0	126.0	137.0
Oamaru	106.0	112.0	114.0	113.0	115.0	112.0	119.0	123.0	134.0
Queenstown	87.3	92.5	93.8	93.3	94.8	92.5	98.0	102.0	110.0
Ranfurly	77.3	81.9	83.1	82.6	83.9	81.9	86.7	90.0	97.4
Roxburgh	76.0	80.5	81.7	81.2	82.5	80.5	85.3	88.5	95.8
Waikouaiti	110.0	117.0	119.0	118.0	120.0	117.0	124.0	129.0	139.0
Wanaka	91.4	96.8	98.2	97.7	99.2	96.8	103.0	106.0	115.0

4.3.4 24-hour duration rainfall

Table 4-10 (50-year ARI) and Table 4-11 (100-year ARI) show modelled historic and projected rainfall depths for a 24-hour rain event. Rainfall depths are projected to increase across both future periods and for all climate change scenarios. Projected rainfall depth increases range from 5% (by 2040 and 2090 under RCP2.6) to 23% (by 2090 under RCP8.5).

Table 4-10: Modelled historic and projected rainfall depths (mm) for a 24-hour rain event with a 50-year ARI. Time periods: mid-century (2031-2050; "2040") and end-century (2081-2100; "2090"); based on the average of six global climate models under four climate change scenarios (RCP2.6, RCP4.5, RCP6.0 and RCP8.5).

	Historic	2040				2090			
	depth (mm)	RCP2.6	RCP4.5	RCP6.0	RCP8.5	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Alexandra	76.6	80.4	81.3	81.0	82.0	80.4	84.4	87.1	93.2
Arrowtown	102.0	107.0	108.0	107.0	109.0	107.0	112.0	115.0	124.0
Balclutha	92.7	97.3	98.5	98.0	99.3	97.3	102.0	105.0	113.0
Brighton	116.0	121.0	123.0	122.0	124.0	121.0	127.0	131.0	141.0
Clyde	72.9	76.5	77.4	77.1	78.1	76.5	80.3	82.9	88.7
Cromwell	81.6	85.7	86.7	86.3	87.5	85.7	89.9	92.8	99.3
Dunedin	121.0	127.0	128.0	128.0	129.0	127.0	133.0	137.0	147.0
Middlemarch	91.7	96.2	97.4	96.9	98.2	96.2	101.0	104.0	112.0
Milton	107.0	113.0	114.0	114.0	115.0	113.0	118.0	122.0	131.0
Mosgiel	125.0	131.0	133.0	132.0	134.0	131.0	138.0	142.0	152.0
Oamaru	121.0	127.0	129.0	128.0	130.0	127.0	134.0	138.0	148.0
Queenstown	101.0	106.0	107.0	107.0	108.0	106.0	111.0	115.0	123.0
Ranfurly	78.8	82.7	83.7	83.3	84.5	82.7	86.8	89.6	95.9
Roxburgh	80.7	84.7	85.7	85.3	86.5	84.7	88.9	91.8	98.2
Waikouaiti	123.0	129.0	131.0	130.0	132.0	129.0	136.0	140.0	150.0
Wanaka	108.0	113.0	114.0	114.0	115.0	113.0	119.0	122.0	131.0

Table 4-11: Modelled historic and projected rainfall depths (mm) for a 24-hour rain event with a 100-year ARI. Time periods: mid-century (2031-2050; "2040") and end-century (2081-2100; "2090"); based on the average of six global climate models under four climate change scenarios (RCP2.6, RCP4.5, RCP6.0 and RCP8.5).

	Historic	2040				2090			
	depth (mm)	RCP2.6	RCP4.5	RCP6.0	RCP8.5	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Alexandra	87.0	91.4	92.5	92.1	93.3	91.4	96.0	99.2	106.0
Arrowtown	115.0	121.0	122.0	121.0	123.0	121.0	127.0	131.0	140.0
Balclutha	107.0	112.0	114.0	113.0	115.0	112.0	118.0	122.0	130.0
Brighton	134.0	141.0	143.0	142.0	144.0	141.0	148.0	153.0	164.0
Clyde	82.6	86.8	87.9	87.4	88.6	86.8	91.2	94.2	101.0
Cromwell	92.4	97.1	98.3	97.8	99.1	97.1	102.0	105.0	113.0
Dunedin	141.0	148.0	150.0	149.0	151.0	148.0	155.0	160.0	172.0
Middlemarch	105.0	110.0	112.0	111.0	113.0	110.0	116.0	120.0	128.0
Milton	124.0	130.0	132.0	131.0	133.0	130.0	137.0	142.0	152.0
Mosgiel	145.0	153.0	155.0	154.0	156.0	153.0	160.0	166.0	178.0
Oamaru	141.0	148.0	150.0	149.0	151.0	148.0	155.0	161.0	172.0
Queenstown	114.0	120.0	121.0	120.0	122.0	120.0	126.0	130.0	139.0
Ranfurly	89.8	94.3	95.5	95.0	96.4	94.3	99.1	102.0	110.0
Roxburgh	92.0	96.6	97.8	97.3	98.7	96.6	102.0	105.0	112.0
Waikouaiti	143.0	150.0	152.0	152.0	154.0	150.0	158.0	163.0	175.0
Wanaka	121.0	127.0	129.0	128.0	130.0	127.0	133.0	138.0	148.0

4.3.5 48-hour duration rainfall

Table 4-12 (50-year ARI) and Table 4-13 (100-year ARI) show modelled historic and projected rainfall depths for a 48-hour rain event. Rainfall depths are projected to increase across both future periods and for all climate change scenarios. Projected rainfall depth increases range from 4% (by 2040 and 2090 under RCP2.6) to 20% (by 2090 under RCP8.5).

Table 4-12: Modelled historic and projected rainfall depths (mm) for a 48-hour rain event with a 50-year ARI. Time periods: mid-century (2031-2050; "2040") and end-century (2081-2100; "2090"); based on the average of six global climate models under four climate change scenarios (RCP2.6, RCP4.5, RCP6.0 and RCP8.5).

	Historic depth (mm)	2040				2090			
		RCP2.6	RCP4.5	RCP6.0	RCP8.5	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Alexandra	86.2	89.9	90.0	90.5	91.6	89.9	93.9	96.6	103.0
Arrowtown	128.0	134.0	135.0	135.0	136.0	134.0	140.0	144.0	153.0
Balclutha	117.0	122.0	123.0	122.0	124.0	122.0	127.0	131.0	139.0
Brighton	152.0	158.0	160.0	159.0	161.0	158.0	165.0	170.0	181.0
Clyde	85.0	88.7	89.6	89.3	90.3	88.7	92.6	95.2	101.0
Cromwell	95.1	99.2	100.0	99.9	101.0	99.2	104.0	107.0	113.0
Dunedin	156.0	162.0	164.0	163.0	165.0	162.0	170.0	174.0	185.0
Middlemarch	112.0	117.0	119.0	118.0	120.0	117.0	123.0	126.0	134.0
Milton	132.0	138.0	140.0	139.0	141.0	138.0	144.0	148.0	158.0
Mosgiel	160.0	167.0	169.0	169.0	171.0	167.0	175.0	180.0	191.0
Oamaru	154.0	161.0	162.0	162.0	164.0	161.0	168.0	173.0	183.0
Queenstown	126.0	131.0	133.0	132.0	134.0	131.0	137.0	141.0	150.0
Ranfurly	89.8	93.7	94.7	94.3	95.5	93.7	97.9	101.0	107.0
Roxburgh	95.4	99.6	101.0	100.0	101.0	99.6	104.0	107.0	114.0
Waikouaiti	151.0	158.0	159.0	159.0	161.0	158.0	165.0	169.0	180.0
Wanaka	134.0	140.0	141.0	141.0	142.0	140.0	146.0	150.0	160.0

Table 4-13: Modelled historic and projected rainfall depths (mm) for a 48-hour rain event with a 100-year ARI. Time periods: mid-century (2031-2050; "2040") and end-century (2081-2100; "2090"); based on the average of six global climate models under four climate change scenarios (RCP2.6, RCP4.5, RCP6.0 and RCP8.5).

	Historic depth (mm)	2040				2090			
		RCP2.6	RCP4.5	RCP6.0	RCP8.5	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Alexandra	96.8	101.0	102.0	102.0	103.0	101.0	106.0	109.0	116.0
Arrowtown	144.0	150.0	152.0	151.0	153.0	150.0	157.0	162.0	172.0
Balclutha	134.0	139.0	141.0	140.0	142.0	139.0	146.0	150.0	159.0
Brighton	176.0	184.0	186.0	185.0	187.0	184.0	192.0	197.0	210.0
Clyde	95.5	99.7	101.0	100.0	102.0	99.7	104.0	107.0	114.0
Cromwell	107.0	111.0	113.0	112.0	114.0	111.0	116.0	120.0	127.0
Dunedin	181.0	189.0	191.0	190.0	192.0	189.0	197.0	203.0	216.0
Middlemarch	128.0	134.0	135.0	135.0	136.0	134.0	140.0	144.0	153.0
Milton	152.0	159.0	161.0	160.0	162.0	159.0	166.0	171.0	182.0
Mosgiel	186.0	194.0	196.0	195.0	198.0	194.0	203.0	209.0	222.0
Oamaru	179.0	186.0	188.0	188.0	190.0	186.0	195.0	200.0	213.0
Queenstown	141.0	147.0	149.0	148.0	150.0	147.0	154.0	158.0	168.0
Ranfurly	102.0	106.0	107.0	107.0	108.0	106.0	111.0	114.0	121.0
Roxburgh	108.0	113.0	114.0	113.0	115.0	113.0	118.0	121.0	129.0
Waikouaiti	175.0	183.0	185.0	184.0	186.0	183.0	191.0	196.0	209.0
Wanaka	150.0	156.0	158.0	158.0	159.0	156.0	163.0	168.0	179.0

4.4 Dry days

Key messages

- By 2040 under RCP4.5 the number of dry days per year decreases near the coast and parts of Central Otago (1-4 fewer dry days per year), with increases of 1-6 more annual dry days for many remaining parts of Otago.
- By 2090 under RCP8.5, 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.
- Seasonally, the largest changes are projected for winter and summer by 2090 under RCP8.5: e.g. 4-10 fewer *winter* dry days projected for many western parts of Otago, with 2-8 more *summer* dry days projected for western and inland parts of Otago.

A dry day considered here is when < 1 mm of rainfall is recorded. Present-day (average over 1986-2005) and future (average over 2031-2050 and 2081-2100) maps for dry days are shown in this section. The present-day maps show annual and seasonal average numbers of dry days and the future projection maps show the change in the number of dry days compared with present. Note that the present-day maps are on a different colour scale to the future projection maps.

At present, the largest annual number of dry days is experienced in parts of Central Otago and about Oamaru (275-300 days per year; Figure 4-17). Areas around Dunedin, the Taieri Plains, Balclutha and Queenstown average around 225-250 dry days per year. Southern-most and northwestern areas of Otago experience the fewest annual dry days for the region, averaging 150-175 dry days per year. Winter is typically the season with the largest number of dry days, with 60-80 dry days for much of the region Figure 4-19. Spring typically has the fewest dry days (50-70 dry days for much of the region).

By 2040 under RCP4.5 (Figure 4-18), the number of dry days per year decreases near the coast and parts of Central Otago (1-4 fewer dry days per year), with increases of 1-6 more annual dry days for many remaining parts of Otago. This pattern is amplified under RCP8.5 at 2040 and RCP4.5 and RCP8.5 at 2090 (decreasing dry days for central and coastal areas and increasing dry days for many other areas). By 2090 under RCP8.5, decreases in annual dry days are projected for coastal and some central parts of Otago (2-6 fewer dry days per year), with increases of 2-10 more dry days per year for many remaining parts of Otago.

Seasonal projections of change in dry days are shown for RCP4.5 by 2040 (Figure 4-20) and 2090 (Figure 4-22), and RCP8.5 by 2040 (Figure 4-21) and 2090 (Figure 4-23). Generally, decreases in dry days are projected for winter (whole region) and spring and autumn (eastern areas), and increases are projected for summer (whole region) and for spring and autumn (western/inland areas). The changes generally get larger with time and emission scenario. The largest changes are projected for winter and summer by 2090 under RCP8.5. For example, 4-10 fewer winter dry days are projected for many western parts of Otago by 2090 under RCP8.5. During summer, 2-8 more dry days are projected for western and inland parts of Otago by 2090 under RCP8.5.

Table 4-14 shows the present and future projected dry days for the model grid point closest to specific locations in the Otago region. Alexandra currently experiences 286 dry days per year, which is the highest of the 16 Otago locations presented. In future, Alexandra is projected to experience five fewer dry days per year (by 2090 under RCP8.5). Wanaka and Arrowtown are projected to experience seven and five more dry days per year by 2090 under RCP8.5, respectively.

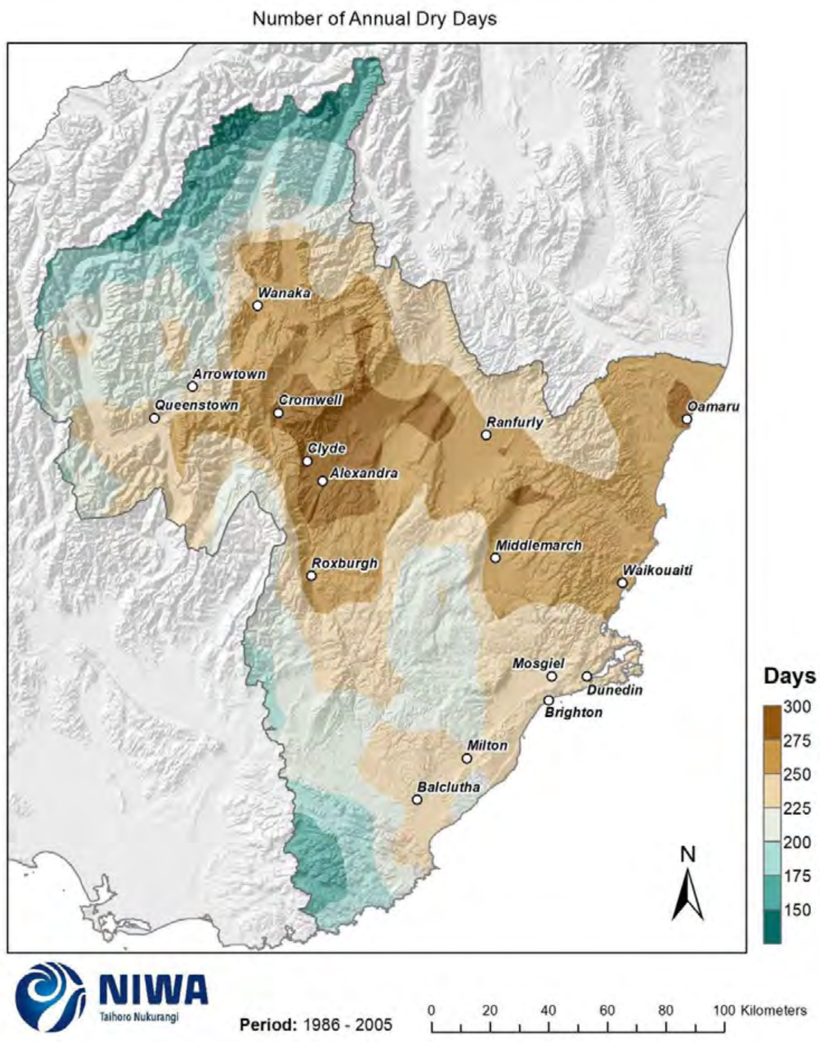

Figure 4-17: Modelled annual number of dry days (daily rainfall <1mm), average over 1986-2005. Results are based on dynamical downscaled projections using NIWA's Regional Climate Model. Resolution of projection is 5km x 5km.

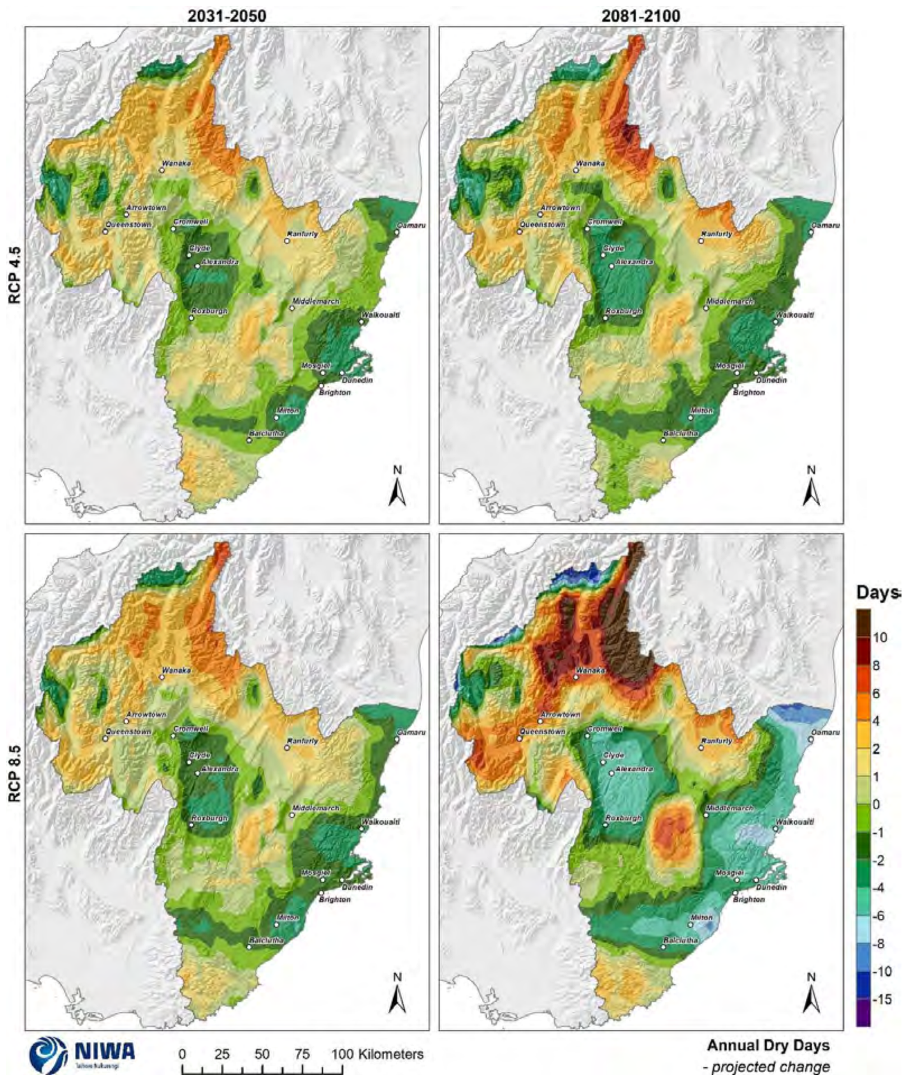

Figure 4-18: Projected annual number of dry day (daily rainfall <1mm) changes by 2040 and 2090, under RCP4.5 and RCP8.5. Climate change scenarios: RCP4.5 (top panels) and RCP8.5 (bottom panels). Time periods: mid-century (2031-2050; "2040" – panels on left) and end-century (2081-2100; "2090" – panels on right). Changes relative to 1986-2005 average, based on the average of six global climate models. Results are based on dynamical downscaled projections using NIWA's Regional Climate Model. Resolution of projection is 5km x 5km.

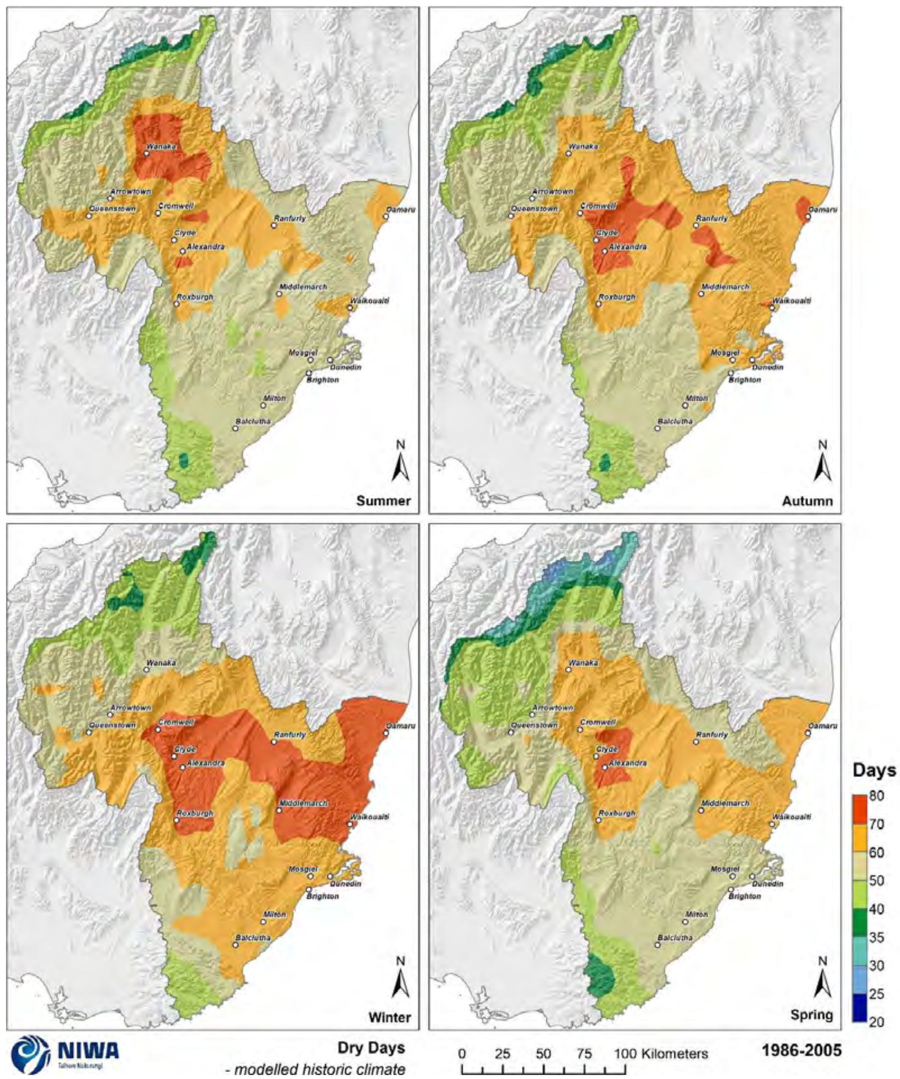

Figure 4-19: Modelled seasonal number of dry days (daily rainfall <1mm), average over 1986-2005. Results are based on dynamical downscaled projections using NIWA's Regional Climate Model. Resolution of projection is 5km x 5km.

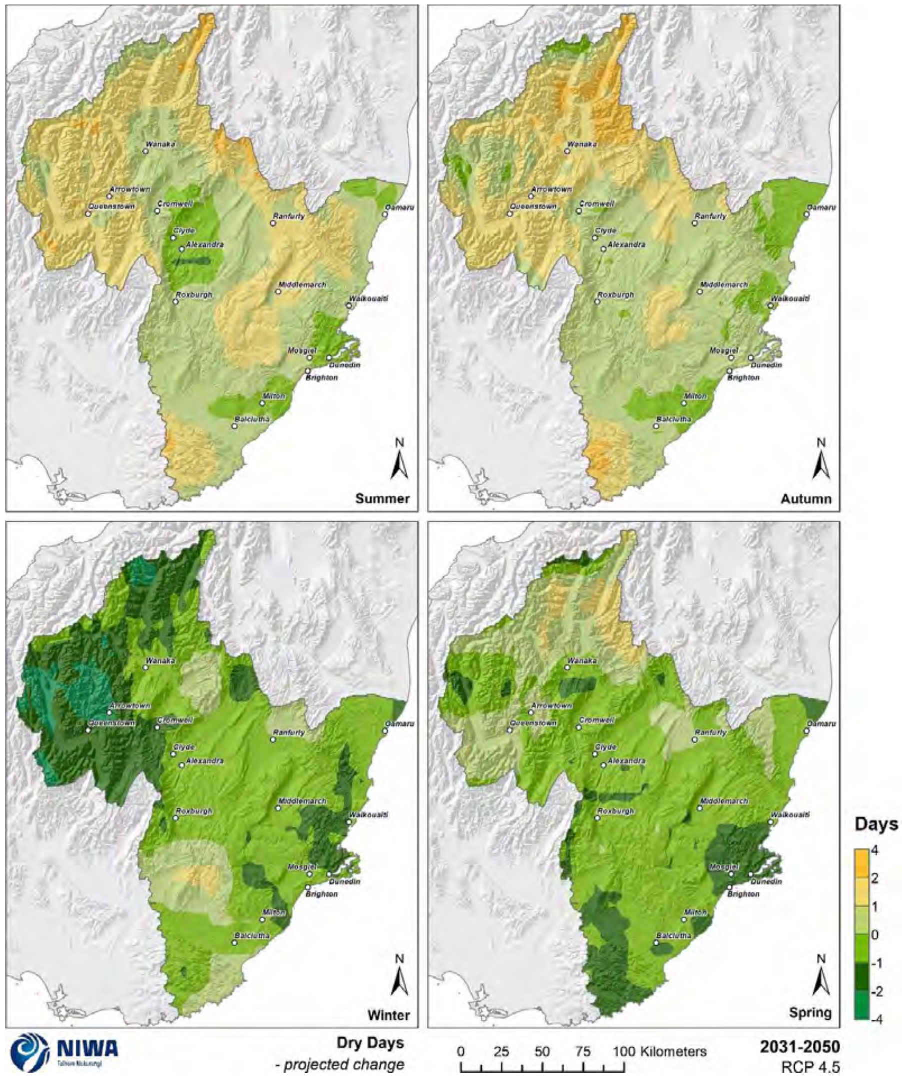

Figure 4-20: Projected seasonal number of dry day (daily rainfall <1mm) changes by 2040 for RCP4.5. Relative to 1986-2005 average, based on the average of six global climate models. Results are based on dynamical downscaled projections using NIWA's Regional Climate Model. Resolution of projection is 5km x 5km.

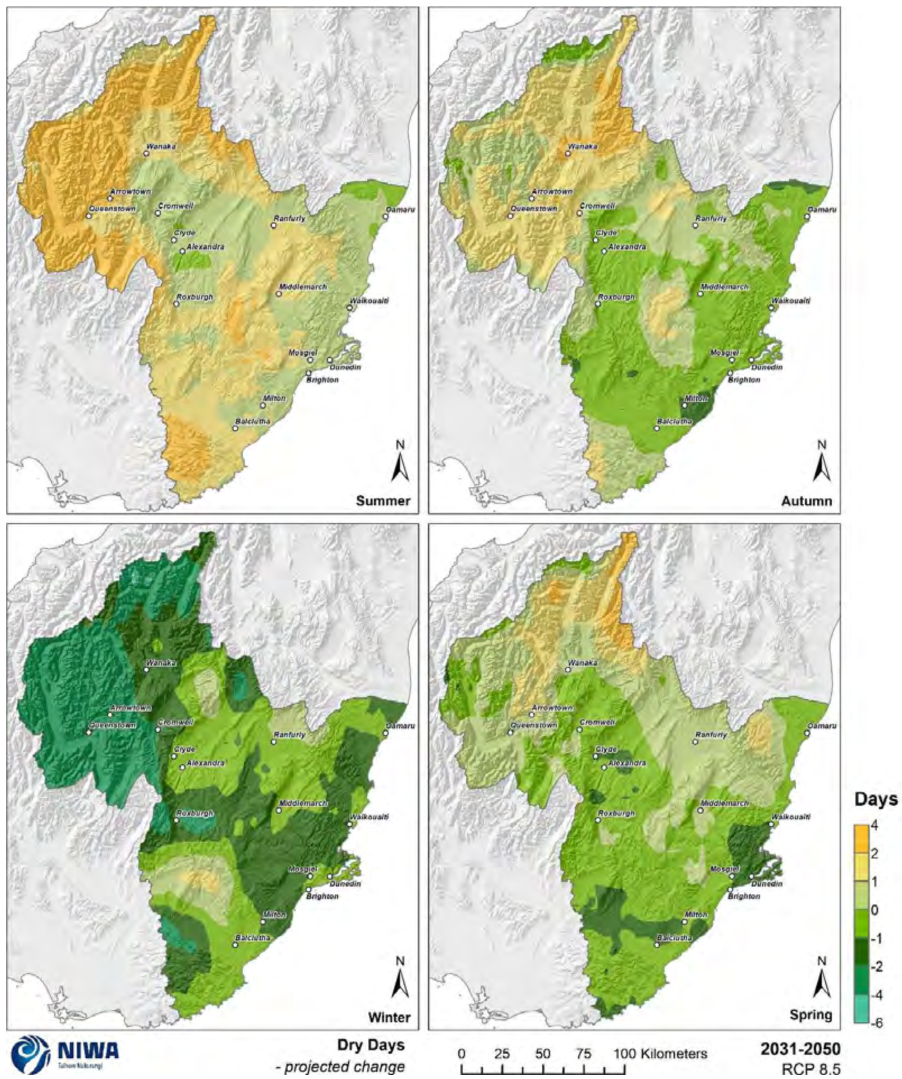

Figure 4-21: Projected seasonal number of dry day (daily rainfall <1mm) changes by 2040 for RCP8.5. Relative to 1986-2005 average, based on the average of six global climate models. Results are based on dynamical downscaled projections using NIWA's Regional Climate Model. Resolution of projection is 5km x 5km.

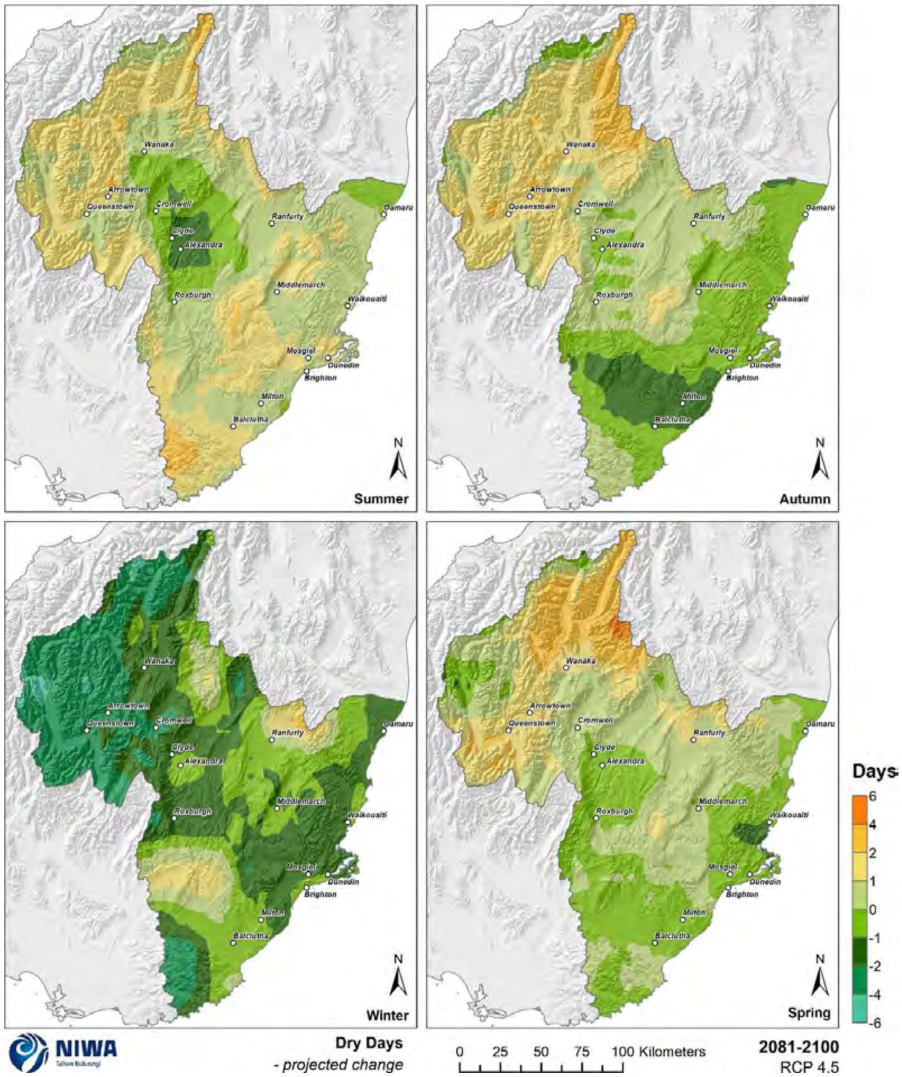

Figure 4-22: Projected seasonal number of dry day (daily rainfall <1mm) changes by 2090 for RCP4.5. Relative to 1986-2005 average, based on the average of six global climate models. Results are based on dynamical downscaled projections using NIWA's Regional Climate Model. Resolution of projection is 5km x 5km.

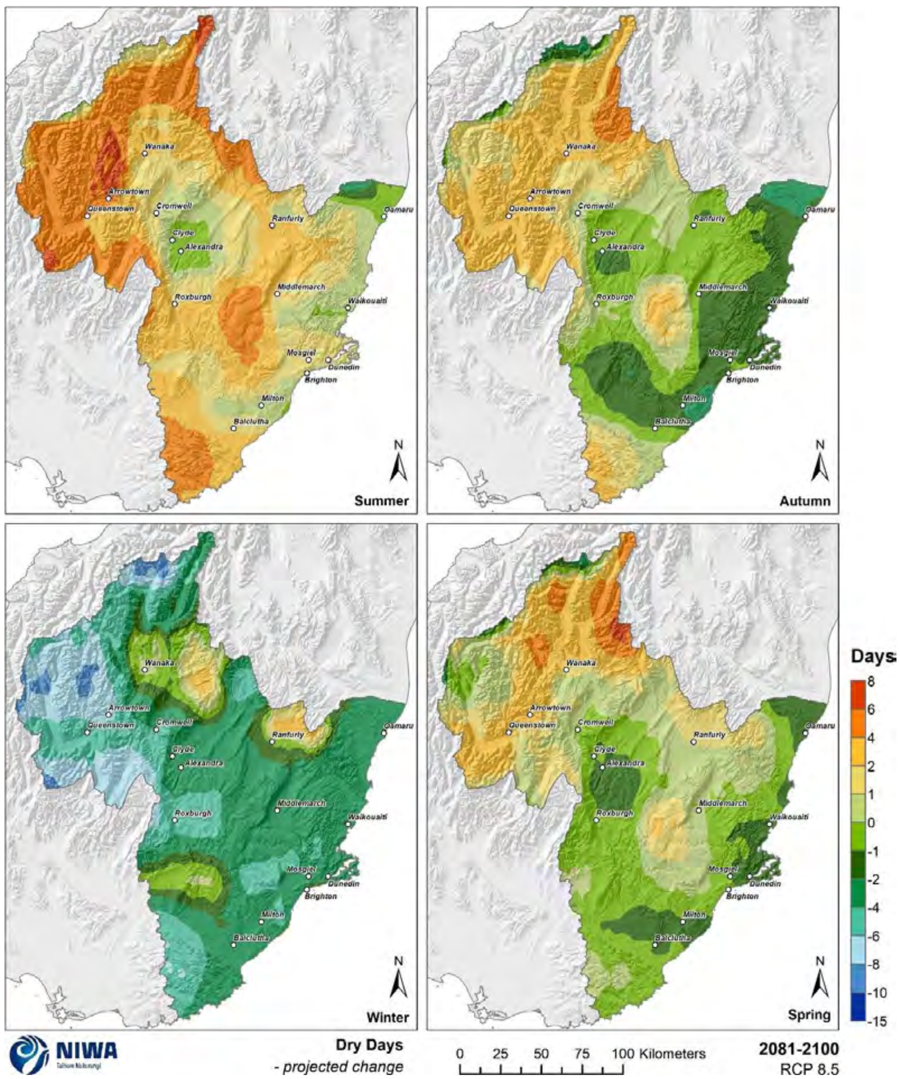

Figure 4-23: Projected seasonal number of dry day (daily rainfall <1mm) changes by 2090 for RCP8.5. Relative to 1986-2005 average, based on the average of six global climate models. Results are based on dynamical downscaled projections using NIWA's Regional Climate Model. Resolution of projection is 5km x 5km.

Table 4-14: Modelled seasonal and annual average number of dry days (<1 mm) for present and two climate change scenarios (RCP4.5 and RCP8.5) at two future time periods . Time periods: present (1986-2005), mid-century (2031-2050; "2040") and end-century (2081-2100; "2090"); based on the average of six global climate models. Annual ("Ann"); Seasons: summer ("Sum"), autumn ("Aut"), winter ("Win") and spring ("Spr").

	PRESENT				
	Sum	Aut	Win	Spr	Ann
Alexandra	69	72	75	71	286
Arrowtown	59	56	58	49	222
Balclutha	55	57	63	55	230
Brighton	53	59	62	55	229
Clyde	67	71	74	69	282
Cromwell	69	70	74	68	281
Dunedin	56	62	67	58	244
Middlemarch	62	69	74	64	267
Milton	53	57	64	55	229
Mosgiel	55	62	67	57	241
Oamaru	65	71	77	67	280
Queenstown	62	59	60	53	233
Ranfurly	62	69	71	64	266
Roxburgh	62	66	72	63	264
Waikouaiti	63	71	76	66	275
Wanaka	72	64	57	64	257

		2040					**2090**				
		Sum	Aut	Win	Spr	Ann	Sum	Aut	Win	Spr	Ann
Alexandra	RCP4.5	0	0	0	-1	-1	-1	0	-1	0	-2
	RCP8.5	0	0	0	-1	-1	0	-1	-3	-1	-5
Arrowtown	RCP4.5	+1	+1	-3	0	-1	+2	+2	-3	+2	+1
	RCP8.5	+3	+1	-4	+1	+1	+6	+3	-7	+3	+5
Balclutha	RCP4.5	0	0	0	-1	-1	+1	-1	0	0	-1
	RCP8.5	+1	-1	0	-1	-1	+1	-1	-2	-1	-3
Brighton	RCP4.5	0	0	0	-1	-1	+1	-1	-1	-1	-1
	RCP8.5	+1	-1	-1	-1	-1	+1	-1	-2	-1	-3
Clyde	RCP4.5	-1	0	0	-1	-2	-1	0	-1	0	-3
	RCP8.5	0	0	0	-1	-2	0	-1	-3	-1	-5
Cromwell	RCP4.5	0	+1	-1	-1	-1	-1	+1	-2	0	-2
	RCP8.5	0	+1	-2	0	-1	+1	+1	-4	-1	-3
Dunedin	RCP4.5	0	0	-1	-1	-2	+1	0	-1	-1	-1
	RCP8.5	+1	0	0	-1	-1	+1	-1	-3	-1	-4
Middlemarch	RCP4.5	+1	0	0	0	+1	+1	0	-1	0	0
	RCP8.5	+1	0	-1	0	0	+1	-1	-3	0	-2
Milton	RCP4.5	0	0	-1	-1	-2	+1	-2	-1	0	-2
	RCP8.5	+1	-1	-1	-1	-2	+1	-2	-3	-1	-6
Mosgiel	RCP4.5	0	0	-1	-1	-1	+1	-1	-1	-1	-1
	RCP8.5	+1	0	-1	-1	-2	+1	-1	-3	-1	-4
Oamaru	RCP4.5	0	-1	0	-1	-2	0	-1	-1	-1	-2
	RCP8.5	0	-1	-1	-1	-2	0	-2	-3	-2	-7
Queenstown	RCP4.5	+1	+2	-2	+1	+2	+1	+2	-2	+2	+3
	RCP8.5	+2	+1	-3	+1	+1	+4	+3	-5	+3	+4
Ranfurly	RCP4.5	+1	+1	0	0	+2	+1	0	0	+1	+2
	RCP8.5	+1	0	0	+1	+2	+2	0	-1	+1	+2
Roxburgh	RCP4.5	0	+1	-1	-1	-1	0	0	-2	0	-2
	RCP8.5	+1	0	-2	0	-2	+2	0	-5	-1	-4
Waikouaiti	RCP4.5	+1	0	-1	-1	-1	+1	-1	-1	-1	-2
	RCP8.5	+1	-1	-1	-1	-2	0	-2	-3	-1	-6
Wanaka	RCP4.5	0	+2	0	0	+1	0	+1	-1	+1	+1
	RCP8.5	+1	+2	-1	0	+2	+2	+3	0	+2	+7

4.5 Snow days

Key message

- The number of snow days reduces everywhere, with the largest reduction in the coldest mountainous areas where there are a relatively large number of snow days in the present climate.

Snow days were estimated by counting precipitation days where the mean temperature was below freezing point. As such, it is a fairly crude measure of snow days. It is likely the modelled number of present (1986-2005) snow days (Figure 4-24 and Table 4-15) is underestimated, particularly for low elevation locations where snowfall often occurs when the ambient air temperature is at or above 0°C. Nevertheless, this measure provides a reference to which future changes can be compared. The modelled present-day conditions suggest that 0-1 snow days per year occur for low elevation areas, and 1-5 days per year for the Maniototo. 10-30 snow days per year occur in higher elevation parts of the region. In the future, the number of snow days reduces everywhere, with the largest reduction (>15 days) in the coldest mountainous areas where there are a relatively large number of snow days in the present climate (Figure 4-25).

A factor needing further analysis is the potential change in snow amounts. In general, climate simulations show a reduction in snow days. It is possible snow amount could increase with rising temperatures in certain circumstances; a warmer atmosphere can hold more moisture, and on a day where temperatures are higher but still cool enough to snow, there is potential for increased heavy snowfalls. No analysis of snow extremes has been carried out at this point, however.

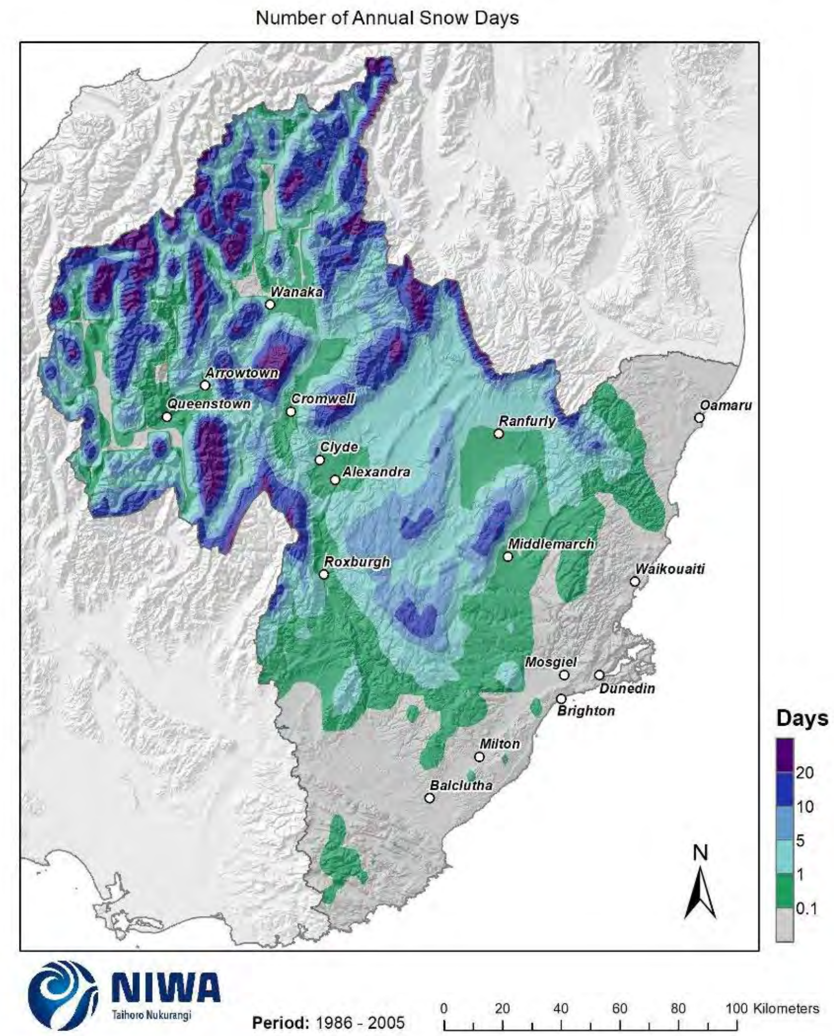

Figure 4-24: Modelled annual number of snow days, average over 1986-2005. Results are based on dynamical downscaled projections using NIWA's Regional Climate Model. Resolution of projection is 5km x 5km.

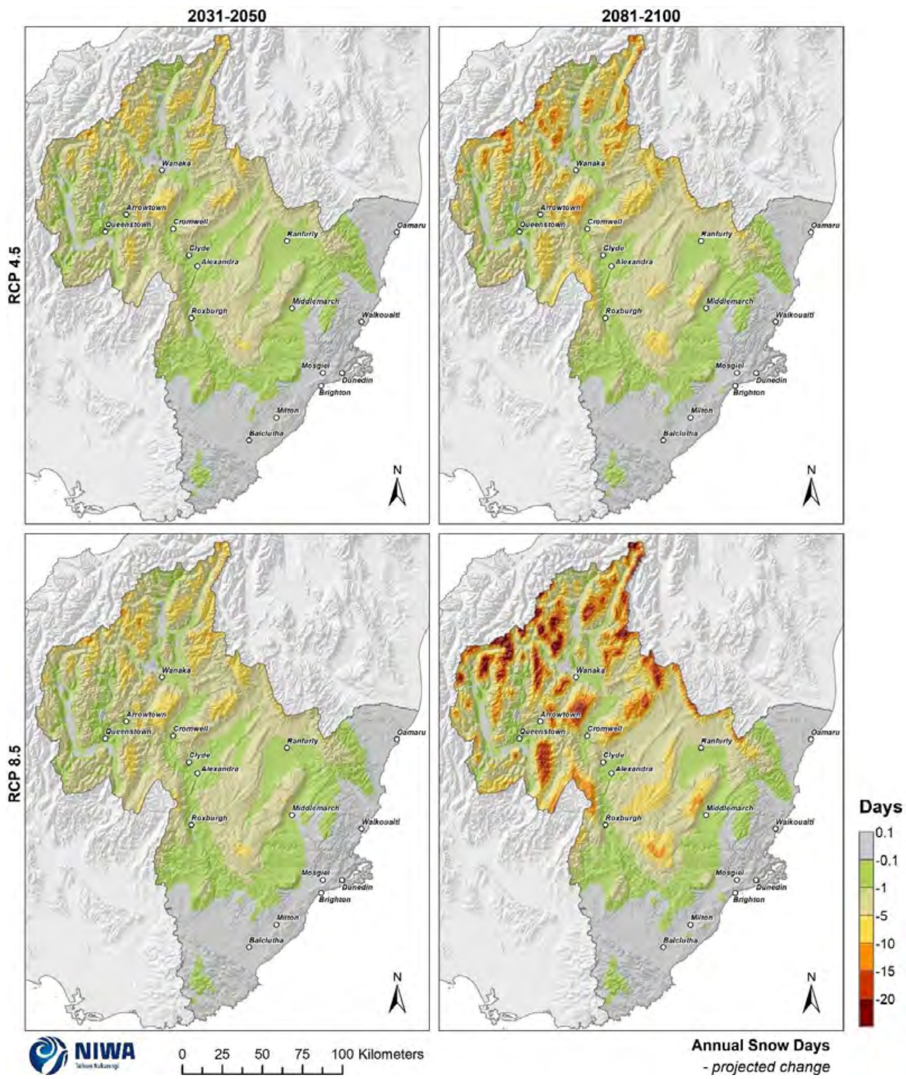

Figure 4-25: Projected change in the number of annual snow days by 2040 and 2090, under RCP4.5 and RCP8.5. Climate change scenarios: RCP4.5 (top panels) and RCP8.5 (bottom panels). Time periods: mid-century (2031-2050; "2040" – panels on left) and end-century (2081-2100; "2090" – panels on right). Changes relative to 1986-2005 average, based on the average of six global climate models. Results are based on dynamical downscaled projections using NIWA's Regional Climate Model. Resolution of projection is 5km x 5km.

Table 4-15: Modelled annual average number of snow days for present and two climate change scenarios (RCP4.5 and RCP8.5) at two future time periods. Future projections are shown as the total future projected number of snow days outside the parentheses, and future change inside the parentheses. Time periods: present (1986-2005), mid-century (2031-2050; "2040") and end-century (2081-2100; "2090"); based on the average of six global climate models.

		2040		**2090**	
	PRESENT	RCP4.5	RCP8.5	RCP4.5	RCP8.5
Alexandra	0.3	0.1 (-0.2)	0.1 (-0.2)	0.1 (-0.2)	0.0 (-0.3)
Arrowtown	0.8	0.2 (-0.6)	0.2 (-0.6)	0.1 (-0.7)	0.0 (-0.8)
Balclutha	0.0	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)
Brighton	0.0	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)
Clyde	0.6	0.2 (-0.4)	0.2 (-0.4)	0.2 (-0.4)	0.0 (-0.6)
Cromwell	0.3	0.1 (-0.2)	0.1 (-0.2)	0.0 (-0.3)	0.0 (-0.3)
Dunedin	0.0	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)
Middlemarch	0.2	0.0 (-0.2)	0.1 (-0.1)	0.0 (-0.2)	0.0 (-0.2)
Milton	0.0	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)
Mosgiel	0.0	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)
Oamaru	0.0	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)
Queenstown	0.5	0.1 (-0.4)	0.2 (-0.3)	0.1 (-0.4)	0.0 (-0.5)
Ranfurly	0.8	0.4 (-0.4)	0.3 (-0.5)	0.2 (-0.6)	0.0 (-0.8)
Roxburgh	0.1	0.0 (-0.1)	0.0 (-0.1)	0.0 (-0.1)	0.0 (-0.1)
Waikouaiti	0.0	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)
Wanaka	0.3	0.2 (-0.1)	0.0 (-0.3)	0.0 (-0.3)	0.0 (-0.3)

5 Wind

Modelled wind data have not had bias correction processes applied as has been carried out for temperature and rainfall data. The bias correction process corrects the historic modelled data to observed values (the Virtual Climate Station Network, which is interpolated climate station data across New Zealand), and there is not enough historic VCSN data coverage for wind to undertake this procedure. This means that current modelled wind conditions are different to actual observed conditions, and therefore not useful for understanding current wind conditions in Otago. For this reason, only the future *relative changes* in this variable has been mapped here using the modelled climate data. By doing this, the effect of biases in absolute values of these variables are minimised.

5.1 Extreme wind

Key messages

- The future magnitude of the 99th percentile 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 6-12% by 2090 under RCP8.5.

Extreme wind is considered here as the 99th percentile of daily mean wind speeds. This equates to the top 1% of daily mean winds recorded, i.e. about the top three windiest days each year. The annual extreme wind from 2000 to 2018 is shown for several Otago locations in Figure 5-1. During this period, the average annual extreme wind speed for Dunedin was 29.7 km/h, whilst in Ranfurly the average was 23.2 km/h.

In the future (Figure 5-2), the magnitude of 99th percentile daily mean wind speed is typically projected to decrease about the eastern coast of Otago, and increase for inland areas about Central Otago and the Southern Lakes. Decreases of 2-6% are projected for eastern areas about Dunedin and Oamaru by 2040 under RCP4.5. By 2090 under RCP8.5, inland areas about Clyde, Cromwell and Queenstown are projected to observe an increase in extreme wind of 6-12%.

Table 5-1 shows the projected change in extreme winds by 2040 and 2090 for the model grid point closest to specific locations in the Otago region.

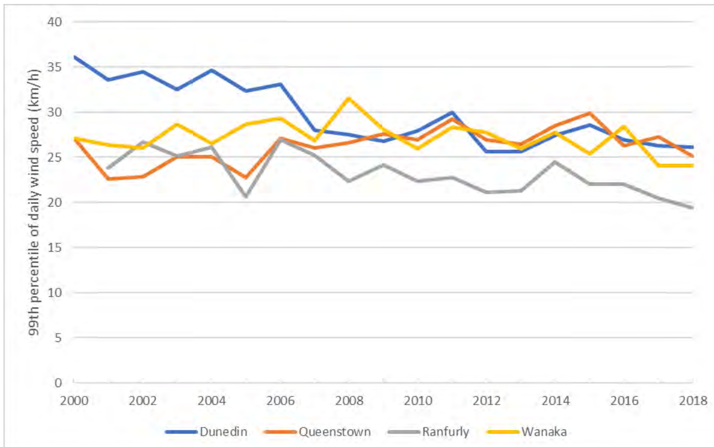

Figure 5-1: 99th percentile of daily wind speed (km/h), 2000-2018. Stations used: Dunedin Musselburgh EWS, Queenstown Aero AWS, Wanaka Aero AWS and Ranfurly EWS.

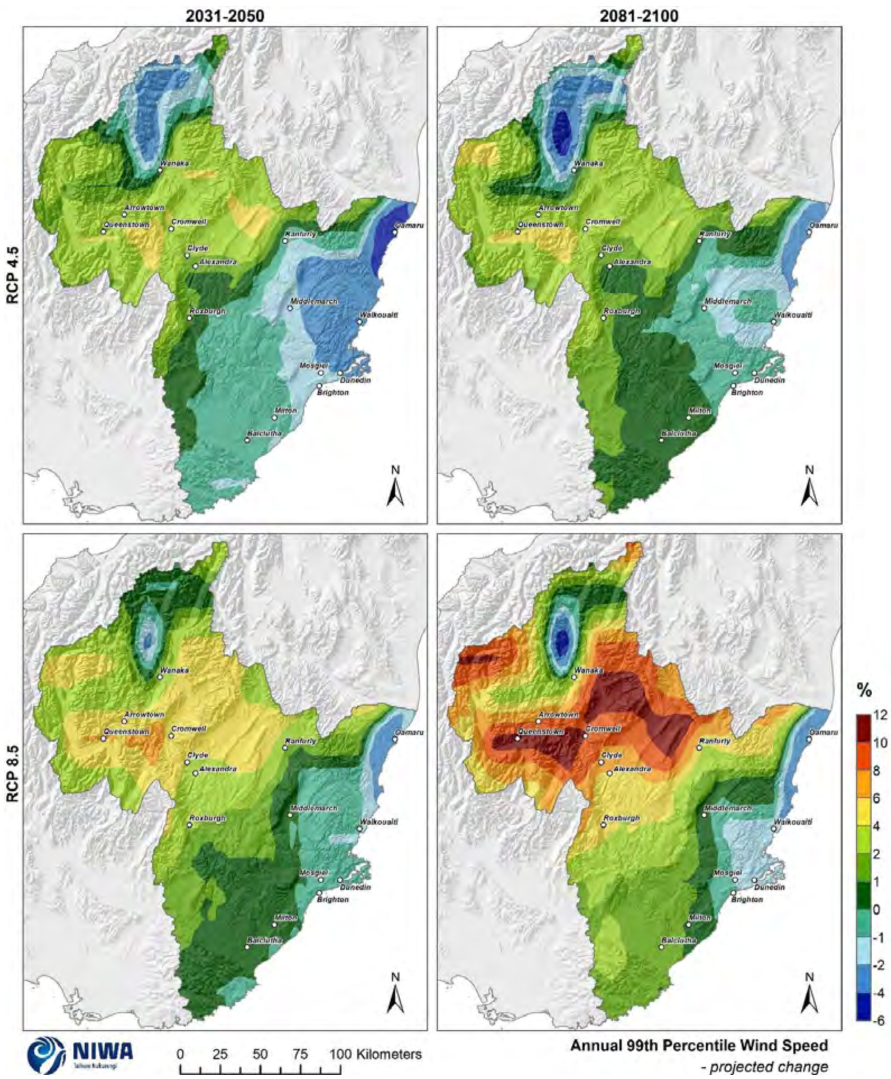

Figure 5-2: Change in the magnitude of the 99th percentile of daily mean wind speed by 2040 and 2090, for RCP4.5 and RCP8.5. Climate change scenarios: RCP4.5 (top panels) and RCP8.5 (bottom panels). Time periods: mid-century (2031-2050; "2040" – panels on left) and end-century (2081-2100; "2090" – panels on right). Changes relative to 1986-2005 average, based on the average of six global climate models. Results are based on dynamical downscaled projections using NIWA's Regional Climate Model. Resolution of projection is 5km x 5km.

Table 5-1: Modelled change in the magnitude (%) of the 99th percentile of daily mean wind speed by 2040 and 2090, for RCP4.5 and RCP8.5. Note, values shown are the percentage change compared to present (1986-2005). Time periods: mid-century (2031-2050; "2040") and end-century (2081-2100; "2090"); based on the average of six global climate models.

	2040		**2090**	
	RCP4.5	RCP8.5	RCP4.5	RCP8.5
Alexandra	+1.5	+3.4	+1.1	+6.4
Arrowtown	+2.9	+4.7	+2.6	+7.6
Balclutha	-0.8	+0.3	+0.5	+1.5
Brighton	-1.5	-0.1	-0.6	-0.6
Clyde	+2.3	+4.0	+1.7	+7.4
Cromwell	+3.8	+5.5	+3.2	+9.8
Dunedin	-2.0	-0.3	-0.6	-1.3
Middlemarch	-1.5	+0.1	-1.0	+0.3
Milton	-0.7	+0.2	+0.4	+0.8
Mosgiel	-1.6	-0.1	-0.6	-0.8
Oamaru	-5.3	-2.3	-2.9	-3.3
Queenstown	+3.9	+6.1	+4.0	+10.8
Ranfurly	-0.3	+2.8	+0.9	+6.0
Roxburgh	+1.1	+2.3	+2.0	+4.5
Waikouaiti	-2.8	-0.9	-0.7	-1.3
Wanaka	+0.5	+2.2	-0.5	+3.8

6 Hydrological impacts of climate change

Key messages

- By the end of the century and with increased emissions, average annual flows are expected to increase across the region (above 50% across all FMUs[2] except headwaters of Taieri and North Otago).
- Large decrease in low flow expected with time and increased radiative forcing for North Otago and Taieri FMUs.
- Mean annual flood is expected to become larger everywhere, with increases up to 100% in some locations by the end of the century.

This section covers the projected differences in several hydrological statistics between the baseline period (1986-2005) and two future periods. These are mid-century (2036-2056) and late-century (2086-2099), and are slightly different from the corresponding time slices of the atmospheric modelling because the modelling was done before this project was initiated. We do not expect that the conclusions drawn would be substantively different if the periods were aligned. The statistics include:

- The Q95% flow[3];
- Mean annual and seasonal discharges;
- The mean annual flood (MAF); and
- Surface water supply reliability

6.1 Low flow

The projected future differences in the Q95% flows for all four RCPs and two time periods are presented in Figure 6-1 and Figure 6-2. There are both increases and decreases projected for the management units of interest, with the more pronounced differences generally manifesting themselves during the late-century period and under higher RCPs. Increases in Q95% are more tangible and consistent in FMU headwaters such as Clutha/Mata Au FMU, mountain ranges between Taieri and North Otago FMUs (increasing by up to 50%) and the Dunedin Coast FMU. Decreases are modelled in all units but consistently in the headwaters of the Taieri FMU and Manuherikia Rohe, dropping below -20%.

[2] FMU: Freshwater Management Unit
[3] Q95: Flow that is exceeded 95 percent of the time

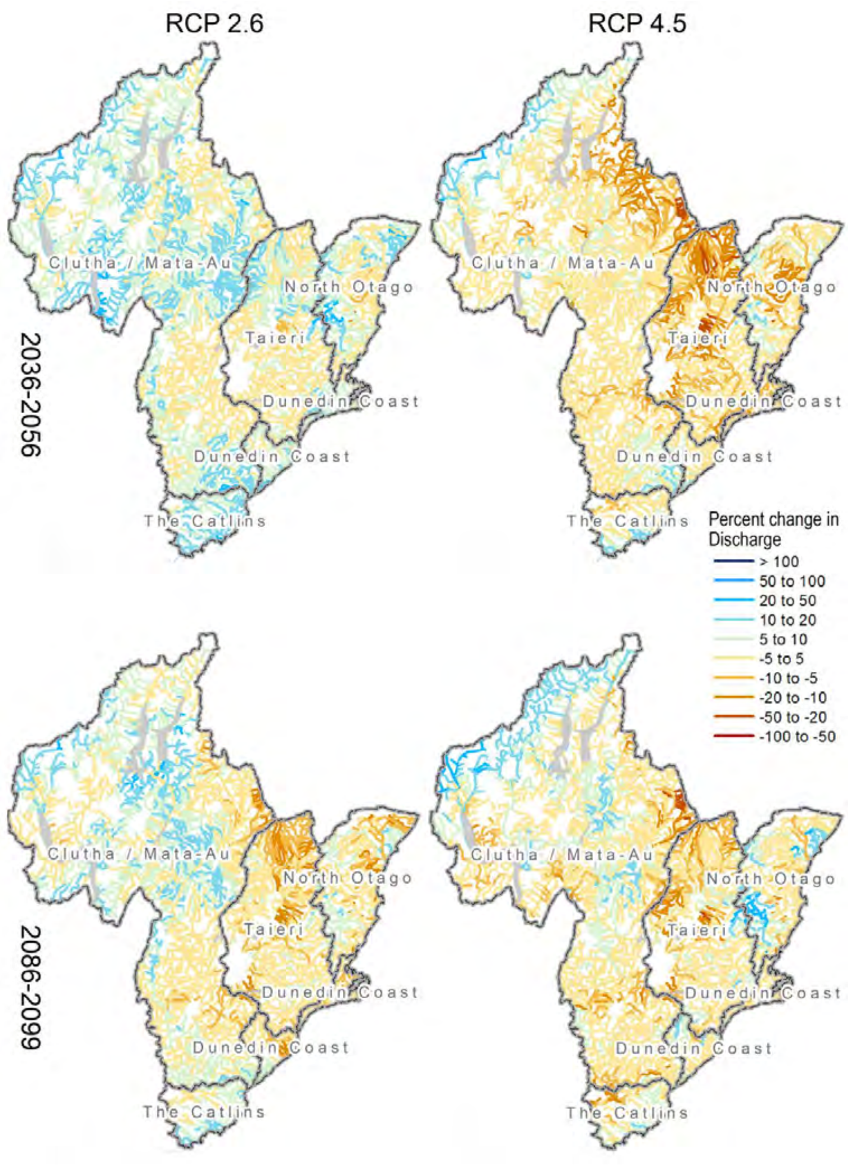

Figure 6-1: Percent changes in multi-model median Q95% across Otago for mid (top) and end of century (bottom). Climate change scenarios: RCP2.6 (left panels) and RCP4.5 (right panels). Time periods: mid-century (2036-2056) and end-century (2086-2099).

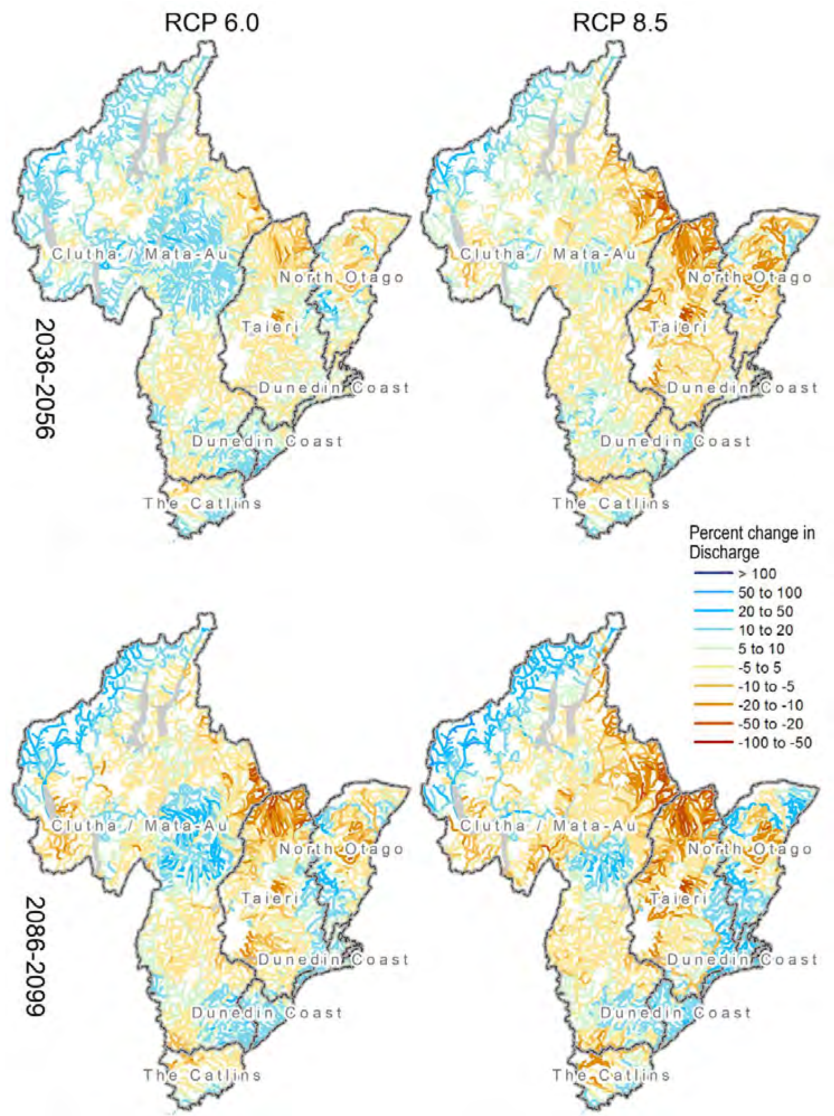

Figure 6-2: Percent changes in multi-model median Q95% across Otago for mid (top) and end of century (bottom). Climate change scenarios: RCP6.0 (left panels) and RCP8.5 (right panels). Time periods: mid-century (2036-2056) and end-century (2086-2099).

6.2 Mean annual discharge

The projected future differences in the annual discharges for all four RCPs and two time periods are presented in Figure 6-3 and Figure 6-4. At the annual scale, mean discharges consistently decrease by mid-century across the FMUs. By late century, mean discharge increase with radiative forcing (up to 50%) except for the headwaters of the Taieri and North Otago FMUs.

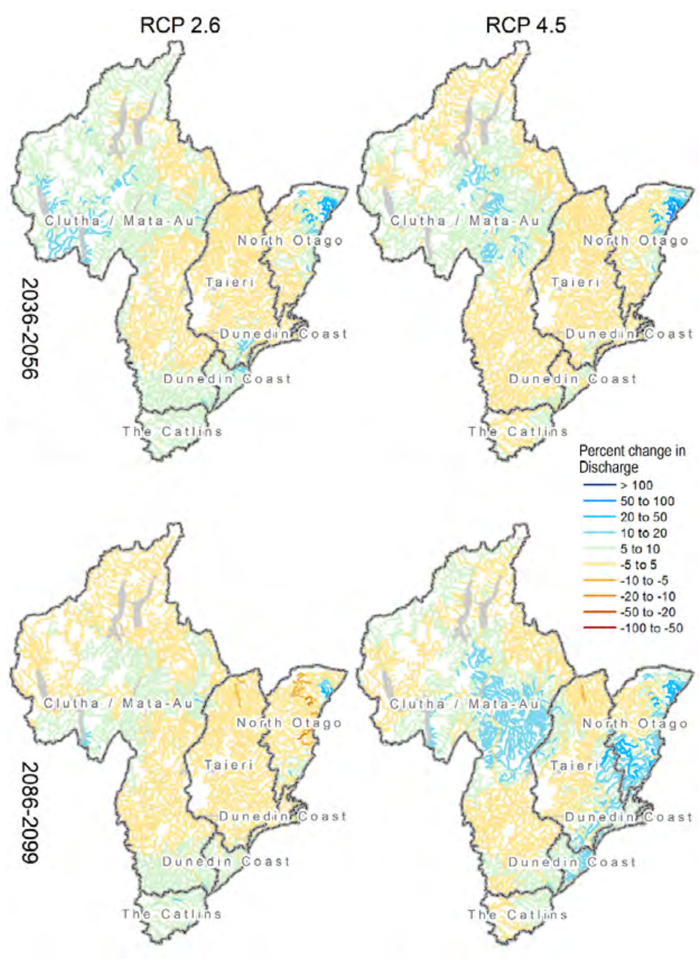

Figure 6-3: Percent changes in multi-model median of the mean discharge across Otago for mid (top) and late-century (bottom). Climate change scenarios: RCP2.6 (left panels) and RCP4.5 (right panels). Time periods: mid-century (2036-2056) and end-century (2086-2099).

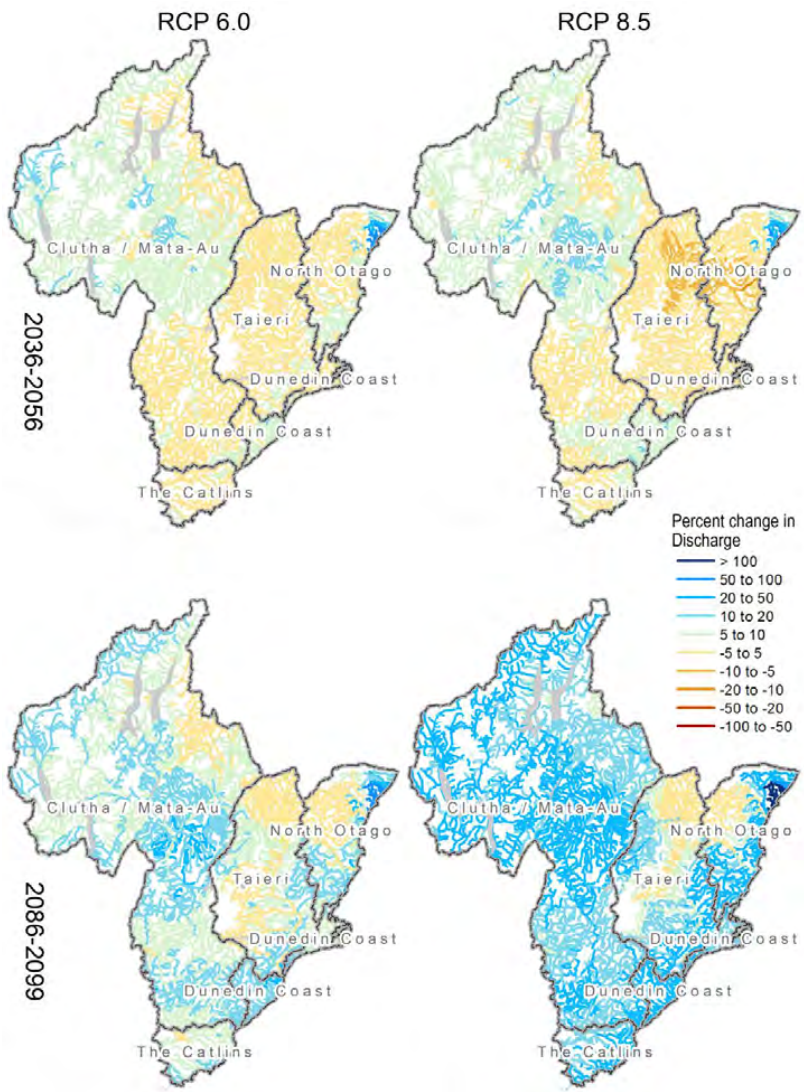

Figure 6-4: Percent changes in multi-model median of the mean discharge across Otago for mid (top) and late-century (bottom). Climate change scenarios: RCP6.0 (left panels) and RCP8.5 (right panels). Time periods: mid-century (2036-2056) and end-century (2086-2099).

6.3 Mean annual flood

The projected future differences in the mean annual flood (MAF) for all four RCPs and two time periods are presented in Figure 6-5 and Figure 6-6. While there are some pockets of little change or decreasing MAF, in general Otago is projected to experience an increase in MAF, with some increases exceeding 100%. There is little difference among the RCPs during the mid-century period, but by late-century, the increases in MAF become larger and more extensive progressively from RCP4.5 to RCP8.5.

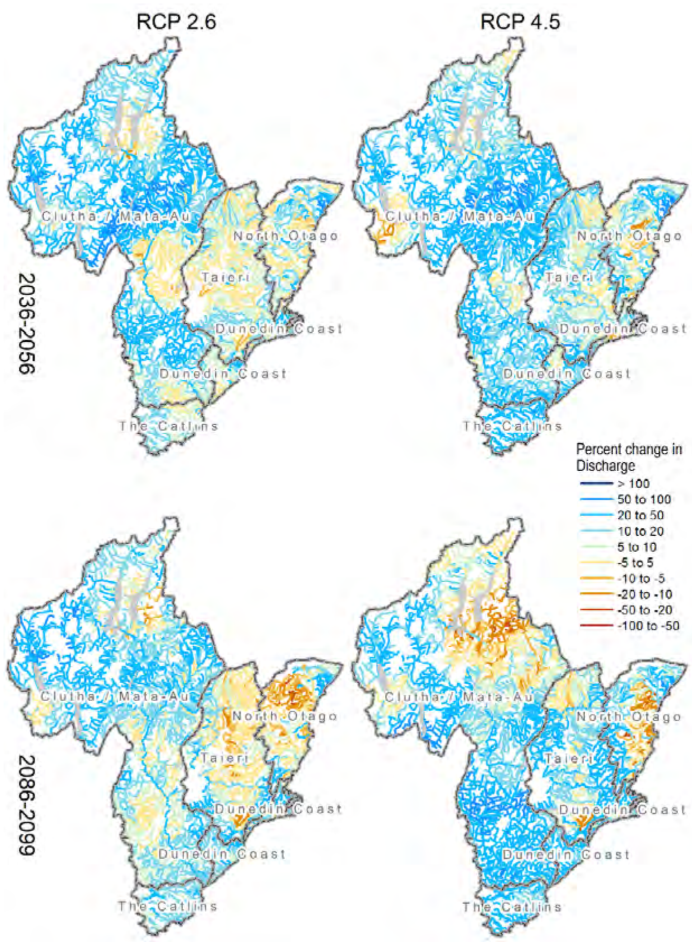

Figure 6-5: Percent changes in multi-model median of MAF across Otago for mid (top) and end of century (bottom). Climate change scenarios: RCP2.6 (left panels) and RCP4.5 (right panels). Time periods: mid-century (2036-2056) and end-century (2086-2099).

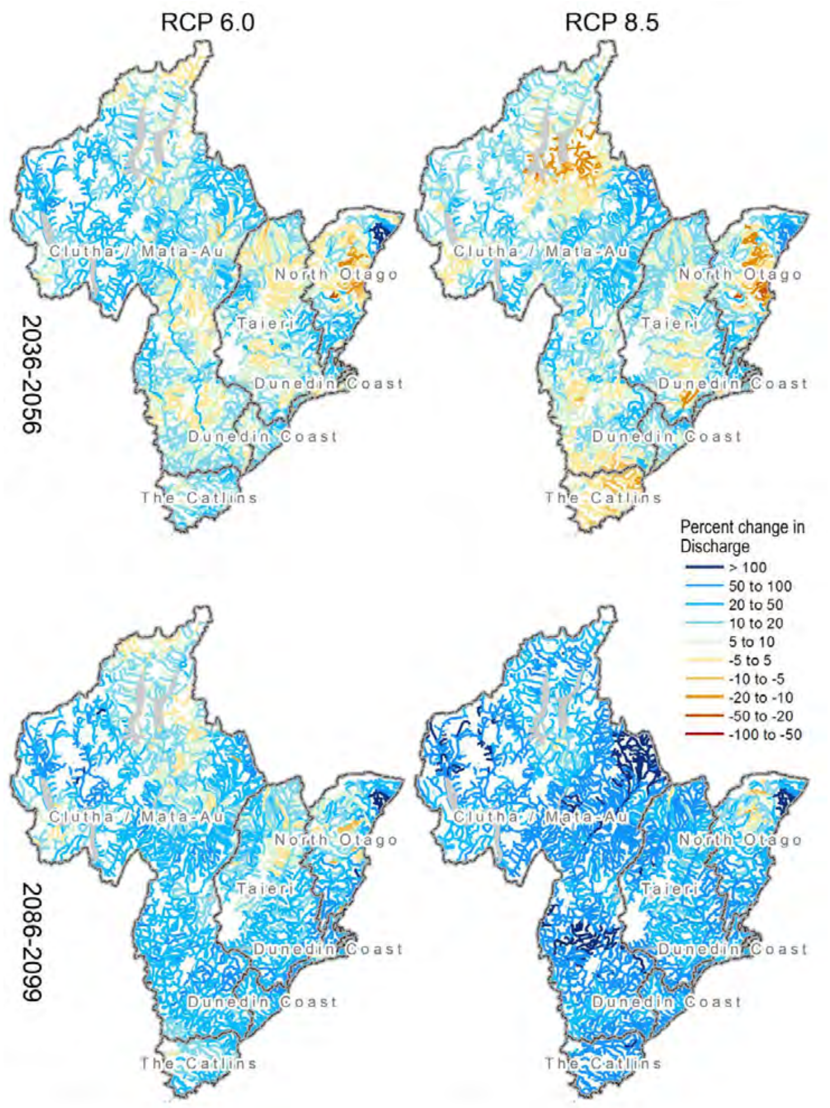

Figure 6-6: Percent changes in multi-model median of MAF across Otago for mid (top) and end of century (bottom). Climate change scenarios: RCP6.0 (left panels) and RCP8.5 (right panels). Time periods: mid-century (2036-2056) and end-century (2086-2099).

The increase in MAF is a change that is largely consistent with the changes to rainfall presented in Ministry for the Environment (2018), especially regarding the 99th percentile of daily rainfall. Analysis of flow records indicates that MAF has a strong correspondence with observed mean annual rainfall (Henderson et al., 2018). It is noteworthy that flood design standards for significant infrastructure are usually made based on events with annual exceedance probabilities much smaller than that represented by MAF (i.e. much rarer events like the 1-in-100-year flood event). Analysis of RCM rainfall projections undertaken for the High Intensity Rainfall Design project (Carey-Smith et al., 2018), has shown that rainfall events with small annual exceedance probability are projected to increase ubiquitously across the country in a way that scales with increasing temperatures. As such, MAF, with its relatively common (annual) occurrence, should not be considered a comprehensive metric for the possible impact of climate change on large, rare floods in New Zealand.

6.4 Surface water supply reliability

Surface water supply reliability refers to the duration of time river water abstraction is unconstrained[4]. The projected future differences in the surface water supply reliability for all four RCPs and two time periods are presented in Figure 6-7 and Figure 6-8. Little appreciable change in reliability is projected across most of the Otago region, with most parts of the region exhibiting slight increases but some with slight decreases. Mountain ranges between North Otago and Taieri FMU are expected to experience an increase in reliability increasing with radiative forcing, while the headwaters of North Otago FMU are expected to experience the largest decrease in flow reliability.

[4] Surface water supply reliability is the fraction of time that the flow is equal to or below the threshold for minimum flows (based on the Proposed National Environmental Standard for Ecological Flows), and in this case without accounting for any water takes. This ranges from 0 to 1 (or 0 to 100 per cent) and is often between 0.9 and 1.0 for New Zealand's rivers. Note that this statistic only considers surface water flows, not groundwater.

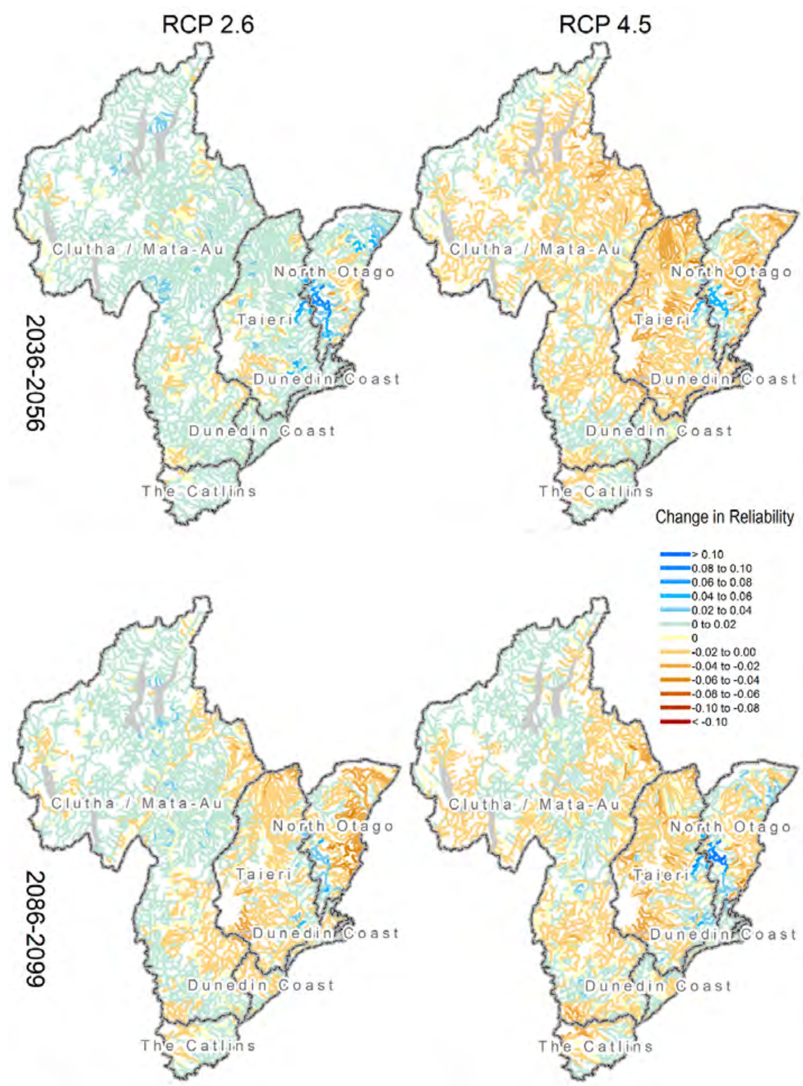

Figure 6-7: Absolute changes in multi-model median of surface water supply reliability across Otago for mid (top) and end of century (bottom). Climate change scenarios: RCP2.6 (left panels) and RCP4.5 (right panels). Time periods: mid-century (2036-2056) and end-century (2086-2099).

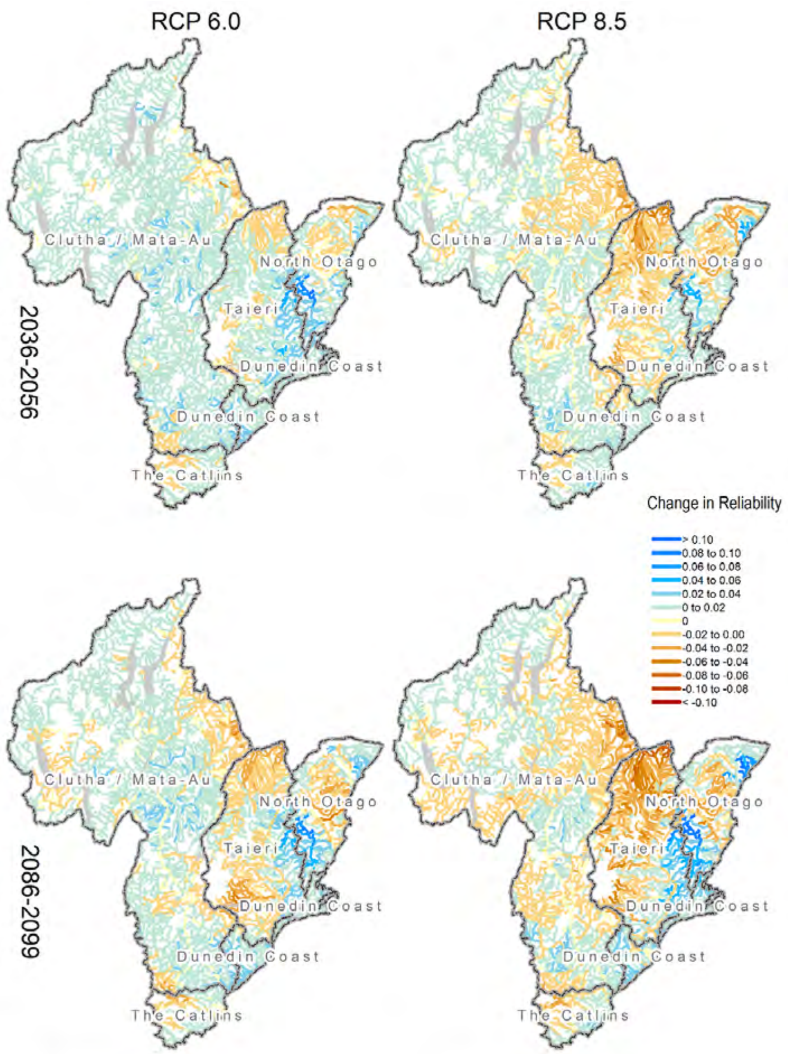

Figure 6-8: Absolute changes in multi-model median of surface water supply reliability across Otago for mid (top) and end of century (bottom). Climate change scenarios: RCP6.0 (left panels) and RCP8.5 (right panels). Time periods: mid-century (2036-2056) and end-century (2086-2099).

7 Limitations

As with any modelling exercise, there are limitations on the results and use of the data. This section outlines some of these limitations and caveats that should be considered when using the results in this report.

- The maps and tables presented in this report (except the model confidence sections 3.1.1 and 4.1.1) show the average of six dynamically downscaled global climate models. This is a relatively small number of models and a clear shift in the distribution of potential future outcomes is not available. This is particularly important when considering extremes (e.g. extreme hot days, extreme rainfall), where the models considered here may not accurately capture how rare events are changing.
- The average of six models is used in this report, which gives no indication of the range of results that the models project. However, the six models chosen represented historic climate conditions in New Zealand well, and span a range of future outcomes. Using the average balances out the errors that may be apparent in each model.
- The time periods chosen for historic and future projection span 20-year periods. This is seen as a relatively short timeframe to understand average conditions in the historic period and in the future, as there is likely an influence of underlying climate variability (e.g. decadal signals from climate drivers like the El Niño-Southern Oscillation etc.). However, the IPCC uses 20-year periods so we have followed that approach for consistency.
- Care needs to be taken when interpreting grid-point-scale projections such as those presented in the tables in this report. The underlying climate data are Virtual Climate Station data, which are interpolated from physical climate stations. Therefore, the data from these grid points may be slightly different to on-the-ground observations, due to the interpolation procedure (particularly if the grid point is surrounded by multiple different stations or if there are no stations nearby). It is useful to look at broader patterns between grid points, e.g. coast vs. inland, and the magnitude of change at different time periods and scenarios, when considering the values.

Although there are limitations and caveats to the approach used here, these climate change projections are the best currently available for New Zealand. A considerable amount of research time has been dedicated to undertaking the modelling and validation of the results, and the projections provide context to base risk assessments and adaptation plans on.

8 Summary and conclusions

This report presents climate change projections for Otago. Present-day climatic conditions are presented to provide a context for future changes. The future changes discussed in this report consider differences between the historical period 1986-2005 and two future time-slices, 2031-2050 and 2081-2100. Note, the modelled differences between two time periods should not be attributed solely to climate change, as natural climate variability is also present and may add to or subtract from the climate change effect. The effect of natural variability has been reduced by averaging results from six GCM simulations, but it will still be present.

It is internationally accepted that further climate changes will result from increasing amounts of anthropogenically produced greenhouse gases in the atmosphere. The influence from anthropogenic greenhouse gas contributions to the global atmosphere is the dominant driver of climate change conditions, and it will continue to become more dominant if there is no slowdown in emissions, according to the IPCC. In addition, the climate will vary from year to year and decade to decade owing to natural variability.

Notably, future climate changes depend on the pathway taken by the global community (i.e. through mitigation of greenhouse gas emissions or a ‘business as usual’ approach). The global climate system will respond differently to future pathways of greenhouse gas concentrations. The representative concentration pathway approach taken here reflects this variability through the consideration of multiple scenarios (i.e. RCP4.5, the mid-range scenario, and RCP8.5, the business-as-usual scenario). The six climate models used to project New Zealand’s future climate were chosen by NIWA because they produced the most accurate results when compared to historical climate and circulation patterns in the New Zealand and southwest Pacific region. They were as varied as possible to span the likely range of model sensitivity. The average of outputs from all six models (known as the ‘ensemble average’), is presented in the climate change projection maps in this report. The ensemble-average was presented as this usually performs better in climate simulations than any individual model (the errors in different models are compensated).

Changes to Otago’s future climate are likely to be significant. An increase in extreme hot days, a reduction in frost days and larger extreme rainfall events are some of the main impacts. The following list summarises the projections of different climate variables in Otago:

1. The projected Otago temperature changes increase with time and emission scenario. Future annual average warming spans a wide range: 0.5-1.5°C by 2040, and 0.5-3.5°C by 2090. Diurnal temperature range (i.e., difference between minimum and maximum temperature of a given day) is expected to increase with time and emission scenarios.
2. Changes in extreme temperatures reflect the changes in the average annual signal. The average number of extreme hot days is expected to increase with time and scenario, with considerable variability between coastal and southernmost parts of Otago compared to Central Otago. For example, coastal and southern parts of Otago are projected to observe 0.1-4 more extreme hot days per year in future. In contrast, the number of extreme hot days in Central Otago are projected to increase by 30-40 days by 2090 under RCP8.5. As expected, the number of frost days is expected to decrease throughout the region. Largest decreases are expected in inland areas; 10-15 fewer frost days per year by 2040, and 20-40 fewer frost days per year by 2090.

3. Projected changes in rainfall show variability across the Otago region. Annual rainfall is expected to slightly increase by mid-century (0-10%), while the increase spans 10-20% (with a larger increase in the western part of the region) at the end of the century. Seasonally the largest increases are projected during winter, with 20-40% increases expected by the end of the century under RCP8.5. Summer precipitation is expected to decrease around Ranfurly and Middlemarch (5-10% decrease at the end of the century under RCP8.5).

4. The number of heavy rain days (i.e., days where the total precipitation exceeds 25 mm) is projected to see little change for most of the Otago region at all time slices and RCPs. The exception is far western parts of Otago, where a 5-15 day increase in heavy rain days is projected for the end of the century under RCP8.5.

5. Extreme, rare rainfall events are projected to become more severe in the future under all four climate change scenarios. Short duration rainfall events have the largest relative increases compared with longer duration rainfall events. The depth of a current 1:100-year 1-hour duration rainfall event is projected to increase by approximately 35% by 2090 under RCP8.5.

6. By mid-century the number of dry days per year are expected to decrease near the coast and parts of Central Otago (1-4 fewer dry days per year), with increases of 1-6 more annual dry days for many remaining parts of Otago. By the end of the century, a decrease in annual dry days of 2-6 days is 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.

7. The number of snow days reduces everywhere, with the largest reduction in the coldest mountainous areas where there are a relatively large number of snow days in the present climate.

8. The future magnitude of the 99th percentile 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.

9. The effects of climate change on hydrological characteristics were examined by driving NIWA's national hydrological model with downscaled Global Climate Model (GCM) outputs from 1971-2099 under different global warming scenarios. Using a combination of six GCMs and four warming scenarios allows us to consider a plausible range of future trajectories of greenhouse gas emissions and climatic responses. The changing climate over this century is projected to lead to the following hydrological effects:

   - By the end of the century and with increased emissions, average annual flows are expected to increase across the region (above 50% across all FMUs except headwaters of Taieri and North Otago).
   - Low flow (expressed as Q95% flow) changes are expected to be variable across the Otago region. Low flows are usually increasing with radiative forcing in the headwaters and slightly decreasing elsewhere. Large decrease in low flow is

expected with time and increased radiative forcing for North Otago and Taieri FMUs.

- Floods (characterised by the Mean Annual Flood) are expected to become larger everywhere, with increases up to 100% in some locations by the end of the century.
- Change in surface water supply reliability are characterised by little appreciable change across Otago by mid-century, with Taieri FMU experiencing the largest decrease in flow reliability. Late-century, however, the decreases in the Taieri headwaters become slightly more accentuated, particularly under a high emissions scenario.

9 Glossary of abbreviations and terms

99th percentile	The top 1 percent of a population.
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.
Air mass	A widespread body of air, the approximately homogeneous properties of which (1) have been established while that air was situated over a region of the Earth's surface, and (2) undergo specific modifications while in transit away from the source region.
Annual exceedance probability (AEP)	The probability of a given event (e.g. flood or sea level or wave height) being equalled or exceeded in elevation, in any given calendar year. AEP can be specified as a fraction (e.g., 0.01) or a percentage (e.g., 1%).
Anomaly	The deviation of a variable from its value averaged over a reference period.
Anthropogenic	Human-induced; man-made. Resulting from or produced by human activities.
Anthropogenic emissions	Emissions of greenhouse gases, greenhouse gas precursors, and aerosols caused by human activities. These activities include the burning of fossil fuels, deforestation, land use changes, livestock production, fertilization, waste management, and industrial processes.
AOGCM	Atmosphere-ocean global climate model – a comprehensive climate model containing equations representing the behaviour of the atmosphere, ocean and sea ice and their interactions.
AR4	IPCC Fourth Assessment Report 2007.
AR5	5th Assessment Report of IPCC – published in 2013/14 covering three Working Group Reports and a Synthesis Report.
ARI	Average recurrence interval. The average or expected value of the periods between exceedances of a given rainfall total accumulated over a given duration. It is implicit in this definition that the periods between exceedances are generally random, e.g. a 50-year ARI rain event doesn't necessarily occur only once every 50 years.
Atmosphere	The gaseous envelope surrounding the Earth. The dry atmosphere consists almost entirely of nitrogen (78.1% volume mixing ratio) and oxygen (20.9% volume mixing ratio), together with a number of trace gases, such as argon (0.93% volume mixing ratio), helium and radiatively active greenhouse gases such as carbon dioxide (0.035% volume mixing ratio) and ozone. In addition, the atmosphere contains the greenhouse gas water vapour, whose amounts are highly variable but typically around 1% volume mixing ratio. The atmosphere also contains clouds and aerosols.

Augmentation factor	The percentage increase of rainfall per degree of warming contained within depth-duration-frequency tables in this report.
Baseline/reference	The baseline (or reference) is the state against which change is measured. A baseline period is the period relative to which anomalies are computed.
BCC-CSM1.1	The Beijing Climate Centre Climate System Model version 1.1. A fully coupled global climate-carbon model. Part of CMIP5.
Bias correction	Procedures designed to remove systematic climate model errors.
Biogeochemical	Relating to or denoting the cycle in which chemical elements and simple substances are transferred between living systems and the environment.
Brown Haze	A local or regional scale phenomena that causes a poor atmospheric visibility mostly associated with high pollution levels, also known as smog.
Business as Usual (BAU)	Business as usual projections assume that operating practices and policies remain as they are at present. Although baseline scenarios could incorporate some specific features of BAU scenarios (e.g., a ban on a specific technology), BAU scenarios imply that no practices or policies other than the current ones are in place. RCP8.5 is known as the 'business as usual' climate change scenario.
Carbon dioxide (CO2)	A naturally occurring gas, also a by-product of burning fossil fuels from fossil carbon deposits, such as oil, gas and coal of burning biomass, of land use changes and of industrial processes (e.g., cement production). It is the principal anthropogenic greenhouse gas that affects the Earth’s radiative balance. It is the reference gas against which other greenhouse gases are measured and therefore has a Global Warming Potential of 1.
Carbon sequestration	Carbon sequestration is the process involved in carbon capture and the long-term storage of atmospheric carbon dioxide. Carbon sequestration involves long-term storage of carbon dioxide or other forms of carbon to mitigate or defer global warming.
CESM1-CAM5	The Community Earth System Model, version 5 of the Community Atmosphere Model primarily developed at the National Center for Atmospheric Research in the USA. Part of CMIP5.
Climate	Climate in a narrow sense is usually defined as the average weather, or more rigorously, as the statistical description in terms of the mean and variability of relevant quantities over a period ranging from months to thousands or millions of years. The classical period for averaging these variables is 30 years, as defined by the World Meteorological Organization. The relevant quantities are most often surface variables such as temperature, rainfall and wind. Climate in a wider sense is the state, including a statistical description, of the climate system.

Climate change	Climate change refers to a change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forcings such as modulations of the solar cycles, volcanic eruptions and persistent anthropogenic changes in the composition of the atmosphere or in land use.
Climate change scenario	A plausible and often simplified representation of the future climate, based on an internally consistent set of climatological relationships that has been constructed for explicit use in investigating the potential consequences of anthropogenic climate change, often serving as input to impact models. Climate projections often serve as the raw material for constructing climate scenarios, but climate scenarios usually require additional information such as the observed current climate. A climate change scenario is the difference between a climate scenario and the current climate.
Climate model	A numerical representation of the climate system based on the physical, chemical and biological properties of its components, their interactions and feedback processes, and accounting for some of its known properties. The climate system can be represented by models of varying complexity, that is, for any one component or combination of components a spectrum or hierarchy of models can be identified, differing in such aspects as the number of spatial dimensions, the extent to which physical, chemical or biological processes are explicitly represented or the level at which empirical parametrizations are involved. Coupled Atmosphere–Ocean General Circulation Models (AOGCMs) provide a representation of the climate system that is near or at the most comprehensive end of the spectrum currently available. There is an evolution towards more complex models with interactive chemistry and biology. Climate models are applied as a research tool to study and simulate the climate, and for operational purposes, including monthly, seasonal and inter-annual climate predictions.
Climate projection	A climate projection is the simulated response of the climate system to a scenario of future emission or concentration of greenhouse gases and aerosols, generally derived using climate models. Climate projections are distinguished from climate predictions by their dependence on the emission/concentration/ radiative forcing scenario used, which is in turn based on assumptions concerning, for example, future socioeconomic and technological developments that may or may not be realized.

Climate system	The climate system is the highly complex system consisting of five major components: the atmosphere, the hydrosphere, the cryosphere, the lithosphere and the biosphere, and the interactions between them. The climate system evolves in time under the influence of its own internal dynamics and because of external forcings such as volcanic eruptions, solar variations and anthropogenic forcings such as the changing composition of the atmosphere and land use change.
Climate variability	Climate variability refers to variations in the mean state and other statistics (such as standard deviations, the occurrence of extremes, etc.) of the climate on all spatial and temporal scales beyond that of individual weather events. Variability may be due to natural internal processes within the climate system (internal variability), or to variations in natural or anthropogenic external forcing (external variability).
Climate variable	An element of the climate that is liable to vary or change e.g. temperature, rainfall.
CMIP5	Coupled Model Inter-comparison Project, Phase 5, which involved coordinating and archiving climate model simulations based on shared model inputs by modelling groups from around the world. This project involved many experiments with coupled atmosphere-ocean global climate models, most of which were reported on in the IPCC Fifth Assessment Report, Working Group I. The CMIP5 dataset includes projections using the Representative Concentration Pathways.
Cold nights	In this report, a cold night (or frost) is defined when the daily minimum temperature is below 0°C.
Confidence	The validity of a finding based on the type, amount, quality, and consistency of evidence (e.g., mechanistic understanding, theory, data, models, expert judgment) and on the degree of agreement. Confidence is expressed qualitatively.
Diurnal temperature range	The difference between the maximum and minimum temperature during a 24-hour period.
Downscaling (statistical, dynamical)	Deriving local climate information (at the 5 kilometre grid-scale in this report) from larger-scale model or observational data. Two main methods exist – statistical and dynamical. Statistical methods develop statistical relationships between large-scale atmospheric variables (e.g., circulation and moisture variations) and local climate variables (e.g., rainfall variations). Dynamical methods use the output of a regional climate/weather model driven by a larger-scale global model.

Drought (meteorological, hydrologic)	A period of abnormally dry weather long enough to cause a serious hydrological imbalance. Drought is a relative term; therefore, any discussion in terms of rainfall deficit must refer to the rainfall-related activity that is under discussion. For example, shortage of rainfall during the growing season impinges on crop production or ecosystem function in general (due to soil moisture drought, also termed agricultural drought), and during the runoff and percolation season primarily affects water supplies (hydrological drought). Storage changes in soil moisture and groundwater are also affected by increases in actual evapotranspiration in addition to reductions in rainfall. A period with an abnormal rainfall deficit is defined as a meteorological drought. A megadrought is a very lengthy and pervasive drought, lasting much longer than normal, usually a decade or more.
Emission scenario	A plausible representation of the future development of emissions of substances that act as radiative forcing factors (e.g., greenhouse gases, aerosols) based on a coherent and internally consistent set of assumptions about driving forces (such as demographic and socioeconomic development, technological change) and their key relationships.
Ensemble	A collection of model simulations characterizing a climate prediction or projection. Differences in initial conditions and model formulation result in different evolutions of the modelled system and may give information on uncertainty associated with model error and error in initial conditions in the case of climate forecasts and on uncertainty associated with model error and with internally generated climate variability in the case of climate projections.
ENSO	El Niño-Southern Oscillation. A natural global climate phenomenon involving the interaction between the tropical Pacific and the atmosphere, but has far-reaching effects on the global climate, especially for countries in the Pacific rim. ENSO is the strongest climate signal on time scales of one to several years, characteristically oscillating on a 3-7-year timescale. The quasi-periodic cycle oscillates between El Niño (unusually warm ocean waters along the tropical South American coast and west-central equatorial Pacific) and La Niña (colder-than-normal ocean waters off South America and along the central-east equatorial Pacific).
ESM	Earth system model. Refers to an AOGCM that also includes interactions with biological processes and natural cycles of chemical components such as ozone, carbon dioxide, nitrogen, and sulphur.
Extra-tropical cyclone or mid-latitude cyclone	A large-scale (of order 1000 km) storm in the middle or high latitudes having low central pressure and fronts with strong horizontal gradients in temperature and humidity. A major cause of extreme wind speeds and heavy rainfall especially in wintertime.
Extreme hot days	In this report, an extreme hot day is defined as a day with a maximum temperature over 30°C.

Flood	The overflowing of the normal confines of a stream or other body of water, or the accumulation of water over areas not normally submerged. Floods include river (fluvial) floods, flash floods, urban floods, pluvial floods, sewer floods, coastal floods, and glacial lake outburst floods.
Flow reliability	The fraction of time river flow is below a minimum flow threshold related to water abstraction (based on the Proposed National Environmental Standard for Ecological Flows). Flow reliability reflects the frequency of drought conditions.
GCM	Global climate model. These days almost all GCMs are AOGCMs (atmosphere-ocean global climate models). See also climate model.
GFDL-CM3	The Coupled physical model version 3, developed by the Geophysics Fluid Dynamics Laboratory at NOAA in the USA. Part of CMIP5.
GIS	A geographic information system (GIS) is a system designed to capture, store, manipulate, analyse, manage, and present all types of geographical information for informing decision making.
GISS-E2-R	The E2-R climate model developed by NASA Goddard Institute for Space Studies in the USA. Part of CMIP5.
Global mean surface temperature	An estimate of the global mean surface air temperature. However, for changes over time, only anomalies, as departures from a climatology, are used, most commonly based on the area-weighted global average of the sea surface temperature anomaly and land surface air temperature anomaly.
Greenhouse effect	The radiative effect of all infrared-absorbing constituents in the atmosphere. Greenhouse gases, clouds, and (to a small extent) aerosols absorb terrestrial radiation emitted by the Earth's surface and elsewhere in the atmosphere. These substances emit infrared radiation in all directions, but, everything else being equal, the net amount emitted to space is normally less than would have been emitted in the absence of these absorbers. This is because of the decline of temperature with altitude in the troposphere and the consequent weakening of emission. An increase in the concentration of greenhouse gases increases the magnitude of this effect; the difference is sometimes called the enhanced greenhouse effect. The change in a greenhouse gas concentration because of anthropogenic emissions contributes to an instantaneous radiative forcing. Surface temperature and troposphere warm in response to this forcing, gradually restoring the radiative balance at the top of the atmosphere.

Greenhouse gas (GHG)	Greenhouse gases are those gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the spectrum of terrestrial radiation emitted by the Earth's surface, the atmosphere itself, and by clouds. This property causes the greenhouse effect. Water vapour (H_2O), carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4) and ozone (O_3) are the primary greenhouse gases in the Earth's atmosphere. Moreover, there are many entirely human-made greenhouse gases in the atmosphere, such as the halocarbons and other chlorine- and bromine-containing substances, dealt with under the Montreal Protocol. Beside CO_2, N_2O and CH_4, the Kyoto Protocol deals with the greenhouse gases sulphur hexafluoride (SF_6), hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs).
Groundwater recharge	The process by which external water is added to the zone of saturation of an aquifer, either directly into a geologic formation that traps the water or indirectly by way of another formation.
Gully erosion	The removal of soil along drainage lines by surface water runoff. Once started, gullies will continue to move by headward erosion or by slumping of the side walls unless steps are taken to stabilise the disturbance.
HadGEM2-ES	Climate model developed by the UK Met Office Hadley Centre, from the UK Unified Model. Part of CMIP5.
HIRDS	High Intensity Rainfall Design System (http://hirds.niwa.co.nz). HIRDS uses a regionalized index-frequency method to predict rainfall intensities at ungauged locations and returns depth-duration-frequency tables for rainfall at any location in New Zealand. Temperature increases can be inserted and corresponding increases in rainfall for each duration and frequency are calculated.
Humidity	Specific humidity is the ratio of the mass of water vapour to the total mass of the system (water plus air) in a parcel of moist air. Relative humidity is the ratio of the vapour pressure to the saturation vapour pressure (the latter having a strong dependence on temperature).
Hydrologic drought	Hydrologic drought occurs when low water supply becomes evident, especially in streams, reservoirs, and groundwater levels, usually after an extended period of meteorological drought.
Industrial Revolution	A period of rapid industrial growth with far reaching social and economic consequences, beginning in Britain during the second half of the 18th century and spreading to Europe and later to other countries including the United States. The invention of the steam engine was an important trigger of this development. The industrial revolution marks the beginning of a strong increase in the use of fossil fuels and emission of, in particular, fossil carbon dioxide.

IPCC	Intergovernmental Panel on Climate Change. This body was established in 1988 by the World Meteorological Organisation (WMO) and the United Nations Environment Programme (UNEP) to objectively assess scientific, technical and socioeconomic information relevant to understanding the scientific basis of risk of human induced climate change, its potential impacts and options for adaptation and mitigation. Its latest reports (the Fifth Assessment) were published in 2013/14 (see www.ipcc.ch/).
IPO	Interdecadal Pacific Oscillation – a long timescale oscillation in the ocean–atmosphere system that shifts climate in the Pacific region every one to three decades.
Likelihood	The chance of a specific outcome occurring, where this might be estimated probabilistically.
Mean annual flood	The average of the maximum flood discharges experienced in a river over a period, which should have a recurrence interval of once every 2.33 years.
Mean annual low flow	The mean of the lowest 7-day average flows in each year of a projection period.
Mean discharge	The average annual streamflow or discharge of a river.
Mean sea level (MSL)	The surface level of the ocean at a point averaged over an extended period such as a month or year. Mean sea level is often used as a national datum to which heights on land are referred. Mean sea level changes with the averaging period used, due to climate variability and long-term sea-level rise.
Mitigation (of climate change)	A human intervention to reduce the sources or enhance the sinks of greenhouse gases.
Model spread	The range or spread in results from climate models, such as those assembled for Coupled Model Intercomparison Project Phase 5 (CMIP5). Does not necessarily provide an exhaustive and formal estimate of the uncertainty in feedbacks, forcing or projections even when expressed numerically, for example, by computing a standard deviation of the models' responses. To quantify uncertainty, information from observations, physical constraints and expert judgement must be combined, using a statistical framework.
NIWA	National Institute of Water and Atmospheric Research Ltd.
NorESM1-M	The Norwegian Earth System Model. Part of CMIP5.
Orographic rainfall	Precipitation that is produced when moist air is lifted as it moves over a mountain range. As the air rises and cools, orographic clouds serve as the source of the precipitation, most of which falls upwind of the mountain ridge.

Ozone	Ozone, the triatomic form of oxygen (O3), is a gaseous atmospheric constituent. In the troposphere, it is created both naturally and by photochemical reactions involving gases resulting from human activities (smog). Tropospheric ozone acts as a greenhouse gas. In the stratosphere, it is created by the interaction between solar ultraviolet radiation and molecular oxygen (O2). Stratospheric ozone plays a dominant role in the stratospheric radiative balance. Its concentration is highest in the ozone layer.
Paris agreement	The Paris Agreement aims to respond to the global climate change threat by keeping a global temperature rise this century well below 2°C above pre-industrial levels and to pursue efforts to limit the temperature increase even further to 1.5°C.
Percentiles	The set of partition values which divides the total population of a distribution into 100 equal parts, the 50th percentile corresponding to the median of the population.
Precipitation	Describes all forms of moisture that falls from clouds (rain, sleet, hail, snow, etc). 'Rainfall' describes just the liquid component of precipitation.
Pre-industrial	Conditions at or before 1750. See also Industrial revolution.
Projection	A numerical simulation (representation) of future conditions. Differs from a forecast; whereas a forecast aims to predict the exact time-dependent conditions in the immediate future, such as a weather forecast a future cast aims to simulate a time-series of conditions that would be typical of the future (from which statistical properties can be calculated) but does not predict future individual events.
Radiative forcing	A measure of the energy absorbed and retained in the lower atmosphere. More technically, radiative forcing is the change in the net (downward minus upward) irradiance (expressed in W/m2, and including both short-wave energy from the sun, and long-wave energy from greenhouse gases) at the tropopause, due to a change in an external driver of climate change, such as, for example, a change in the concentration of carbon dioxide or the output of the sun.
Regional Climate Model (RCM)	A numerical climate prediction model run over a limited geographic domain (here around New Zealand), and driven along its lateral atmospheric boundary and oceanic boundary with conditions simulated by a global climate model (GCM). The RCM thus downscales the coarse resolution GCM, accounting for higher resolution topographical data, land-sea contrasts, and surface characteristics. RCMs can cater for relatively small-scale features such as New Zealand's Southern Alps.
Representative Concentration Pathways (RCPs)	Representative concentration pathways. They describe four possible climate futures, all of which are considered possible depending on how much greenhouse gases are emitted in the years to come. The four RCPs, RCP2.6, RCP4.5, RCP6, and RCP8.5, are named after a possible range of radiative forcing values in the year 2100 relative to pre-industrial values (+2.6, +4.5, +6.0, and +8.5 W/m2, respectively)

Resolution	In climate models, this term refers to the physical distance (metres or degrees) between each point on the grid used to compute the equations. Temporal resolution refers to the time step or time elapsed between each model computation of the equations.
Return period	An estimate of the average time interval between occurrences of an event (e.g., flood or extreme rainfall) of (or below/above) a defined size or intensity.
SAM	Southern Annular Mode. Represents the variability of circumpolar atmospheric jets that encircle the Southern Hemisphere that extend out to the latitudes of New Zealand. Positive phases of SAM are associated with relatively settled weather in New Zealand, whereas negative phases are associated with unsettled weather over the country.
Scenario	In common English parlance, a 'scenario' is an imagined sequence of future events. The IPCC Fifth Assessment describes a 'climate scenario' as: A plausible and often simplified representation of the future climate, based on an internally consistent set of climatological relationships that has been constructed for explicit use in investigating the potential consequences of anthropogenic climate change, often serving as input to impact models. The word 'scenario' is often given other qualifications, such as 'emission scenario' or 'socio-economic scenario'. For the purpose of forcing a global climate model, the primary information needed is the time variation of greenhouse gas and aerosol concentrations in the atmosphere.
Sea surface temperature (SST)	The sea surface temperature is the subsurface bulk temperature in the top few metres of the ocean, measured by ships, buoys and drifters.
Seven-station series	This refers to seven long-term temperature records used to assess New Zealand's warming on the century time-scale. The sites are located in Auckland, Wellington, Masterton, Nelson, Hokitika, Lincoln, and Dunedin.
Simulation	Simulation is the imitation of the operation of a real-world process or system over time. The act of simulating something first requires that a model be developed; this model represents the key characteristics, behaviours and functions of the selected physical or abstract system or process. The model represents the system itself, whereas the simulation represents the operation of the system over time.
SOI	Southern Oscillation Index, representing seesaws of atmospheric pressure in the tropical Pacific, one pole being at Tahiti and the other at Darwin, Australia. Extreme states of this index are indicative of El Niño or La Niña events in the equatorial Pacific. Typically, El Niño events produce more south-westerly flow than usual over New Zealand and associated cooler conditions, with more rainfall in western parts and frequently drought conditions in the east. La Niña events produce more high pressures over the South Island and warmer north-easterly airflow over the North Island, sometimes with drought conditions in the South Island.

Spatial and temporal scales	Climate may vary on a large range of spatial and temporal scales. Spatial scales may range from local (less than 100,000 km2), through regional (100,000 to 10 million km2) to continental (10 to 100 million km2). Temporal scales may range from seasonal to geological (up to hundreds of millions of years).
SRES	Special Report on Emissions Scenarios (SRES) was published by the IPCC in 2000. The greenhouse gas emissions scenarios described in this report were used in the IPCC Third Assessment Report (2001) and IPCC Fourth Assessment Report (2007).
Storm tracks	Originally, a term referring to the tracks of individual cyclonic weather systems, but now often generalized to refer to the main regions where the tracks of extratropical disturbances occur as sequences of low (cyclonic) and high (anticyclonic) pressure systems
Surface temperature	Air temperatures measured near or 'at' the surface (usually 1.5 m above the ground).
Synoptic	Weather patterns viewed at a scale of 1000 km or more to be able to see features such as high and low pressure systems.
TopNet	A semi-distributed hydrological model for simulating catchment water balance and river flow, developed by NIWA.
Trend	In this report, the word trend designates a change, generally monotonic in time, in the value of a variable.
Tropical cyclone	A strong, cyclonic-scale disturbance that originates over tropical oceans. Distinguished from weaker systems (often named tropical disturbances or depressions) by exceeding a threshold wind speed. A tropical storm is a tropical cyclone with 1-minute average surface winds between 18 and 32 m s–1. Beyond 32 m s–1, a tropical cyclone is called a hurricane, typhoon, or cyclone, depending on geographic location.
Uncertainty	A state of incomplete knowledge that can result from a lack of information or from disagreement about what is known or even knowable. It may have many types of sources, from imprecision in the data to ambiguously defined concepts or terminology, or uncertain projections of human behaviour. Uncertainty can therefore be represented by quantitative measures (e.g., a probability density function) or by qualitative statements (e.g., reflecting the judgment of a team of experts).
VCSN	Virtual Climate Station Network. Made up of observational datasets of a range of climate variables: maximum and minimum temperature, rainfall, relative humidity, solar radiation, and wind. Daily data are interpolated onto a 0.05° longitude by 0.05° latitude grid (approximately 4 kilometres longitude by 5 kilometres latitude), covering all New Zealand (11,491 points). Primary reference to the spline interpolation methodology is Tait et al (2006).

Appendix A Climate modelling methodology

Key messages

- Climate model simulation data from the IPCC Fifth Assessment has been used to produce climate projections for New Zealand.
- Six climate models were chosen by NIWA for dynamical downscaling. These models were chosen because they produced the most accurate results when compared to historical climate and circulation patterns in the New Zealand and southwest Pacific region.
- Downscaled climate change projections are at a 5 km x 5 km resolution over New Zealand.
- Climate projection maps and the historic baseline maps present the average of the six downscaled models.
- Climate projections are presented as a 20-year average for two future periods: 2031-2050 (termed '2040') and 2081-2100 (termed '2090'). All maps show changes relative to the baseline climate of 1986-2005 (termed '1995').

NIWA has used climate model simulation data from the IPCC Fifth Assessment to update climate change scenarios for New Zealand through both regional climate model (dynamical) and statistical downscaling processes. The downscaling processes are described in detail in a climate guidance manual prepared for the Ministry for the Environment (2018a), but a short explanation is provided below. Dynamical downscaling results are presented for all variables in this report, and statistical downscaling results are also presented for mean temperature and rainfall projections.

Global climate models (GCMs) are used to make future climate change projections for each future scenario, and results from these models are available through the Fifth Coupled Model Inter-comparison Project (CMIP5) archive (Taylor et al., 2012). Six GCMs were selected by NIWA for dynamical downscaling, and the sea surface temperatures (SSTs) from these six CMIP5 models used to drive an atmospheric global model, which in turn drives a higher resolution regional climate model (RCM) nested over New Zealand. These CMIP5 models were chosen because they produced the most accurate results when compared to historical climate and circulation patterns in the New Zealand and southwest Pacific region. In addition, they were chosen because they were as varied as possible in the parent global model to span the likely range of model sensitivity. For climate simulations, dynamical downscaling utilises a high-resolution climate model to obtain finer scale detail over a limited area based on a coarser global model simulation.

The six GCMs chosen for dynamical downscaling were BCC-CSM1.1, CESM1-CAM5, GFDL-CM3, GISS-E2-R, HadGEM2-ES and NorESM1-M. The NIWA downscaling (GCM then RCM) produced simulations that contained hourly precipitation results from 1970 through to 2100. The native resolution of the regional climate model is 27 km and there are known biases in the precipitation fields derived from this model. The daily precipitation projections, as well as daily maximum and minimum temperatures, have been bias-corrected so that their statistical distributions from the RCM matches those from the Virtual Climate Station Network (VCSN) when the RCM is driven by the observed sequence of weather patterns across New Zealand (known as 're-analysis' data). When the RCM is driven from the free-running GCM, forced only by CMIP5 SSTs, there can be an additional bias in the distribution of weather patterns affecting New Zealand, and the RCM output data for the historical climate will therefore not match the observed distributions exactly.

The RCM output is then downscaled statistically (by interpolation from the model 27 km grid) to a ~5 km x ~5 km resolution with a daily time-step. The ~5 km grid corresponds to the VCSN grid[5]. Figure 9-1 shows a schematic for the dynamical downscaling method used in this report.

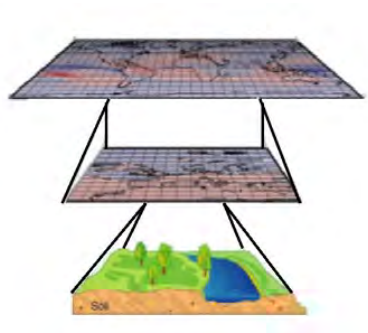

Figure 9-1: Schematic showing dynamical downscaling method used in this report.

Statistical downscaling uses statistical relationships to relate the large-scale climate simulation outputs (which are gridded) to regional, catchment or local station scales. The statistical downscaling is very fast, and so has been applied to a much larger number of CMIP5 GCMs (up to 41) than the dynamical downscaling).

The climate change projections from each of the six dynamical models are averaged together, creating what is called an ensemble-average. The ensemble-average is mapped in this report, because the models were chosen to cover a wide range of potential future climate conditions. The ensemble-average was presented as this usually performs better in climate simulations than any individual model (the errors in different models are compensated).

Climate projections are presented as a 20-year average for two future periods: 2031-2050 (termed '2040') and 2081-2100 (termed '2090'). All maps show changes relative to the baseline climate of 1986-2005 (termed '1995'), as used by IPCC. Hence the projected changes by 2040 and 2090 should be thought of as 45-year and 95-year projected trends. Note that the projected changes use 20-year averages, which will not entirely remove effects of natural variability. The baseline maps (1986-2005) show modelled historic climate conditions from the same six models as the future climate change projection maps.

[5] Virtual Climate Station Network, a set of New Zealand climate data based on a 5 km by 5 km grid across the country. Data have been interpolated from 'real' climate station records (TAIT, A., HENDERSON, R., TURNER, R. & ZHENG, X. G. 2006. Thin plate smoothing spline interpolation of daily rainfall for New Zealand using a climatological rainfall surface. *International Journal of Climatology,* 26**,** 2097-2115.)

Appendix B Hydrological modelling methodology

Key messages

- NIWA's TopNet model was used in this study. TopNet is a spatially semi-distributed, time-stepping model of water balance. The model is driven by time-series of precipitation and temperature, and additional weather elements where available.
- TopNet was run continuously from 1971 to 2100, with the spin-up period 1971 excluded from the analysis. The climate inputs were stochastically disaggregated from daily to hourly time steps.
- The simulation results comprise time-series of modelled river flow for each computational sub-catchment, and for each of the six GCMs and four RCPs considered.
- Hydrological projections are presented as the average for two future periods: 2036-2056 (termed 'mid-century') and 2086-2099 (termed 'late-century'). All maps show changes relative to the baseline climate (1986-2005 average).

To assess the potential impacts of climate change on agricultural water resources and flooding, a hydrological model is required that can simulate soil moisture and river flows continuously and under a range of different climatic conditions, both historical and future. Ideally the model would also simulate complex groundwater fluxes but there is no national hydrological model capable of this at present. Because climate change implies that environmental conditions are shifting from what has been observed historically, it is advantageous to use a physically based hydrological model over one that is more empirical, with the assumption that a better representation of the biophysical processes will allow the model to perform better outside the range of conditions under which it is calibrated.

The hydrological model we will use in this study is NIWA's TopNet model (Clark et al. 2008), which is routinely used for surface water hydrological modelling applications in New Zealand. It is a spatially semi-distributed, time-stepping model of water balance. It is driven by time-series of precipitation and temperature, and of additional weather elements where available. TopNet simulates water storage in the snowpack, plant canopy, rooting zone, shallow subsurface, lakes and rivers. It produces time-series of modelled river flow (without consideration of water abstraction, impoundments or discharges) throughout the modelled river network, as well as evapotranspiration, and does not consider irrigation. TopNet has two major components, namely a basin module and a flow routing module.

The model combines TOPMODEL hydrological model concepts (Beven et al. 1995) with a kinematic wave channel routing algorithm (Goring 1994) and a simple temperature based empirical snow model (Clark et al. 2008). As a result, TopNet can be applied across a range of temporal and spatial scales over large watersheds using smaller sub-basins as model elements (Ibbitt and Woods 2002; Bandaragoda et al. 2004). Considerable effort has been made during the development of TopNet to ensure that the model has a strong physical basis and that the dominant rainfall-runoff dynamics are adequately represented in the model (McMillan et al. 2010). TopNet model equations and information requirements are provided by Clark et al. (2008) and McMillan et al. (2013).

For the development of the national version of TopNet used in here, spatial information in TopNet was provided by national datasets as follows:

- Catchment topography based on a nationally available 30 m Digital Elevation Model (DEM).
- Physiographical data based on the Land Cover Database version two and Land Resource Inventory (Newsome et al. 2012).
- Soil data based on the Fundamental Soil Layer information (Newsome et al. 2012).
- Hydrological properties (based on the River Environment Classification version one (REC1) (Snelder and Biggs 2002)[6].

The method for deriving TopNet's parameters based on GIS data sources in New Zealand is given in Table 1 of Clark et al. (2008). Due to the paucity of some spatial information at national/regional scales, some soil parameters are set uniformly across New Zealand.

To carry out the simulations required for this study, TopNet was run continuously from 1971 to 2100, with the spin-up period 1971 excluded from the analysis. The climate inputs were stochastically disaggregated from daily to hourly time steps. As the GCM simulations are "free-running" (based only on initial conditions, not updated with observations), comparisons between present and future hydrological conditions can be made directly (as each GCM is characterised by specific physical assumptions and parameterisation), but this also means that simulated hydrological hindcasts do not track observational records.

Hydrological simulations are based on the REC 1 network aggregated up to Strahler[7] catchment order three (approximate average catchment area of 7 km^2) used within previous national and regional scale assessments (Pearce et al. 2017a, b); residual coastal catchments of smaller stream orders remain included. The simulation results comprise hourly time-series of various hydrological variables for each computational sub-catchment, and for each of the six GCMs and four RCPs considered. To manage the volume of output data, only river flows information was preserved; all the other state variables and fluxes can be regenerated on demand.

Because of TopNet assumptions, soil and land use characteristics within each computational sub-catchment are homogenised. Essentially this means that the soil characteristics and physical properties of different land uses, such as pasture and forest, will be spatially averaged, and the hydrological model outputs will be an approximation of conditions across land uses.

[6] Due to time constraints associated with this project, it is not possible to assess the potential impact of climate change on the Digital River Network 3 available for the Otago region.
[7] Strahler order describes river size based on tributary hierarchy. Headwater streams with no tributaries are order 1; 2nd order streams develop at the confluence of two 1st order tributaries; stream order increases by 1 where two tributaries of the same order converge.

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REPORT

Tonkin+Taylor

Otago Climate Change Risk Assessment

Main report

Prepared for
Otago Regional Council

Prepared by
Tonkin & Taylor Ltd

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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 °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).

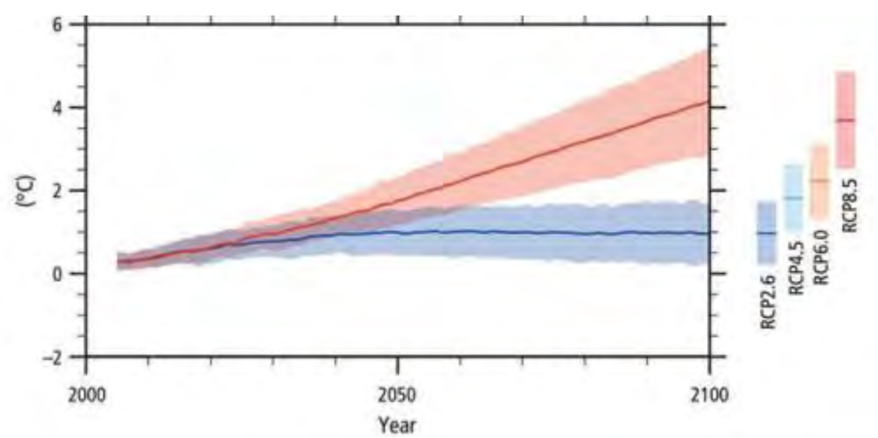

Figure 2-1: Global average surface temperature change from 2006 to 2100 as determined by multi-model simulations relative to 1986 – 2005. Shaded areas show uncertainty associated with RCPs (IPCC, 2014).

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.

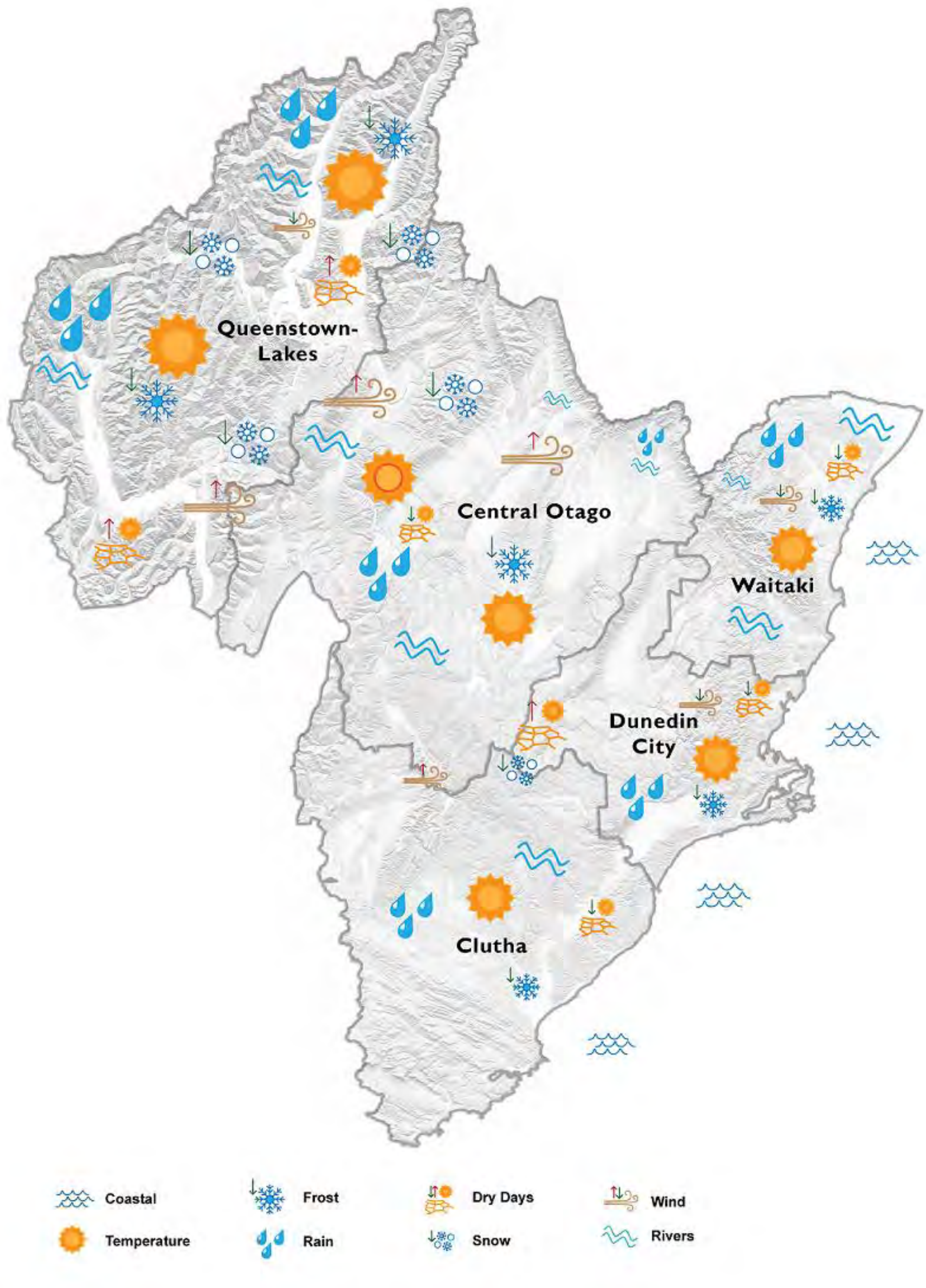

Figure 2-2: Summary of expected climatic changes for the Otago Region (source: provided by ORC summarised from Macara et al., (2019)). Location of symbol is not specific it refers to the general locality. The larger the symbol the more significant the impact, an upwards arrow means an increase, a downwards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

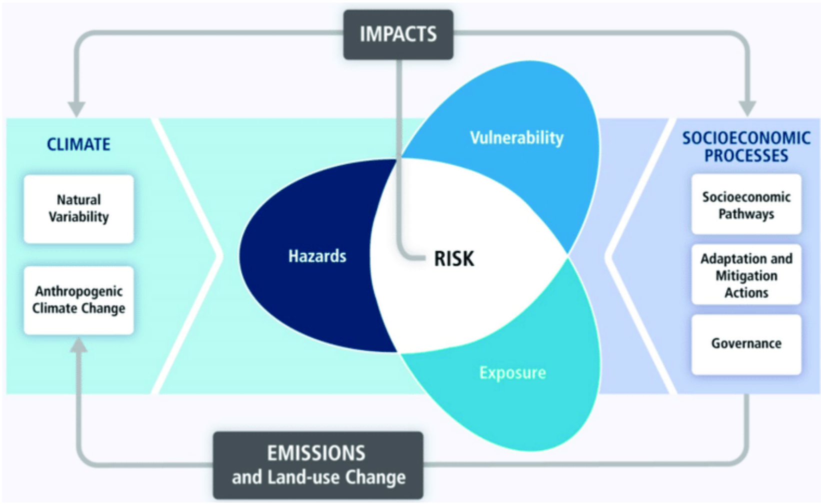

Figure 3-1: The IPCC AR5 conceptual framework with risk at the centre (IPCC, 2014).

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.

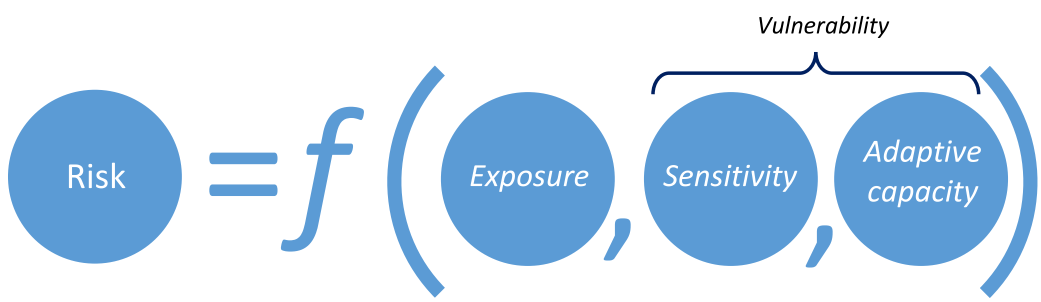

Figure 3-2: Risk equation based on exposure, sensitivity and adaptive capacity.

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

		Sensitivity			
		Low	Moderate	High	Extreme
Adaptive Capacity	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

		Exposure			
		Low	Moderate	High	Extreme
Vulnerability	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				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

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

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[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).

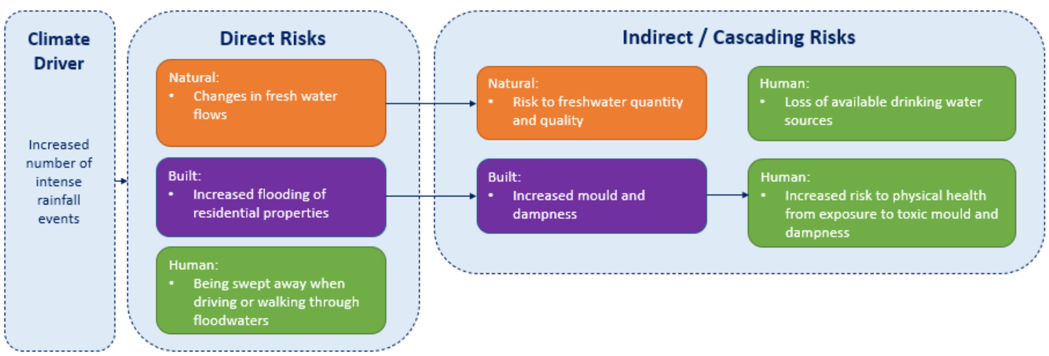


Figure 4-1: Direct and indirect effects of climate change examples.

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.

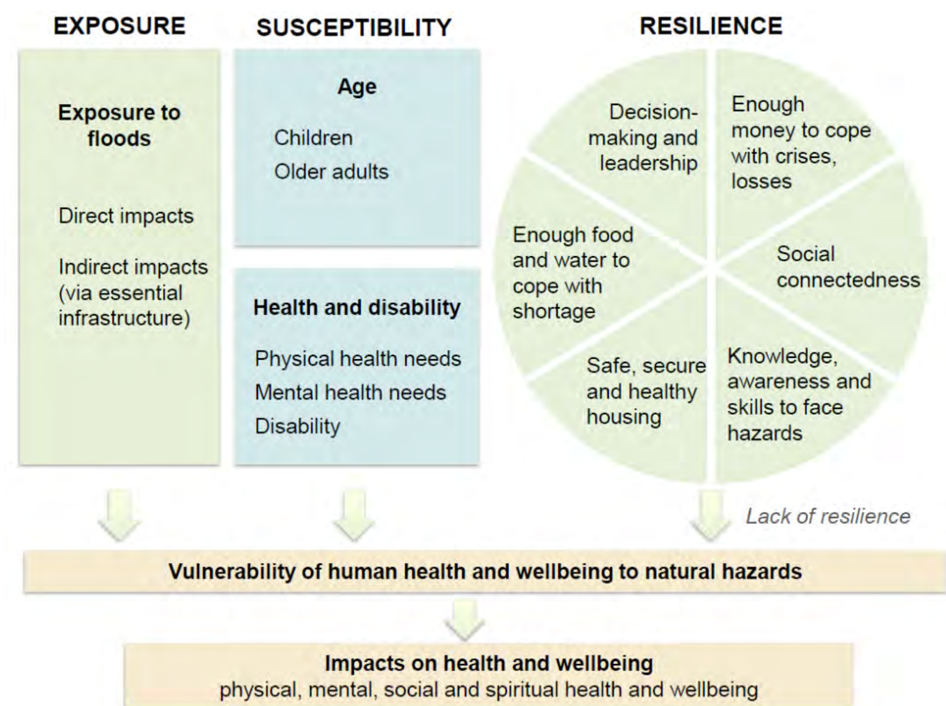


Figure 4-2: Social vulnerability framework and dimensions relating to flooding in Aotearoa, New Zealand (Mason et al., 2019).

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).

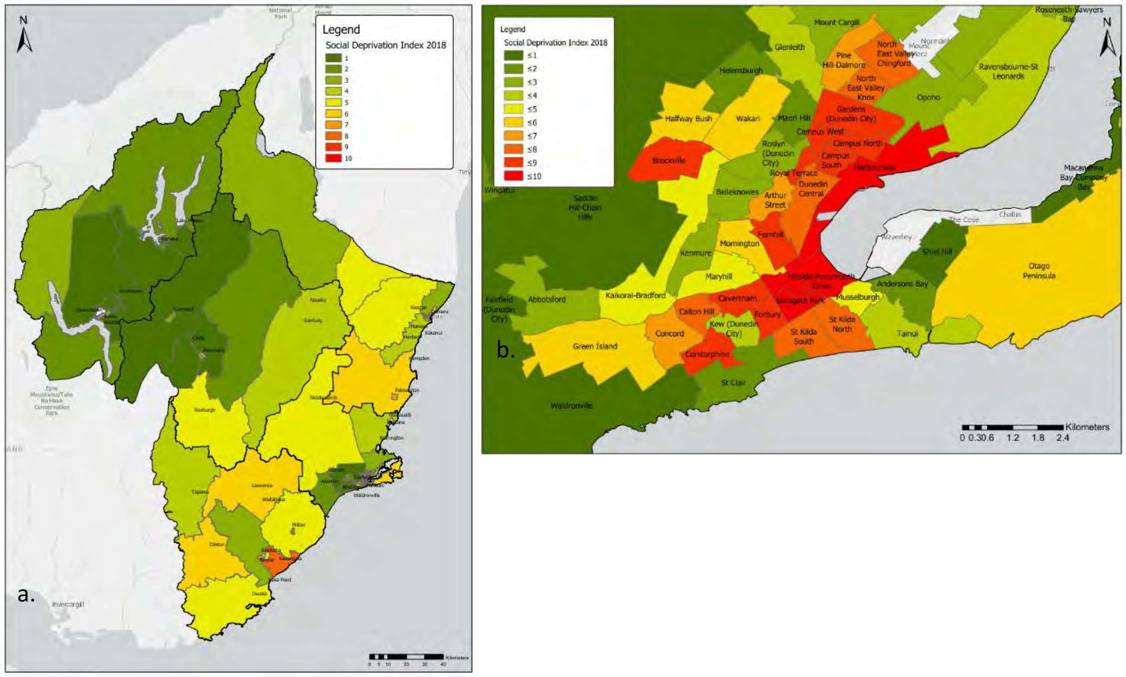


Figure 4-3: a. Social Deprivation Index by statistical area 2 for Otago region, b. Social Deprivation Index by statistical area for Dunedin City.

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.

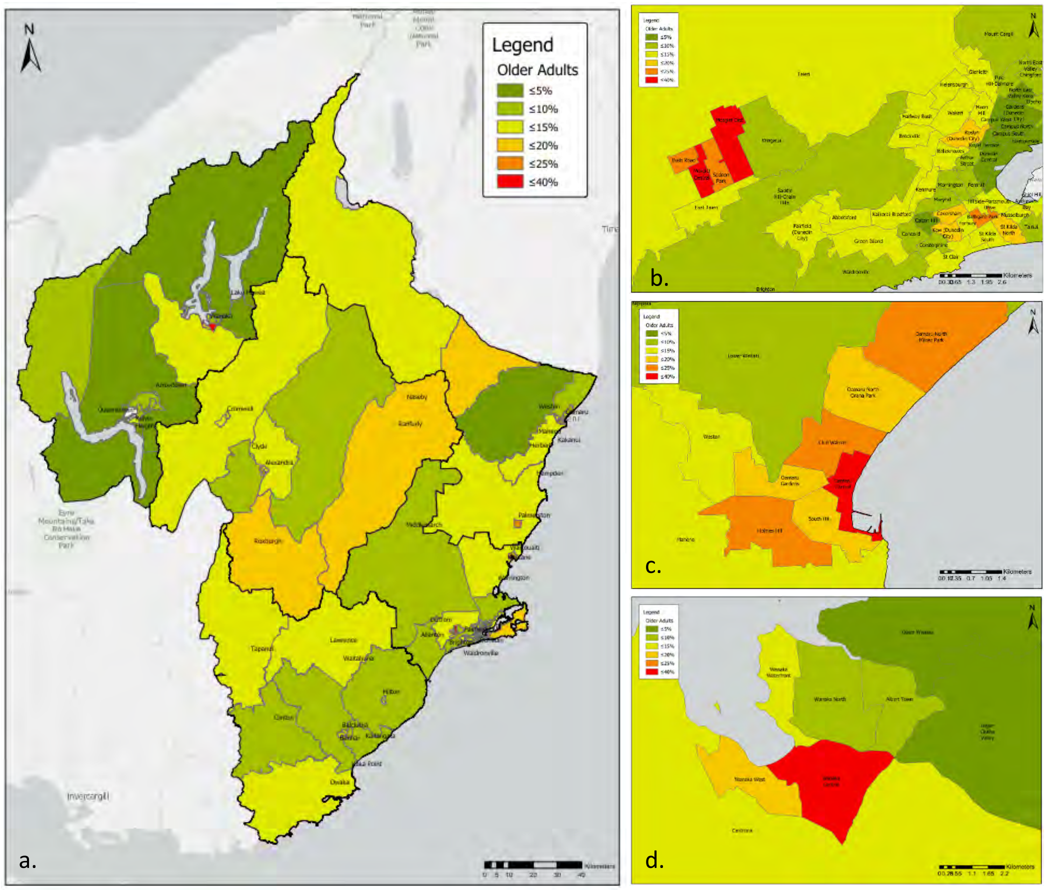


Figure 4-4: a. Percentage of older adults by statistical area 2 for the Otago region, b. percentage of older adults by statistical area 2 in Dunedin City, c. percentage of older adults by statistical area 2 in Oamaru, d. percentage of older adults by statistical area 2 in Wanaka.

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).

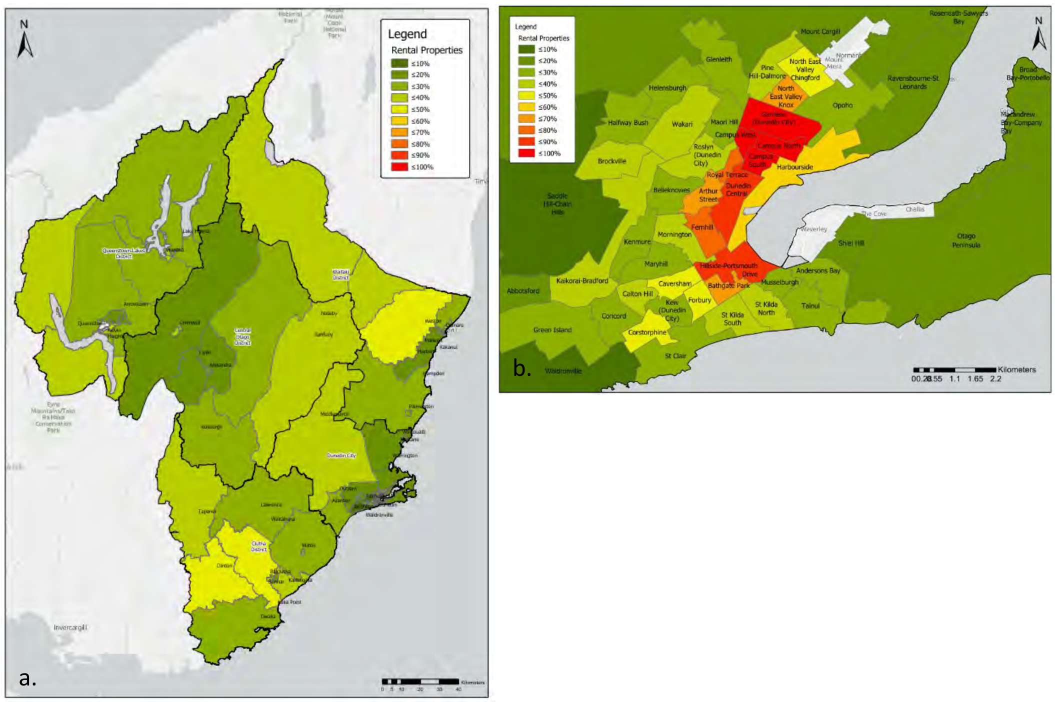


Figure 4-5: a. Percentage of total population living in rented dwellings by statistical area 2, b. percentage of people living in rented dwellings by statistical area 2 in Dunedin City.

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.

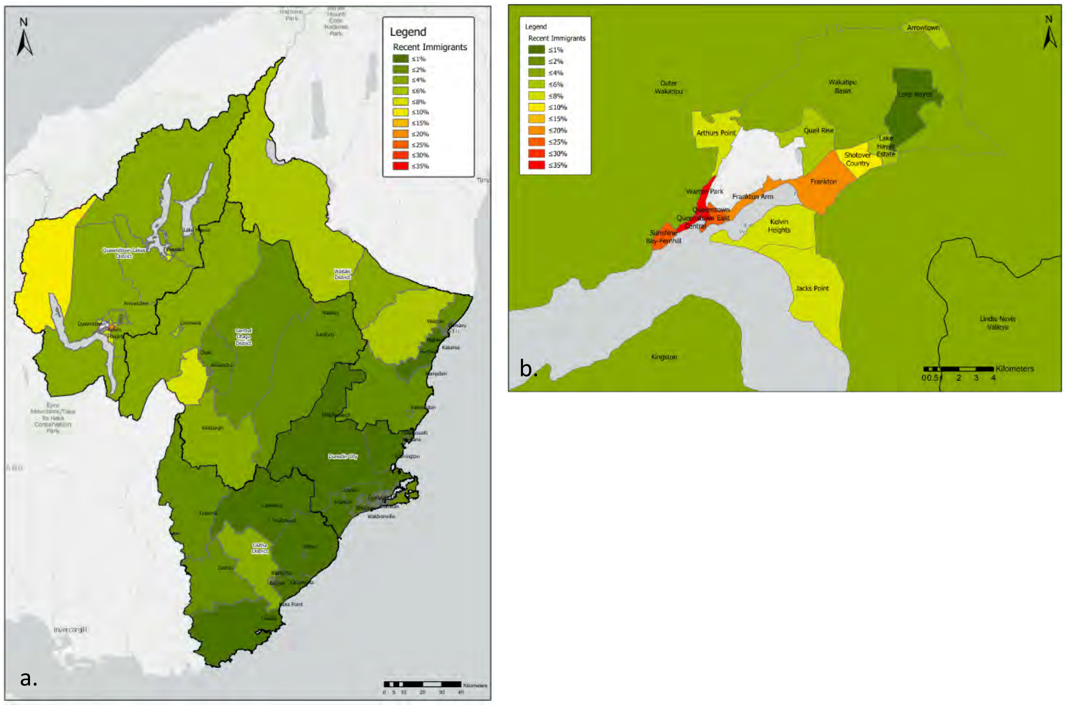


Figure 4-6: a. Percentage of the total population who have recently migrated in the last 0-1year by statistical area 2 for the Otago Region, b. percentage of the people migrated in the last 0-1 year by statistical area 2 for Queenstown.

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.

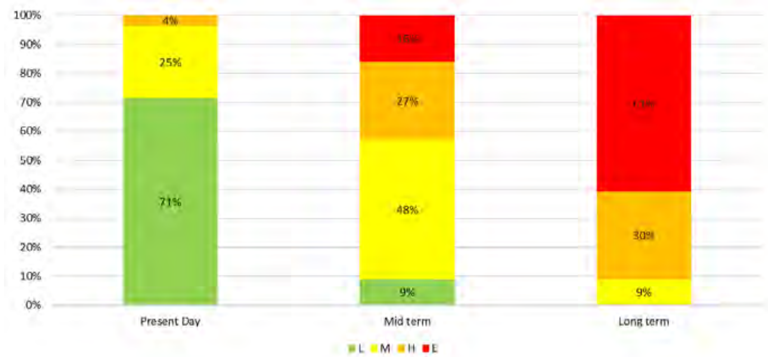


Figure 5-1: Summary of natural environment risks by risk rating.

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.

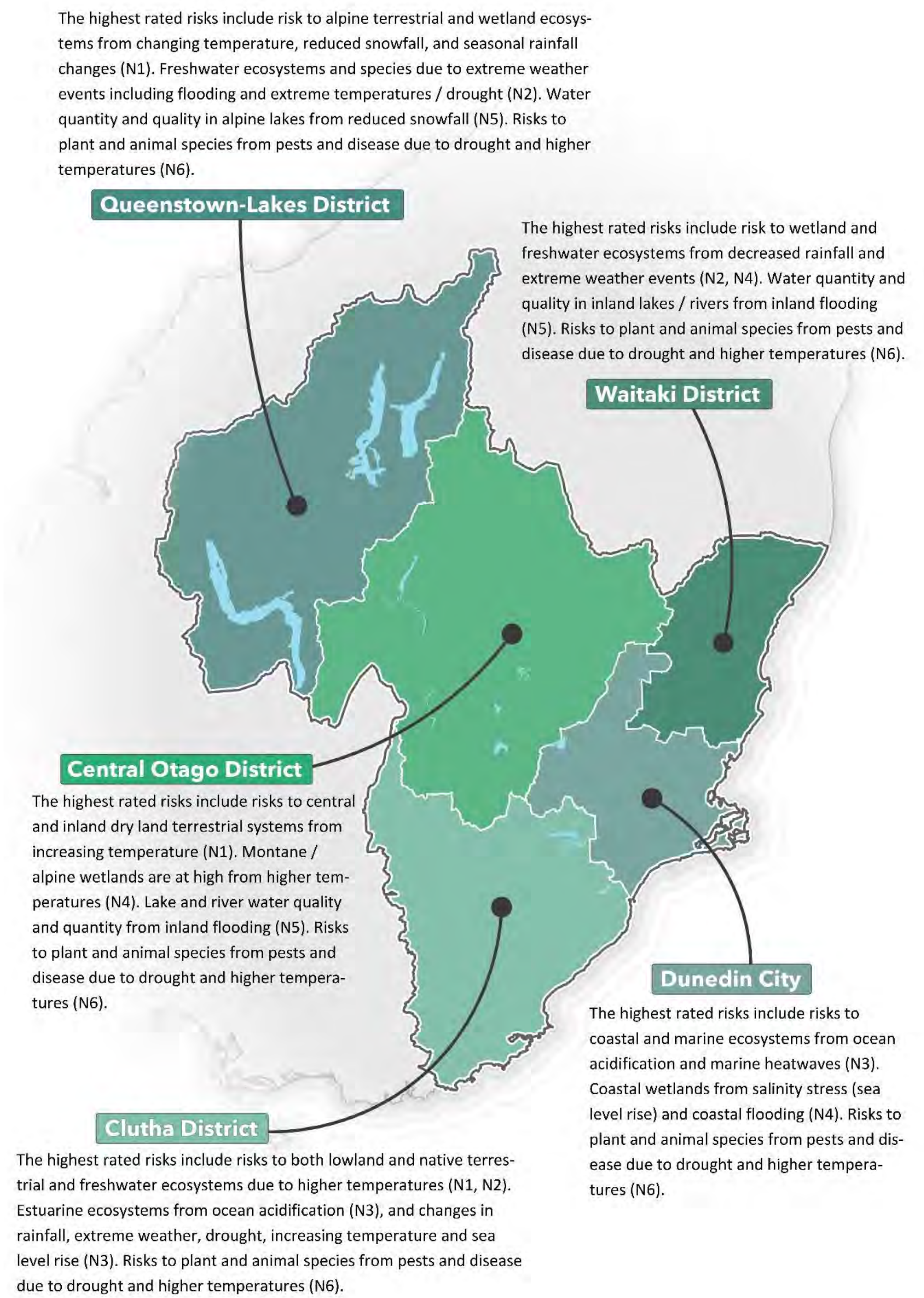


Figure 5-2: Overview of the projected changes through the different districts of the Otago region by 2090 in the natural domain.

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).

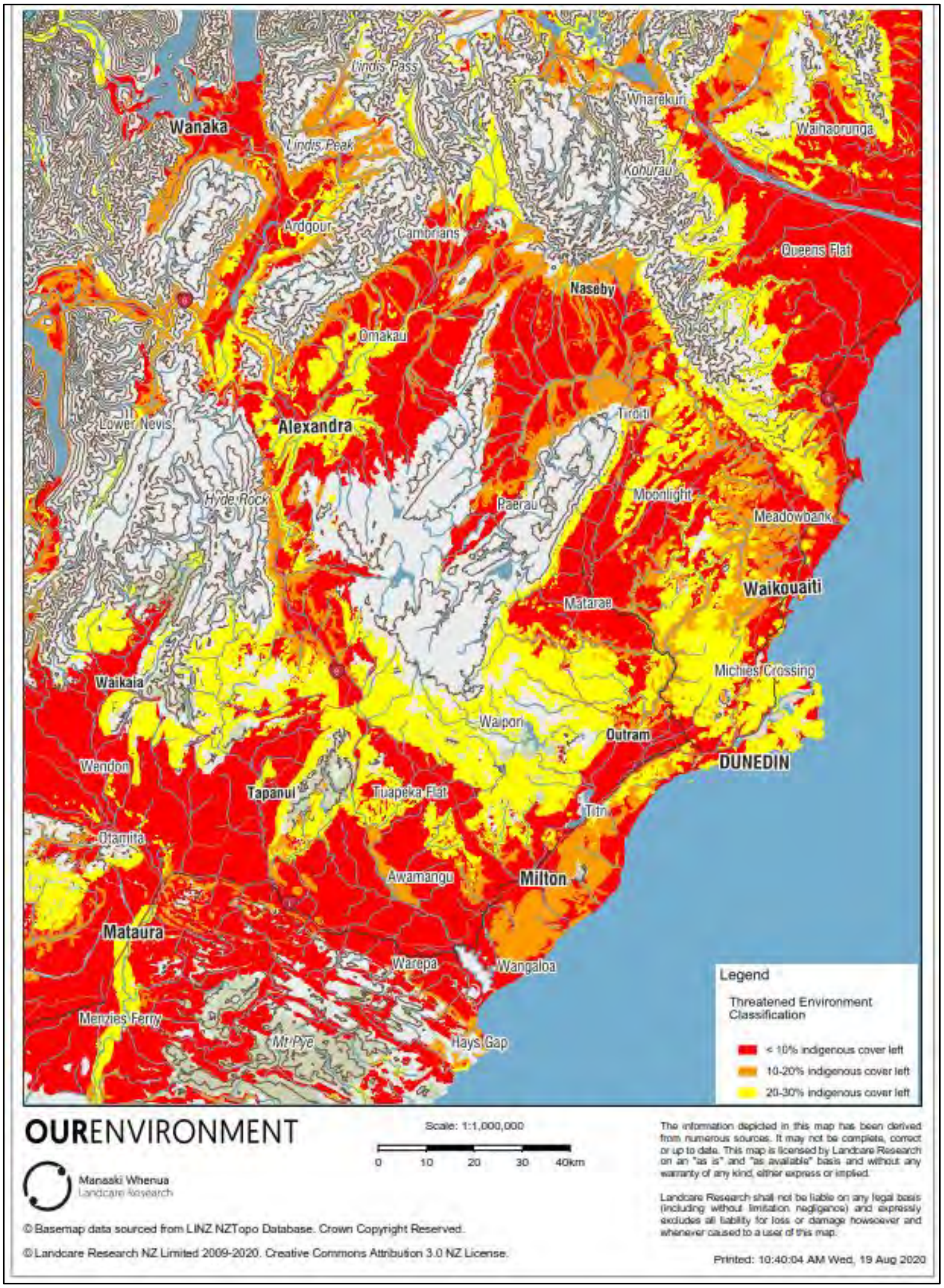


Figure 5-3: Threatened environment classification for Otago. Note: white areas indicate >30% indigenous cover remains, Source – Landcare Research.

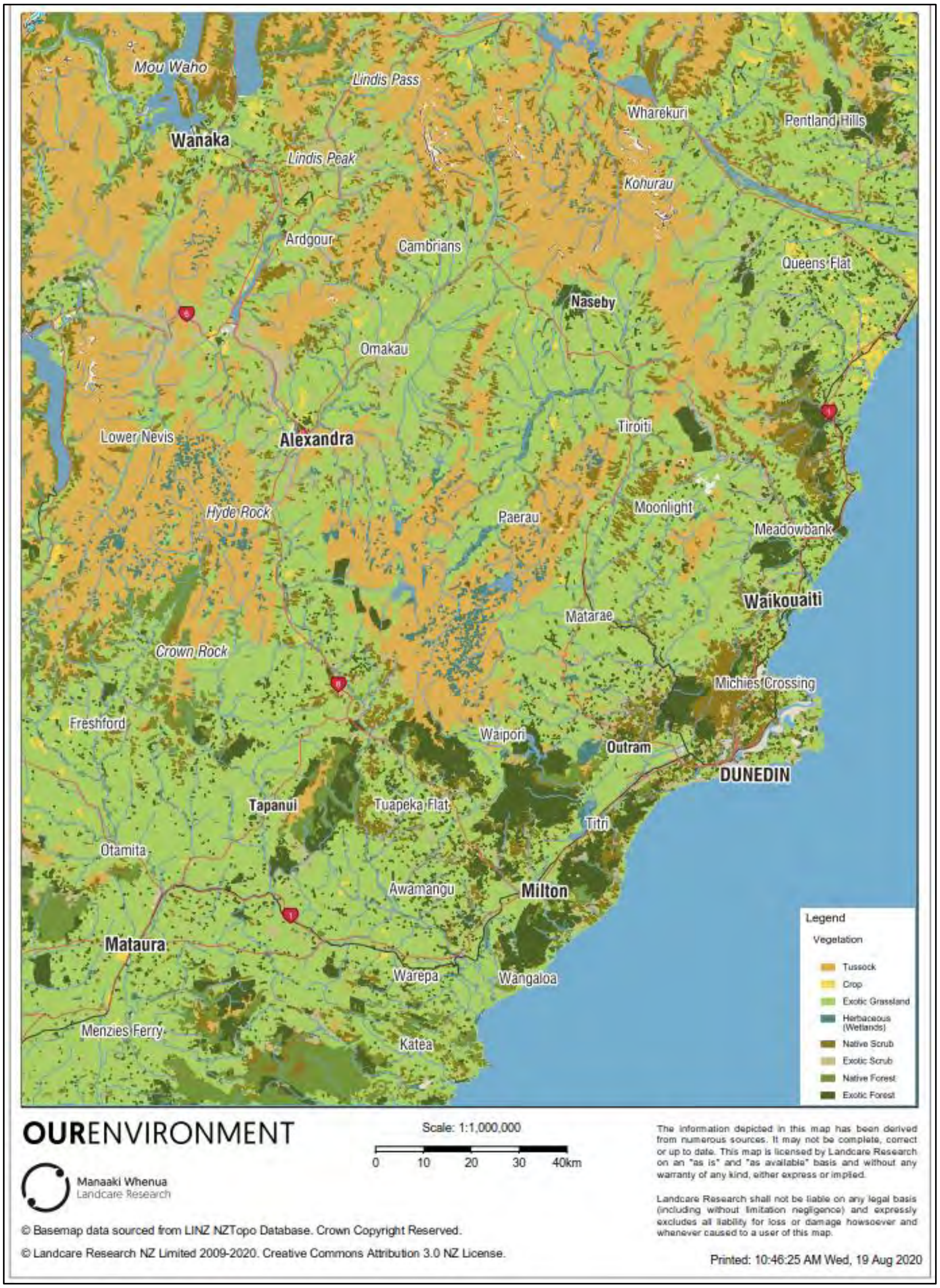


Figure 5-4: Vegetation cover for Otago, Source: Landcare Research.

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.

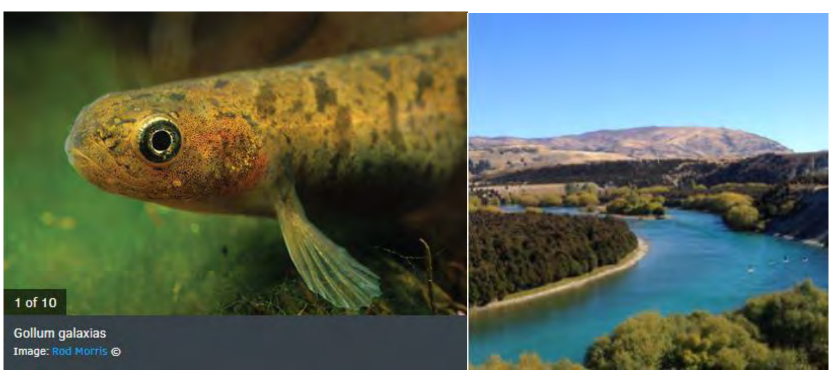


Figure 5-5: (left) Gollum galaxias, a non-migratory native fish species, (right) the Upper Clutha River (Source – Department of Conservation, 2020).

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.

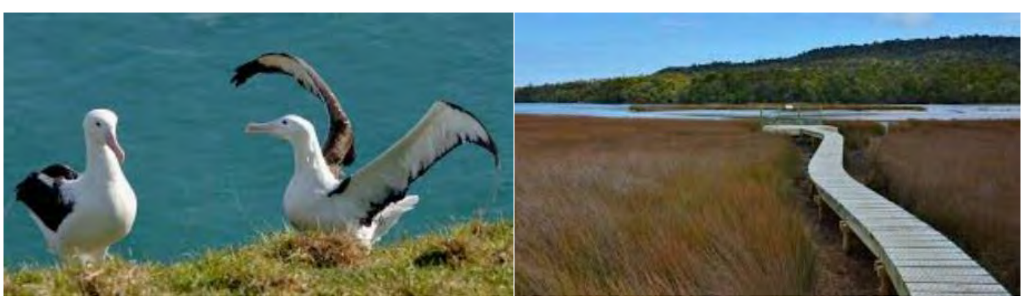


Figure 5-6: Royal albatross at Taiaroa Head (https://albatross.org.nz/), and Tuatuku Bay (https://www.doc.govt.nz/parks-and-recreation/places-to-go/otago/places/catlins-coastal-area/things-to-do/tautuku-walks).

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.

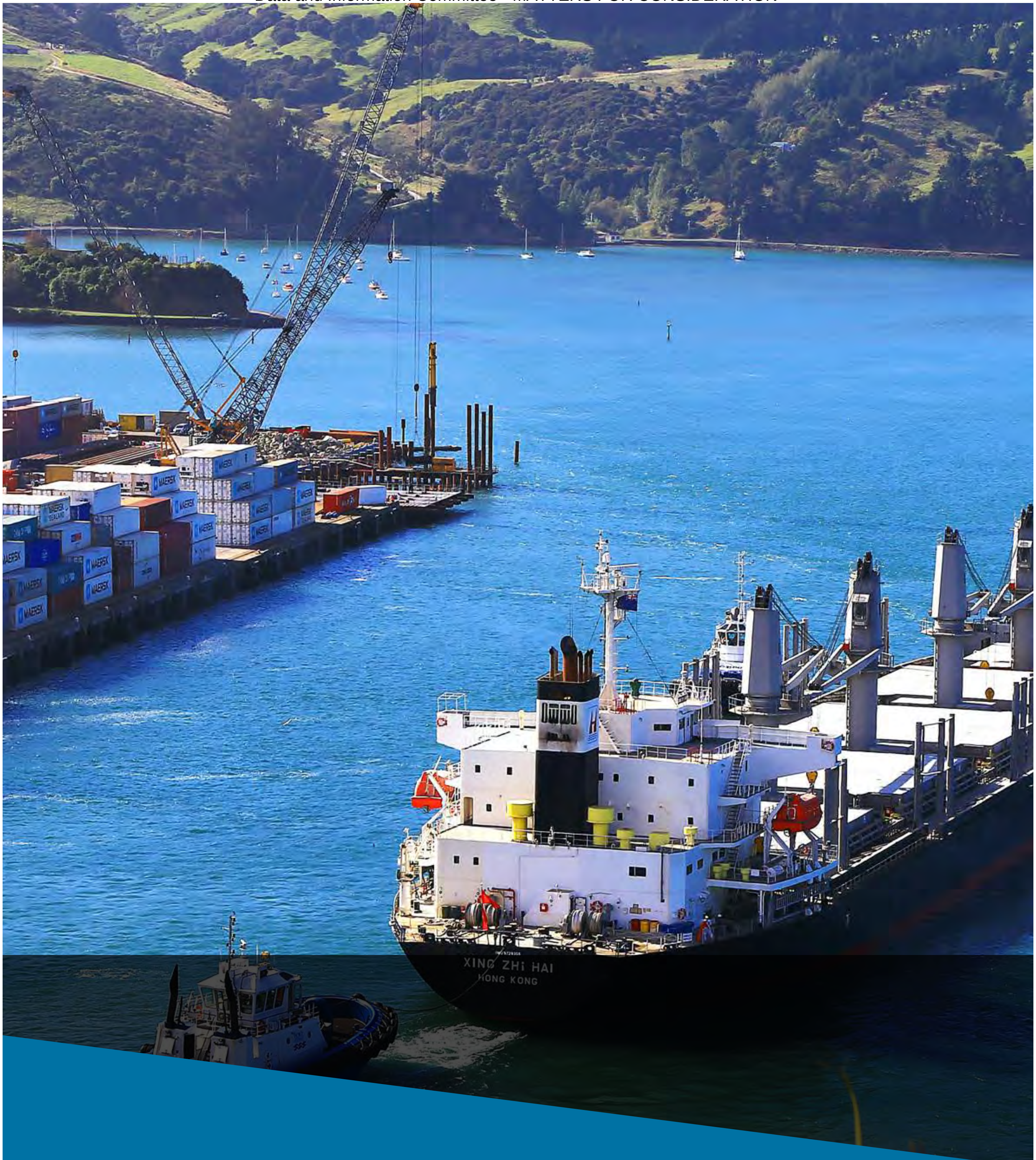
Increased populations of plant and animal pests and spread of disease is likely to result in decreased biodiversity within native ecosystems.

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.

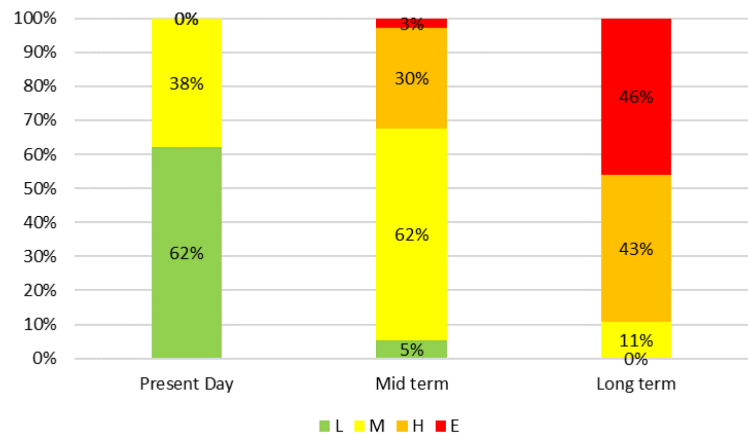


Figure 6-1: Summary of economic domain risks by risk rating.

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.

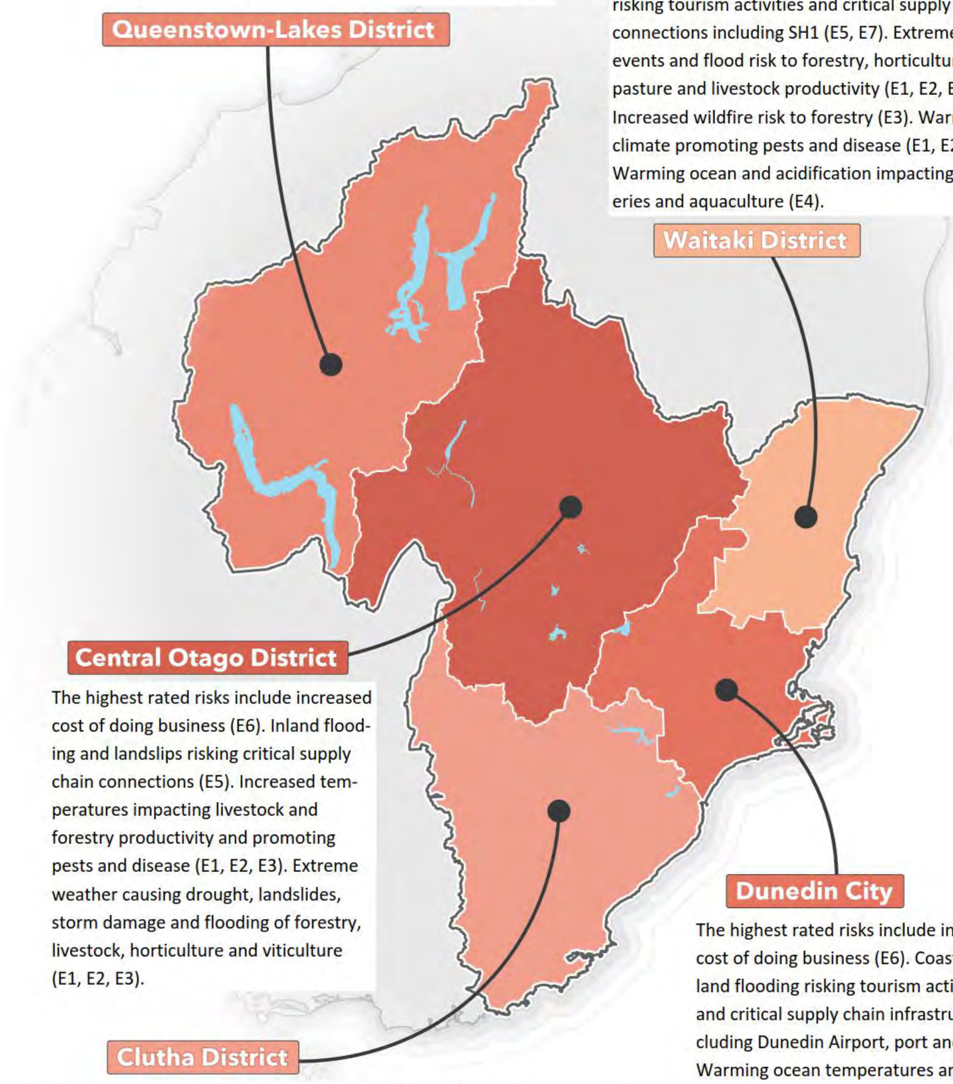


Figure 6-2: Overview of the projected changes through the different districts of the Otago region by 2090 in the economic domain.

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).

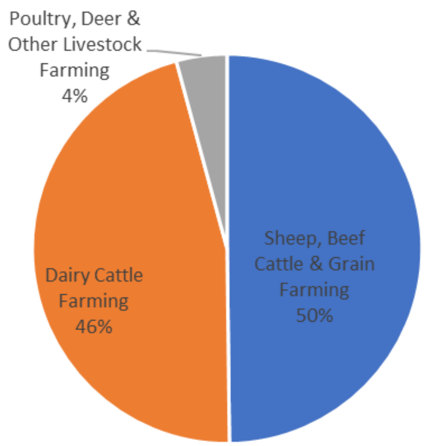


Figure 6-3: Livestock farming activity in Otago, showing % GDP (Infometrics, 2019).

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 20ºC and 25ºC 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).

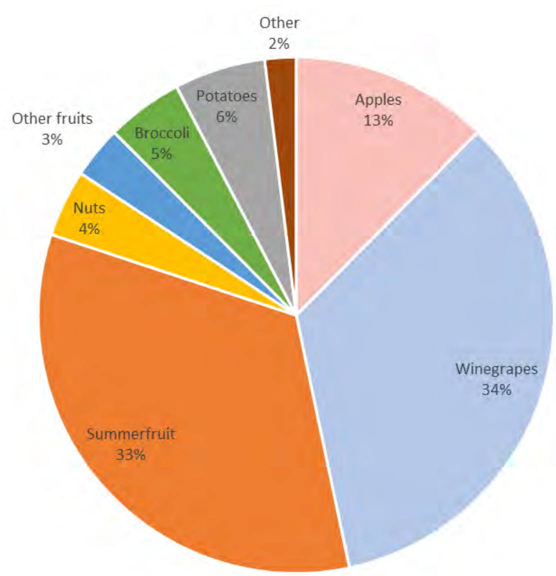


Figure 6-5: Percentage of planted area of fruit and vegetables in Otago in 2017 (Aitken & Warrington, 2019).

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.

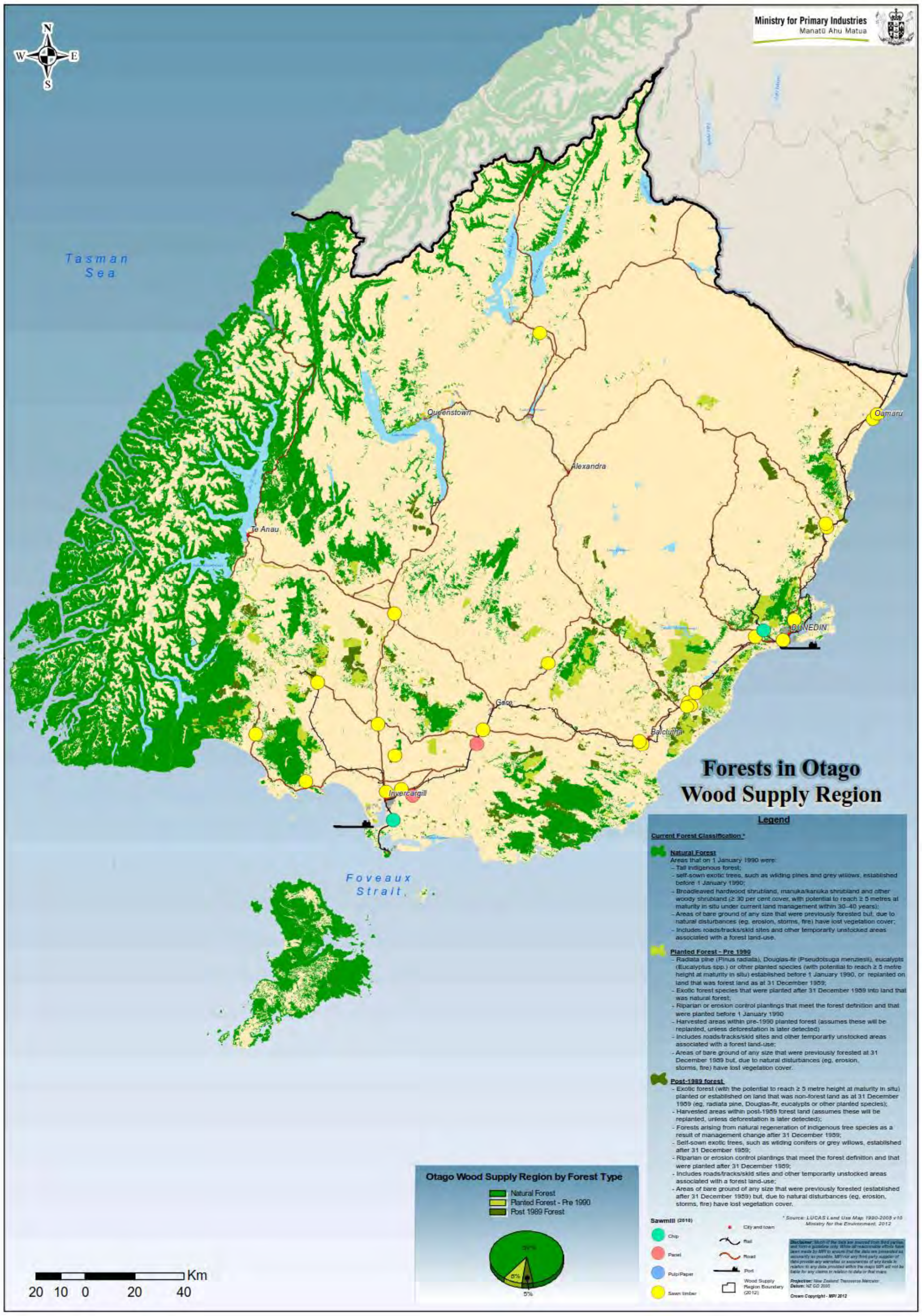


Figure 6-6: Forestry in Otago, source: MPI, 2012.

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°C, with an upper limit of 18°C (Whitehead et al., 1992). Present day annual mean temperatures currently range between 8-12°C for most coastal and inland low-lying parts of Otago and are projected to increase by 1.5-3.5°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 CO2 in the atmosphere, which is expected to continue until atmospheric GHG concentrations stabilize (Ministry for the Environment & Statistics New Zealand, 2016).

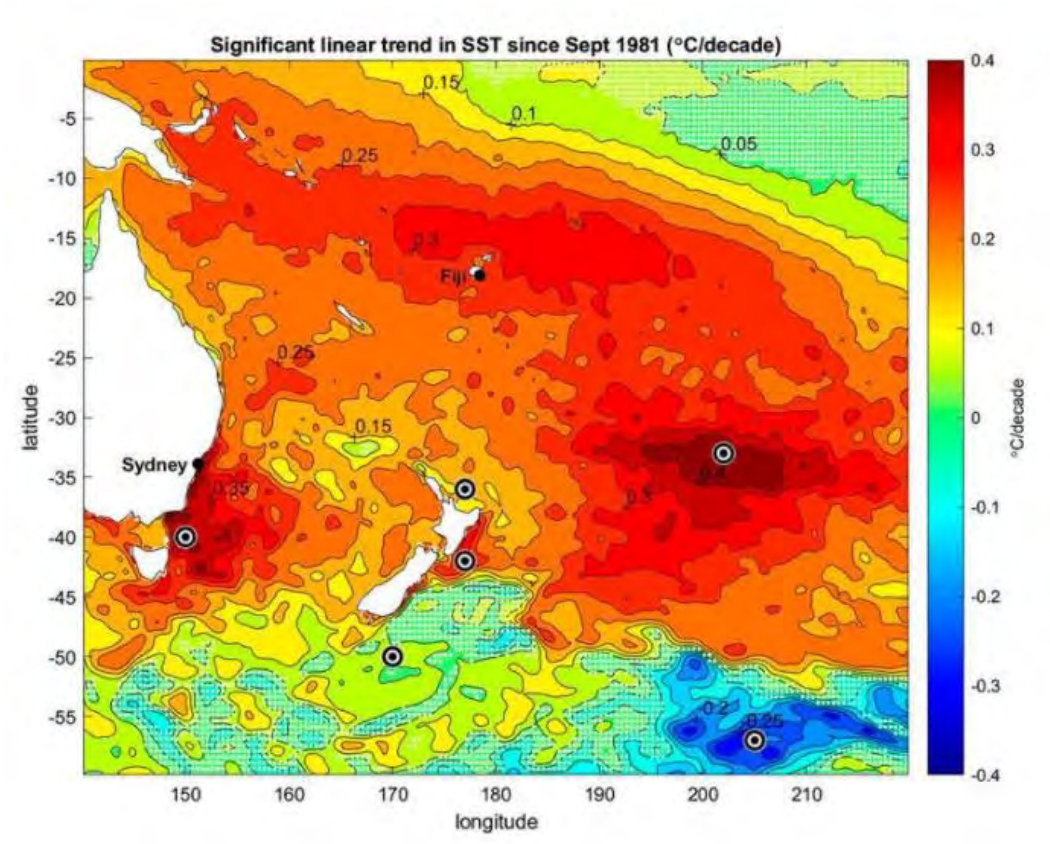


Figure 6-9: Sea surface temperature trend in °C per decade since 1981 (Sutton et al., 2019).

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).

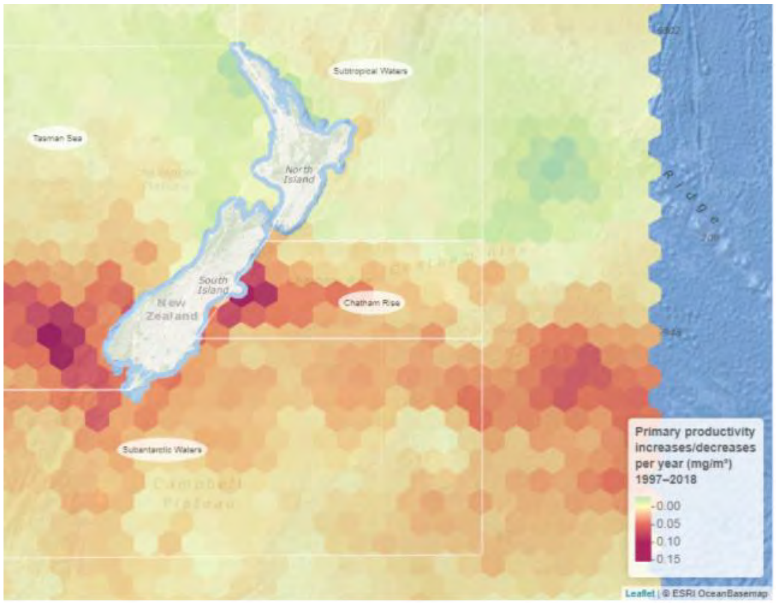


Figure 6-10: Marine primary productivity in offshore New Zealand (Statistics NZ, 2019).

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).

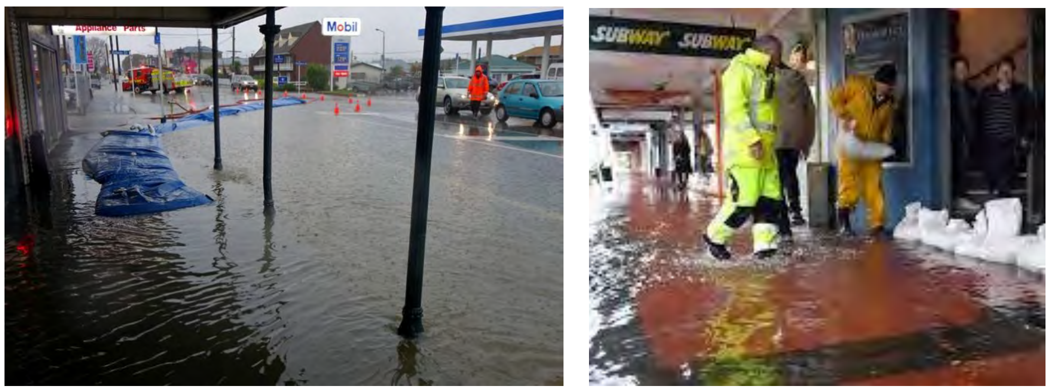


Figure 6-13: Dunedin businesses flooded in 2015 (left) and again in 2018 (right).

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.

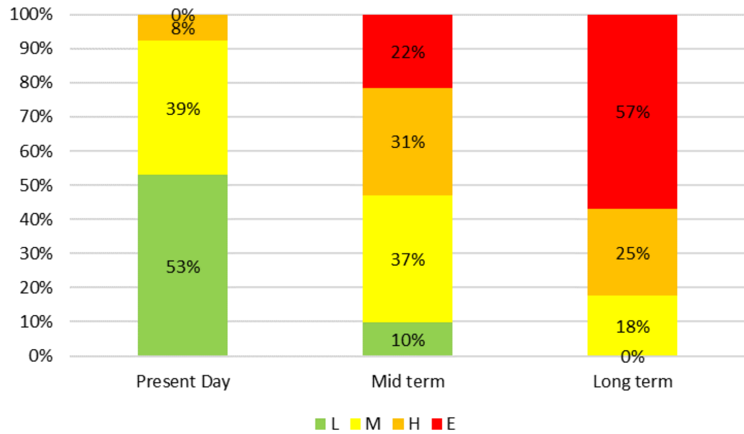


Figure 7-1. Summary of built environment risks by risk rating.

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.

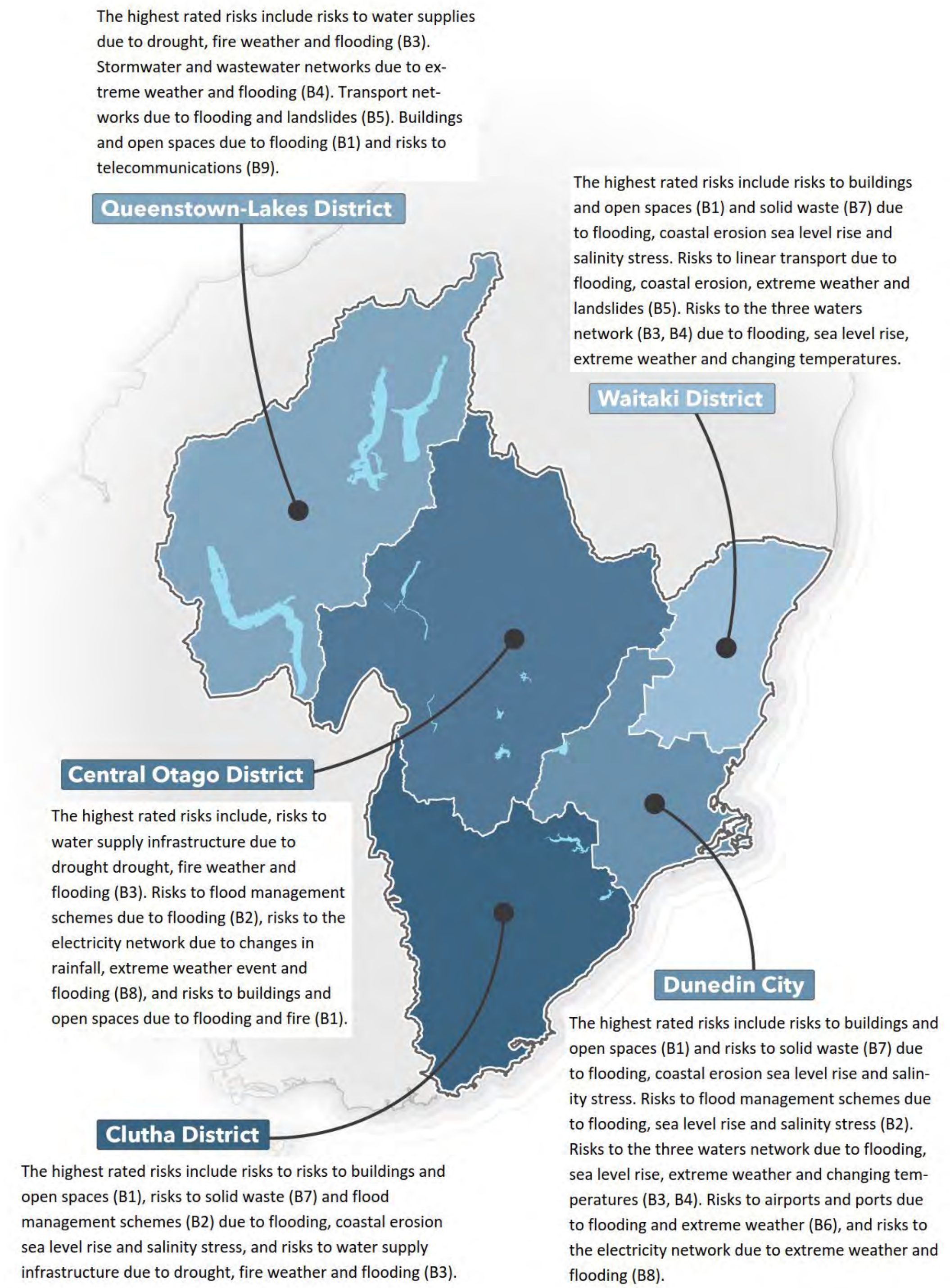


Figure 7-2: Overview of the projected changes through the different districts of the Otago region by 2090 in the built domain.

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).

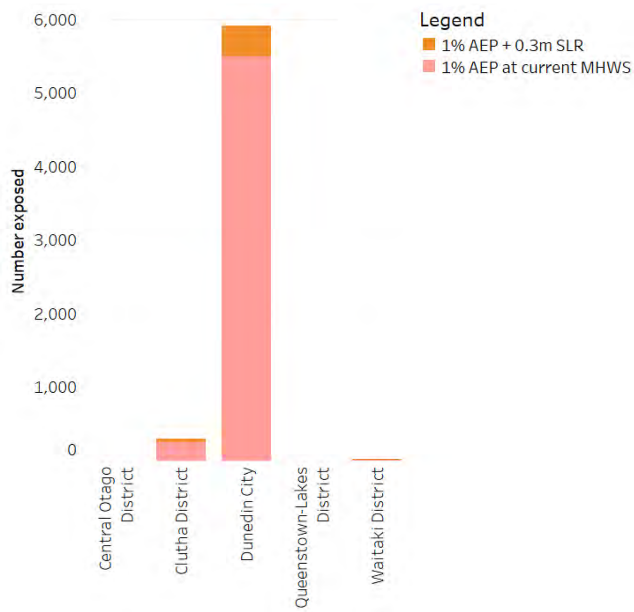


Figure 7-3: Building exposure to current and future coastal flooding scenarios, per district (Paulik et al., 2019a).

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.

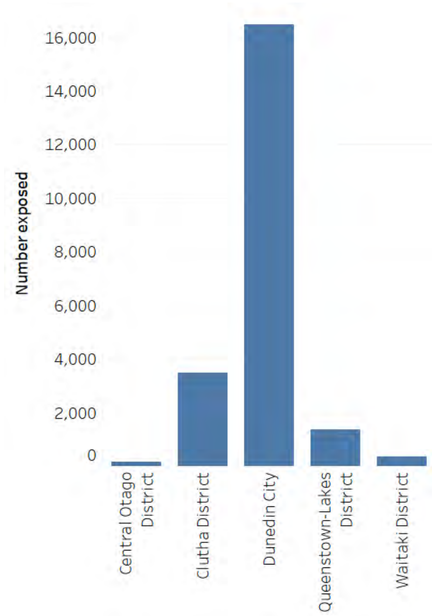


Figure 7-4: Building exposure to flooding, per district (Paulik et al., 2019).

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.

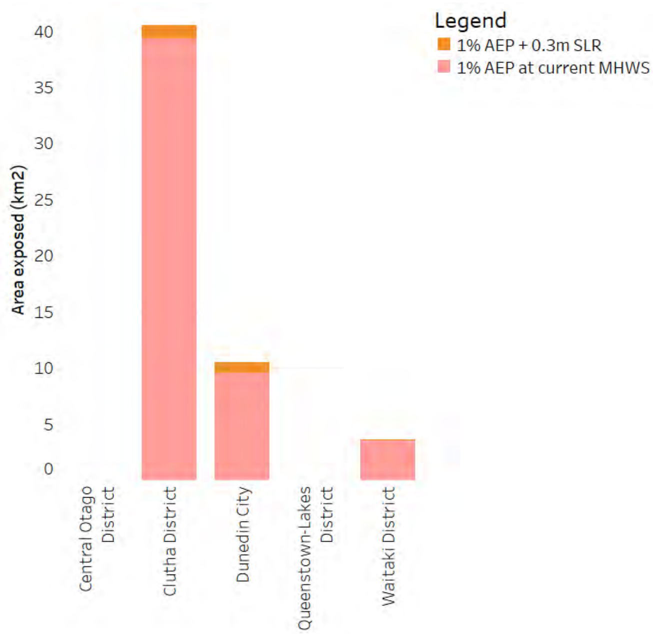


Figure 7-5: Exposure of undeveloped land to current and future coastal flooding scenarios, per district (Paulik et al., 2019a).

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.

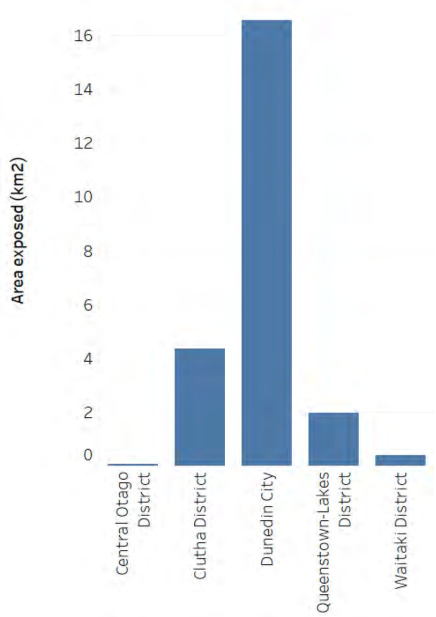


Figure 7-6: Exposure of undeveloped land to flooding, per district (Paulik et al., 2019).

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).

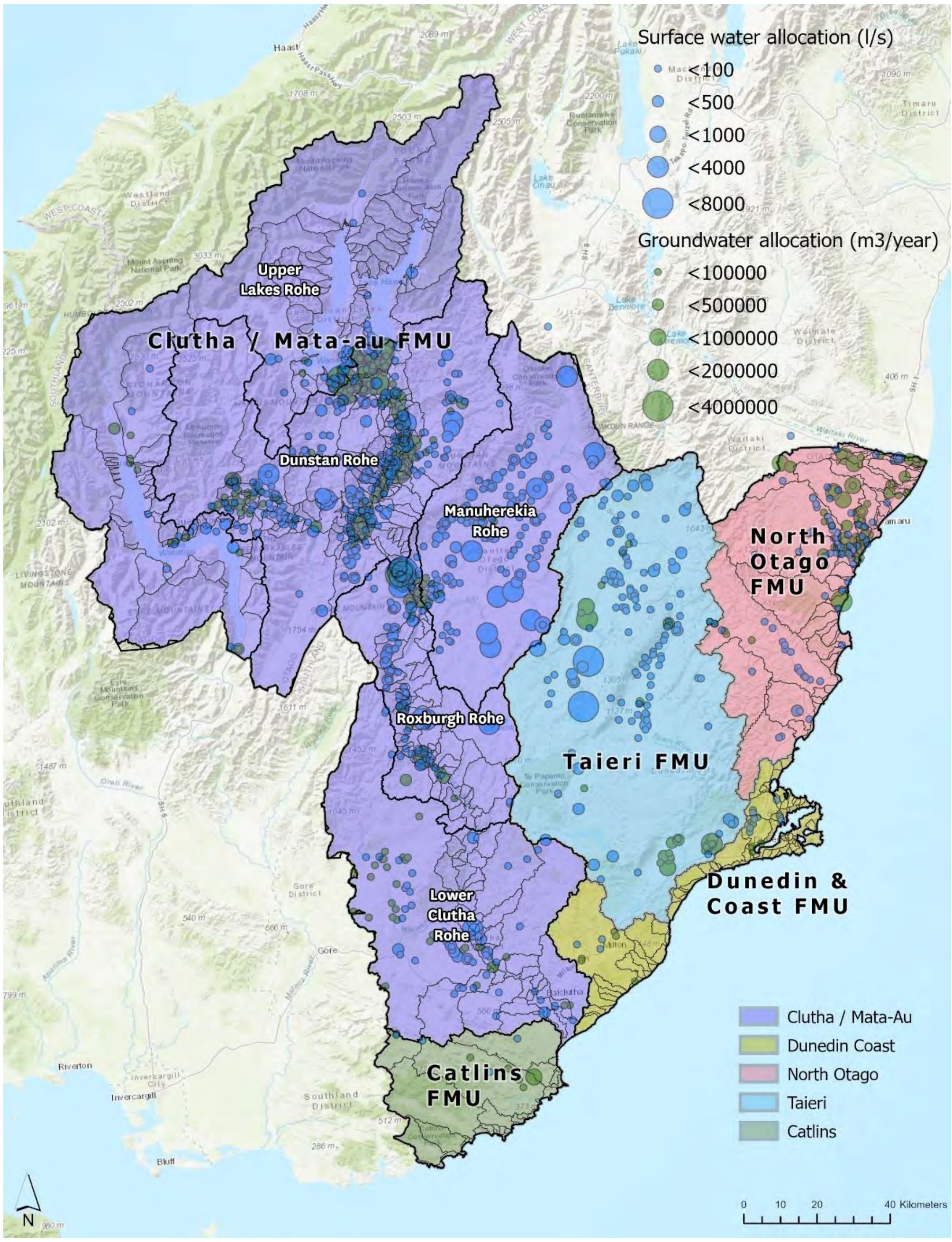


Figure 7-9: Locations of water takes within Otago (provided by ORC).

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.

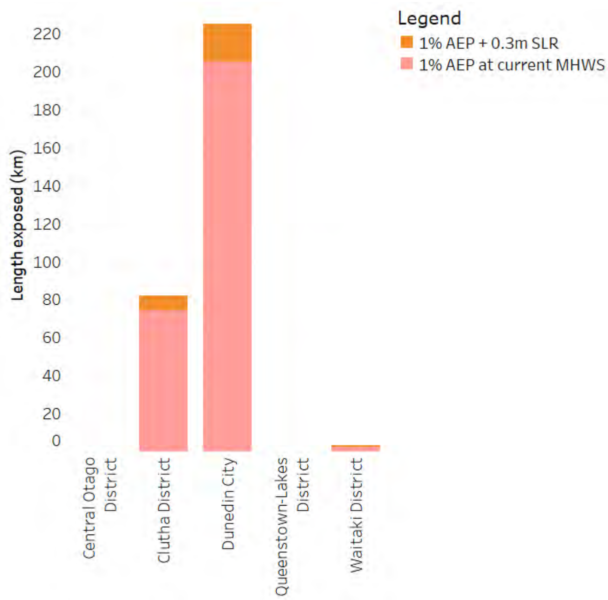


Figure 7-10: Exposure of water supply pipes to current and future coastal flooding scenarios, per district (Paulik et al., 2019a).

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.

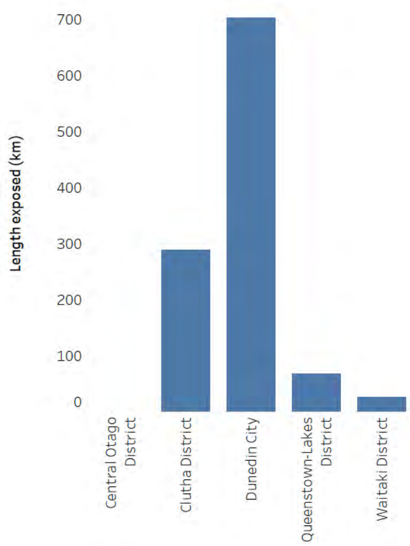


Figure 7-11: Exposure of water supply pipes to flooding, per district (Paulik et al., 2019).

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.

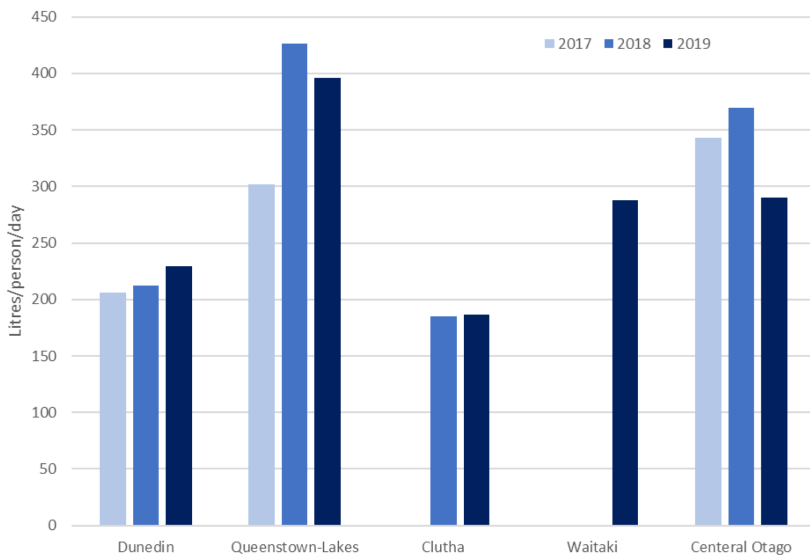


Figure 7-12: Average daily residential water usage for 2017-2019 in the five districts of the Otago region (Water New Zealand, 2020). Based on available data.

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).

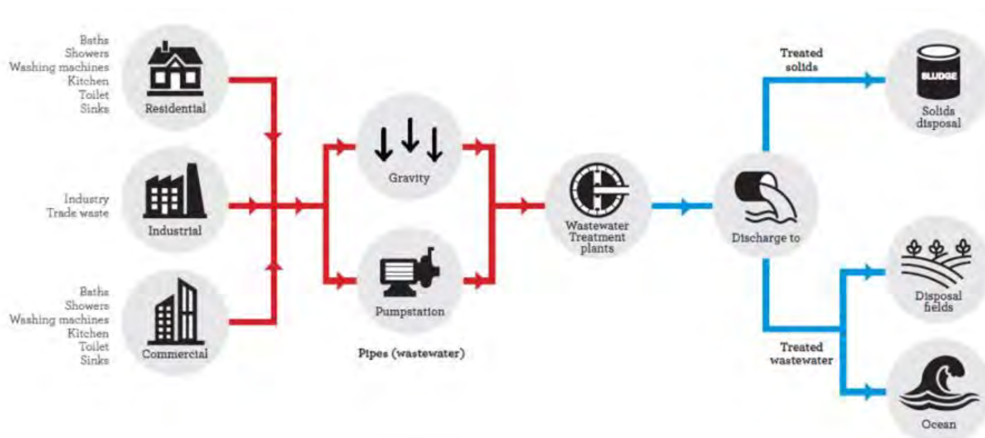


Figure 7-13: Diagram outlining how wastewater infrastructure works (Dunedin City Council, 2020a).

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.

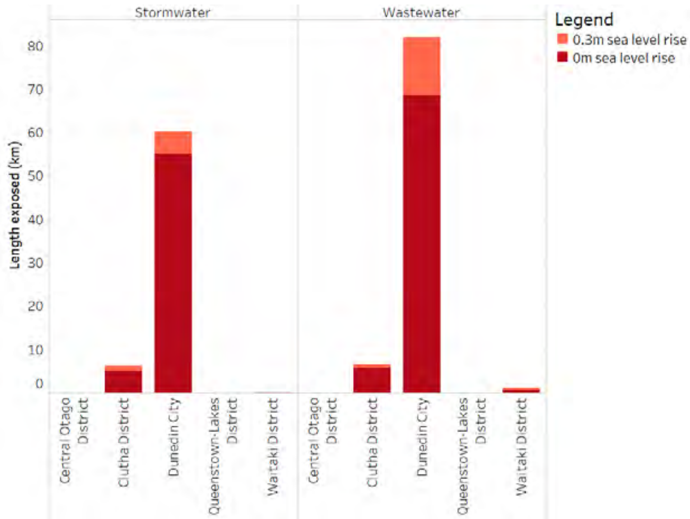


Figure 7-14: Stormwater and wastewater pipe exposure to current and future coastal flooding scenarios, per district (Paulik et al., 2019a).

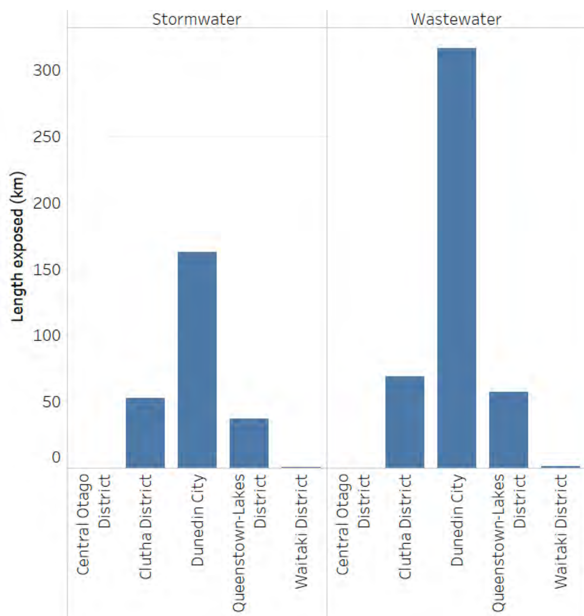


Figure 7-15: Stormwater and wastewater exposure to flooding, per district (Paulik et al., 2019).

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.

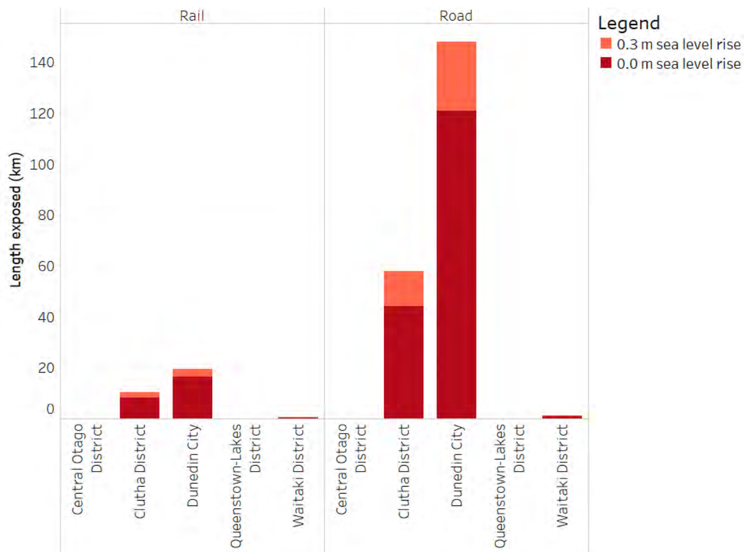


Figure 7-16: Road and rail exposure to current and future coastal flooding scenarios per district (Paulik et al., 2019a).

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.

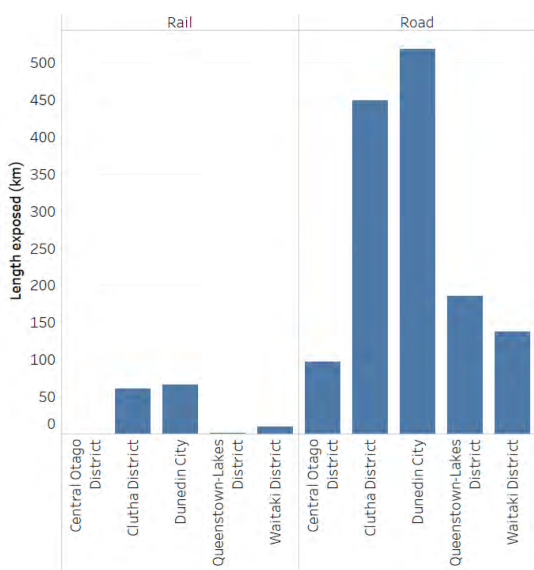


Figure 7-17: Road and rail exposure to flooding per district (Paulik et al., 2019).

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.

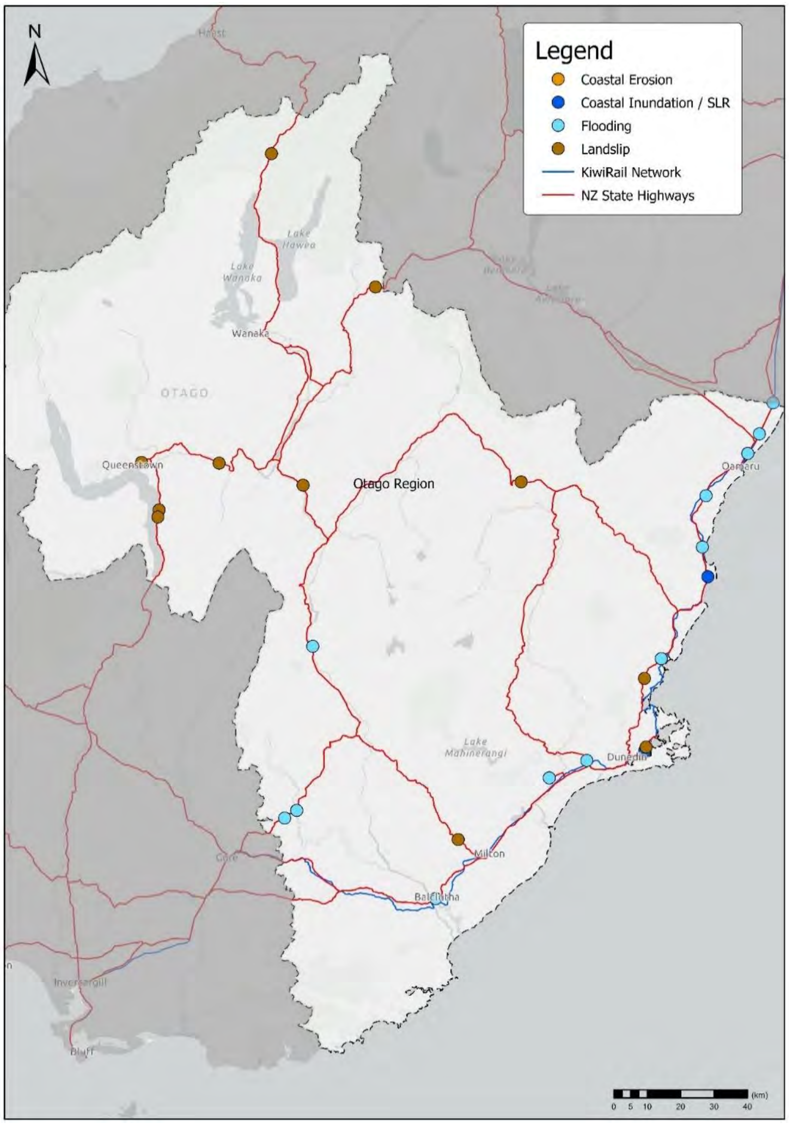


Figure 7-18: Point locations of State Highways and rail lines of elevated importance within the Otago region (NZTA, 2020c).

[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).

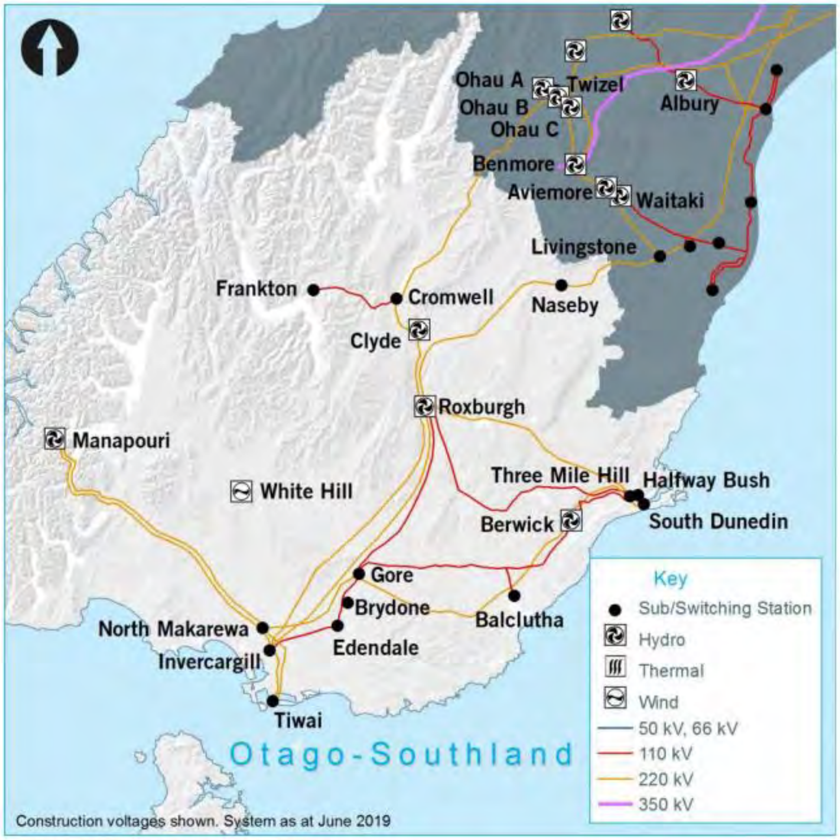


Figure 7-23: Transmission network asset locations in Otago/Southland (Transpower, Transmission Planning Report, 2019).

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.

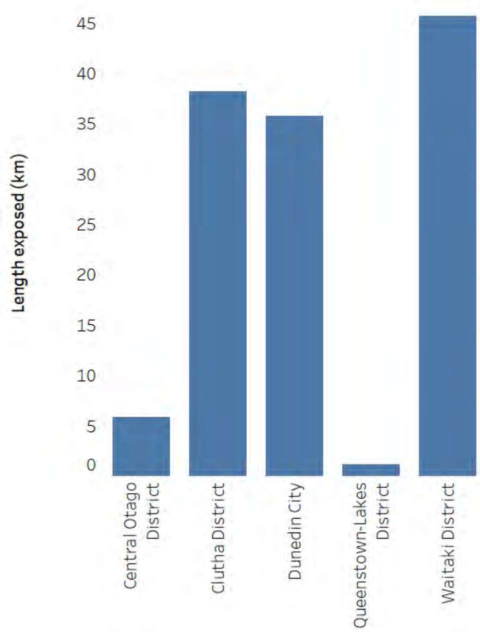


Figure 7-24: Transmission lines (National Grid) currently exposed to flooding, per district (Paulik et al., 2019).

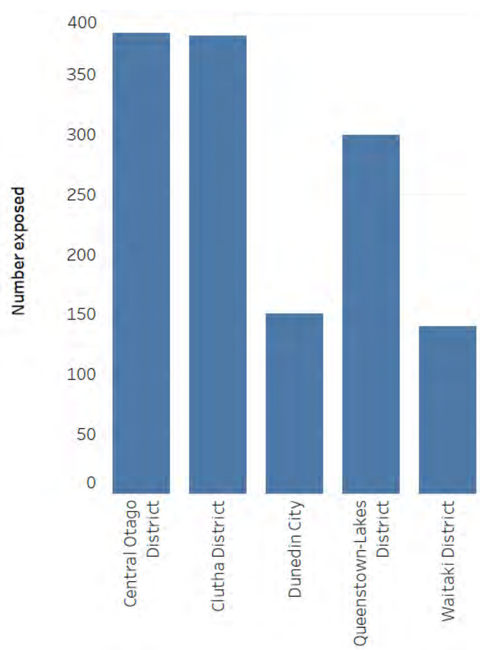


Figure 7-25: Structures currently exposed to flooding, per district (Paulik et al., 2019).

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).

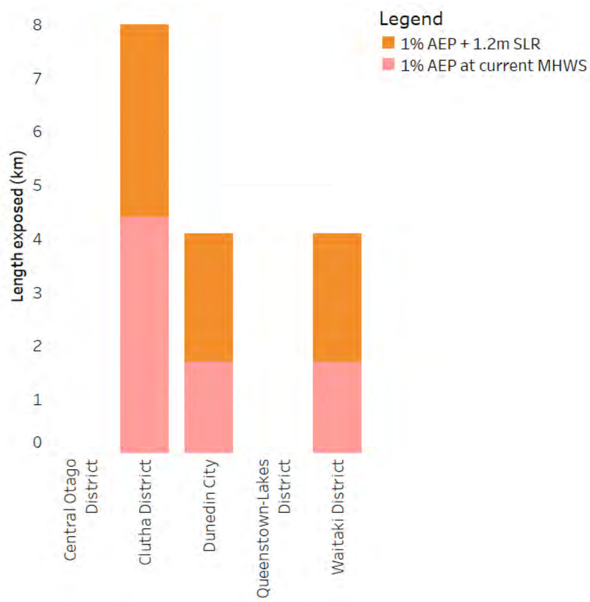


Figure 7-26: Transmission lines exposed to current and future coastal flooding scenarios (Paulik et al., 2019a).

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).

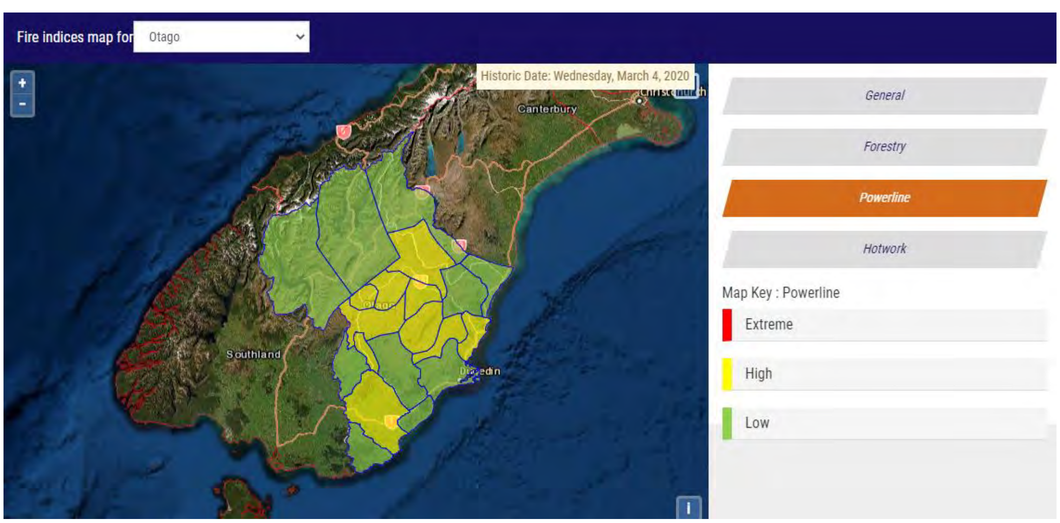


Figure 7-27: Example fire index map for Otago (https://fireweather.niwa.co.nz/region/Otago).

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

Generation

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).

Transmission and distribution

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).

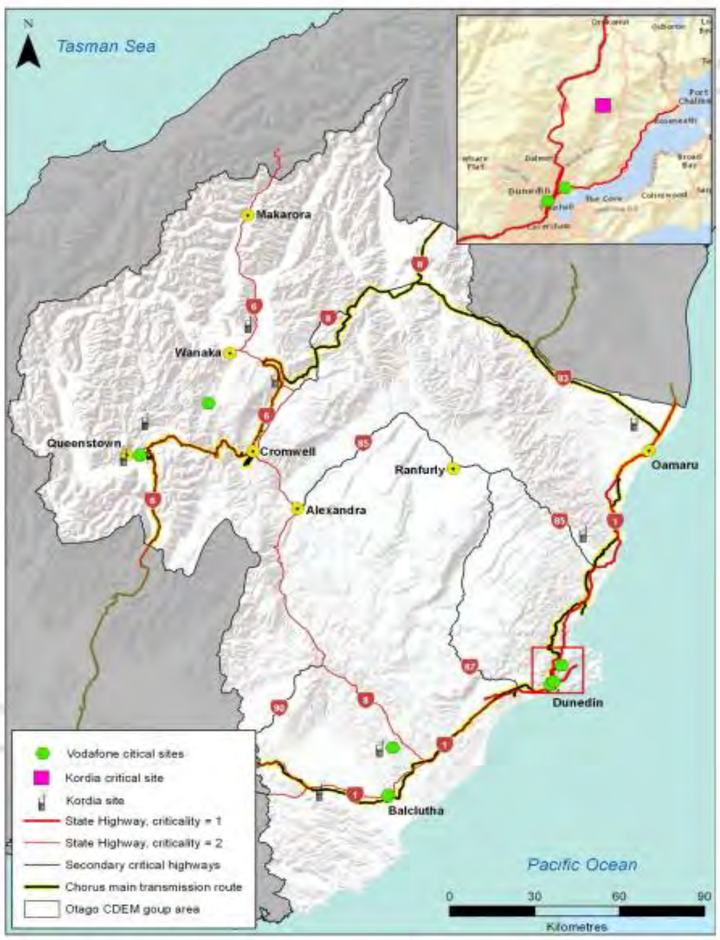


Figure 7-28: Critical communications infrastructure in the Otago region (Hexamer, 2018).

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).

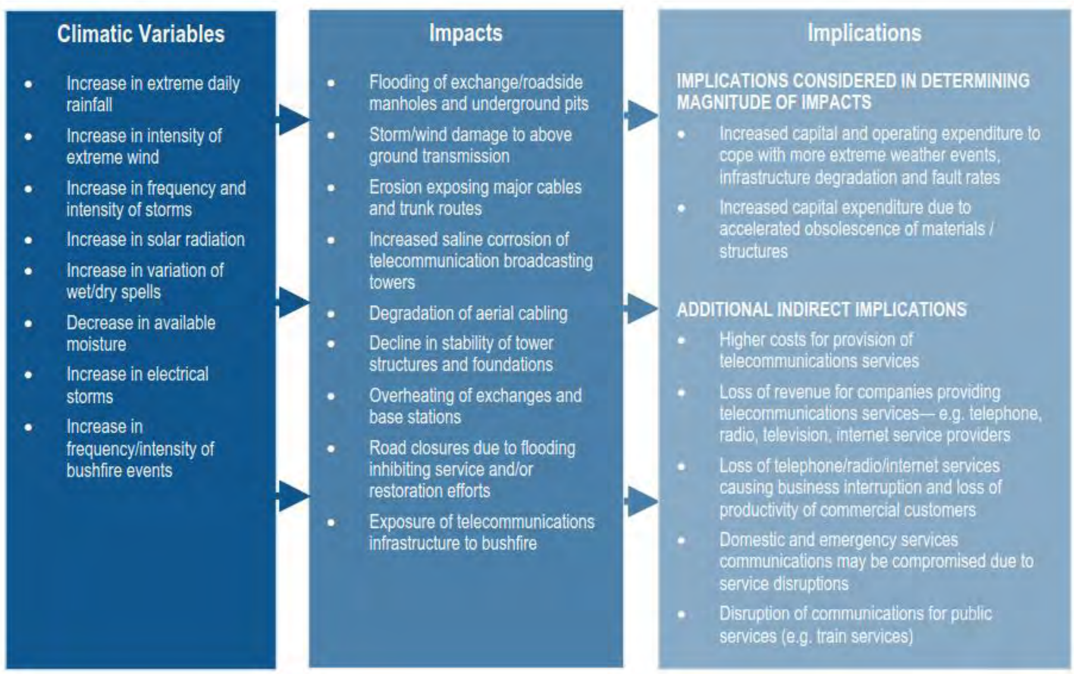


Figure 7-29: Impact timeline for telecommunication infrastructure (Maunsell Australia Pty Ltd, 2008).

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.

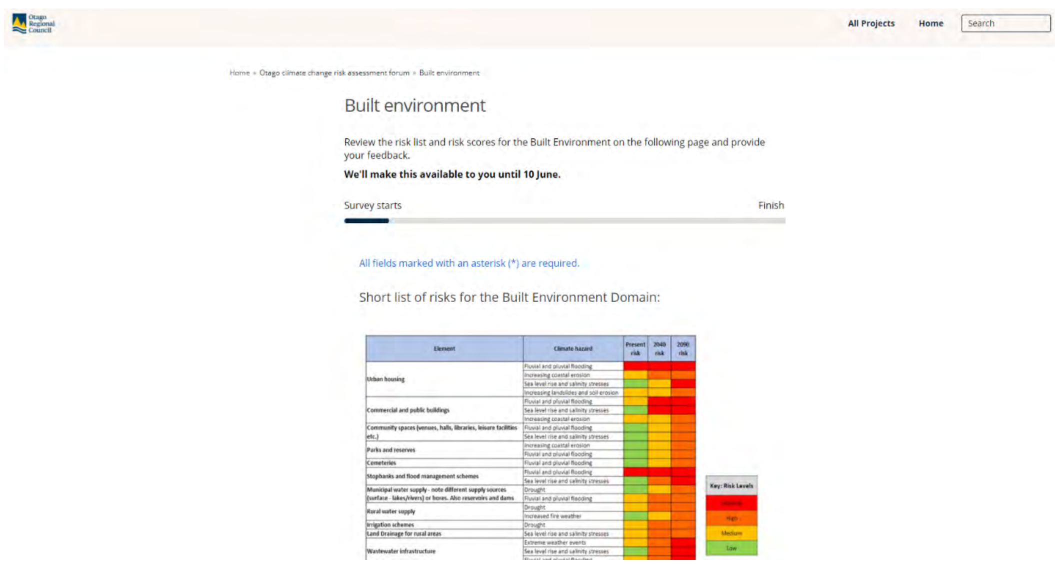
This page will be open for your feedback until 10 June.

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:



Otago Regional Council

All Projects Home Search

Home » Otago climate change risk assessment forum » Built environment

Built environment

Review the risk list and risk scores for the Built Environment on the following page and provide your feedback.

We'll make this available to you until 10 June.

Survey starts Finish

All fields marked with an asterisk (*) are required.

Short list of risks for the Built Environment Domain:

Element	Climate hazard	Present risk	2040 risk	2090 risk
Urban housing	Fluvial and pluvial flooding			
	Increasing coastal erosion			
	Sea level rise and salinity stresses			
	Increasing landslides and soil erosion			
Commercial and public buildings	Fluvial and pluvial flooding			
	Sea level rise and salinity stresses			
	Increasing coastal erosion			
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			
Stopbanks and flood management schemes	Fluvial and pluvial flooding			
	Sea level rise and salinity stresses			
Municipal water supply - note different supply sources (surface - lakes/rivers) or bores. Also reservoirs and dams	Drought			
	Fluvial and pluvial flooding			
Rural water supply	Drought			
	Increased fire weather			
Irrigation schemes	Drought			
Land Drainage for rural areas	Sea level rise and salinity stresses			
Wastewater infrastructure	Extreme weather events			
	Sea level rise and salinity stresses			

Key: Risk Levels
Medium
Low

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

   - [x] 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

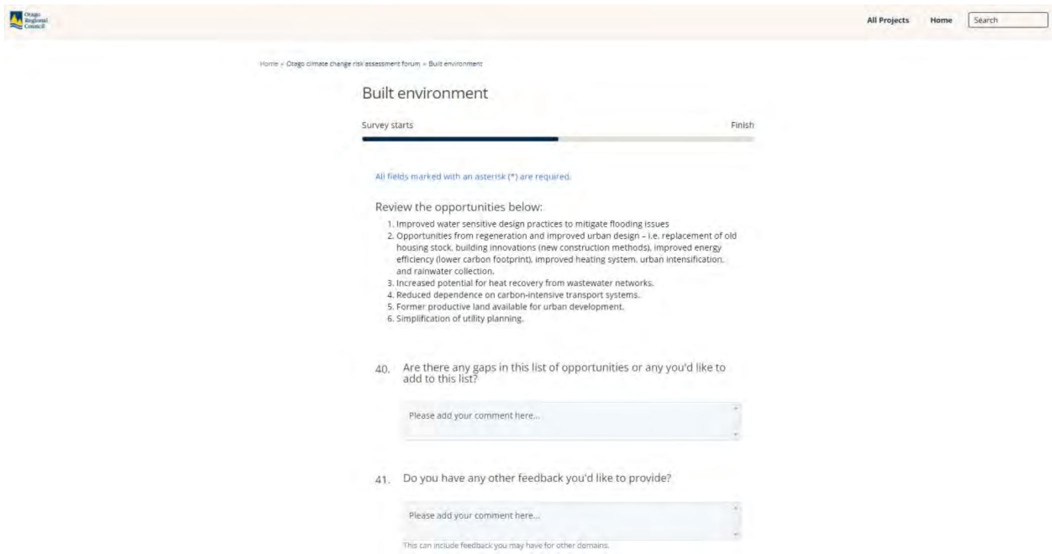
   - [x] Agree
   - [ ] Disagree

3. Urban housing, increasing coastal erosion
   Present risk: medium
   2040 risk: high
   2090 risk: high

   - [ ] Agree
   - [x] Disagree

4. If you disagree, why?

   Please add your comment here...



All Projects Home Search

Home » Otago climate change risk assessment forum » Built environment

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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7.2. Overview of Groundwater Quality State of Environment for Otago

Prepared for:	Data and Information Committee
Report No.	SPS2106
Activity:	Governance Report
Author:	Amir Levy & Marc Ettema (Groundwater Scientists)
Endorsed by:	Gwyneth Elsum, General Manager Strategy, Policy and Science
Date:	1 March 2021

PURPOSE

[1] This paper presents the groundwater State of the Environment (SoE) report as of December 2019. It highlights key findings identified in the report regarding groundwater quality in Otago and identifies a range of measures to consider for improving ORC's monitoring programme, public awareness, and the protection of groundwater quality.

EXECUTIVE SUMMARY

[2] The Otago Regional Council (ORC) monitors groundwater quality in a selection of bores through the long-term State of the Environment (SoE) monitoring programme. This report compiles and reviews groundwater quality data from the start of monitoring in each bore (which varies, with the earliest being August 1985) to December 2019. This is the first comprehensive summary of Otago's groundwater SoE results.

[3] The results were evaluated against the Drinking Standards for New Zealand (DWSNZ [2005, revised 2018]) for dissolved arsenic, E. coli (an indicator for faecal contamination), and nitrate concentrations.

[4] They were also assessed for ecosystem health because elevated groundwater nutrient concentrations (i.e., nitrate-nitrogen, Dissolved Reactive Phosphorus [DRP], and ammonia) can adversely impact surface water quality, particularly for shallow bores and for catchments dominated by groundwater-surface water interaction. However, the main standards usually used by ORC for ecosystem health assessments, i.e. the Regional Plan: Water (RPW) and the National Policy Statement for Freshwater Management (NPS-FM, 2020), do not have limits for groundwater nutrient concentrations. The assessment of groundwater quality (nutrient concentrations) and ecosystem health therefore adopted a similar approach to Environment Canterbury where relevant statistics in the RPW and NPS-FM (2020) were calculated in bores shallower than 20m and then compared to the surface water limits in these standards.

[5] The results show high variability of groundwater quality in Otago, with good groundwater quality measured in some Freshwater Management Units (FMU)/rohe (e.g., the Upper Clutha/Lakes) and degraded water quality in others (e.g., Lower Clutha, North Otago).

[6] The results identified elevated E. coli, high nutrient concentrations, and elevated dissolved arsenic concentrations in some bores as the main groundwater quality issues

in Otago. Nutrient concentrations, particularly nitrate and DRP, exceed the RPW and NPS-FM limits in many areas.

RECOMMENDATION

That the Committee:

1) ***Receives** this report.*

BACKGROUND

[7] ORC currently monitors groundwater quality in 55 bores across the Otago region as part of its long-term SoE monitoring programme. The monitoring bore network has been developed over approximately 30 years, and there are established monitoring sites located within Otago's five recently established FMUs. However, the distribution of monitoring sites is uneven and some of the region's aquifers are currently not monitored. The bores are situated on both public and private land with varying degrees of borehead security (i.e., prevention of down-hole contamination or tampering).

[8] Groundwater quality in the SoE bores is monitored quarterly for microbiological parameters (E. coli), major cation/anion (e.g., calcium, magnesium, chloride, etc.), metal (e.g., arsenic), and nutrient (nitrate-nitrogen, ammonia, and DRP) concentrations.

[9] The assessment against the DWSNZ compared the SoE results against the following Maximum Acceptable Values [MAV]: E. coli: <1 MPN (Most Probable Number)/100mL; nitrate: 11.3mg/L, and dissolved arsenic: 0.01mg/L.

[10] The NPS-FM 2020 and the RPW do not contain limits for groundwater nutrient concentrations. Groundwater quality (nutrient concentrations) and ecosystem health were therefore assessed using a similar approach to Environment Canterbury where relevant statistics in the standards were calculated in bores shallower than 20m. For the RPW this is the 80th percentile nutrient concentrations, while for the NPS-FM (2020) key measures are the median, 95th percentile, and maximum concentrations. These calculated statistics were then compared with the surface water limits in the RPW's Schedule 15 and the NPS-FM's National Objective Framework (NOF) attributes.

RESULTS AND DISCUSSION

[11] E. coli was detected in many bores across the region. The results show that 75% of the SoE bores exceeded the DWSNZ MAV for E. coli at a point in time during the bore's monitoring period. Exceedances were detected in each of Otago's FMU/rohe. Exceedances were also measured in various bore depths, including those greater than 60m. Although most exceedances in the bores were not persistent, regular exceedances were noted in the Lower Taieri and Lower Waitaki areas. It is important to put these results in context and note some of the limitations of the data:

a. It includes the full monitoring period for each bore (which varies based on the duration of monitoring), hence some of the exceedances did not occur recently.
b. Some of these reported exceedances are potentially due to using different testing laboratories.
c. Elevated E. coli concentrations are localised to a specific site and are strongly dependent on bore security, hence, E. coli measurements may not reflect the

conditions across the wider aquifer. Nevertheless, the data clearly indicate that the potential for faecal contamination of groundwater is high across all of Otago, regardless of location or bore depth.

[12] Groundwater nitrate concentration data shows that none of the aquifers in Otago have a median concentration above the DWSNZ limit of 11.3mg/L. However, it does highlight a variable degree of nitrate contamination, with median concentrations in some aquifers near the 11.3mg/L limit, particularly in North Otago and the Lower Clutha. The median concentrations in other areas, e.g., the Upper Lakes/Clutha and most of the Dunstan rohe, were substantially lower. The results have also identified that some of the individual bores have median concentrations that exceed the MAV, particularly in North Otago and the Lower Clutha.

[13] Elevated arsenic concentrations were primarily detected in the Upper Lakes/Clutha area (i.e., Queenstown Lakes/Central Otago areas). The maximum concentrations in some bores exceed the NZDWS MAV by between 2 and 84 times. The highest recordings are associated with known localities such as monitoring bores in Glenorchy. It is likely that the source of arsenic is the underlying geology, i.e., the prevalent schist lithology. Notices for bore owners to test their bore water have been previously issued via various media channels (e.g., *On-Stream*, ORC website, letters to residents). Joint community meetings with QLDC and SDHB, where residents will receive information regarding drinking water safety, are planned in these areas for March 2021.

[14] Nitrate and DRP concentrations commonly exceed the Regional Plan (RPW) /NPS-FM limits, particularly in areas of intensive farming (e.g., North Otago) and rapid development (e.g., Glenorchy, Kingston). These issues can be potentially attributed to land use (e.g., intensive farming, septic tanks), soil type & geology, and local factors (shallow, poorly secured boreheads).

OPTIONS FOR IMPROVEMENT

[15] The report contains several recommendations and suggestions to improve groundwater quality and protection, the monitoring network, and public awareness. These are summarised below:

- Ensure good borehead security is practiced across Otago to prevent contaminant migration into aquifers. This includes improving ORC's regulatory systems and educational campaigns regarding bore construction, security, and maintenance. The Science team is working collaboratively with Compliance and Consents teams on improving consent conditions. Science will work with Policy in strengthening this aspect of the new Land and Water Regional Plan (LWRP).

- Review the legislation and management of known high risk activities to water quality in areas of poor groundwater quality.

- Phased replacement of unsuitable SoE bores with new dedicated SoE bores. New bores should be located based on their representation of the different FMU/aquifers. They should be placed on public land with legal agreements to ensure long term access. It is also recommended ORC have an ongoing maintenance programme for the bores.

- Publish SoE groundwater quality monitoring results online with suitable symbology that clearly indicates when parameters exceed the limits.

CONSIDERATIONS

Policy Considerations

[16] Issues with the current planning approach for land use will be addressed, as far as practicable, through the new LWRP. In the meantime, considerable effort is being put into:

a. 'Ground truthing' of existing bore locations;
b. Review and upgrade of the groundwater SoE network;
c. Improving consent conditions;
d. Development and consistent implementation of a process to report exceedances; and
e. Building better relationships with SDHB and TAs.

Financial Considerations

[17] The replacement of existing unsuitable SoE bores with new dedicated bores has been noted as an annual capital expense in the proposed LTP. In addition, an ongoing maintenance programme for the existing SoE bores has been provided for in the proposed LTP.

Significance and Engagement

[18] Various responsibilities for drinking water quality are currently split between ORC, SDHB, and TAs. Furthermore, much of the ongoing responsibility to ensure safe drinking water lies with private bore owners. Some of these roles, however, particularly for drinking water suppliers, are likely to change following the new Water Services Bill and the establishment of the new Three Waters regulator (Taumata Arowai). The ORC is currently working with the SDHB and Territorial Authorities to clarify areas of responsibility and are also engaged in educational campaigns alongside them to inform private bore holders of their ongoing obligations to ensure good water quality. It is recommended to continue support these campaigns.

Legislative Considerations

[19] As noted above the upcoming changes regarding the Three Waters Bill and parallel structural changes which may alter ORC's roles and responsibilities.

Risk Considerations

[20] Providing this information helps the community and ORC to better understand and manage the risks associated with potential groundwater contamination.

NEXT STEPS

[21] A comprehensive SoE reporting is a statutory requirement which is undertaken every five years and provides a detailed review of water reporting on regional state and trends in water quality and performance against the NPS-FM and the effectiveness of the RPW. The next report will cover the period up until June 2022 to align with notification of the proposed LWRP. Groundwater data (including quantity and quality) will be updated and included in this report.

[22] The communications team has developed a high-level communications plan that includes key messages and a commitment to communicate about the SOE groundwater report. This will ensure the community understands that this report sets a benchmark for our SOE groundwater monitoring programme, what the results mean, and what steps ORC will take to address issues identified in the report. The communications for SOE groundwater will be ongoing and we will continue to update the community as we learn more.

ATTACHMENTS

1. Groundwater State of the Environment report for Otago March 2021 [**7.2.1** - 194 pages]

State of the Environment

Groundwater Quality in Otago

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Executive Summary

This report summarises the results from Otago Regional Council (ORC)'s groundwater quality State of the Environment (SoE) monitoring programme which monitors groundwater quality across the region. The aims of the programme include data provision and assessment of groundwater quality/quantity in Otago, understanding groundwater flow and associated surface water ecosystems, assessing the impacts of land use and the effectiveness of resource management policies, and environmental reporting in accordance with the Resource Management Act (RMA).

Groundwater is an important resource in Otago and is used across the region for drinking, irrigation, industry and stock water supply. In addition to that, groundwater discharge significantly impacts stream flow, water quality, and ecology in various catchments across the region (e.g. the Kakanui-Kauru, Shag). In contrast to the extensive gravel aquifers found in some New Zealand regions (e.g. the Canterbury Plains, Hawke's Bay) most of Otago's aquifers are small and are situated in a variety of geological settings (e.g. disconnected river valley basins associated with glacial outwash or moraine deposits, limestone, fractured rock).

The groundwater quality SoE monitoring network currently consists of 55 monitoring bores, situated on both public and private land with varying degrees of borehead security. The bores are located across Otago's five Freshwater Management Units (FMU). However, their distribution is uneven, with the Catlins and Dunedin & Coast FMUs having only one monitoring bore each. Furthermore, some of the aquifers in the region are currently not monitored. This report assesses groundwater quality results from the start of monitoring in each currently active SoE bore to the end December 2019. Groundwater quality in the SoE bores is monitored quarterly for microbiological parameters, major ion geochemistry, and metals concentrations. The sampling follows the National Environmental Monitoring Standards [NEMS] (2019) and the samples are analysed in an accredited laboratory.

This report summarises the state of groundwater quality in Otago in relation to drinking water quality. This is assessed by comparing groundwater E. coli, dissolved arsenic, and nitrate concentrations against the Drinking Water Standards for NZ (DWSNZ) thresholds. The E. coli data indicates that potential faecal contamination is a significant water quality issue across Otago, with exceedances of the DWSNZ Maximum Acceptable Value (MAV) of <1MPN/100mL detected in 75% of the bores in the region at a point during the monitoring period. Exceedances were detected in each of Otago's FMU/rohes. However, it is important to note that the data includes the full monitoring period for each bore and that some of these reported exceedances are potentially due to changing laboratories.

The proportion of E. coli exceedance across Otago (75%) is similar to that of the Clutha, North Otago and Taieri FMUs. However, a wider variability was observed within the different rohes of the Clutha FMU, with higher proportions (and contamination risk) than the regional one measured in the Manuherikia and Lower Clutha rohes. Conversely, the proportion of exceedance in the Upper Lakes rohe was lower, whilst that of the Dunstan rohe was similar to the regional. An assessment of E. coli exceedance and bore depth shows that the highest proportion of E. coli exceedance was in bores shallower than 10m (92%) and the lowest (40%) in bores deeper than 60m.

The E. Coli data indicate that groundwater and bores in Otago are vulnerable to faecal contamination. However, elevated E. Coli can also be a local issue and is strongly dependent on bore security, hence, the SoE data does not present a complete mapping of this risk. Nevertheless, it is strongly recommended that bore owners/groundwater users ensure

adequate borehead security (to prevent contaminant entry into the aquifer) and regularly test their groundwater for indicator bacteria. This is particularly important after periods of heavy rainfall. If E. Coli is detected, water should be boiled or disinfected.

Arsenic is a toxic, though naturally occurring, element, present at low concentrations in soil, water, plants, animals and food. Chronic exposure to elevated arsenic can lead to a range of cancers. Arsenic in groundwater can originate from anthropogenic (e.g. sheep dips, treated timber posts) and geological sources (e.g. schist lithology, reduced peat deposits, and volcanic rocks). The spatial distribution of maximum arsenic concentrations in Otago groundwater shows that concentrations exceeded the MAV in only seven SoE monitoring bores, five of which are in the Upper Clutha/Wakatipu Basin area, which are underlain by schist lithology known to contain arsenic. No arsenic above the MAV was detected in any bores in the North Otago, Dunedin & Coast, or Catlins FMUs. Nevertheless, due to the abundance of arsenic-containing schist lithology, particularly in the Upper Clutha, and the high spatial variability of arsenic in groundwater, it is strongly recommended that bore owners regularly test their bore water for arsenic in an accredited laboratory.

Nitrate (NO_3-N) is a dissolved, inorganic form of nitrogen (N), a key nutrient required for the growth of plants and algae. Excess nitrate can adversely impact water quality (e.g. eutrophication) and cause health concerns. Groundwater nitrate concentration data shows that none of the aquifers in Otago has a median nitrate concentration above the DWSNZ MAV of 11.3mg/L. However, it did highlight a variable degree of nitrate contamination in relation to the MAV, with the median concentration in some aquifers, particularly in North Otago and the Lower Clutha, closer to the MAV. Conversely, the median nitrate concentrations in many aquifers are much lower.

The report also assessed the potential impacts of groundwater nutrient concentrations (nitrate nitrogen, Dissolved Reactive Phosphorus (DRP), and ammoniacal nitrogen (ammonia) on surface water quality. This was done by comparing groundwater nutrient concentrations in shallow bores with surface water limits from regional (Regional Plan: Water [RPW] Schedule 15 limits for receiving water bodies) and national (National Policy Statement for Freshwater Management [NPS-FM]) standards for surface water quality. However, It is important to note that these standards do not include limits for groundwater, hence, this approach solely provides an overview. The results show that most groundwater nitrate and DRP concentrations exceed the surface water limits. Conversely, most ammonia concentrations were below the limit. However, that these standards (i.e. the RPW limits and NPS-FM bands) are for surface water, hence this comparison only provides a guideline/screening exercise rather than a direct assessment.

The groundwater quality assessment for each FMU/aquifer shows that, similar to surface water, groundwater quality across the region is also highly variable. The results from the Clutha FMU show a high variability, with good groundwater quality in some rohe (i.e. the Upper Lakes, Dunstan) and degraded quality in others, particularly the Lower Clutha. The main issues in this FMU are elevated E. coli and dissolved arsenic concentrations in some bores, with elevated nutrient concentrations also common. The results from the Upper Lakes and Dunstan rohes generally show compliance with the DWSNZ, although elevated E. coli counts were measured in some bores. Elevated dissolved arsenic concentrations were also measured in some bores, although their source is likely to be geological, i.e. the prevalent schist lithology. Nutrient concentrations are generally below the DWSNZ for nitrates. High DRP and nitrate concentrations were measured in Kingston and Glenorchy, likely due to high septic tanks density, shallow bores, and poor borehead security. These can potentially adversely impact water quality in Lake Wakatipu, although groundwater (and nutrient) fluxes into the Lake are likely to be substantially lower than the surface water inflows. Groundwater quality in the Manuherikia rohe is generally fair although E. coli exceedances were measured in most bores, albeit at low counts. Nitrate concentrations are below the DWSNZ MAV in all monitoring bores, with concentrations in the Manuherikia Alluvium Aquifer and Manuherikia Claybound Aquifer monitoring bores generally near the low intensity landuse reference value (<2.5mg/L). However, an increasing trend has been observed in the Manuherikia Groundwater Management Zone (GWMZ) monitoring bore, where concentrations exceed ½ of the MAV. No elevated arsenic concentrations were measured in any of the monitoring bores in the rohe. In relation to potential impacts on ecosystem health, the results from the shallow monitoring bores show that nitrate and DRP concentrations exceed the RPW limits. This suggests that groundwater-surface water interaction in this area can adversely impact surface water quality. Groundwater quality results from the Lower Clutha rohe indicate some water quality issues, with elevated E. coli and nitrate concentrations in most bores, notably in the Ettrick and Clydevale basins. One of the bores in the Inch Clutha gravel aquifer also has elevated arsenic concentrations above the MAV. The results also show issues with elevated nutrient concentrations, some of which are due to shallow, poorly-secured monitoring bores. These results also support the reported poor surface water quality results from this area (ORC, 2017).

Groundwater results from the Taieri FMU indicate potential risk for faecal contamination, with E. coli exceedance measured in all three of the FMU's aquifers. The pattern of nitrate concentrations is mixed, with elevated concentrations over ½ of the MAV in some bores whilst concentrations in others are within the low intensity landuse reference conditions. The assessment against surface water quality indicates potential issues, with several exceedances of the Schedule 15 nutrient limits. It is likely that some of these elevated results are due to monitoring bores being shallow, insecure, and located near dairy farms and/or septic tanks. Nevertheless, these can potentially adversely impact surface water quality.

The results from the North Otago FMU indicate significant water groundwater quality issues, particularly regarding E. coli exceedances and elevated nitrate concentrations, which are the highest in the region. Nitrate concentrations in monitoring bores in the North Otago Volcanic Aquifer (NOVA) and Kakanui-Kauru aquifers substantially exceed the 11.3mg/L MAV, with concentrations in some bores exceeding 32.2mg/L (though the bores are not used for drinking). Nitrate concentrations in some bores in the Lower Waitaki aquifer are over ½ of the DWSNZ MAV. Potential faecal contamination is also a concern, with elevated E. coli measured in some bores in each of the aquifers within the FMU. The results indicate potential adverse impacts on surface water quality, with elevated nutrient concentrations substantially exceeding the RPW and NPS-FM limits, and this FMU having the region's most degraded groundwater quality. Due to the strong groundwater-surface water interaction in many North Otago catchments, it is imperative to understand the groundwater and surface water interactions in this FMU.

There are several recommendations in light of this report. These include:

- Ensure bore owners practice good bore security to prevent contaminant migration to bores. This includes improving ORC's regulatory and education regimes regarding this.
- Publishing the SoE groundwater quality monitoring results online with suitable symbology that clearly indicates when parameters exceed the DWSNZ MAVs.
- Review the legislation and management of known high risk activities to water quality in areas of poor groundwater quality.
- Embark on a programme to replace existing unsuitable SoE bores with new dedicated ones. It is recommended that new bores will be placed based on their representation of the different FMU/aquifers. These should be located on public land to ensure long term access. It is also recommended to have an ongoing maintenance programme for

the bores, where they are pumped, surveyed, and the head security is confirmed on a regular basis.

1. Introduction

The Otago region covers an area of approximately 32,000km^2, with its boundary stretching from the Waitaki River in the north to Brothers Point in the south and inland to Lake Wakatipu and the Haast and Lindis Passes. The Otago landscape varies greatly in climate, land use and topography. It includes the Southern Alps and alpine lakes; dry central areas with tussock, grassland and tors; dramatic coastlines around the Catlins and Otago Peninsula; extensive high country stations; and lowland pasture in the western part of the region. The character of the region's groundwater and surface water bodies is also highly diverse, reflecting the region's variation in environmental conditions and land use.

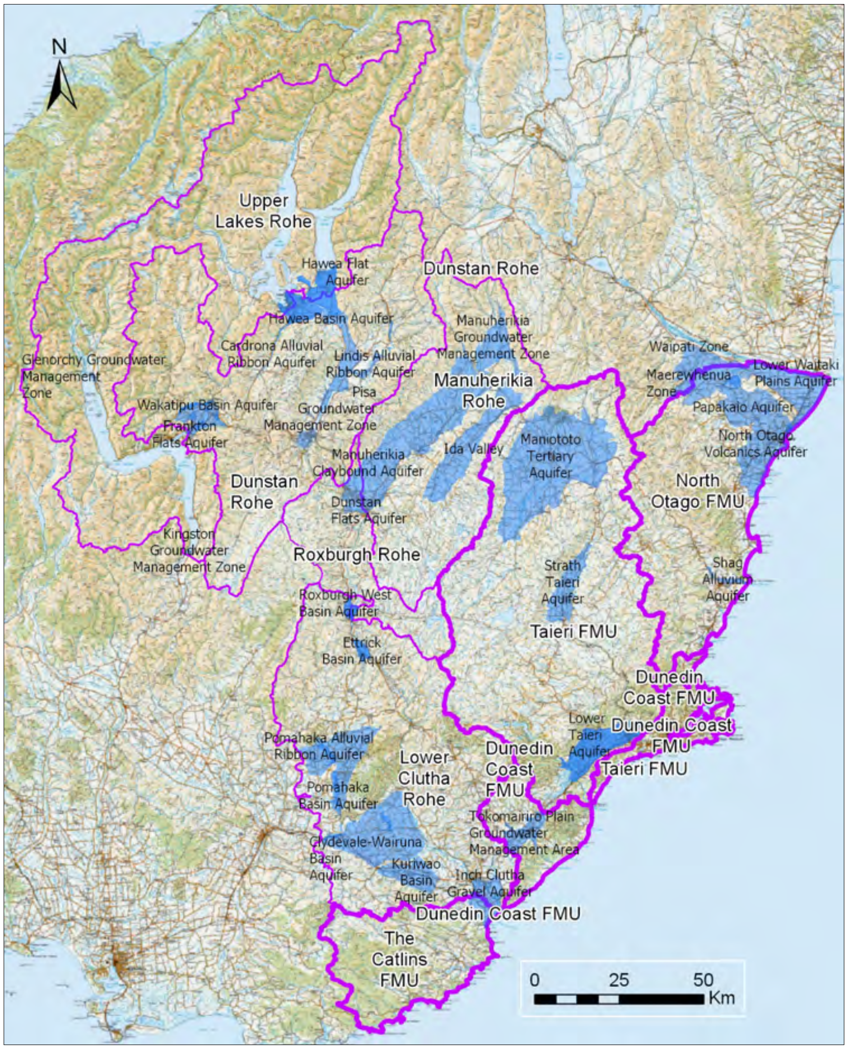
The main Clutha /Mata-Au River drains most of the Otago region, with a catchment area of around 21,000km^2. The river is mainly fed by outflows from the large Wanaka, Hawea, and Wakatipu alpine lakes, which provide 75% of the flow at Balclutha. In addition to the lakes, the Clutha catchment also receives flow from other large rivers: the Kawarau, Cardrona, Lindis, Shotover, Fraser, Nevis, Manuherikia, Teviot, Pomahaka, Waitahuna and Waiwera.

The Taieri River catchment is the second largest in Otago, with an area of 5,060km^2. The Taieri rises in the uplands of Central Otago and meanders around the Rock and Pillar block mountain range before passing through a gorge. It then flows through the Taieri Plain, where it joins the Lake Waipori and Waihola catchments and become tidal before emptying into the sea at Taieri Mouth.

Other significant catchments are located in North Otago, which include the Kakanui, Shag, and Waitaki Rivers. These rise in high country and pass through mainly dry downlands. There is also the Tokomairiro River, which flows through Milton and drains rolling hill country situated between the Taieri and Clutha catchments. Rivers in the southern part of Otago, particularly in the Catlins area, emerge from wetter, and often forested, hills (Otago Regional Council [ORC], 2017a). The catchments in Otago are grouped into five Freshwater Management Units (FMU), Figure 1.

- Clutha Mata-Au FMU (sub divided into five *Rohe*):
    - Upper Lakes
    - Dunstan
    - Manuherikia
    - Roxburgh
    - Lower Clutha
- North Otago FMU
- Taieri FMU
- Dunedin & Coast FMU
- The Catlins FMU

Figure 1: Location of Otago's Freshwater Management Units (FMU) and rohe (delineated in purple) and aquifers (in blue).



The environmental context in which Otago's water bodies exist is characterised by a wide variability in precipitation, from high rainfall in the Southern Alps, to very low rainfall and high evaporation in the rain-shadows resulting in semi-arid central Otago valleys. Despite the large water volumes in the region, distinct parts of Otago are among the driest in New Zealand, with several rivers and tributaries characterised as "water-short". These include the Lindis, Manuherikia, Taieri, Kakanui, and the Shag (ORC, 2004). Due to this high variability, groundwater forms an important part of Otago's hydrology and water resources.

Groundwater is used across the Otago region for drinking, frost-protection, irrigation, industry and stock water supply. In addition to that, groundwater discharges significantly impacts stream flow, water quality, and ecology in various streams across the region (e.g. the Kakanui-Kauru, or the Shag). However, overlying land uses may also impact groundwater quality and levels. Monitoring the state and trends of groundwater quality and quantity is therefore important for informing resource management policy and assessing its effectiveness.

The Otago Regional Council (ORC) operates a long term State of Environment (SoE) programme for monitoring groundwater quality and levels across the region. The monitoring of groundwater quality and levels is conducted for various purposes which include:

- Understanding groundwater and associated surface water ecosystems,
- Assessing the impacts land use on groundwater,
- Determining the suitability of groundwater for specific uses (e.g. drinking water, irrigation, and stock watering),
- Assessing the effectiveness of resource management policies.

The information is also used for reporting under to the obligations in s35 of the Resource Management Act (1991). The aims of the SoE monitoring are:

- Collecting baseline information regarding groundwater quality/levels
- Providing a continuous record to allow detection of state and trends in groundwater levels and quality
- Assess the impact of land use (e.g. irrigation, farming) and policy changes on groundwater levels and quality.

The groundwater SoE monitoring network currently includes 76 bores, which are located across Otago's five FMUs. The bores are located on both private land and public land, particularly public road reserves. Groundwater levels are currently monitored continuously in 34 bores using pressure transducers that record bore water level every 15 minutes. Groundwater quality is assessed by collecting quarterly grab samples from 55 bores and their analysis in an accredited laboratory. The samples are analysed for microbiological (Escherichia Coli, [E. Coli]) and geochemical (major anions and cations, metals) parameters (Appendix 1). In addition to that, water level and physicochemical parameters (temperature, pH, Electrical Conductivity, Dissolved Oxygen) are also measured in the bore as part of the sample collection procedure. The sampling protocols follow the National Environmental Monitoring Standards for groundwater sampling, measurement, processing, and data archiving (NEMS, 2019).

This report summarises the SoE groundwater quality results by referring to relevant drinking water and water quality standards for ecosystem health. It provides a regional summary of groundwater quality parameters followed by a more detailed analysis at the FMU/rohe and aquifer levels. Section 2 briefly describes Otago's groundwater resources and main uses. Section 3 describes the SoE groundwater quality monitoring network, the methodology for collecting groundwater samples, and their analysis. Section 4 provides the groundwater quality monitoring results at the regional, FMU/rohe, and aquifer scales. A discussion of the results and recommendations are provided in Section 5.

2. Groundwater resources in Otago

Groundwater is used across the Otago region for drinking, irrigation, industry, and stock water supply. In addition to that, groundwater discharge also significantly impacts stream flow, water quality, and ecology in various streams across the region (e.g. the Kakanui-Kauru, Shag). However, in contrast to the extensive aquifers located in other New Zealand regions (such as Canterbury and Hawke's Bay), the aquifers in Otago are generally small. Otago aquifers were identified within various geological settings, mainly disconnected basins that are associated with glacial outwash or moraine deposits in river valleys (i.e. alluvial/fluvial depositional environments), that can contain multiple aquifers, depending on the environment in which they were formed. The geological strata where aquifers were identified within the Otago region include:

- Quaternary outwash and recent alluvial gravel (unconfined aquifers)
- Tertiary units of varying properties (normally confined/semi-confined aquifers)
- Claybound alluvial gravels and sediments in higher and therefore older terrace settings (unconfined aquifers)
- Volcanic deposits
- Other units (limestone, fractured schist, and basal quartz conglomerates)

Although groundwater is present within the substrata of most localities within Otago, there are limited areas where bores can sustain a reliable supply of water (Heller, 2001). Within these restricted areas, bores can provide economically significant water.

3. Groundwater monitoring methodology

The groundwater quality network consists of 54 bores, whose depths range between 3.3m (bore no. J42/0762) and 90m (J41/0249). However, the details on each bore for many SoE bores lack information such as screen depth or interval (only available for 18 bores), and lithological logs (geological description of the bore), only available for 33 bores. The location of the monitoring bores within each FMU are shown on Figure 1. Details of the SoE monitoring bores are provided in Appendix 1.

The earliest available data is from August 1985 (bore J41/0249), with other bores in North Otago (J41/0008 and J41/0317) also being monitored for over 25 years. The sampling frequency varied during the monitoring periods, becoming quarterly since March 2011. The parameters for analysis and the laboratory have also changed over time, with Hill Laboratories (Hill) in Christchurch providing the analysis since December 2017. Some of the monitoring bores were also disused and replaced over the course of the monitoring period.

The monitoring bores are situated on both private and public land and there is a wide variability in borehead condition and security. Bores recently installed by ORC usually benefit from substantially higher construction standards and security, Figure 2. SOE monitoring bores located in public land are desirable since losing access for sampling due to permission not continuing has been the main cause for the loss of monitoring at particular bores. Conversely, many of the private bores suffer from very poor borehead security and other practices that increase the risk for contaminant migration into the aquifer and compromising sample integrity (i.e. livestock access to the borehead, storage of chemicals near the bore, access difficulties, pumps continuously running). An example of purpose-drilled monitoring bores is provided in Figure 2.

Figure 2: Examples of suitable, secure, purpose-drilled monitoring bores. Note the sealed concrete pad surrounding the bore head, raised casing above ground level, and the lockable cap.

The SoE monitoring programme samples and analyses groundwater for microbiological (Escherichia Coli, [E. Coli]), cations and metals (e.g. dissolved arsenic, iron, calcium, magnesium) major anions (e.g. sulphate, bicarbonate, chloride), and nutrients (Nitrate Nitrogen, Dissolved Reactive Phosphorus, Ammoniacal Nitrogen). The full list of parameters and analytical methods is provided in Appendix 2.

The ORC SoE groundwater sampling follows the National Environmental Monitoring Standards (NEMS, 2019) methodology. This method obtains a representative sample by purging[1] a minimum of three well volumes prior to the sample collection. The volume is calculated using the bore depth and the Static Water Level (SWL) in the bore, which is measured using a dip meter upon arrival on site. In addition to that, groundwater physicochemical parameters (pH, temperature, Dissolved Oxygen [DO], and Electrical Conductivity [EC]) are monitored during the purging using a handheld YSI probe in order to ensure their stability, which indicates that the bore is adequately purged. After a minimum of three volumes are purged and the parameters are observed to stabilise, the sample is then collected in bottles supplied by the laboratory. The equipment used for sampling is washed in representative water at least three times in order to prevent cross contamination between sites. The samples are stored in a dark, chilled bin and couriered to Hill Laboratory at the end of the sample day. The results are then coded based on the NEMS (2019) Quality Codes and digitally recorded in Hilltop Sampler. The main parameters analysed for ORC's groundwater SoE monitoring and the laboratory analytical Limits of Detection (LoD) are shown in Table 1. The LoD is provided by Hill Laboratories.

[1] In effect, pumping and discarding bore water

Table 1: Analytical Limit of Detection for SoE groundwater quality parameters

Parameter	Limit of Detection (LoD)
Microbiology	
Escherichia coli	1 MPN/100mL
Anions	
Bicarbonate Alkalinity	1.0g/m^3 as $CaCO_3$
Carbonate Alkalinity	1.0g/m^3 as $CaCO_3$
Total Alkalinity	1.0g/m^3 as $CaCO_3$
Total Hardness	1.0g/m^3 as $CaCO_3$
Hydroxide Alkalinity	1.0g/m^3 as $CaCO_3$
Chloride	0.5g/m^3
Fluoride	0.05g/m^3
Sulphate	0.5g/m^3
Cations & metals	
Dissolved Arsenic	0.0010g/m^3
Dissolved Cadmium	0.00005g/m^3
Dissolved Calcium	0.05g/m^3
Dissolved Chromium	0.0005g/m^3
Dissolved Iron	0.02g/m^3
Dissolved Magnesium	0.02g/m^3
Dissolved Manganese	0.0005g/m^3
Dissolved Potassium	0.05g/m^3
Dissolved Sodium	0.02g/m^3
Approx. Total Dissolved Salts	2g/m^3
Nutrients	
Total Nitrogen	0.010g/m^3
Total Ammoniacal-N	0.005g/m^3
Nitrite-N Trace	0.0010g/m^3
Nitrate-N	0.0010g/m^3
Nitrate-N + Nitrite-N (NNN) Trace	0.0010g/m^3
Total Organic Nitrogen (TON), trace level	0.012g/m^3
Dissolved Reactive Phosphorus (trace)	0.0010g/m^3
Total Phosphorus	0.004g/m^3

4. Monitoring results

This section assesses the SoE groundwater quality monitoring results in relation to drinking water quality and ecosystem health. Drinking water quality is assessed against the New Zealand Drinking Water Standards [DWSNZ] (Ministry of Health [MoH], 2005 revised 2018), with a focus on Escherichia Coli (E. coli), dissolved arsenic, and nitrate nitrogen, all determinants that have manifested concentrations of health concern in past groundwater monitoring. The report also assesses ecosystem health using groundwater nutrient concentrations for nitrate nitrogen (nitrate), ammoniacal nitrogen (ammonia), and Dissolved Reactive Phosphorus [DRP]). These concentrations are assessed against regional and national water quality standards for ecosystem health (i.e. nuisance plant/algal growth and toxicity). The results cover the period between the start of monitoring in each active SoE bore (i.e. a monitoring bore that is currently being sampled) and the end of the 2019 calendar year.

This section follows the following structure:

- Section 4.1 describes the monitoring parameters and the standards against which they are assessed followed by a regional overview of groundwater quality in Otago.
- Sections 4.2 – 4.5 describes groundwater quality results in the different FMUs/rohes and aquifers across Otago.
- In addition to the groundwater quality results, each section also includes a brief description of the monitored aquifers and SoE bores within the different FMUs.

4.1 Regional overview of groundwater quality

4.1.1 Drinking Water Standards

4.1.1.1 Escherichia Coli (E. Coli)

Groundwater can be compared to the drinking water standards for New Zealand with reasonable justification. In rural communities without reticulated water, groundwater is the primary and preferred drinking / domestic water source. Shallow groundwater is consumed by people across significant areas of Otago often without water treatment or regular monitoring for potential contaminants. Therefore, considering the regional SoE groundwater analysis results in the context of drinking water standards relates to the same magnitude of concentrations that humans would be exposed to from bore, well or spring water supplies.

While groundwater is less vulnerable to contamination by potentially pathogenic microorganisms than surface water, groundwater may still manifest instances of microorganism occurrence. Faecal bacteria contamination in (drinking) water can originate from livestock, wastewater discharges, effluent application, and stormwater discharge, with contamination risk increasing following heavy rainfall. Escherichia Coli (E. Coli) is used as the indicator organism for bacterial compliance testing for the DWSNZ, where its presence suggests contamination of drinking water by faecal material and pathogenic microorganisms. The DWSNZ Maximum Acceptable Value (MAV) for E. Coli is <1 MPN (Most Probable Number)/100mL. Although any measurement above and including this value exceeds the DWSNZ MAV, a single exceedance is not always a reliable indication for contamination risk status, as groundwater quality can vary temporally. This report therefore assesses the percentage of exceedances above the MAV for each FMU and aquifer, following a similar approach to Environment Canterbury [ECan] (2018). The calculated percentage exceedance of the MAV for each SoE bore (i.e. the number of exceedances divided by the total number of samples from each bore) are shown on Figure 3. Bores delineated in blue and light green suggest low risk, with no exceedances and <5% exceedance, respectively. Bores delineated in yellow are at a higher risk (5-50% exceedances) and may not be suitable for drinking water without treatment. Bores delineated in red are at the highest risk, with >50% of the samples exceeding the DWSNZ MAV.

The percentage of bores in each exceedance category for the Otago region and the number of bores for each category for the different FMUs and rohe are provided in Figure 4 and Figure 5, respectively. This indicates that E. coli was detected in 75% of the bores in the region at **a point** during the monitoring period and that E. Coli exceedances were detected in each of Otago's FMU/rohes, Figure 4. Again, it is important to note that the data includes the **full** monitoring period for each bore. It is also important to note that the results between October 2014 and June 2017, which read <1.6MPN/100mL, were analysed by a different laboratory (i.e. Water Care), hence, these results are potentially related to a higher Limit of Detection rather than an exceedance. Nevertheless, this report took a conservative approach which considers the results of <1.6MPN/100mL as exceedances.

Figure 3: Percentage exceedance of the E. Coli MAV for each bore. The map also shows Otago's FMUs and rohe (in purple) and aquifers (teal). The aquifer names are shown in Figure 1.

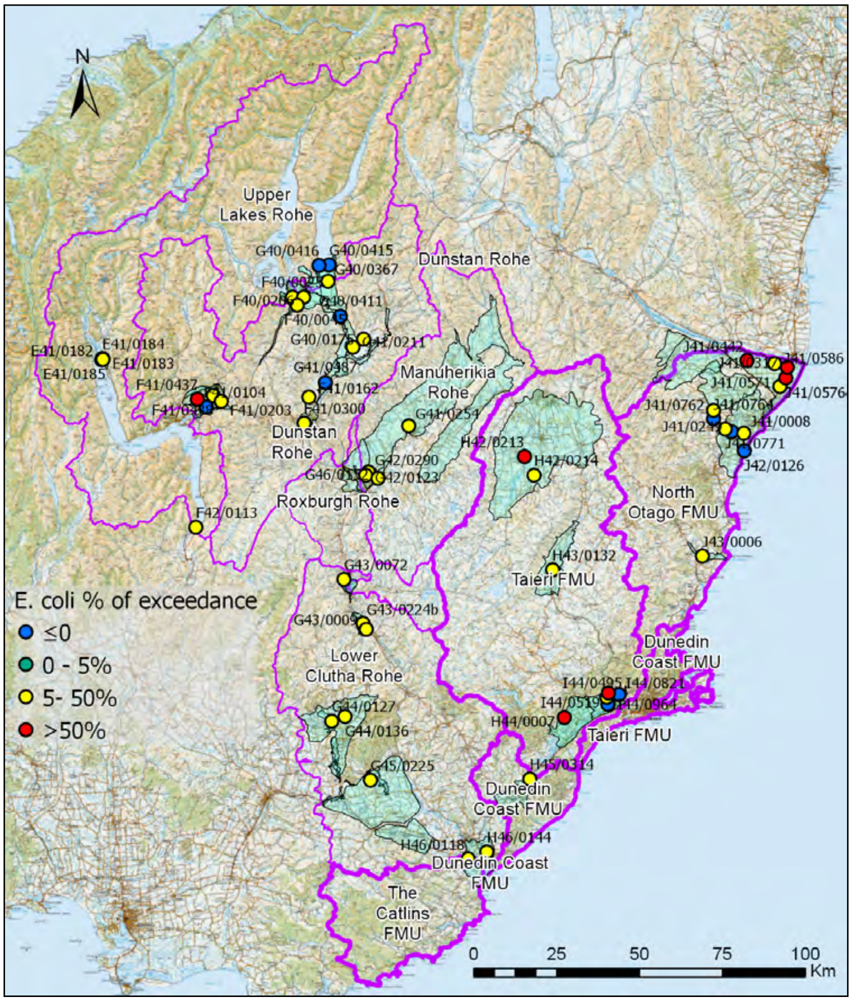
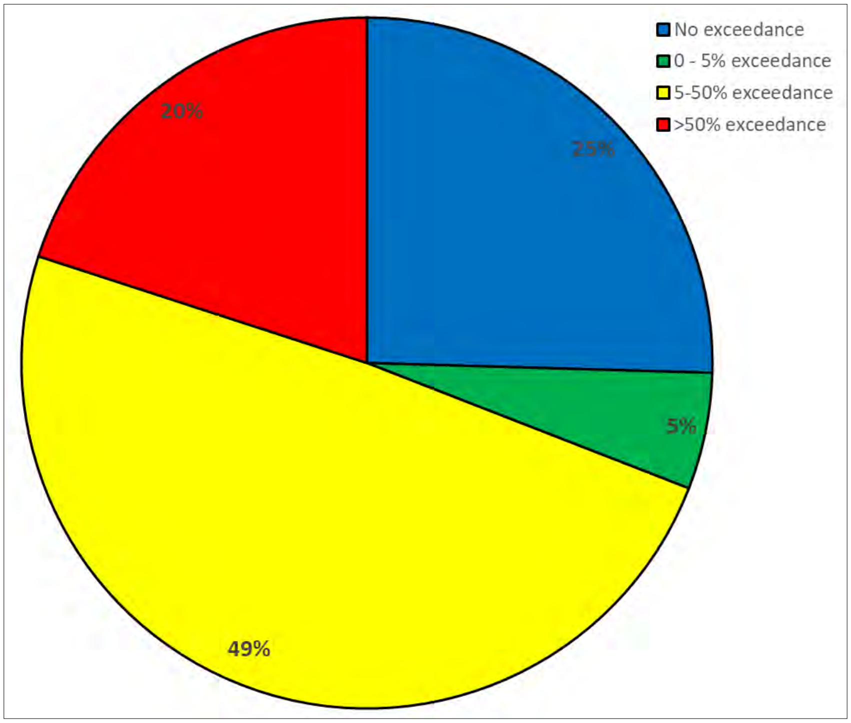


Figure 4: Percentage of bores in each of the exceedance categories (i.e. percentage of the samples that exceeded the MAV) for the whole Otago region

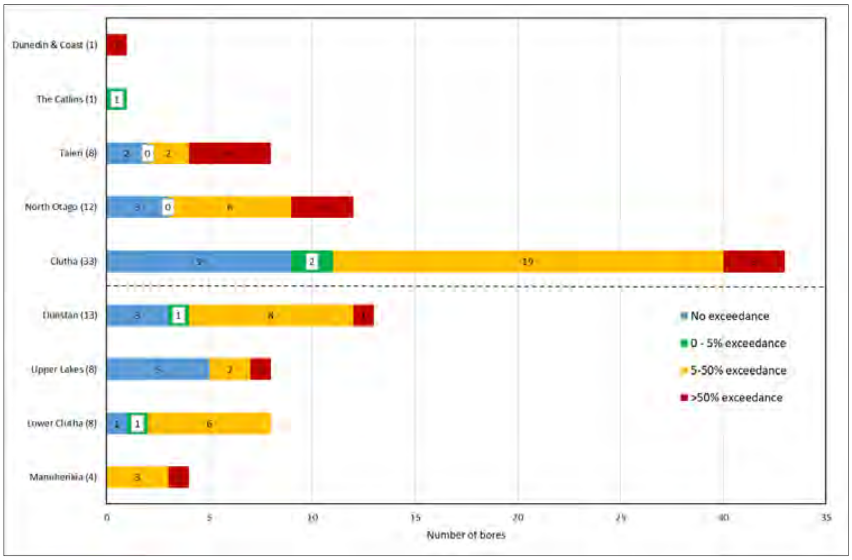


The exceedance data for the different FMU/rohe is shown in Figure 5. This indicates that the proportion of regional exceedance (75%) is similar to that of the Clutha, North Otago and Taieri FMUs. However, a wider variability was observed within the different rohes of the Clutha FMU. The exceedance percentage in the Dunstan rohe (77%) was similar to the regional one, whereas the exceedance percentage in the Upper Lakes rohe (38%) was lower than the regional. Conversely, the exceedance percentage in the Lower Clutha (88%) and Manuherikia (100%) were higher than the regional one, indicating a higher contamination risk in these rohes. The Catlins FMU have exceedance in <5% of the samples and the Dunedin & Coast FMU having exceedances >50% of the samples. However, there is only one SoE monitoring bore in each of these FMUs, hence the data is highly skewed.

The E. Coli monitoring data indicates that potential faecal contamination is a serious water quality issue across the Otago region. However, despite the wide spread of E. Coli exceedance across the region (

Figure 4), it is also important to note that elevated E. Coli can be a local issue and is strongly dependent on bore security, hence, the SoE monitoring data does not present a complete mapping of this risk. It is also important to note that the analysis provided summarises all the available data to December 2019, hence, it does not look at whether E. Coli exceedances have changed over time. It also only addresses the exceedance/no exceedance criteria, regardless of the measured E. Coli count.

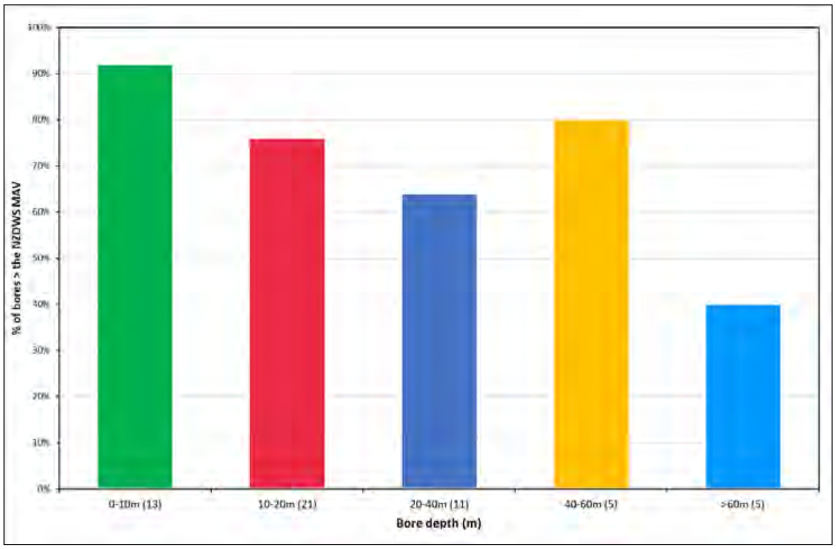
Figure 5: Summary of E. Coli exceedance per FMU and rohe. The number of monitoring bores in each FMU/rohe is shown in brackets. Data below the dashed line shows the rohes of the Clutha FMU.



In addition to the spatial distribution of E. Coli exceedance, the percentage of exceedance and bore depth was also analysed, Figure 6. This was analysed due to the relationship between bore depth and faecal bacteria, which enter groundwater from the surface and is filtered out or dies off over time as it travels through the aquifer and its overlying strata. Hence, deeper bores are usually at a lower risk of contamination (MoH, 2017; 2018).

The data for Otago shows that the highest proportion of detections was in bores shallower than 10m (92%) and the lowest in bores deeper than 60m (40%). The proportion of detection in bores of intermediate depth was 76% for bores between 10-20m deep and 64% for bores between 20-40m, Figure 6. Although most of the data supports the hypothesis of lower E. Coli with increasing bore depth, the proportion of exceedances in bores 40-60m deep was higher than the proportions of exceedance at the shallower depths between 10 and 40m. This can be potentially attributed to the small number of bores in this deeper category (40-60m). Nevertheless, the relatively high percentage of E. Coli exceedances, measured even in the deeper bores, clearly indicate that faecal contamination of groundwater in Otago is a risk at every bore depth.

Figure 6: percentage of E. Coli MAV exceedance for different bore depths. The number of bores in each category is shown in brackets.



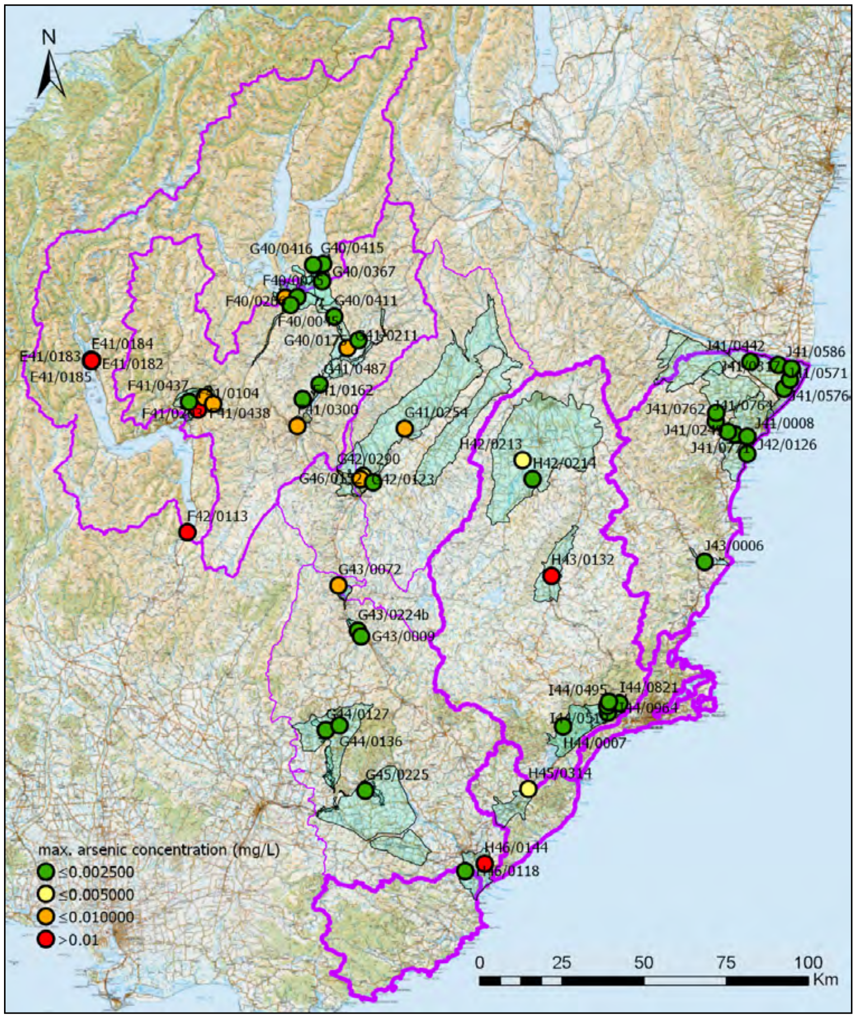
In summary, despite the aforementioned limits of the SoE monitoring data, the E coli results indicate that groundwater and bores in Otago are vulnerable to faecal contamination, regardless of location and/or bore depth. In order to lower this risk, it is strongly recommended that bore owners ensure adequate borehead security to prevent contaminant entry into the aquifer through the borehead. Further information regarding bore security can be found in the following link: https://www.orc.govt.nz/media/5634/bore-brochure.pdf . It is also recommended that groundwater used for drinking is regularly tested in an accredited laboratory, with testing being particularly important after periods of heavy rainfall. If E. Coli is detected, water should be boiled or disinfected (MoH, 2018).

4.1.1.2 Dissolved arsenic

Arsenic is a toxic, though naturally occurring, element, present at low levels in soil, water, plants, animals and food. Arsenic in groundwater can originate from either anthropogenic or natural sources. The former includes economic activities such as sheep dips and treated timber posts. The latter includes geology such as reduced peat deposits alongside volcanic rocks (e.g. Piper and Kim, 2006) and schist rocks, with the latter being particularly prevalent in Otago due to its abundance (Bloomberg *et al*., 2019). In addition to geological factors and activities that use or formerly used arsenic, dissolved arsenic concentrations in groundwater are also controlled by geochemical oxidation/reduction conditions plus water level fluctuations. Exposure to elevated arsenic can lead to a range of cancers, with bladder or lung cancer being the most common, and other non-cancer effects (Piper and Kim, 2006). The DWSNZ MAV for arsenic is 0.01mg/L (equivalent to 10 µg/L), based on a lifetime excess bladder or lung cancer risk (MoH, 2018).

The prevalence of arsenic in Otago groundwater was determined by computing the maximum value from each bore, followed by further scrutiny of any results above the MAV. The maximum arsenic concentrations in the SoE monitoring bores are shown in Figure 7.

Figure 7: Maximum dissolved arsenic concentrations. The map also shows Otago's FMUs and rohe (in purple) and aquifers (teal) . The aquifer names are shown in Figure 1.



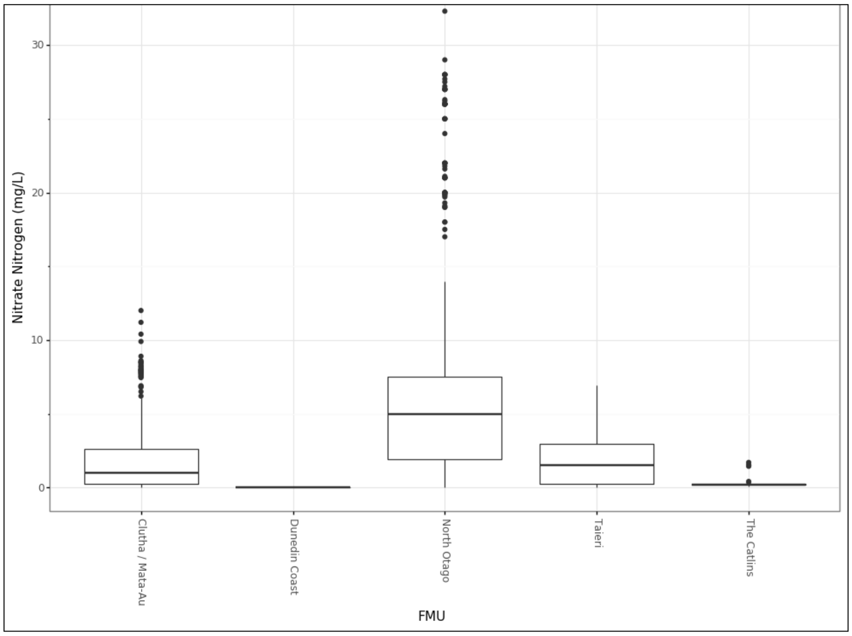
The spatial distribution of maximum arsenic concentrations shows that exceedances of the MAV were only measured in seven SOE monitoring bores across Otago. Of these, five are located in the Upper Clutha/Wakatipu Basin area (i.e. the Glenorchy Groundwater Management Zone (GWMZ), Kingston GWMZ, and the Wakatipu Basin Ladies Mile aquifer). These areas are underlain by schist lithology, known to contain arsenic which is common in groundwater of the Wanaka/Queenstown/Central Otago areas (Bloomberg *et al*., 2019). The other two bores with elevated arsenic concentrations are located in the Strath Taieri (H43/0132) and the Inch Clutha (H46/0144) aquifers. The Strath Taieri bore had only one exceedance of the MAV in March 2009, with all other samples being two to three orders of magnitude lower the MAV. It is therefore may be an outlier result related to sampling or analytical errors. The bore in the Inch Clutha aquifer has persistently elevated arsenic concentrations although the source is unknown, potentially attributable to peat deposit geochemistry in the delta. The bore is not used for drinking water. No arsenic above the MAV was detected in any bores in the North Otago, Dunedin & Coast, or Catlins FMUs, Figure 7. Nevertheless, due to the abundance of arsenic containing schist lithology, particularly in the Upper Clutha, and high spatial variability of arsenic in groundwater, it is strongly recommended that bore owners regularly test their bore water in an accredited laboratory. As arsenic concentrations can be impacted by fluctuations in groundwater levels (e.g. MoH, 2018), it is further recommended that testing is also conducted during different seasons.

4.1.1.3 Nitrate nitrogen

Nitrate (NO_3-N) is a dissolved, inorganic form of nitrogen (N), a key nutrient required for the growth of plants and algae. Dissolved nitrogen is the most readily available nutrient for uptake by plants, hence it is an important source of fertiliser. However, excess nitrate can adversely impact water quality and also lead to health concerns. The primary health concern regarding nitrate in drinking water is the formation of methemoglobinemia, or "blue baby syndrome", which impedes oxygen transport around the body in infants (MoH, 2017). The DWSNZ MAV for nitrate nitrogen is 11.3mg/L – N. Using groundwater dating techniques, the baseline nitrate concentration for natural groundwater (i.e. groundwater unimpacted by anthropogenic activity) in New Zealand was identified at around 0.25mg/L NO_3-N. The threshold for groundwater impacted by low intensity agriculture is between 0.25 and 2.5mg/L mg/L NO_3-N. Groundwater with nitrate concentrations >2.5mg/L NO_3-N are considered impacted by high intensity agriculture (Morgenstern and Daughney, 2012).

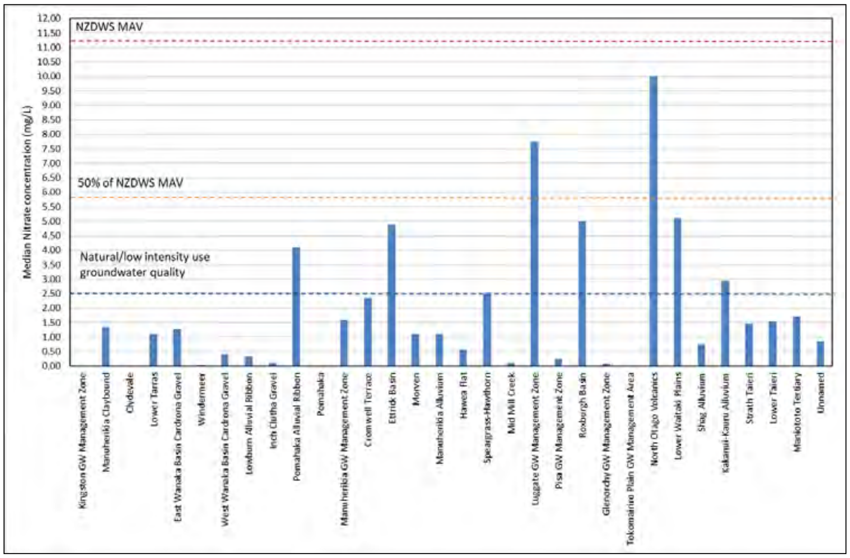
Nitrate concentrations from Otago's FMUs are shown in Figure 8. This shows that the North Otago FMU has the highest median groundwater concentrations, with many samples exceeding the DWSNZ MAV of 11.3mg/L. The median nitrate concentrations in the Clutha (0.99mg/L) and Taieri (1.5mg/L) FMUs are similar, with their values emplaced within the threshold for low intensity landuse (Daughney and Morgenstern, 2012). However, the Clutha FMU also has a relatively large number of outliers. Median nitrate concentrations in the Dunedin & Coast and the Catlins FMUs are lower than the threshold for natural groundwater (0.25mg/L, Daughney and Morgenstern, 2012) although the Catlins FMU has several outliers. However, the results from these two FMU are skewed due to each only has one SoE monitoring bore. The aforementioned low nitrate concentrations can also be attributed to denitrification, which is a function of reduction-oxidation reactions. However, denitrification potential is beyond the scope of this report.

Figure 8: Nitrate concentrations from the Otago FMUs



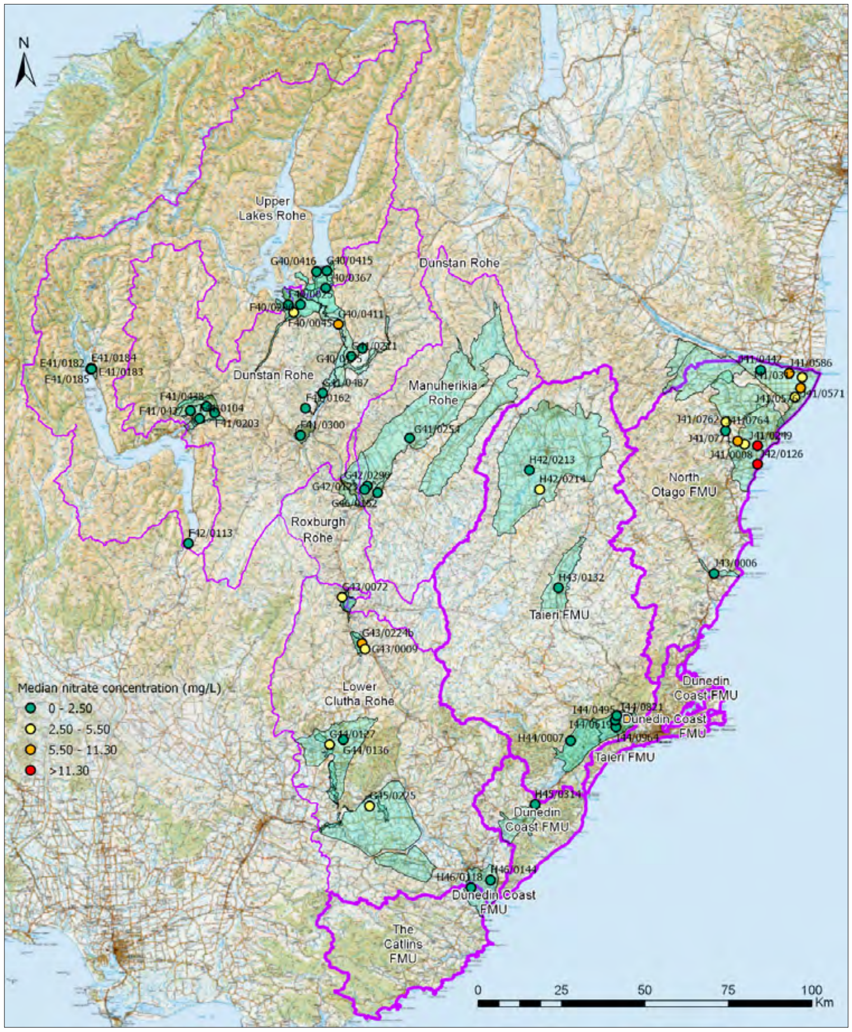
The median nitrate concentrations for the different Otago aquifers are shown in Figure 9. This indicates that there are no aquifers with a median value that exceeds the DWSNZ MAV. However, the median nitrate concentration in the North Otago Volcanic Aquifer (NOVA) and the Luggate GWMZ exceeds 50% of the MAV. There are also aquifers where the median groundwater concentration is above the natural/low intensity use baseline, notably in the Lower Clutha (Pomahaka Alluvial Aquifer, Ettrick Basin, and Roxburgh Basin) and North Otago (Lower Waitaki Plains and the Kakanui-Kauru Alluvium Aquifers). These results, in addition to the aforementioned high median concentration in the NOVA, highlight the elevated nitrate concerns in the North Otago FMU.

Figure 9: Median nitrate concentrations for Otago aquifers



In addition to the assessment of aquifer median concentration, specific bores with elevated nitrate were also considered, Figure 10. An analysis of maximum nitrate concentration indicates that concentrations elevated above the MAV were measured in several bores. Four of these bores are in the North Otago FMU (J41/0008 [located in the NOVA] and J42/0126, J42/0126, and J41/0771 [in the Kakanui-Kauru Alluvial Aquifer]). The remaining bore is in the Pomahaka Alluvial Ribbon Aquifer in the Lower Clutha rohe (G45/0225). These results, in addition to the aforementioned high median concentration in the NOVA, highlight the elevated nitrate concerns in the North Otago and the Lower Clutha.

Figure 10: Median groundwater nitrate concentrations in Otago SoE bores. The map also shows Otago's FMUs and rohe (in purple) and aquifers (teal) . The aquifer names are shown in Figure 1

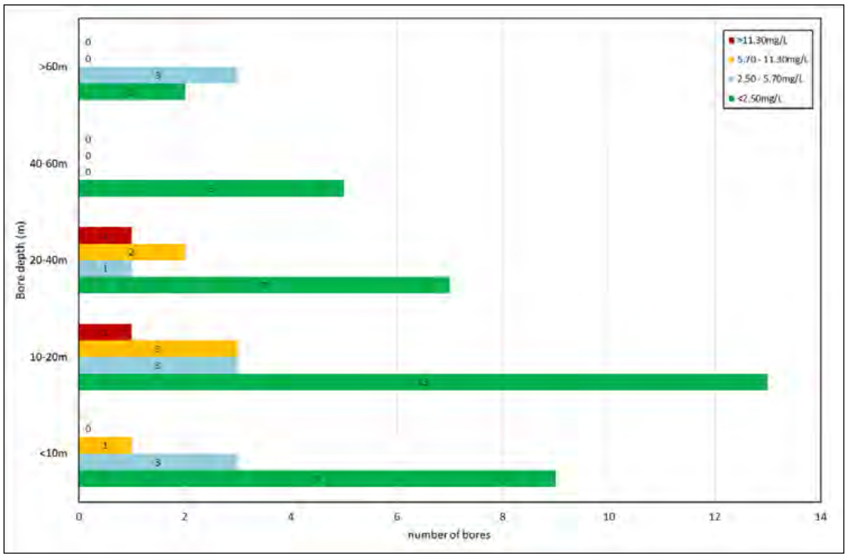


In addition to the spatial analysis of nitrate concentrations, median concentrations were also assessed against bore depth, Figure 11. The concentration was banded according to the proportion of the DWSNZ MAV (11.3mg/L):

- Natural/low intensity land use concentration (<2.50mg/L);
- ½ of the MAV (2.50 – 5.50mg/L);
- ½ MAV - MAV (5.50 – 11.30mg/L); and
- Concentrations above the MAV (>11.30mg/L).

The data shows that the median concentrations in over 50% of the samples for most depth categories are at or below the natural concentration/low intensity landuse baseline. It also shows that the deeper bores have lower nitrate concentrations, with the highest nitrate concentrations in bores >40m deep lower than ½ of the MAV. However, the relationship between bore depth and median nitrate concentrations is not very clear, with bores at depths between 10 and 40m having higher median nitrate concentrations and higher number of bores with elevated concentrations than the shallowest bores (<10m deep). These are likely due to differences in geology, land use practice, and bore security between the different sites.

Figure 11: analysis of median nitrate concentration and bore depth



In summary, groundwater nitrate concentration data shows that none of the aquifers in Otago has a median nitrate concentration above the DWSNZ MAV. However, it has also highlighted a variable degree of nitrate contamination in relation to the MAV, with concentrations in some aquifers, notably in North Otago and the Lower Clutha, approaching the MAV. Conversely, the median nitrate concentrations in many aquifers suggest low impact from landuse. The variability was also illustrated on the analysis of nitrate concentration versus bore depth, with bores between 10 and 40m having the highest median concentrations. This may be related to variability in geology, landuse, and bore security between the different sites.

4.1.2 Ecosystem health

4.1.2.1 Overview

In addition to assessing groundwater quality against the DWSNZ (Section 4.1.1), groundwater quality also impacts surface water quality and ecosystem health, particularly for groundwater-fed surface water systems. The main impacts are stimulation of periphyton growth and toxicity in surface water ecosystems, which are caused by elevated groundwater concentration of nutrients (nitrate nitrogen, Dissolved Reactive Phosphorus [DRP], and ammoniacal nitrogen [ammonia]). Nitrite-nitrate nitrogen (NNN, which is mainly composed of nitrate) and DRP are dissolved inorganic forms of the nutrients nitrogen (N) and phosphorus (P), which are the two key nutrients required for the growth of aquatic plants and algae. Although there are numerous other forms of N and P, these dissolved forms are most readily available for uptake by plants, hence they are the most relevant for assessing nuisance growth in rivers. The terms Total Nitrogen (TN) and Total Phosphorus (TP) refer to the summed total of all forms of N and P in a sample and are more relevant when assessing lake water quality. Additionally, nitrate and ammonia at sufficiently elevated concentrations also have toxic effects on aquatic biota, with this effect independent of their significance as plant nutrients (ORC, 2017).

This was done using nitrate, DRP, and ammonia concentrations from shallow SoE bores (<20m depth), following a similar approach to ECan (2018). The details of the bores are provided in the relevant sections of the report. These nutrient concentrations were then compared against the limits in Schedule 15 of ORC's Regional Plan: Water (2004) and standards in the National Policy Statement for Freshwater Management [NPS-FM] (Ministry for the Environment [MfE], 2017). However, although groundwater nutrient loads undoubtedly affect surface water bodies, the mixing and dilution of inflowing nutrient loads from groundwater with surface water profoundly changes the resultant nutrient concentrations, which can also change due to biological transformations. These processes weaken the linkage between groundwater-measured nutrient concentrations and the concentrations to which aquatic ecosystems are exposed. It is acknowledged that Schedule 15 and the NPS-FM, including the NOF bands were developed for surface water and therefore are not an entirely appropriate set of ecosystem health guidelines with which to assess groundwater. But, there has yet to be a set guideline developed for groundwater with ecosystem health objectives, hence, in the absence of groundwater-specific water quality guidelines, this report has made reference to both surface water ecosystem health criteria. It is also important to note some of the limitations of this comparison:

- Nutrient concentrations in groundwater are generally higher than those in surface water, for which the standards apply
- Surface water quality standards are assessed against various statistics for nutrient concentration (i.e. median, 80th and 95th percentiles). These assessments also depend on variables such as flow thresholds (i.e. samples collected at or below median flow) and river type classification which are not directly comparable with the SoE groundwater quality samples.

Due to all these factors, this assessment provides an overview, rather than a direct comparison, of the potential impacts of groundwater quality on surface water ecosystems.

4.2.1 Otago Water Plan Schedule 15

The ORC Regional Plan: Water (RPW) Rural Water Quality plan change (PC6A) was approved in March 2014 and provided measures for controlling contaminants and sediment coming off rural properties into waterways from runoff, leaching, and drains. Schedule 15 of the RPW lists the contaminant concentration limits and targets for good quality surface water in Otago, as required by the NPS-FM (MfE, 2020). The limits are provided in Table 15.2 of the Water Plan, a copy of which is shown in Table 2. The location of the bores (in relation to the groups) is shown in Figure 12.

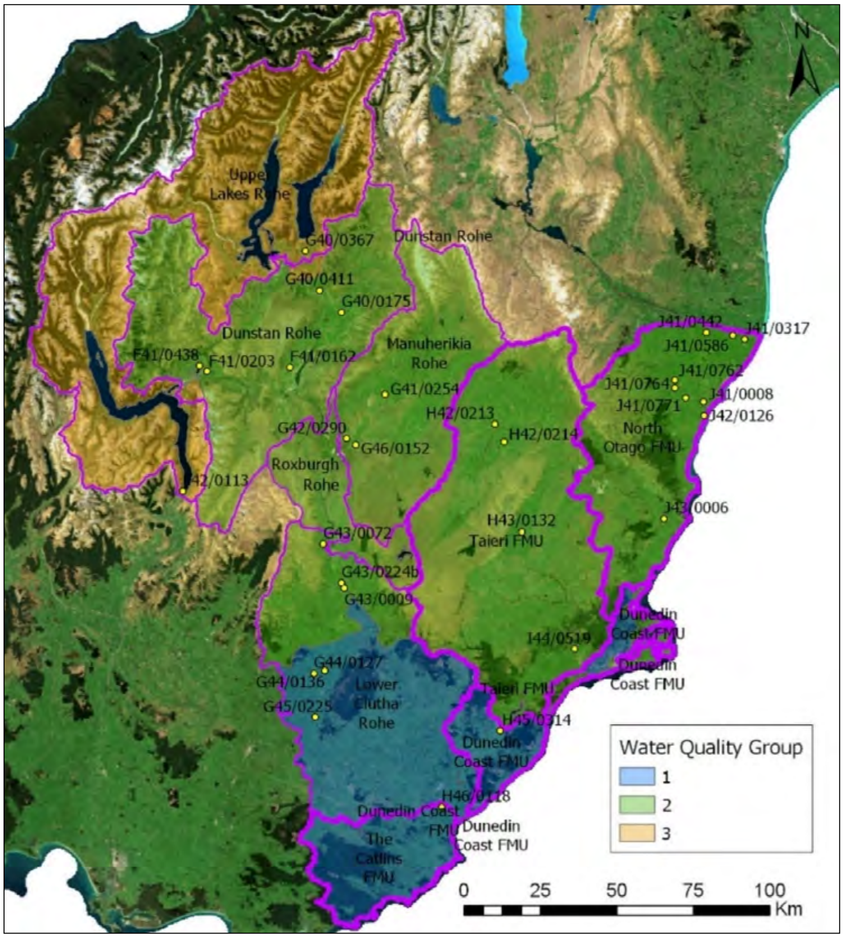
Many of the guideline values for Schedule 15 were obtained from the Australia New Zealand Environmental Conservation Council (ANZECC, 2000, revised 2018) and general water quality guidelines. Environmental guidelines can be used to describe the general state of a natural resource even though these guidelines may not be directly applicable in a regulatory context. The ANZECC (2000, 2018) guidelines are used to indicate "baseline" (unaffected) or "pseudo-baseline" (lightly impacted) conditions for catchments. The trigger values are based on water quality conditions collected from sites at NIWA's National River Water Quality Monitoring Network [NRWQMN] (Davies-Colley, 2000). The trigger values relate to the 80th-20th percentile values for the data range obtained from the NRWQMN. The numerical limits provided in Schedule 15 (Table 2) were partly based on the ANZECC (2000) guidelines. These limits are based on nutrient thresholds for periphyton growth. However, in contrast to ANZECC's approach of using the median values at all flows, the Schedule 15 limits are based on the 80th percentile when flows are at or below median flow for the reference flow site.

The ANZECC (2000) guidelines distinguish between lowland and upland rivers. The guidelines were updated in 2018, where the thresholds under the revised version relate to the River Environment Classification (REC), which account for a range of natural factors that influence water quality such as climate, topography, and geology (McDowell *et al*., 2013). The location of the SoE bores in relation to the receiving water groups in Schedule 15 is shown in Figure 12.

Table 2: Receiving water numerical standards by surface water catchment group (based on the five year 80th percentile when flows are at or below median flow.

Schedule 15[3]	NNN (mg/L)	DRP (mg/L)	NH_4-N (mg/L)	*E. coli* (CFU/100 ml)	Turbidity NTU	TN (mg/L)	TP (mg/L)
Group 1	0.444	0.026	0.10	260	5		
Group 2	0.075	0.010	0.10	260	5		
Group 3	0.075	0.005	0.01	50	3		
Group 4			0.10	126	5	0.55	0.033
Group 5			0.01	10	3	0.10	0.005

Figure 12: Location of shallow monitoring bores and their groups under Schedule 15



The assessment of nutrient concentrations from shallow SoE bores against the Schedule 15 limits are shown in Table 3. The results indicate poor compliance with the Schedule 15 limits for nitrate and DRP, with nitrate concentrations in two bores out of five in Group 1 substantially exceeding the 80th percentile nitrate limit of 0.444mg/L. The DRP results also showed poor compliance, with three bores out of five exceeding the Schedule 15 limit of 0.026mg/L. Conversely, the limits for ammonia, of 0.10mg/L, were not exceeded in any of the bores. Poor compliance results were also observed in Group 2, with nitrate concentrations in all bores exceeding the RPW limit of 0.075mg/L. DRP compliance was also poor, with 80th percentile DRP concentration in only three out of 23 bores below the RPW limit of 0.010mg/L. Similar to Group 1, the compliance with the ammonia limits were better, with concentrations in only two bores exceeding the RPW limit of 0.01mg/L. There were only two bores located in Group 3. The compliance results for this group show that DRP concentrations in both bores exceeded the RPW limits. The results for nitrate and ammonia show that concentrations in one bore were above the RPW limits whilst those in the other were below. Further details are provided in the individual FMU sections.

Table 3: 80th percentile values for Schedule 15 water quality variables. The orange cells show where the 80th percentile exceeds the Schedule 15 limit.

Bore number				**Nitrate (NO_3-N)**	**Dissolved Reactive Phosphorus (DRP)**	**Ammoniacal nitrogen (NH_4-N)**
Group 1 Sched. 15 limit (mg/L)	**FMU**	**Rohe**	**Aquifer**	**0.444**	**0.026**	**0.10**
H46/0118	Clutha	Lower Clutha	Inch Clutha	0.282	0.270	0.013
G44/0127	Clutha	Lower Clutha	Pomahaka Alluvial	5.020	0.015	0.010
G44/0136	Clutha	Lower Clutha	Pomahaka	0.050	0.099	0.016
H45/0314	Dunedin & Coast		Tokomairiro	0.006	0.152	0.072
G43/0224b	Clutha	Lower Clutha	Ettrick	8.340	0.005	0.005
Group 2 Sched. 15 limit (mg/L)				**0.075**	**0.010**	**0.100**
G42/0290	Clutha	Manuherikia	Manuherikia Claybound	2.460	0.020	0.010
J41/0008	N. Otago		NOVA	27.660	0.057	0.010
J41/0317	N. Otago		Lower Waitaki	5.800	0.032	0.010
J43/0006	N. Otago		Shag	1.116	0.011	0.010
G40/0175	Clutha	Dunstan	Tarras	0.938	0.018	0.010
F41/0162	Clutha	Dunstan	Lowburn	0.410	0.008	0.010
I44/0519	Taieri		Lower Taieri	2.900	0.006	0.102
G41/0254	Clutha	Manuherikia	Manuherikia	3.100	0.017	0.010
J42/0126	N. Otago		Kakanui (township)	21.600	0.026	0.010
G43/0009	Clutha	Lower Clutha	Ettrick	4.960	0.013	0.010
F41/0203	Clutha	Dunstan	Morven Ferry (Wakatipu)	3.200	0.005	0.010
J41/0762	N. Otago		Kakanui	4.940	0.011	0.016
J41/0764	N. Otago		Kakanui	3.400	0.011	0.006
Kakanui bore 10	N. Otago		Kakanui	11.000	0.010	0.012
G46/0152	Clutha	Manuherikia	Manuherikia Alluvium	1.216	0.027	0.005
H42/0213	Taieri		Maniototo Tertiary	0.109	0.143	0.386
H42/0214	Taieri		Maniototo Tertiary	4.320	0.047	0.007
F41/0438	Clutha	Dunstan	Lake Hayes	0.212	0.004	0.012
J41/0442	N. Otago		Lower Waitaki	1.072	0.005	0.005
J41/0586	N. Otago		Lower Waitaki	7.280	0.009	0.005
G40/0411	Clutha	Dunstan	Luggate	8.340	0.005	0.006
G43/0072	Clutha	Lower Clutha	Roxburgh	5.320	0.010	0.011
H43/0132	Taieri		Strath Taieri	1.600	0.048	0.010
Group 3 Sched. 15 limit (mg/L)				**0.075**	**0.005**	**0.01**
F42/0113	Clutha	Upper Lakes	Kingston	0.156	0.100	0.282
G40/0367	Clutha	Upper Lakes	Hawea Flat	1.642	0.007	0.006

4.2.2 National Policy Statement for Freshwater Management (NPS-FM [2017])

The NPS-FM came into effect in August 2014. It includes a National Objectives Framework (NOF) aimed at providing “an approach to establish freshwater objectives and national values and any other values that:

a) Is nationally consistent
b) Recognises regional and local circumstances (Objective CA1).

The NPS-FM was amended in 2017 and again in 2020. The NOF includes various tables of attribute and targets, where water quality parameters are categorised in Bands A-D (with Band A representing the highest water quality and D being the lowest). These attributes are taken from the proposed NPS-FM (2019) amendments, Table 4. The NOF attributes include “National Bottom Lines” – thresholds of poor water quality attributes that good management should prevent waterways from reaching, i.e. the minimum water quality level that all water bodies must achieve. The bottom line is the boundary between bands C and D, with results in Band D situated below the national bottom line. However, it is important to note that the NPS-FM’s nitrate and ammonia concentrations thresholds are for protecting ecosystem health and life supporting capacity against toxicity effects, which substantially exceed the nutrient concentrations which stimulate algal growth and eutrophication effects (on which the ANZECC/RPW Schedule 15 limits are based). Due to these different issues (i.e. periphyton growth versus toxicity) the RPW limits are substantially more stringent than the NPS-FM (i.e. sites can be emplaced in Band A under the NPS-FM and fail to comply with the Schedule 15 limits).

Table 4: NPS-FM attributes and NOF bands for nitrate, DRP, and ammonia (from MfE, 2020)

Nitrate (Toxicity) Note: This attribute measures the toxic effects of nitrate, not the trophic state. Where other attributes measure trophic state, for example periphyton, freshwater objectives, limits and/or methods for those attributes will be more stringent.		
Band & Description	**Annual Median (mg/L)**	**Annual 95th percentile**
A High conservation value system. Unlikely to be effects even on sensitive species.	≤1.0	≤1.5
B Some growth effect on up to 5% of species.	>1.0 and ≤2.4	>1.5 and ≤3.5
National Bottom Line	**2.40**	**3.50**
C Growth effects on up to 20% of species (mainly sensitive species such as fish). No acute effects.	>2.4 and ≤6.9	>3.5 and ≤9.8
D Impacts on growth of multiple species, and starts approaching acute impact level (i.e. risk of death) for sensitive species at higher concentrations (>20 mg/L).	>6.9	>9.8
DRP Numeric attribute state must be derived from the rolling median of monthly monitoring over five years.		
A Ecological communities and ecosystem processes are similar to those of natural reference conditions. No adverse effects attributable to DRP enrichment are expected.	≤ 0.006	≤ 0.021
B Ecological communities are slightly impacted by minor DRP elevation above natural reference conditions. If other conditions also favour eutrophication, sensitive ecosystems may experience additional algal and plant growth, loss of sensitive macroinvertebrate taxa, and higher respiration and decay rates.	> 0.006 and ≤0.010	> 0.021 and ≤0.030
C Ecological communities are impacted by moderate DRP elevation above natural reference conditions. If other conditions also favour eutrophication, DRP enrichment may cause increased algal and plant growth, loss of sensitive macro-invertebrate & fish taxa, and high rates of respiration and decay.	> 0.010 and ≤ 0.018	> 0.030 and ≤ 0.054
D Ecological communities impacted by substantial DRP elevation above natural reference conditions. In combination with other conditions favouring eutrophication, DRP enrichment drives excessive primary production and significant changes in macroinvertebrate and fish communities, as taxa sensitive to hypoxia are lost.	>0.018	>0.054
Ammonia (toxicity) Numeric attribute state is based on pH 8 and temperature of 20°C. Compliance with the numeric attribute states should be undertaken after pH adjustment		
	Annual Median (mg/L)	Annual Maximum (mg/L)
A 99% species protection level: No observed effect on any species tested	≤0.03	≤0.05
B 95% species protection level: Starts impacting occasionally on the 5% most sensitive species	>0.03 and ≤0.24	>0.05 and ≤0.40
National Bottom Line	**0.24**	**0.40**
C 80% species protection level: Starts impacting regularly on the 20% most sensitive species (reduced survival of most sensitive species)	>0.24 and ≤1.30	>0.40 and ≤2.20
D Starts approaching acute impact level (i.e. risk of death) for sensitive species.	>1.30	>2.20

4.2 The Clutha FMU

4.2.1 Background information

The Clutha/Mata-Au is the largest FMU in Otago and encompasses the catchment of the Clutha/ Mata-Au River. The Clutha/Mata-Au River originates in the headwaters of lakes Wakatipu, Wanaka and Hawea and drains much of the Otago region with a total catchment area of 21,022 km^2. The Clutha/Mata-Au is the second longest river in New Zealand and the longest river in the South Island, flowing for a total distance of 322 km from its uppermost point in the headwaters of the Makarora River to its mouth downstream of Balclutha. The Clutha River has a mean annual flow of 575 m^3/s, with 75% of the total flow measured at Balclutha comes from the combined outflows of lakes Wakatipu, Wanaka and Hawea (Ozanne, 2012a).

The Upper Clutha reporting region encapsulates the following catchments (from upstream to downstream by confluence): the Makarora (area of 745 km^2), Matukituki (801 km^2), Hunter (1473 km^2), Cardrona (347 km^2), Luggate Creek (123 km^2), Lindis (1039 km^2), Dart (631 km^2), Rees (405 km^2), Shotover (1091 km^2) and Mill Creek (14 km^2). The iconic Southern Great Lakes of Wakatipu, Wanaka and Hawea are central to the region. Of these larger lakes, Wanaka and Wakatipu are not impounded by dams whilst Hawea is regulated. The Clutha and its principal tributary, the Kawarau River, pass through gorges, two of which are dammed for hydro-electricity generation forming lakes Dunstan and Roxburgh. The headwaters of the catchment are predominantly located in rugged, steep terrain with the highest point, Mt. Aspiring, reaching 3,027m. Numerous headwater streams such as the Dart and Matukituki Rivers originate along the eastern boundary of the Southern Alps and are fed by permanent glaciers (ORC, 2017).

The Clutha FMU and catchment is divided into five rohes: the headwaters of Lakes Wakatipu, Wanaka and Hawea in the north (Upper Lakes rohe), the Upper Clutha River catchment (Dunstan Rohe), the Manuherikia Rohe, the Clutha catchment between the Clyde and Roxburgh Dams (Roxburgh Rohe) and the area between Roxburgh Dam and the Clutha mouth (Lower Clutha Rohe). The FMU also includes the catchments for major tributaries of the Clutha such as the Pomahaka and the Manuherikia Rivers. The main land use in the central part is horticulture/viticulture. The southern part is dominated by sheep/beef and dairy farming (ORC, 2017).

4.2.2 Summary of groundwater quality results

The median results for the DWSNZ and ecosystem health parameters from the Clutha FMU are summarised in Table 5. The compliance with the RPW Schedule 15 and NPS-FM for the Clutha FMU are provided in Table 6 and Table 7. Groundwater quality results from the Clutha FMU show a large variability, with good groundwater quality in some rohe (i.e. the Upper Lakes, Dunstan) and potentially degraded quality in others, particularly the Lower Clutha. The main issues are elevated E. coli and dissolved arsenic concentrations in some bores, with elevated nutrient concentrations also common in many bores.

The results from the Upper Lakes and Dunstan rohes generally show compliance with the DWSNZ, although elevated E. coli were measured in some bores. Elevated dissolved arsenic concentrations were also measured in some bores, while their source is likely to be the prevalent schist lithology, i.e. geological, rather than anthropogenic. Nutrient concentrations are generally below the DWSNZ for nitrate. However, nutrient concentration usually exceeds the RPW and NPS limits, with particularly high DRP and nitrate concentrations in Kingston and Glenorchy. The elevated nutrient concentrations in these rapidly developing areas are likely due to high septic tanks density, shallow bores, and poor borehead security. These can potentially adversely impact water quality in the northern/southern arm of Lake Wakatipu, although groundwater (and nutrient) fluxes into the Lake are likely to be substantially lower than the surface water inflows.

Groundwater quality in the Manuherikia rohe is generally fair although E. coli exceedances were measured in most monitoring bores, albeit at low counts. Nitrate concentrations are below the DWSNZ MAV in all monitoring bores, with concentrations in the Manuherikia Alluvium Aquifer and Manuherikia Claybound Aquifer monitoring bores generally near the reference conditions for low intensity landuse, i.e. <2.5mg/L (Daughney and Morgenstern, 2012). However, an increasing trend has been observed in the Manuherikia GWMZ monitoring bore, where concentrations exceed ½ of the MAV for nitrate. No elevated arsenic concentrations were measured in any of the monitoring bores in the rohe. In relation to potential impacts on ecosystem health, the results from the shallow monitoring bores suggest elevated nitrate and DRP, with concentrations exceeding the Schedule 15 limits and DRP concentrations for the Manuherikia Alluvium bore below the National Bottom Line. This suggests that interaction of groundwater from these aquifers with surface water could adversely impact surface water quality in the absence of significant dilution of inflowing groundwater.

Groundwater quality results from the Lower Clutha rohe indicate some issues, with elevated E. coli and nitrate concentrations in most bores, notably in the Ettrick and Clydevale basins. One of the bores in the Inch Clutha gravel aquifer also has elevated arsenic concentrations above the MAV. The results also show issues with elevated nutrient concentrations, some of which are due to shallow monitoring bores and poor bore security. These results also support the reported poor surface water quality results from this area (ORC, 2017).

Table 5: median results for DWSNZ/ecosystem health parameters for the Clutha FMU

Arsenic Dissolved (mg/L)	0.001
E-Coli MPN (MPN/100mL)	0.500
Total Nitrogen (mg/L)	1.080
Nitrate Nitrogen (mg/L)	0.990
Ammoniacal Nitrogen (mg/L)	0.005
Dissolved Reactive Phosphorus (mg/L)	0.008

Table 6: NPS-FM NOF comparison results for the Clutha FMU

		Nitrate concentration		**NOF Band**	
Bore no.	Rohe	Median (mg/L)	95^{th} percentile (mg/L)	Median	95^{th} percentile
F41/0203	Dunstan	1.1	5.9	B	C
G40/0175	Dunstan	0.86	1.0395	A	A
F41/0162	Dunstan	0.33	0.47	A	A
F41/0438	Dunstan	0.113	0.2805	A	A
G40/0411	Dunstan	7.75	9.45	D	C
G44/0127	Lower Clutha	4.1	5.9455	C	C
G44/0136	Lower Clutha	0.005	0.05	A	A

G43/0009	Lower Clutha	4.6	5.52	C	C
G43/0224b	Lower Clutha	7.9	8.66	D	C

		DRP		NOF Band	
Bore number	**Rohe**	**Median (mg/L)**	**95th percentile (mg/L)**	**Median**	**95th percentile**
F41/0203	Dunstan	0.0025	0.0066	A	A
G40/0175	Dunstan	0.014	0.02195	C	B
F41/0162	Dunstan	0.00325	0.01095	A	A
F41/0438	Dunstan	0.002	0.005	A	A
G40/0411	Dunstan	0.023	0.006	D	A
G44/0127	Lower Clutha	0.011	0.0325	C	C
G44/0136	Lower Clutha	0.019	0.1146	D	D
G43/0009	Lower Clutha	0.009	0.0198	B	A
G43/0224b	Lower Clutha	0.002	0.03195	A	C
G43/0072	Lower Clutha	0.006	0.012	B	A
G42/0290	Manuherikia	0.017	0.024	C	B
G41/0254	Manuherikia	0.014	0.021	C	B
G46/0152	Manuherikia	0.0235	0.02905	D	B
F42/0113	Upper Lakes	0.0875	0.11	D	D
G40/0367	Upper Lakes	0.0048	0.0079	A	A
G43/0072	Lower Clutha	5	5.5	C	C
G42/0290	Manuherikia	2.3	2.6	B	B
G41/0254	Manuherikia	1.6	4.4	B	C
G46/0152	Manuherikia	1.1	1.341	B	A
F42/0113	Upper Lakes	0.005	0.097	A	A
G40/0367	Upper Lakes	1.4	1.853	B	B
		Ammoniacal nitrogen	**NOF Band**		
Bore number	**Rohe**	**median (mg/L)**	**Max (mg/L)**	**Median -**	**Max.**
F41/0203	Dunstan	0.005	0.1	A	B
G40/0175	Dunstan	0.005	0.018	A	A
F41/0162	Dunstan	0.005	0.021	A	A
F41/0438	Dunstan	0.0025	0.074	A	B
G40/0411	Dunstan	0.0025	0.073	A	B
G44/0127	Lower Clutha	0.005	0.056	A	B
G44/0136	Lower Clutha	0.012	0.023	A	A
G43/0009	Lower Clutha	0.005	0.38	A	B
G43/0224b	Lower Clutha	0.0025	0.062	A	B
G43/0072	Lower Clutha	0.0025	0.113	A	B
G42/0290	Manuherikia	0.005	0.13	A	B
G41/0254	Manuherikia	0.005	0.01	A	A
G46/0152	Manuherikia	0.0025	0.017	A	A
F42/0113	Upper Lakes	0.255	0.36	C	B
G40/0367	Upper Lakes	0.0025	0.44	A	C

Table 7: Schedule 15 comparison results for the Clutha FMU for 80th percentile for nitrate, DRP, and ammonia

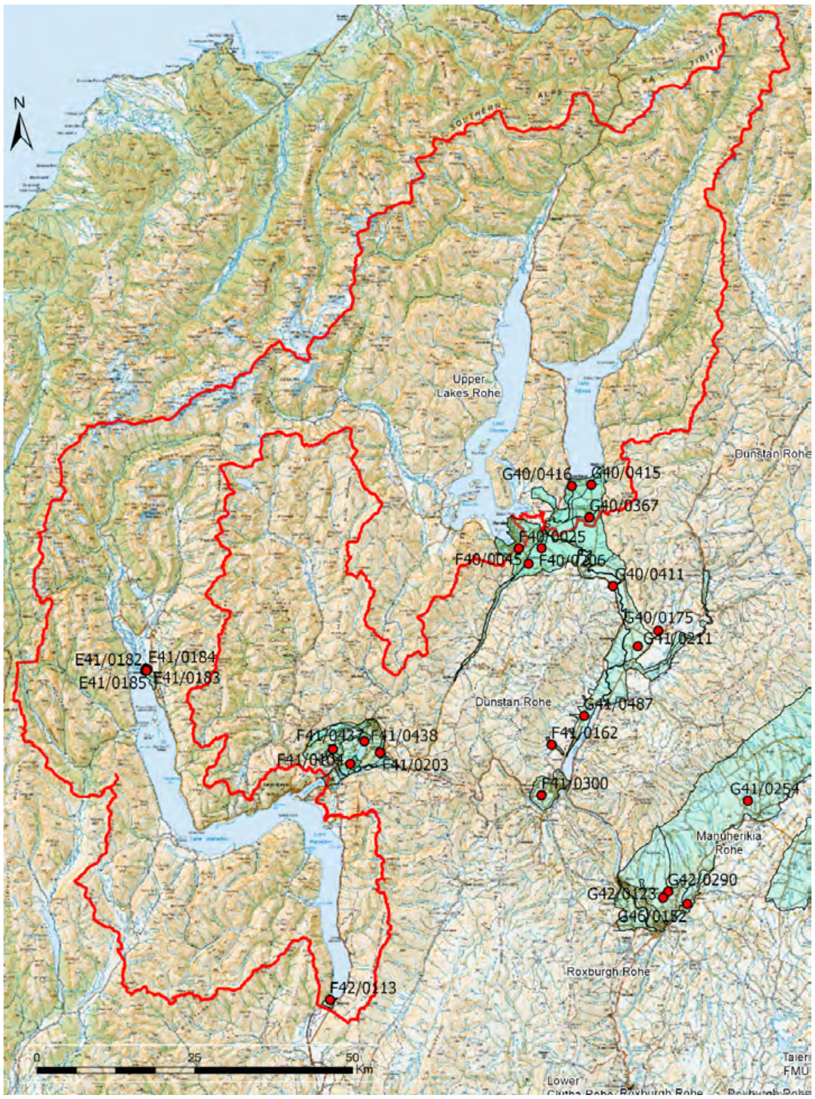
Bore number			Nitrate (NO_3-N)	Dissolved Reactive Phosphorus (DRP)	Ammoniacal nitrogen (NH_4-N)
Group 1 Sched. 15 limit (mg/L)	**Rohe**	**Aquifer**	**0.444**	**0.026**	**0.10**
H46/0118	Lower Clutha	Inch Clutha	0.282	0.270	0.013
G44/0127	Lower Clutha	Pomahaka Alluvial	5.020	0.015	0.010
G44/0136	Lower Clutha	Pomahaka	0.050	0.099	0.016
G43/0224b	Lower Clutha	Ettrick	8.340	0.005	0.005
Group 2 Sched. 15 limit (mg/L)			**0.075**	**0.010**	**0.100**
G42/0290	Manuheriki a	Manuherikia Claybound	2.460	0.020	0.010
G40/0175	Dunstan	Tarras	0.938	0.018	0.010
F41/0162	Dunstan	Lowburn	0.410	0.008	0.010
G41/0254	Manuheriki a	Manuherikia	3.100	0.017	0.010
G43/0009	Lower Clutha	Ettrick	4.960	0.013	0.010
F41/0203	Dunstan	Morven Ferry (Wakatipu)	3.200	0.005	0.010
G46/0152	Manuheriki a	Manuherikia Alluvium	1.216	0.027	0.005
F41/0438	Dunstan	Lake Hayes	0.212	0.004	0.012
G40/0411	Dunstan	Luggate	8.340	0.0246	0.006
G43/0072	Lower Clutha	Roxburgh	5.320	0.010	0.011
Group 3 Sched. 15 limit			**0.075**	**0.005**	**0.01**
F42/0113	Upper Lakes	Kingston	0.050	0.100	0.282
G40/0367	Upper Lakes	Upper Lakes	1.642	0.007	0.006

4.2.3 The Upper Lakes Rohe

The Upper Clutha region covers an area of around 11,970km^2, which represents around 57% of the Clutha catchment. Around 85% of the region is composed of steep terrain typical of the mountain ranges which surround the lakes. The River Environment Classification (REC) framework indicates that the rohe contains a broad range of river types, of which a significant total length is classified as cool/wet (mean annual rainfall of 500-1,000mm/year) or cool/extremely wet (mean annual rainfall >1,500mm). The Upper Clutha rohe contains the highest percentage of these high yielding river types in Otago. Additional significant river types within the Upper Clutha include glacial-fed and lake-fed rivers. The predominant land cover throughout the Upper Clutha is native vegetation followed by low producing grassland. A high proportion of the native cover in the upper catchments of the large lakes experiences high to very high rainfall and snowfall, providing high volume of exceptional quality water from pristine catchments which feed the lakes (ORC, 2017).

The Upper Lakes Rohe includes 12 SoE monitoring bores in three aquifers/GWMZ: Hawea Flat, Kingston, and Glenorchy (Figure 13). These areas experience rapid expansion and urban development which are likely to increase the pressure on groundwater quality/quantity in these areas.

Figure 13: Location of the Upper Lakes Rohe (red outline), aquifers (teal) and SoE monitoring bores (red dots). Aquifer names are shown in Figure 1.



The assessment of groundwater quality data from the Upper Lakes bores against the DWSNZ generally suggests good water quality, although some local issues are also identified. These include substantial exceedances of the dissolved arsenic MAV in both Glenorchy and Kingston and some E. coli exceedances in these GWMZ, although the E. coli counts were relatively low. In contrast to that, the bores in Hawea did not exceed the E. Coli, dissolved arsenic, or nitrate nitrogen MAVs. The elevated arsenic concentrations in Glenorchy and Kingston are likely due to the prevalent schist lithology. The E. coli exceedances are likely due to the high density of septic tanks in the townships and potentially to poor borehead security and/or shallow bores. Despite of these results, none of the monitoring bores is used for drinking. Furthermore, Glenorchy is served by a reticulated town supply, hence the use of groundwater, and the associated potential risk, is lower.

Table 8: Median concentrations for DWSNZ/ecosystem health parameters for the Upper Lakes rohe

Aquifer	Ammoniacal Nitrogen (mg/L)	Arsenic Dissolved (mg/L)	Dissolved Reactive Phosphorus (mg/L)	E-Coli MPN (MPN/100mL)	Nitrate Nitrogen (mg/L)
Glenorchy GW Management Zone	0.203	0.089	0.002	0.500	0.080
Hawea Flat	0.003	0.001	0.006	0.500	0.570
Kingston GW Management Zone	0.255	0.010	0.088	0.500	0.005

Groundwater quality results from the Upper Lakes rohe were then assessed for ecosystem health impacts based on the methodology described in section 4.1.2. Two of the bores in the Upper Lakes FMU are shallower than the 20m threshold for ecosystem health assessment. These bores are located in the Kingston GWMZ (F42/0113) and Hawea Flat (G40/0367). The bores are located in Group 3 of Schedule 15, with the Kingston and Glenorchy bores also located very close to Lake Wakatipu, which is in Group 5. The 80th percentile values for the bores and their compliance with Schedule 15 are provided in Table 9. Although the bores in the Glenorchy GWMZ are also shallower than 20m, their monitoring only began in October 2019, hence, their results were not assessed. Nevertheless, the available data still provides some useful insights.

The results show that the 80th percentile for DRP in both bores exceeded the Schedule 15 limits for Group 3 (Table 9). Nitrate concentrations in Hawea Flat substantially exceeded the limit although ammonia was below it. The results from Kingston were also calculated for the 80th percentile for Total Nitrogen (TN), and Total Phosphorus (TP), which are used in lake water quality assessment. The TN and TP concentrations substantially exceed the limits for Group 5 (Table 9). This is likely due to the high density of septic tanks in the settlement. These elevated nutrient concentrations can potentially adversely impact the water quality in Lake Wakatipu. However, this impact on the lake is unknown due to lack of monitoring in these parts of the lake. It is also likely that groundwater flow contributions are much lower than surface water, hence potential nutrient contribution from groundwater flow will be diluted by the higher volumes of surface water.

Table 9: Upper Lakes rohe 80th percentile concentrations (mg/L) for water quality variables and comparison with Schedule 15 limits

Bore number		Nitrate (NO_3-N)	Dissolved Reactive Phosphorus (DRP)	Ammoniacal nitrogen (NH_4-N)
	Sched. 15 Group 3 limit (mg/L)	**0.075**	**0.005**	**0.01**
F42/0113	Kingston	0.050	0.100	0.282
G40/0367	Hawea Flat	1.642	0.007	0.006
		Total Nitrogen	**Total Phosphorus**	
	Group 5 limit (mg/L)	**0.10**	**0.005**	
F42/0113	Kingston	0.4	0.092	

Nutrient concentrations in the shallow bores were then assessed against the NPS-FM NOF. It is important to note that the NOF nitrate and ammonia attributes focus on ecosystem health and life supporting capacity by providing protection against toxicity impacts, whilst the Schedule 15 limits are based on periphyton growth which are more stringent. Therefore, as the NPS-FM NOF limits substantially exceed those of the RPW and the ANZECC (2000, 2018), sites can be placed in the “A” NOF band and fail to comply with the RPW limits.

The summary of NOF compliance for the Upper Clutha rohe is provided in Table 10. For nitrate, the bore in the Kingston GWMZ is within Band A for both median and 95th percentiles. For a site classified in Band A there are “unlikely to be [toxicity] effects even for sensitive species (MfE, 2020)”, indicating that at the current concentration there is a high level of protection against nitrate toxicity. The Hawea Flat bore (G40/0367) nitrate concentration is emplaced in Band B for both the median and 95th percentile. This band reflects an environment that may have “some growth effect on up to 5% of species”, which provides a good level of protection with some minor effects on growth rate of the most sensitive species (Hickey, 2013).

The assessment against the ammonia NOF bands indicate potential ecosystem issues, with the median and maximum concentrations in Kingston classified in Bands C and B, respectively. Band C provides protection for 80% of species, starting to impact regularly on the 20% of most sensitive species (MfE, 2020). The concentrations in the Hawea Flat bore are in Band A for the median and C for the maximum. Both the A and B bands provide a good level of protection against toxicity effects and in the case of nitrate, it is highly unlikely that there would be any chronic toxicity effects on aquatic species present at these sites. However, the ammonia concentrations in Hawea Flat indicate a potential concern.

The DRP concentrations indicate serious potential issues in Kingston, with both median and the 95th percentile in Band D, where ecological communities are impacted by substantial DRP concentrations, elevated above natural reference conditions. In addition to other conditions that favour eutrophication, DRP enrichment drives excessive primary production and significant changes in macroinvertebrate and fish communities, as taxa sensitive to hypoxia is lost (MfE, 2020). Regarding the NOF standard for lakes, which is assessed using median Total Phosphorus concentration. The median TP concentration for the Kingston bore is 0.0895mg/L, equivalent to 89.5mg/m^3. This will emplace the site substantially below the TP National Bottom Line of >50mg/m^3 (MfE, 2020). Again, these impacts are currently unknown and are likely to be diluted due to the relatively small proportion of groundwater contribution to the lake (in comparison to surface water).

Table 10: NPS-FM NOF comparison for the Upper Clutha rohe

	Nitrate		**NOF Band**	
Bore number	Median (mg/L)	95th percentile (mg/L)	Median	95th percentile
F42/0113	0.005	0.097	A	A
G40/0367	1.4	1.853	B	B
	DRP		**NOF Band**	
Bore number	Median (mg/L)	95th percentile (mg/L)	Median	95th percentile
F42/0113	0.0875	0.11	D	D
G40/0367	0.0048	0.0079	A	A
	Ammoniacal nitrogen		**NOF Band**	
Bore number	median (mg/L)	Max (mg/L)	Median -	Maximum
F42/0113	0.255	0.36	C	B
G40/0367	0.0025	0.44	A	C

4.2.3.1 The Hawea Basin

4.2.3.1.1 Aquifer information

The Hawea Basin aquifer consists of unconsolidated deposits of fluvial (i.e. gravels) and glacial (moraine and till) origin. The unconsolidated strata overlie low permeability basement strata with an estimated thickness of between 50 and >100m thick (Heller, 2003).

The basin was divided into several separate domains based on topography and surface water boundaries. Groundwater flow in the aquifer is driven by seepage from Lake Hawea alongside runoff and land surface recharge. The overall groundwater flow direction in the aquifer is to the southwest, with groundwater eventually discharging into the Clutha River, to which the aquifer is well connected. The depth to groundwater varies across the aquifer, with shallower depths in the northern Hawea Flats (5-10m) and increasing depth to the south (>20m deep), where the area is dominated by terraces (ORC, 2012b).

The main groundwater use in the area is irrigation with water also being used for domestic and stock water supply. In addition to these uses, groundwater is also important for the two regionally-significant wetlands at Campbells Reserve and Butterfield wetland. Bores in the Hawea Flats area are shallow, hence their supply can be vulnerable to over abstraction and contamination. There is a proposed limit to abstraction volume from the aquifer in order to protect the wetlands and shallow bores in the area (ORC, 2012b). The Hawea basin was considered as a high priority area for risk from septic tank leachate (high development) although some of it is on a reticulated supply.

4.2.3.1.2 Groundwater quality monitoring results

There are three monitoring bores within the Hawea Basin aquifer. A summary of the bore information is provided in Table 11. The monitoring of the bores only began in 2016.

Bore G40/0367 (150mm diameter) was drilled in June 2014. It is located at Loach Road, Hawea, at NZTM E1305561 N5047533. The bore depth is 17.1m. The bore log describes fine/coarse sand with some silt to 8m underlain by coarse gravel with some sand/silt to 14m. There is then coarse sand with some gravel to 16.5m underlain by fine sand to the bore bottom at 17.1m. The bore is screened within the bottom sand layer, at a depth of 16.6 to 17.1m. The Static Water Level

(SWL) in the bore ranges between approximately 12.15 and 13.42m below Measuring Point (MP).

Bore G40/0415 (250mm diameter) was drilled in October 2016. The bore is located at Gladstone Road, Hawea, at NZTM E1305860 N5052754. The total bore depth is 30.07m. The bore log describes moist silt to 4.8m underlain by silty gravel to 10.3m. There is then sandy gravel with some silt to the bottom of the bore at 30.9m. The bore is screened at a depth of between 27.0 and 30.0m, within the bottom sandy gravel horizon. The SWL in the bore ranges between 23.05m and 27.35m below MP.

Bore G40/0416 (200mm diameter) was drilled in October 2017. The bore is located on Domain Road, Hawea, NZTM E1302748 N5052499. The total bore depth is 30.5m. The bore log describes sandy gravel with some silt to 6.5m underlain by a large boulder to 10.3m. There is then sandy gravel with minor silt to 17.2m underlain by sandy silt and gravel to 23.2m. There is then silty gravel to the bottom of the bore at 30.5m. The bore is screened at a depth of between 27.65 and 30.5m, within the bottom silty gravel horizon. The SWL in the bore ranges between 24.51 and 27.10m below MP.

These logs suggest that the bores in this area abstract from an unconfined/semi confined sandy gravel/sand aquifer, with finer overlying layers (e.g. silt/silty gravel/silty sands) that potentially provide a degree of confinement. The bores are screened within sandy/silty gravel and sand horizons. These logs also illustrate the heterogeneity of the deposits in the area.

Table 11: summary of monitoring bore information for the Hawea Basin

Bore Number	**Depth (m)**	**Diameter (mm)**	**Easting NZTM**	**Northing NZTM**	**Screen Top (m)**	**Screen bottom (m)**	**Bore log available**
G40/0367	17.1	150	1305561	5047533	16.6	17.1	Yes
G40/0415	30.07	250	1305860	5052754	27.0	30.0	Yes
G40/0416	30.5	200	1302748	5052499	27.65	30.5	Yes

Groundwater E. coli, dissolved arsenic, nitrate, and ammonia concentrations in the Hawea basin are provided in Figure 14, Figure 15, Figure 16, and Figure 17. There were no E. Coli, dissolved arsenic, or nitrate nitrogen measurements which exceeded the DWSNZ MAV in any of the bores. The highest nitrate concentrations were measured in bore G40/0367, ranging between approximately 0.5 and 2.0mg/L. There appears to be a seasonal fluctuation in nitrate concentrations, with concentrations falling in summer and increasing in winter. Concentrations in the other bores are lower and less variable temporally, with the lowest concentrations measured in bore no. G40/0415.

Figure 14: Groundwater dissolved arsenic concentration for the Hawea Basin

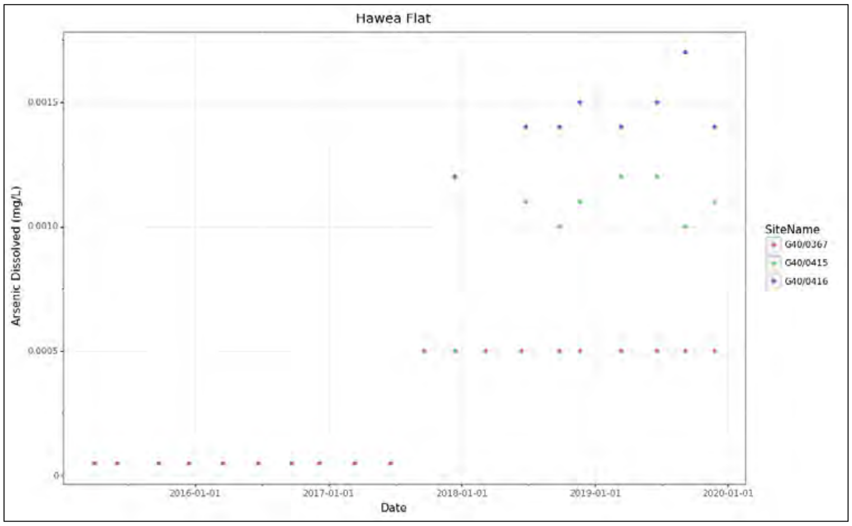


Figure 15: Groundwater nitrate concentration for the Hawea Basin

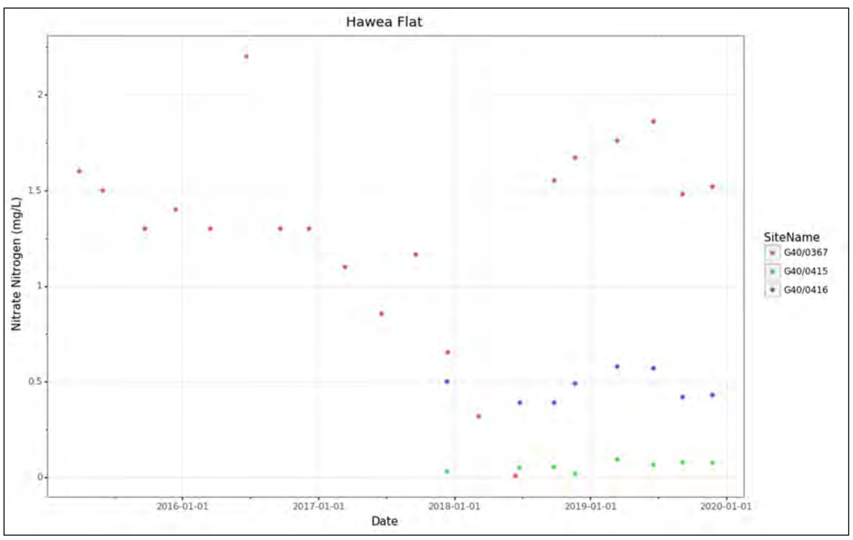


Figure 16: Groundwater E. coli count for the Hawea Basin

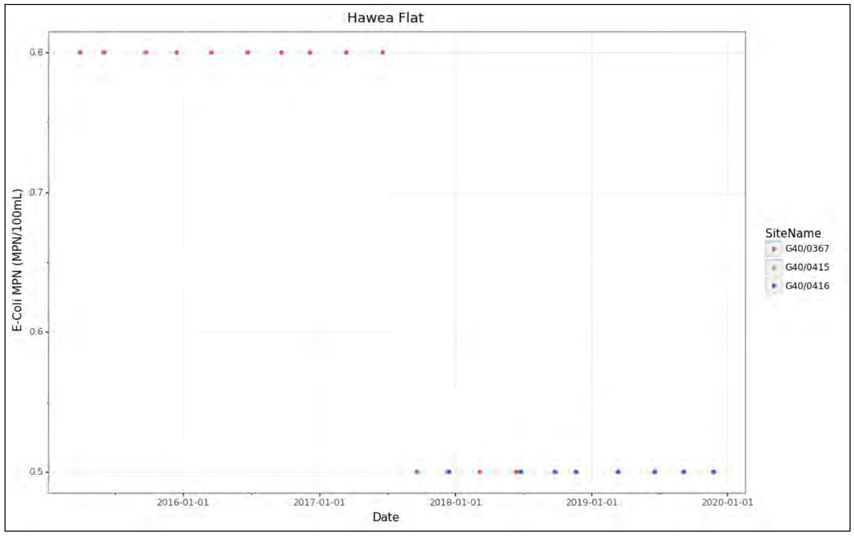
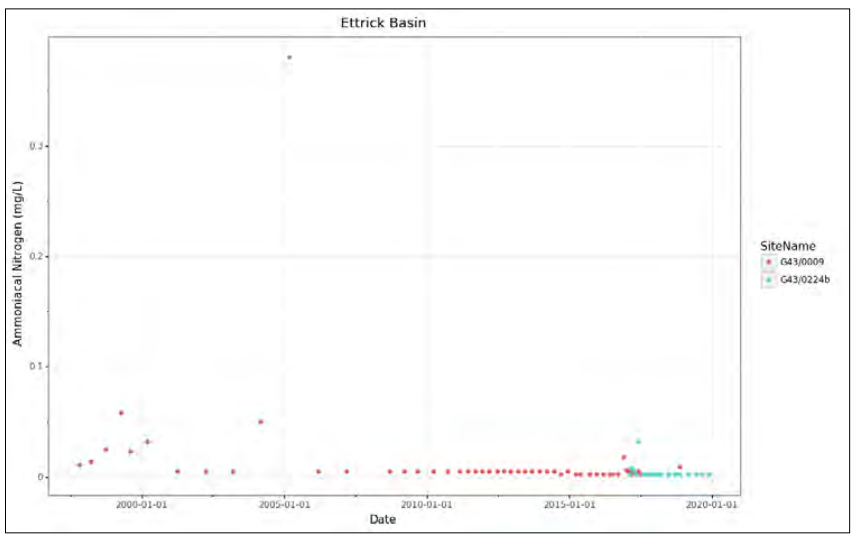


Figure 17: Groundwater Ammonia concentrations for the Hawea Basin



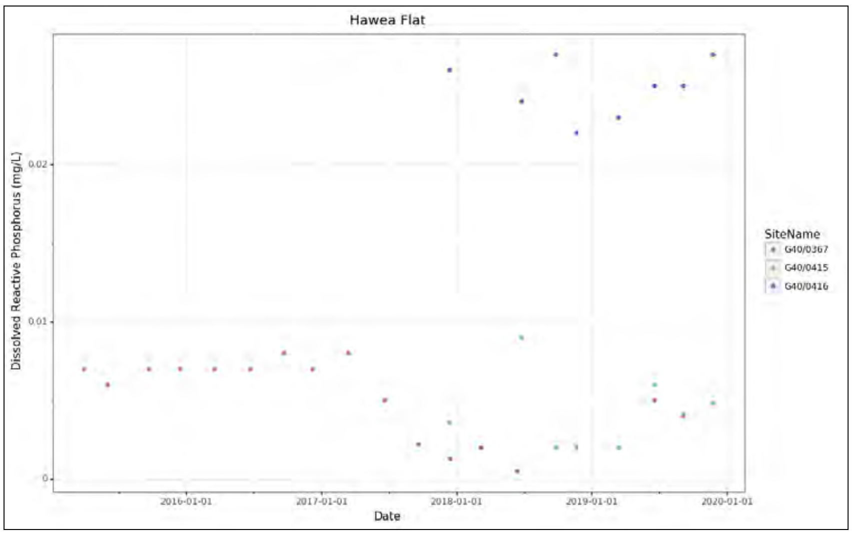
Regarding ecosystem health, bore No. G40/0367 is the only one shallower than 20m. The Hawea Flat area is located in Group 3 of Schedule 15. The comparison of the 80th percentile against the Schedule 15 limits is shown in Table 12, where concentrations that exceed the limits are in orange. The results show that the 80th percentile for ammonia was below the limit. However, nitrate concentrations (1.642mg/L) substantially exceeded the Schedule 15 limit of 0.075mg/L whilst the DRP concentration of 0.007mg/L slightly exceeded the limit (

Figure 18).

Table 12: Hawea Basin 80th percentile concentrations (mg/L) for water quality variables and comparison with Schedule 15 limits

Bore number				Nitrate (NO_3-N)	Dissolved Reactive Phosphorus (DRP)	Ammoniacal nitrogen (NH_4-N)
Group 3 Sched. 15 limit				**0.075**	**0.005**	**0.01**
G40/0367	Clutha	Upper Lakes	Upper Lakes	1.642	0.007	0.006

Figure 18: Groundwater DRP concentration for the Hawea Basin



4.2.3.2 Kingston Groundwater Management Zone

4.2.3.2.1 Aquifer information

Kingston is situated at the southern end of Lake Wakatipu, around 40km south of Queenstown. The area is underlain by glacial moraine deposits and post glacial alluvial fan and lake shore deposits. The Kingston Stream alluvial fan extends to the lake shore on the southeastern side of the township and several unnamed streams drain the western margin. The Eyre Mountains, situated on the west side of the lake and the Hector Mountains, on the east side, are composed of schist.

The area has been substantially impacted by glacial and post glacial activity. Geomorphological evidence such as substantial preserved river channels situated south of the town, which are now swamp filled, indicates that Lake Wakatipu catchment drained southwards, down the Mataura River, during the last glaciation. These former higher lake shores are indicated by relics of 1-2m high terraces, located within the township, that are aligned parallel with the modern lake shore.

Following a glacial or post glacial lake level high, the receding lake appears to have dropped in stages. In Kingston, and across the Wakatipu deltas, this recession left a gently sloping profile with several low lakeward-sloping terraces. This process has also left a succession of generally low permeability till deposits overlain by better sorted gravelly sand alluvium and lake shore gravels of variable thickness (around 1-3m) which forms the resultant shallow aquifer system (ORC, 1997a).

4.2.3.2.2. Groundwater quality monitoring

There is only one SoE monitoring bore in the Kingston GWMZ, no. F42/0113 (75mm diameter). The bore is situated at Cornwall Street NZTM E1264431 N4971121, approximately 40m south of the shore of Lake Wakatipu. The bore is very shallow (4.4m). There is no information regarding the screen depth in the bore and a log is not available. The SWL in the bore ranges between approximately 0.83 and 1.45m below MP. The bore is solely used for groundwater monitoring. However, due to its shallow depth, poor security, and proximity to the lake it is inadequate for monitoring and should be replaced as soon as practically possible.

The assessment of groundwater quality in the Kingston GWMZ against the DWSNZ is shown in Figure 19, Figure 20, Figure 21, and Figure 22. The DRP concentrations are shown in Figure 23. The bore previously had high arsenic concentration above the DWSNZ MAV of 0.01mg/L, with maximum concentrations of around 0.017mg/L. Although the concentrations seem to fall, some of the results still exceed the MAV (Figure 19). These exceedances are likely due to the prevalent schist lithology in this area.

The E. Coli data shows that 35% of the samples exceeded the DWSNZ MAV. However, the measured E. Coli count was generally low, with a maximum of 6MPN/100mL (March 2013). The E. coli exceedances are potentially due to the high density of septic tanks in the township, the bore's shallow depth, and poor borehead security. Furthermore, most of the exceedances were <1.6MPN/100mL and were reported between September 2014 and June 2017, when the analysis was performed by Water Care. Apart from that, the only exceedance was 6 MPN/100mL in March 2013 (Figure 20). Nitrate concentrations in the bore are low, ranging between 0.001 and 0.57mg/L, substantially below the DWSNZ MAV of 11.3mg/L NO_3-N.

Figure 19: Groundwater dissolved arsenic concentration in the Kingston GWMZ

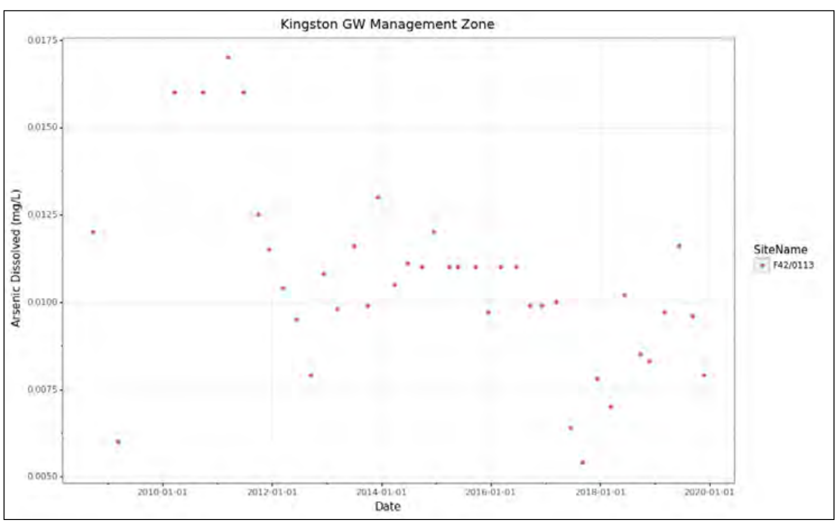


Figure 20: Groundwater E. coli counting in the Kingston GWMZ

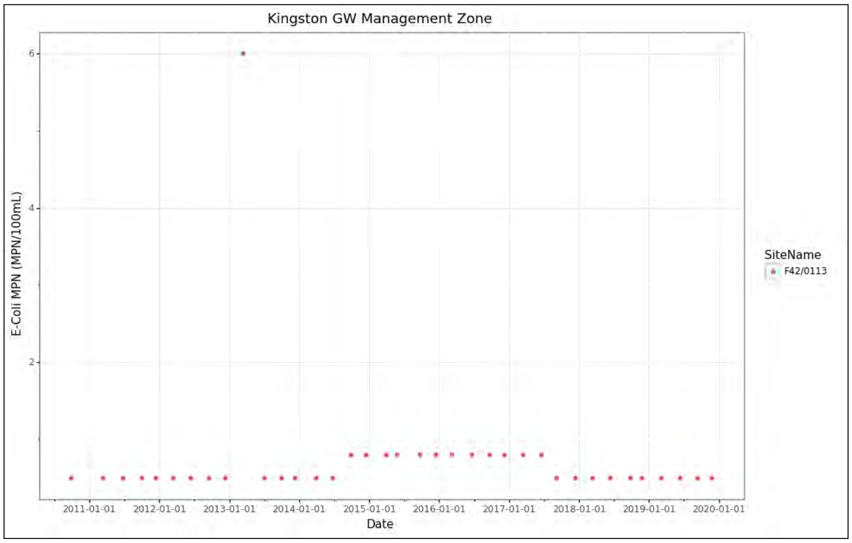


Figure 21: Groundwater nitrate concentration in the Kingston GWMZ

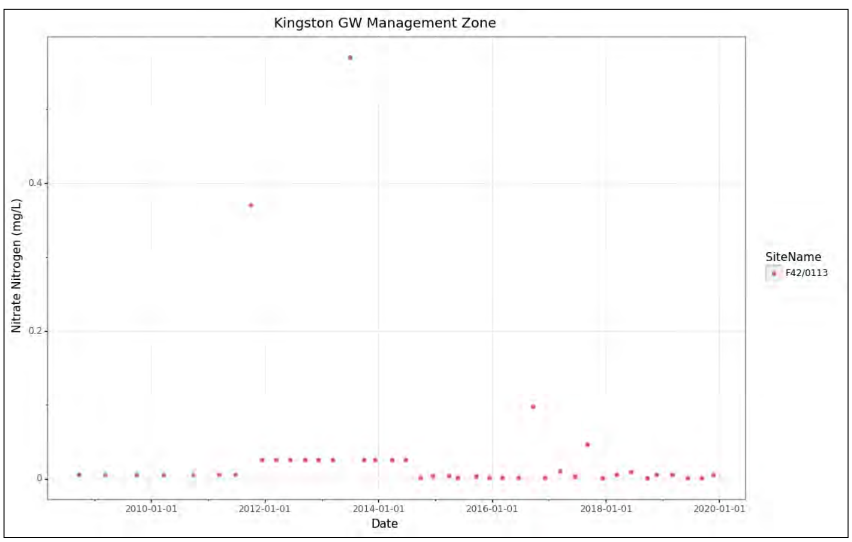


Figure 22: Groundwater ammonia concentration in the Kingston GWMZ

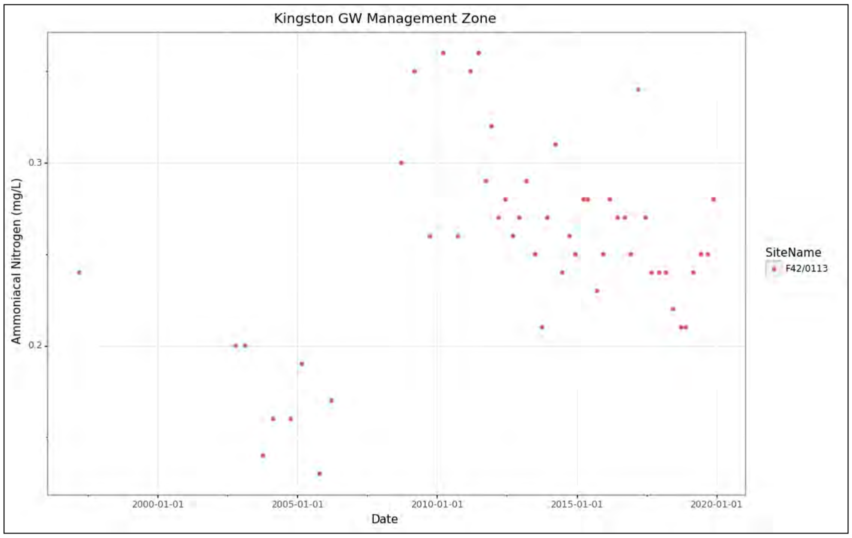
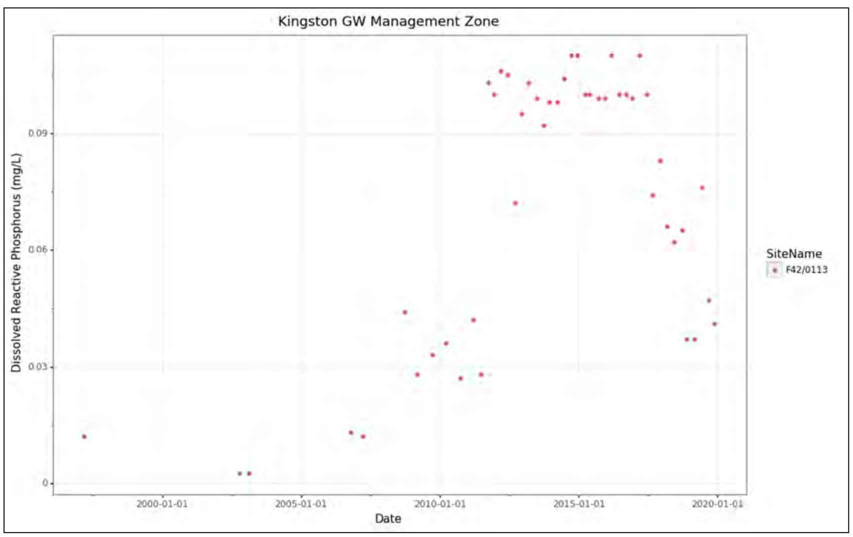


Figure 23: Groundwater DRP concentration in the Kingston GWMZ



Groundwater quality from the Kingston SoE bore was also assessed against Schedule 15 of the RPW and NPS-FM, Table 13. The bore is located in Group 3 of Schedule 15, and is also very close to the southern end of Lake Wakatipu, which is in Group 5. The data indicates that groundwater quality can adversely impact the lake, with the 80th percentile for DRP and ammonia substantially exceeding the Schedule 15 limits for both Groups 3. Due to the proximity to Lake Wakatipu, the 80th percentile for Total Nitrogen (TN) and Total Phosphorus (TP) were also assessed. TN has only been monitored continuously since September 2017, and the 80th percentile is 0.384mg/L, which substantially exceeds the Schedule 15 limit of 0.10mg/L. The data also shows that most of the TN is sourced from ammonia and Total Organic Nitrogen, as the nitrate concentration is low. Total Phosphorus has also been monitored since September 2017, with an 80th percentile concentration of 0.0912mg/L, which substantially exceed the Schedule 15 limit of 0.005mg/L. This indicates that groundwater discharge from the Kingston GWMZ into the lake can adversely impact its water quality. It is likely that the elevated ammonia and DRP concentrations are due to the high density of septic tanks, the bore's shallow depth and its location at the end of the flow path.

Table 13: Kingston GWMZ 80th percentile nutrient concentration comparison against the Schedule 15 limits for of nitrate, DRP, and ammonia concentrations. Values in orange exceed the threshold.

Bore number				Nitrate (NO_3-N)	Dissolved Reactive Phosphorus (DRP)	Ammoniacal nitrogen (NH_4-N)
Group 3 Sched. 15 limit				**0.075**	**0.005**	**0.01**
F42/0113	Clutha	Upper Lakes	Kingston	0.050	0.100	0.282

4.2.3.3. Glenorchy

4.2.3.3.1 Aquifer information

The township of Glenorchy is situated at the northern end of Lake Wakatipu. It is bordered by Lake Wakatipu to the west, old river terraces at the foot of the Richardson Mountains to the east, the Glenorchy Lagoon and Dart/Rees River delta to the north and the Buckler Burn to the south. The delta comprises of alluvial sands, mud flats, mires, and ponds which include a Department of Conservation (DoC) reserve. The area is also surrounded by schist mountains to the west and east. The mountains contain the mineral scheelite (Ca_2WO_4) which was formerly mined in the catchment.

The town is located on low terraced flats that gradually slope towards the lake. It is partly underlain by peaty soil and sandy gravel. Deposits in the area have high angle bedding surface that dip towards the lake, typical of sub-aqueous fan delta slope deposits. There are also well exposed, high terrace deposits underlain by remains of the Buckler Burn gravel delta which propagated into the lake during early post-glacial periods. The alluvial deposits are mainly composed of sandy gravels with low proportion of fines. (ORC, 1997b).

Some groundwater and surface water quality samples were collected during a study in 1996. The geochemistry results have identified strong connection between surface water of the Buckler Burn and the aquifer. It also showed low faecal concentration counts and nitrogen concentrations, the highest being 3.6mg/L NO_3^-. This sample was collected in the holiday park and potentially reflects contamination from septic tank, fertiliser, or animal waste. (ORC, 1997b).

More recent investigations by E3Scientific Limited [E3S] (2018) have refined the conceptual groundwater model for Glenorchy, which highlights the area's complex hydrology. Monitoring showed that groundwater flows from the north, east and south underneath the township towards Lake Wakatipu. Sources of groundwater recharge include the Lagoon/Rees River (groundwater flow to the southwest towards the Jetty and Harbour), rainfall that flows off the Richardson Mountains (water flows west towards the Lake) and the Buckler Burn (flow to the northwest towards the Lake).

The model suggests that oxygen-rich surface water to the north (the Lagoon and its outflow into the Rees) has mixed redox status due to bio-geochemical processes involving organic matter. This water then becomes oxygen-depleted as it flows beneath the township, where septic tanks provide additional organic inputs that geochemically reduce iron oxides and sulphates. This highly reduced iron-rich groundwater discharges into the lake near the Jetty, where significant deposition of iron has been observed (E3S, 2018). Further evidence for the reducing conditions is provided by high dissolved arsenic groundwater concentrations in bore E41/0182, which is situated near the jetty. The flow from the south/east (Buckler Burn) is similar although the groundwater conditions are less reducing, hence, nitrate and sulphate concentrations are higher and iron concentration is lower. This was attributed to the increased depth to groundwater and the lower density of septic tanks in the southern half of the town, which lowers the leaching of organic material to the groundwater. On site wastewater management in Glenorchy (i.e. septic tanks) will initially impact groundwater beneath the township then Lake Wakatipu, which serves as the receiving environment. However, as the reticulated town water supply is sourced from groundwater upgradient of the township, the main risk from this wastewater management in terms of exposure is through recreational use of the lake (E3S, 2018).

4.2.3.3.2 Groundwater quality

Due to the rapid development that is experienced in Glenorchy and the high number of septic tanks, it was recommended as a high priority for groundwater monitoring (PDP, 2017). SoE groundwater monitoring by ORC began in October 2019 using the four piezometers drilled by E3S for their investigation on behalf of Queenstown Lakes District Council (QLDC). A map of the piezometers is provided in Figure 24 and the bore details are provided in Table 14. The piezometers were given ORC numbers using the ORC database. However, for clarity, the map also shows the piezometers' E3S (2018) original names (P1-P4). As sampling in Glenorchy only began in October 2019 the data is not sufficiently long for analysis. However, the results still provide very useful insight.

Figure 24: Location of SoE monitoring bores in Glenorchy (red dots)

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Table 14: Details of monitoring bores in Glenorchy

Bore number	Depth (m)	Diam. (mm)	Easting	Northing	Screen Top (m)	Screen Bottom (m)	Log available	SWL (m below MP)
E41/0182 (P1)	10.1	25	1235134	5023214	2.10	10.10	Yes	0.300
E41/0183 (P2)	10.2	25	1235510	5023479	2.20	10.20	Yes	2.785
E41/0184 (P3)	10.0	25	1235260	5023606	2.00	10.00	Yes	0.10
E41/0185 (P4)	10.0	25	1235380	5023306	2.00	10.00	Yes	2.845

Despite the short duration of groundwater monitoring in Glenorchy, the data clearly indicates several notable issues. Arsenic concentrations in three bores (Figure 25) exceed the DWSNZ MAV of 0.01mg/L, with concentrations ranging between 0.0121mg/L (bore no. E41/0185) and 0.84mg/L (E41/0182), which is the maximum groundwater arsenic concentration in Otago. The arsenic source is likely to be geological, i.e. schist from the surrounding geology. The high arsenic concentrations are likely attributed to the reducing groundwater conditions, caused by the high density of septic tanks, which provide organic matter that lead to reducing geochemical conditions and increase arsenic mobility. However, Glenorchy is on a reticulated water supply, which is monitored by QLDC, hence the public health risk from arsenic consumption is low.

There were also some exceedances of the E. Coli DWSNZ MAV, with a count of 5MPN/100mL in bore E41/0185, situated near a hotel (Figure 26). This bore also had ammonia concentration of 16.9mg/L which substantially exceeds the DWSNZ aesthetic Guideline Value (GV) of 1.5mg/L (

Figure 27). There were no exceedances of the nitrate MAV in any of the bores, with concentrations ranging between 0.0005 and 2.0mg/L (Bore E41/0185, Figure 28).

Due to the shallow depths of the bores in Glenorchy the groundwater quality was also assessed against Schedule 15 of the RPW and NPS-FM. The bores are located in Group 3 of Schedule 15, and are also very close to the northern end of Lake Wakatipu, which is in Group 5. Despite the short data availability, the results show that ammonia and TP concentrations in all bores apart from E41/0183 exceed the Schedule 15 limits. Total Nitrogen in all bores exceed the Group 5 limits. Conversely, the DRP limit for Group 3 (0.005mg/L) is only exceeded in bore E41/0185 (Figure 29). The observed elevated nutrient concentrations are likely due to septic tanks input, particularly near bore E41/0185.

In summary, despite the short availability of data from Glenorchy the data indicates several groundwater quality issues, related to both drinking water and nutrient impact on Lake Wakatipu. The risks to drinking water are diminished as Glenorchy is on a reticulated town supply. However, nutrient input through groundwater discharge to the lake can adversely impact lake water quality. Further risk to recreation water quality is the area near the jetty, where groundwater transits from strongly reducing to oxidised conditions which lead to the deposition of iron (ES3, 2018).

Figure 25: Groundwater dissolved arsenic concentration in the Glenorchy GWMZ

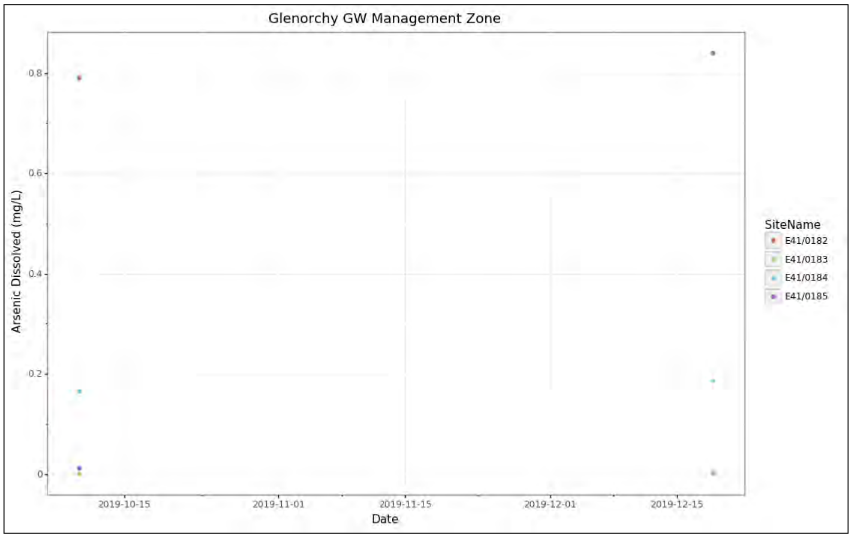


Figure 26: Groundwater E. coli results for the Glenorchy GWMZ

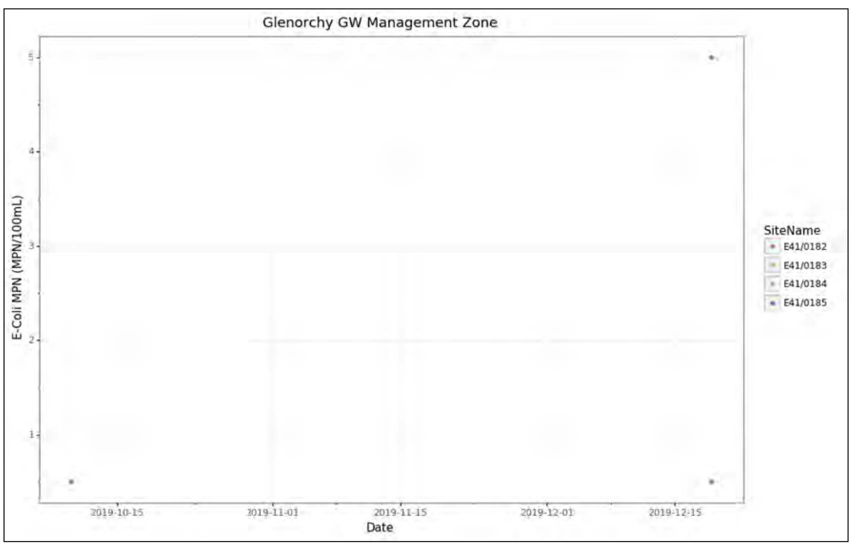


Figure 27: Groundwater ammonia concentration in the Glenorchy GWMZ

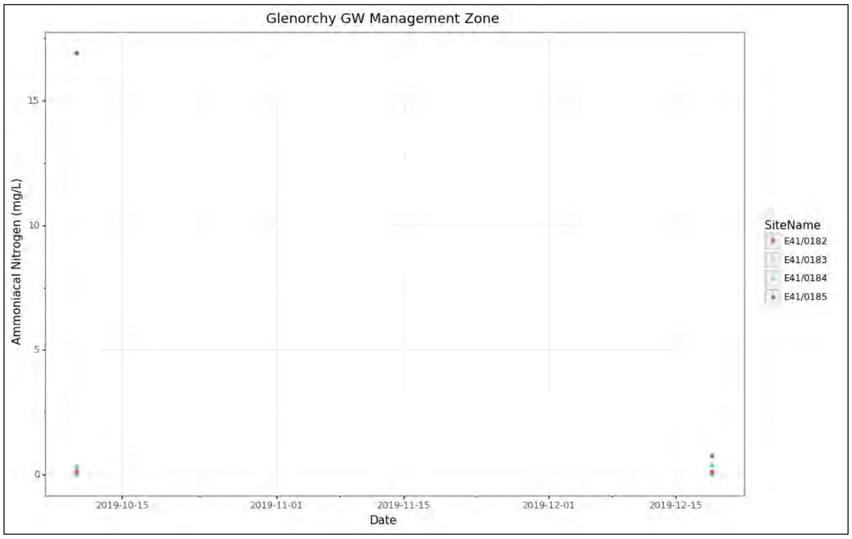


Figure 28: Groundwater nitrate concentration in the Glenorchy GWMZ

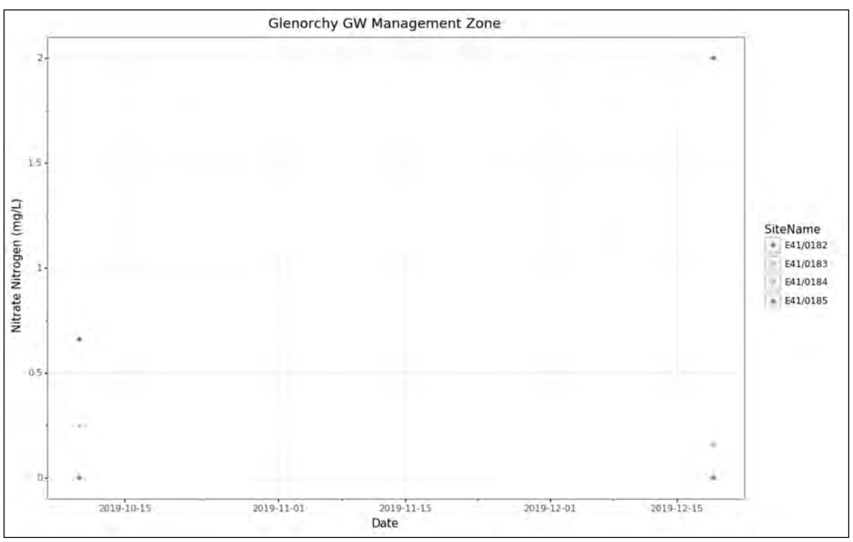


Figure 29: Groundwater DRP concentration in the Glenorchy GWMZ

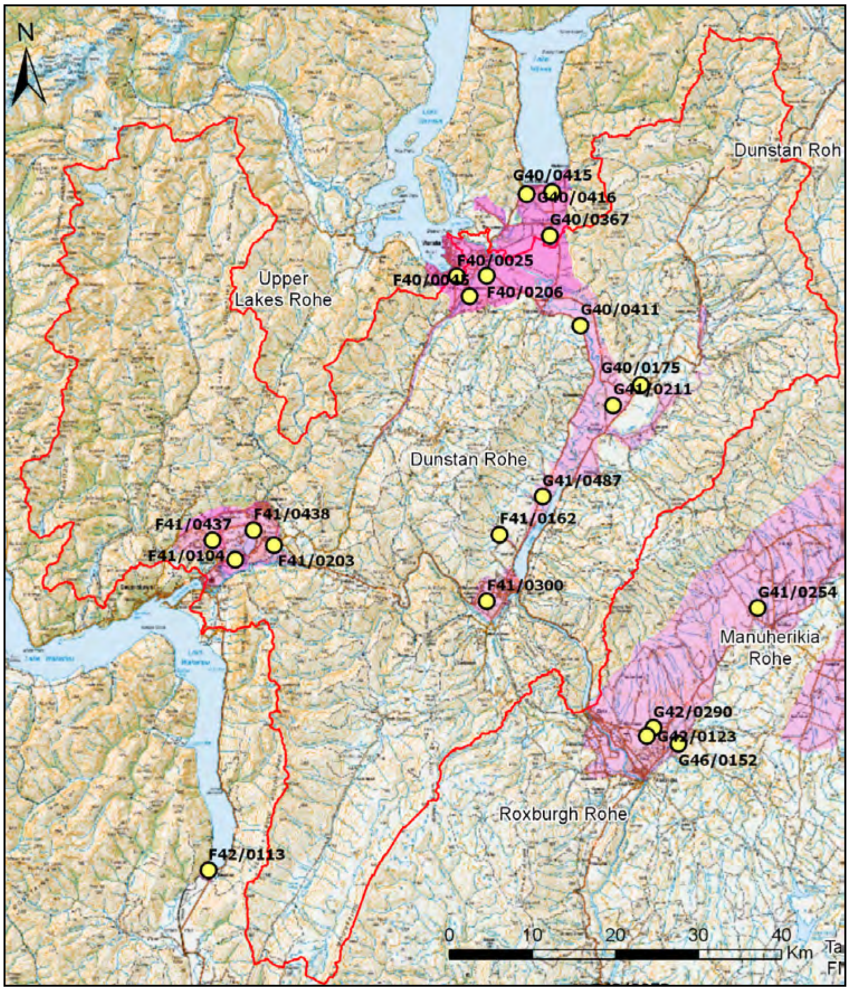
4.2.4. The Dunstan Rohe

The Dunstan Rohe encompasses the upper catchment of the Clutha River between south of Wanaka and Lake Dunstan alongside the Shotover catchment to the north of Queenstown. It runs from the outlets of lakes Wanaka, Wakatipu and Hawea down to Clyde dam. This rohe includes the Kawarau, Nevis, Shotover, Upper Clutha, Hawea, Cardrona, Arrow, and Lindis Rivers alongside many smaller tributaries of the Clutha such as the Lowburn, Amisfield Burn, Bannock Burn and Luggate Creek. The outflows of Lakes Wanaka and Wakatipu are un-regulated whereas the outflow of Lake Hawea is controlled by the Hawea Dam. This rohe also includes Lake Dunstan, a hydroelectric power lake created by the Clyde Dam, Figure 30. These catchments contain diverse landforms from the rugged Kawarau gorge, primarily native covered Shotover catchment to extensive agriculture and fruit growing areas around Lake Dunstan.

The bores in this rohe are divided to the following aquifers and GWMZ:

- The Wanaka & Cardrona Basin (Section 4.2.4.1)
- The (former) Wakatipu Basin (Section 4.2.4.2)
- The Cromwell Terrace Aquifer (Section 4.2.4.3)
- Lowburn Alluvial Aquifer (Section 4.2.4.4)
- The West Bank of the Upper Clutha (section 4.2.4.5)
- Lower Tarras (Section 4.2.4.6)

Figure 30: Location of the Dunstan Rohe (red outline), aquifers (green) and SoE monitoring bores (red dots). Aquifer names are shown in Figure 1.



The SoE results suggest that groundwater quality in the monitoring bores in the Dunstan rohe is generally good (particularly in the Cromwell Terrace aquifer and Lowburn Alluvial aquifer monitoring bores), with low E. coli and nitrate concentrations below the DWSNZ MAV in most bores. However, groundwater quality in some bores, particularly in Wanaka, the former Wakatipu basin, and Lower Tarras reflect issues of the rapid development in these areas which can lead to elevated E. coli, nitrate, and DRP concentrations. Although arsenic concentrations in most of the monitoring bores in the rohe are generally below the MAV, due to the prevalence of schist lithology in these areas, it is important that bore owners regularly test their water.

Groundwater quality from most of the shallow monitoring bores suggests potential for adversely impacting surface water quality that interact with groundwater, with nitrate and DRP concentrations in most bores exceeding the Schedule 15 limits. Ammonia concentrations are usually below the limits (Table 3, Table 15). It is likely that some of the elevated nitrate and DRP concentrations are also due to poor borehead protection.

Table 15: Median concentrations for DWSNZ/ecosystem health parameters for the Dunstan rohe

Aquifer	Ammoniacal Nitrogen (mg/L)	Arsenic Dissolved (mg/L)	Dissolved Reactive Phosphorus (mg/L)	E-Coli (MPN/100mL)	Nitrate Nitrogen (mg/L)	Total Nitrogen (mg/L)
Cromwell Terrace	0.005	0.001	0.007	0.500	2.350	1.525*
East Wanaka Basin Cardrona Gravel	0.005	0.001	0.005	0.500	1.270	2.050
Lowburn Alluvial Ribbon	0.005	0.001	0.003	0.500	0.330	0.355
Lower Tarras	0.005	0.001	0.004	0.500	1.095	1.160
Luggate GW Management Zone	0.003	0.001	0.023	0.500	7.750	7.700
Mid Mill Creek	0.003	0.001	0.002	0.800	0.113	0.144
Morven	0.005	0.001	0.003	0.500	1.100	0.170
Pisa GW Management Zone	0.003	0.001	0.002	0.500	0.245	0.230
Speargrass-Hawthorn	0.003	0.000	0.004	0.800	2.500	2.500
Unnamed	0.005	0.001	0.014	0.500	0.860	0.940
West Wanaka Basin Cardrona Gravel	0.005	0.001	0.003	0.500	0.390	0.400
Windemeer	0.260	0.014	0.009	0.500	0.028	0.280
Rohe median	**0.005**	**0.001**	**0.004**	**0.500**	**0.978**	**0.670**

***Note that TN has only been monitored since September 2017, which can potentially explain why the TN for the Cromwell Terrace aquifer and the rohe is lower than the median nitrate concentration. Some samples also show higher nitrate than TN, although the result is within the analytical variation for these methods.**

4.2.4.1 The Wanaka and Cardrona Basin

4.2.4.1.1 Aquifer information

The Wanaka Basin and the Cardrona Gravel Aquifer cover a sedimentary basin that consists of gravel-dominated strata downstream of the Cardrona River's Larches flow site. The aquifer is bounded by Lake Wanaka to the northwest and the Clutha River to the north east. The aquifer has complex hydrogeology due to deposition and reworking by glacial and fluvial activity over several phases of glacial advance and retreat. However, it generally behaves as a relatively consistent unit. There are also two outliers of basement strata within the basement.

The main source of recharge in the aquifer is flow losses from the Cardrona River where it enters the basin alongside some land surface recharge. Groundwater generally flows in a northerly direction from the low permeability hills toward the aquifer discharge points, which include the downstream reach of the Cardrona River, the Clutha River and Lake Wanaka. Groundwater depth varies across the aquifer, being around 20-30m deep below ground level where the Cardrona enters the basin, with shallower groundwater levels at the points of discharge near the Clutha River and Lake Wanaka. Bullock Creek, which flows through the township of Wanaka and has high value for the community, is spring-fed, hence, abstractions from the aquifer are likely to impact its flow. Groundwater use in the basin include irrigation and domestic supply (PDP, 2017b).

4.2.4.1.2. Groundwater quality results

Groundwater quality in the Wanaka area is monitored in three bores, details of which are summarised in Table 16. The aquifer is divided to and East and West Wanaka basins. Bore F40/0025 (150mm diameter) is located at Golf Course Road, Wanaka, at NZTM E1294352 N5042604. The bore depth is 40.0m. There is no bore log or screen information for this bore. Bore F40/0045 (100mm diameter) is situated at Faulks Road, approximately 470m east of the Cardrona River, at NZTM E1295870 N5040239. The bore depth is 60m. There is no bore log or screen information for this bore. Bore no. F40/0206 (150mm diameter) is located at Morris Road, at NZTM E1297955 N5042689. The log for this bore describes fine sand to 4.2m underlain by silty fine sands and gravels to 18.6m. There is then sandy gravel to the well bottom at 45.0m. There is no screen information for this bore, but it is likely that it is screened within the lower sandy gravels unit. Both bores F40/0045 and F40/0206 are located in the East Wanaka Basin.

Table 16: A summary of details for monitoring bores in the Wanaka Basin

Bore no.	Depth	Diameter (mm)	Easting	Northing	Screen Top (m)	Screen Bottom (m)	Bore log available?
F40/0025	40.0	150	1294352	5042604	N. A.	N. A.	No
F40/0045	60.0	100	1295870	5040239	N. A.	N. A.	No
F40/0206	45.0	150	1297955	5042689	N. A.	N. A.	Yes

The groundwater quality results from the East and West Wanaka Basins were compared against the DWSNZ. The results show no exceedances of the dissolved arsenic MAV (Figure 31). The E. Coli results are generally below the MAV, although an exceedance of 4 MPN/100mL was measured in bore F40/0025 in December 2019 (Figure 32). Nitrate concentrations are all below the DWSNZ MAV, ranging between 1.5 and 4.5mg/L. However, one substantially higher sample of 11.2mg/L, which is just below the MAV, was measured in December 2012 (Figure 33). Although these results are below the MAV, some of them exceed the nitrate groundwater concentration for natural/low intensity land use (Daughney and Morgenstern, 2012). Nitrate concentrations in the remaining bores are lower, ranging between 0.61 and 1.13mg/L (F40/0206) and 0.21 to 0.78mg/L (F40/0025).

Due to the depth of all bores exceeding 20m, the results were not assessed against the RPW or NPS-FM standards for surface water quality. However, the DRP and nitrate concentrations in bore F40/0045 would exceed the Schedule 15 limits for Group 3 (Table 2, Figure 34). The ammonia concentrations are below the GV, with a maximum value of 0.06mg/L (bore F40/0025, Figure 35).

Figure 31: Groundwater dissolved arsenic concentrations for the Wanaka Basin

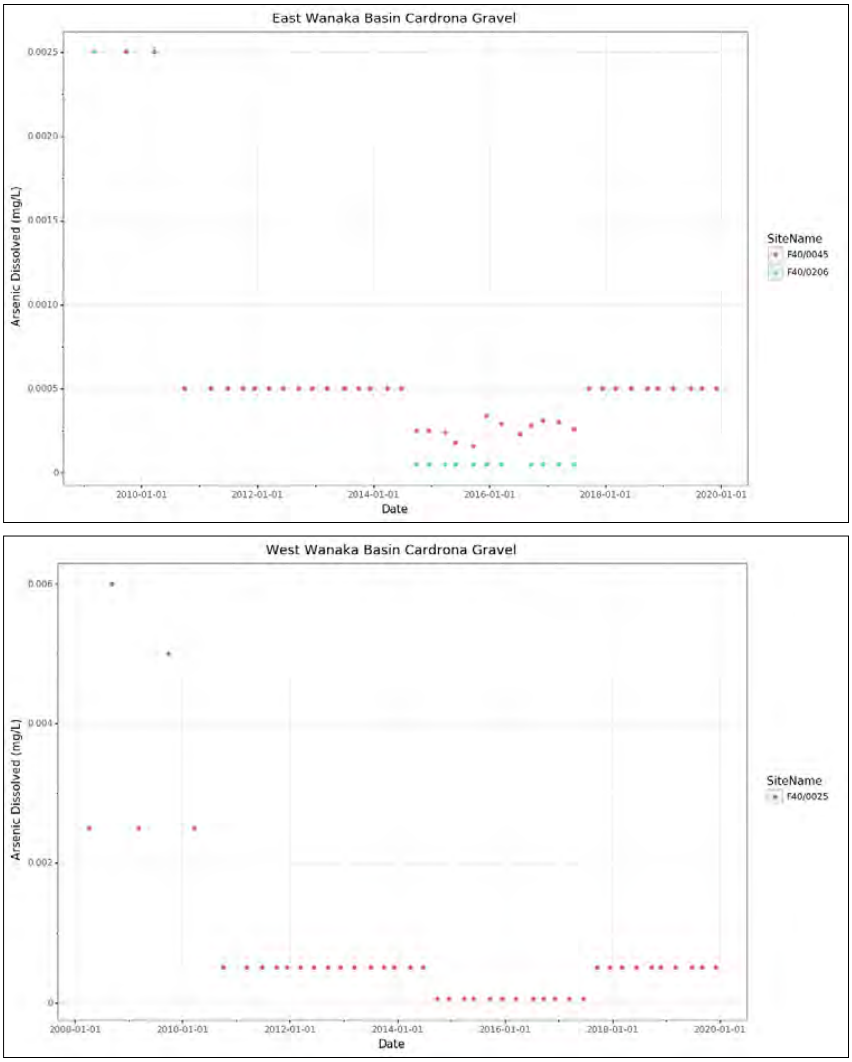


Figure 32: Groundwater E. coli count for the Wanaka Basin

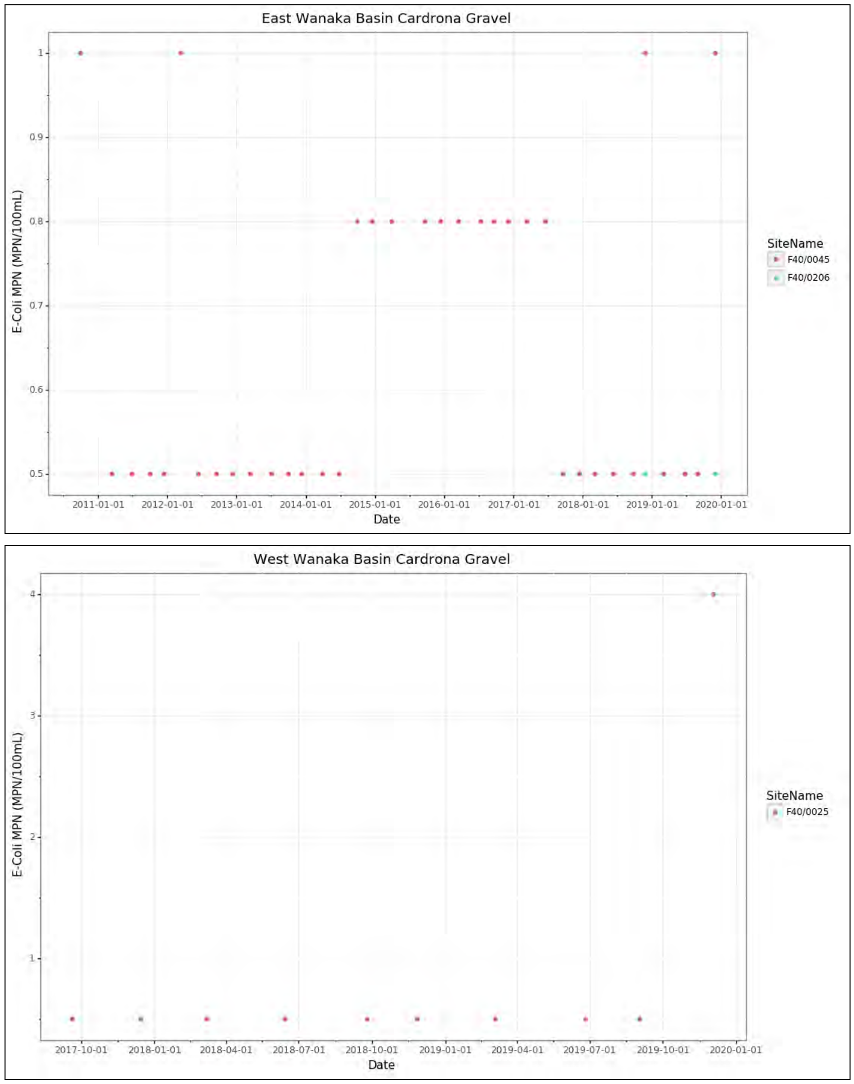
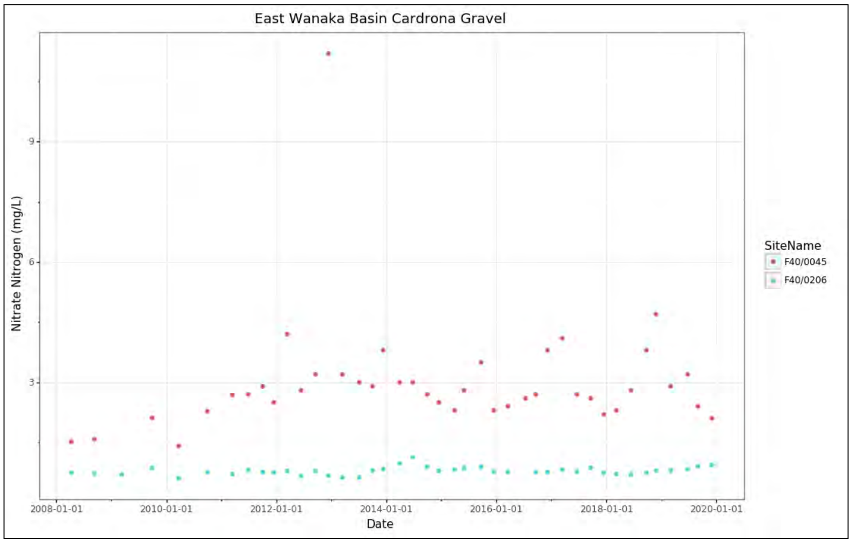


Figure 33: Groundwater nitrate concentrations for the Wanaka Basin



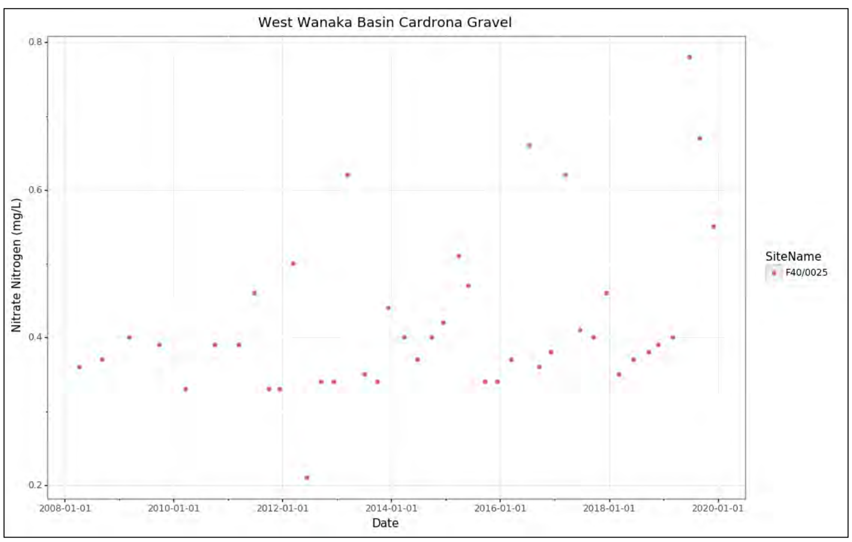
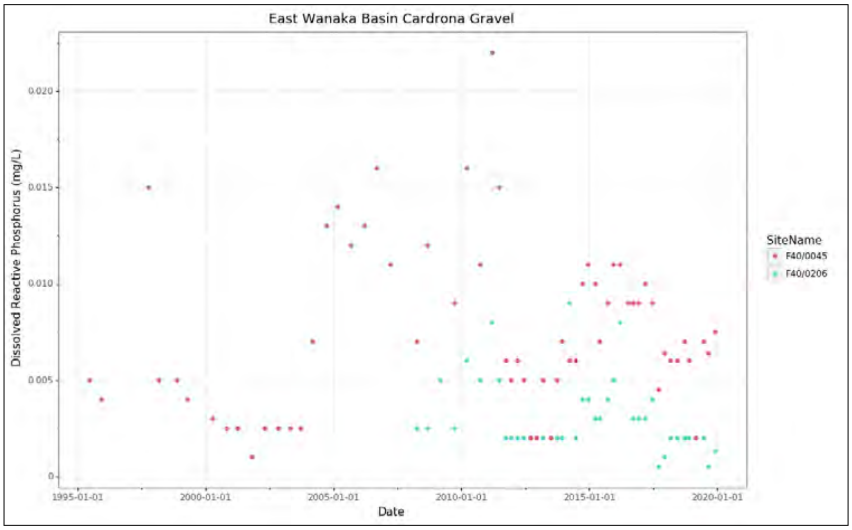


Figure 34: Groundwater Dissolved Reactive Phosphorus for the Wanaka Basin



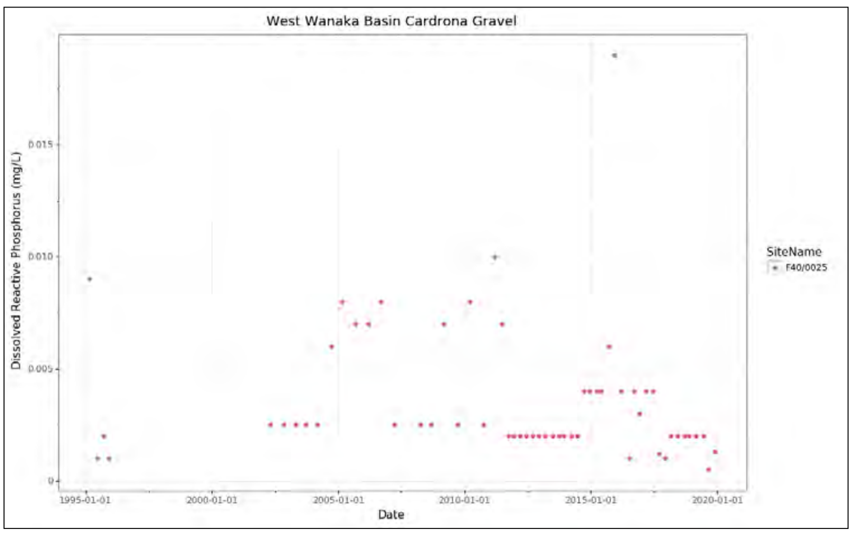
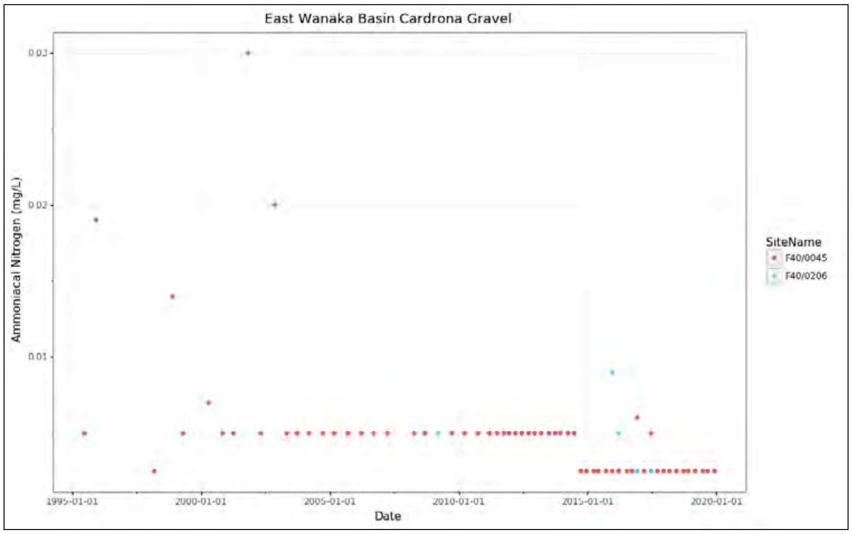
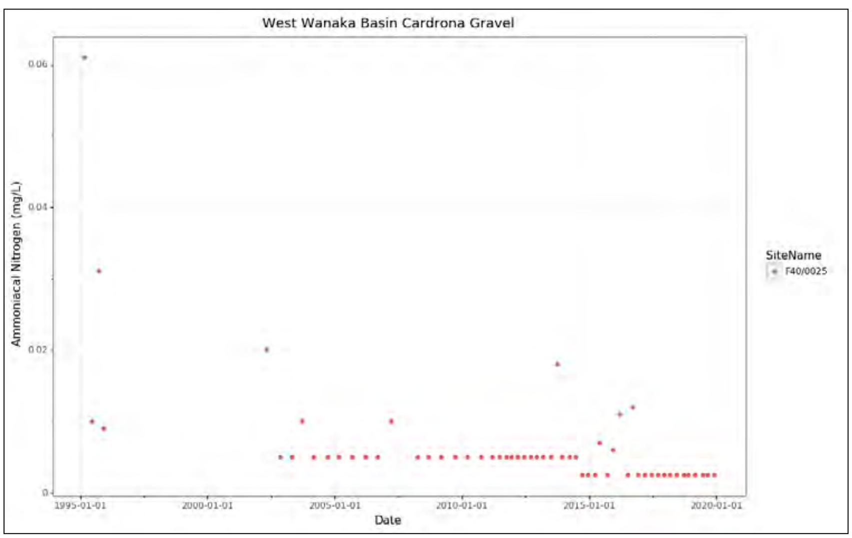


Figure 35: Groundwater ammonia concentrations for the Wanaka Basin





4.2.4.2 The Wakatipu Basin

4.2.4.2.1 Aquifer information

The Wakatipu basin is located near Queenstown and it contains some of the Upper Clutha's main surface water features: Lake Wakatipu and the Kawarau, Arrow, and Shotover Rivers. The basin is composed of metamorphosed schist bedrock overlain by Quaternary sediments from the Pleistocene and Holocene periods. In contrast to other parts of inland Otago, there are almost no Manuherikia Tertiary sediments in the basin. The geomorphology and hydrogeology of the Wakatipu Basin were significantly altered by glacial processes, where the glaciation/interglaciation cycles left characteristic deposits (i.e. glacial till, lacustrine deposits, fan, and alluvial sand/gravels, and terrace alluvium) and significantly impacted the levels of Lake Wakatipu (ORC, 2014a).

The Wakatipu Basin was originally considered in the RPW as one basin that contains several aquifers. The conceptual model is of eight small, laterally separated aquifers that are separated by basement ridges, groundwater flow divides, and rivers. The aquifers are thin and laterally distributed, and some were defined as alluvial ribbon aquifers. The individual Mean Annual Recharge (MAR) and allocation limits for each aquifer were based on the rainfall, soil, and aquifer area (ORC, 2014a). However, these were refined when the area, and allocation for some aquifers, was reviewed and adjusted (ORC, 2017b). The recharge and allocation from the revised aquifer areas was recalculated in November 2019 by using current climate data up to that period (ORC, 2019).

The dominant groundwater type in the basin is calcium-carbonate, indicative of fresh, young groundwater. The main groundwater uses in the area are municipal/community water supply and irrigation (ORC, 2014a). Groundwater quality in the aquifer is generally fair, although there are issues regarding the protection of drinking water quality (MoH, 2018). These include some areas with elevated nutrients due to grazing and septic tanks associated with this rapidly developing area. It also includes elevated arsenic concentrations in some aquifers, e.g. Ladies Mile (formerly known as Windemeer), which are attributed to the prevalent schist minerals that form the bedrock of the basin (e.g. Bloomberg, 2018) and potentially anthropogenic activities e.g. historical sheep dips (ORC, 2014a).

4.2.4.2.2 Groundwater quality monitoring

There are currently four SoE groundwater quality monitoring bores in the aquifers of the former Wakatipu Basin, whose details are summarised in Table 17. The bore locations are shown in Figure 30). Bore no. F41/0104 (100mm diameter) is located at Howards Drive, Queenstown, at NZTM E1267649 N5008496, in the Ladies Mile (former Windemeer) aquifer. The bore depth is 60m. There is no available screen information or lithological log for this bore. The SWL in the bore in November 2019 was 40.70m. The Morven aquifer is monitored through bore F41/0203 (50mm diameter), situated at Morven Ferry Road, NZTM E1272318 N5010248. The bore depth is 4.1m and the log describes gravel fill and sand to 1.2m underlain by gravels and sand to the bore bottom. There is no information regarding the screen depth in the bore. The SWL in the bore in November 2019 was 4.26m below MP. Groundwater quality in the Speargrass Hawthron aquifer is monitored in bore F41/0437, situated at Domain Road, NZTM E1264923 N5010849. The bore log describes 0.5m of top soil/silt underlain by fine to coarse gravel to 20.0m. There is then fine to coarse sand with some fine gravel underlain by fine, sandy silt to the bore bottom at 30m. The bore is screened between 24.35 and 24.85m, within the coarse sand/fine gravel horizon. The SWL in November 2019 was 23.745m below MP. The fourth monitoring bore, F41/0438, is located north of Lake Hayes, NZTM E1269859 N5012093. The bore log describes sandy gravels to the bore bottom at 6.0m. The bore is screened at a depth of 5.5m within this horizon. The SWL in the bore in November 2019 was 0.607m below MP.

Table 17: Summary of monitoring bore details for the Wakatipu Basin

Bore No.	Aquifer	Depth (m)	Diam. (mm)	Eastings	Northings	Screen Top (m)	Screen bottom (m)	Bore Log avail.?
F41/0104	Ladies Mile (Windemeer)	60.00	100	1267649	5008496	N.A.	N.A	No
F41/0203	Morven Ferry	4.10	50	1272318	5010248	N.A.	N.A	Yes
F41/0437	Speargrass-Hawthorn	24.85	N.A	1264923	5010849	24.85	24.35	Yes
F41/0438	Mid-Mill Creek	6.0	N.A	1269859	5012093	6.0	5.5	Yes

In relation to the DWSNZ, the dissolved arsenic concentrations for the Wakatipu Basin are shown in Figure 36. The results show that arsenic concentrations in the Ladies Mile bore (F41/0104) consistently exceed the DWSNZ MAV of 0.01mg/L, with most of the results range between 0.01 and 0.019mg/L. The concentrations in the other bores are below the MAV, although the Morven Ferry and Mill Creek bores each had one result between 0.0075 and 0.01mg/L in December 2015. The results in the Speargrass-Hawthorn bore were substantially below the MAV. The consistent elevated arsenic concentrations in the Ladies Mile bore are concerning, although elevated arsenic is common within the Wakatipu Basin due to the local schist lithology (e.g. Bloomberg, 2018). None of the bores had ammonia concentrations that exceeded the 1.5mg/L Guideline Value for aesthetic determinants (Figure 37).

Figure 36: Groundwater dissolved arsenic concentrations for the Wakatipu Basin

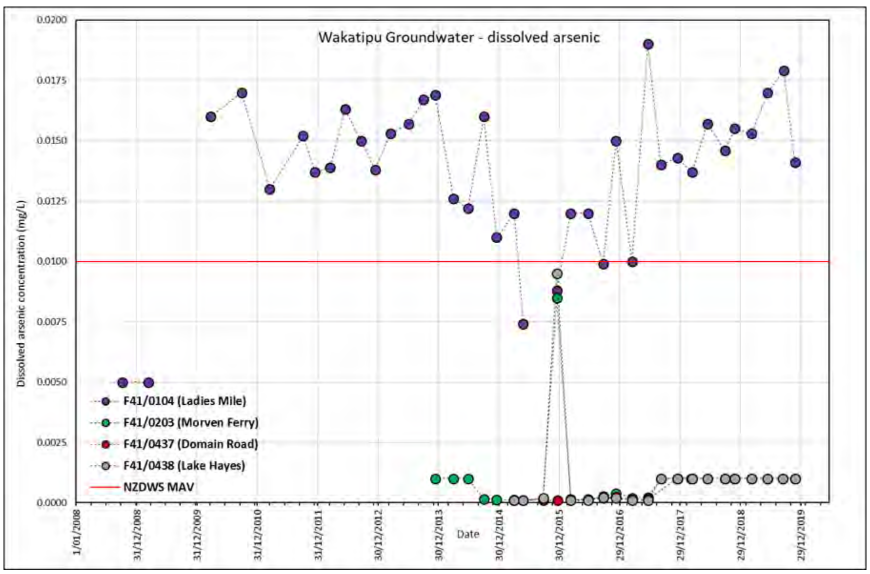
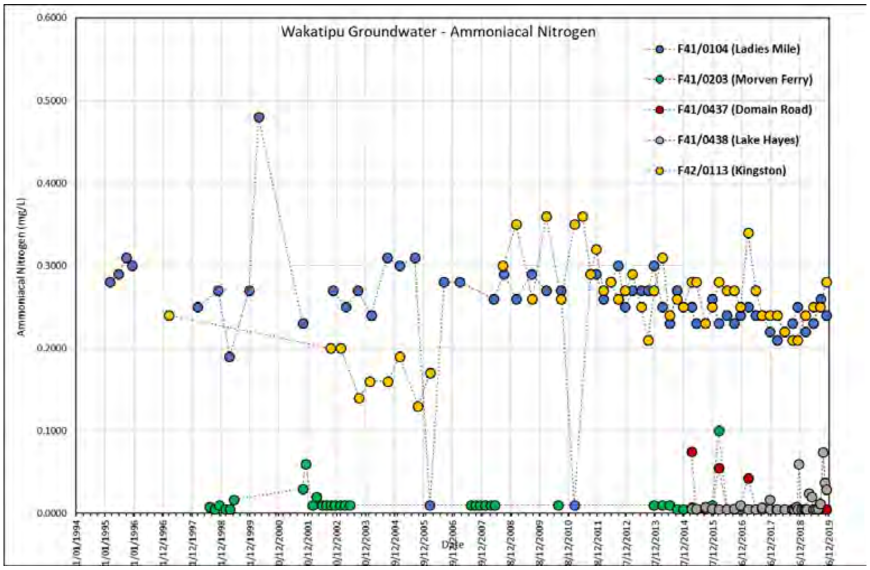


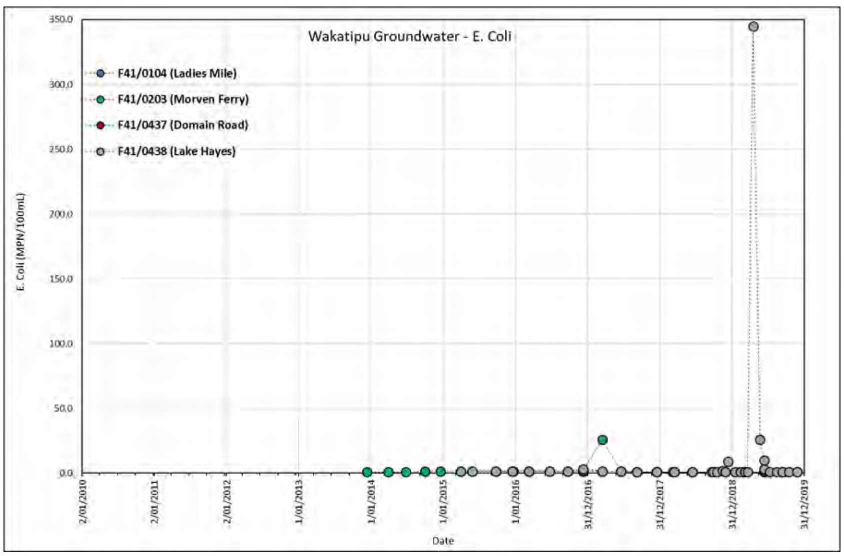
Figure 37: Groundwater ammonia concentrations for the Wakatipu Basin



The E. coli data for the Wakatipu basin is shown in

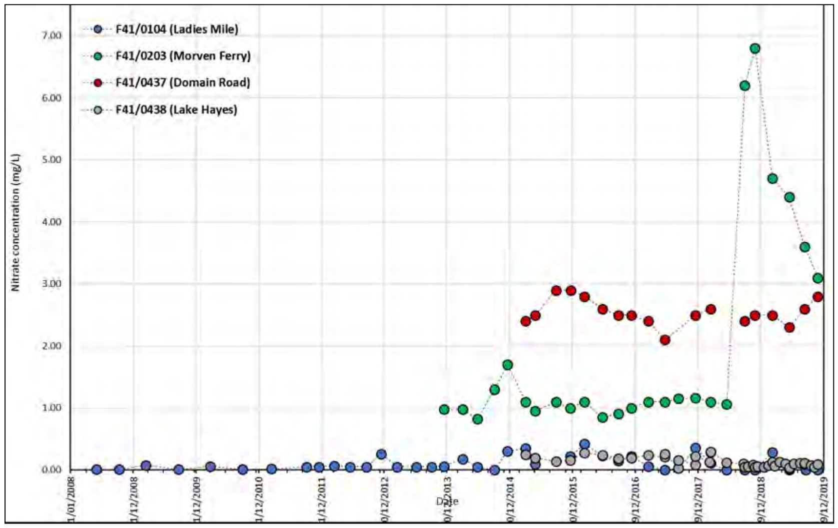
Figure 38. Bores F41/0104 and F41/0437 had no E. coli exceedances over the DWSNZ MAV of 1 MPN/100mL. The E. Coli in bore F41/0203 was generally below the DWSNZ MAV, with one exceedance of 26 MPN/100mL in March 2017. In contrast to these, bore no. F41/0438 had several exceedances, notably between April and June 2019, with measurements of 345, 26, and 10MPN/100mL. However, these exceedances are potentially due to poor bore security, as the borehead is located at ground level, in an area known to be occasionally flooded by surface water and is frequented by rabbits/ducks. Nevertheless, faecal contamination is likely to be prevalent in this area due to the rural life style and high density of septic tanks. It is therefore imperative that bore owners maintain bore security and regularly check their water supply to avoid faecal contamination.

Figure 38: Groundwater E. Coli counts for the Wakatipu Basin



Nitrate concentrations in all bores were below the DWSNZ MAV of 11.3mg/L, although some concentrations above ½ of the MAV were measured in the Morven Ferry bore (F41/0203), Figure 39. The concentrations in this bore ranged between approximately 1.0 and 2.0 mg/L between the start of measurements in January 2013 and September 2018, where concentrations substantially increased to 6.2mg/L. Concentrations then steadily declined, falling to 3.1mg/L in November 2019. The causes for this high increase are unclear and can be potentially related to a change in land use. In contrast to these higher concentrations, those in the remaining bores were lower, with the Speargrass-Hawthorn bore ranging between approximately 2.0 and 3.0mg/L and the Ladies Mile (F41/0104) and Mid Mill Creek (F41/0438) below 1.0mg/L.

Figure 39: Groundwater nitrate concentrations for the Wakatipu Basin



Potential impacts on surface water were then assessed from the shallow monitoring bores (<20m) in the Wakatipu Basin, with the results compared against Schedule 15 of the RPW (Table 18) and the NPS-FM NOF (Table 19). This included the bores in the Morven and Mid Mill Creek aquifers. The results show that the 80th percentile nitrate concentrations in both bores exceed the Schedule 15 limits, with the Morven bore concentrations exceeding the limit by 42 times. These exceedances are likely due to the shallow bore depths, surrounding land use, and potential issues with bore security. In contrast to that, the ammonia and DRP concentrations in both bores are below the RPW limits.

Table 18: Wakatipu Basin 80th percentile values for water quality variables & comparison with Schedule 15 limits

Bore number	Aquifer	Nitrate (NO_3-N)	Dissolved Reactive Phosphorus (DRP)	Ammoniacal nitrogen (NH_4-N)
Group 2 Sched. 15 limit (mg/L)		**0.075**	**0.010**	**0.100**
F41/0203	**Morven**	3.200	0.005	0.010
F41/0438	**Mid Mill Creek**	0.212	0.004	0.012

Compliance with the NPS-FM NOF is shown in Table 19. This again highlights potential issues, particularly for nitrate. The Morven bore nitrate concentration is emplaced in band B for the median concentration and Band C for the 95th percentile. When a site falls in Band C there are "Growth effects on up to 20% of species (mainly sensitive species such as fish). No acute effects (MfE, 2020)." The Mid Mill Creek bore is in Band A for both the median and 95th percentile nitrate concentration.

The results for ammonia show that the median concentrations in both bores are in Band A, with maximum concentrations in Band B. Band A reflects an environment where there is no observed toxicity effect on tested species, which provides a 99% protection level. Band B reflect a site where ammonia concentrations begin to occasionally impact the 5% of the most sensitive species (MfE, 2020). The DRP concentrations are in Band A for both bores.

The results against the RPW and NOF suggest that interaction of groundwater from these bores with surface water may adversely impact surface water quality, particularly regarding nitrate in the Morven Ferry bore. Although the Mid Mill Creek bore was placed in Band B for ammonia, due to the already existing water quality issues in Lake Hayes (ORC, 2017a) it is not likely that interaction with the groundwater will further degrade it.

Table 19: NPS-FM NOF comparison summary for the Wakatipu Basin

		Nitrate concentration (mg/L)		NOF Band	
Bore no.	**Aquifer**	**Median**	**95th percentile**	**Median**	**95th percentile**
F41/0203	**Morven (Wakatipu)**	1.1	5.9	B	C
F41/0438	**Mid Mill Creek**	0.113	0.2805	A	A
		Ammoniacal nitrogen concertation (mg/L)		**NOF Band**	
Bore number	**Aquifer**	**Median**	**Max.**	**Median**	**Maximum**
F41/0203	**Morven (Wakatipu)**	0.005	0.1	A	B
F41/0438	**Mid Mill Creek**	0.0025	0.074	A	B
		DRP concentration (mg/L)		**NOF Band**	
Bore number	**Aquifer**	**Median**	**95th percentile (mg/L)**	**Median**	**95th percentile**
F41/0203	**Morven (Wakatipu)**	0.0025	0.0066	A	A
F41/0438	**Mid Mill Creek**	0.002	0.005	A	A

4.2.4.3. Cromwell Terrace Aquifer

4.2.4.3.1 Aquifer information

The Cromwell Terrace aquifer is located on an elevated glacial outwash surface that rests on the fork of the Upper Clutha/Kawarau Rivers confluence. Despite its small area of 22km^2, the Cromwell Terrace aquifer is of great significance to the local communities. The aquifer is shallow and unconfined and is closely impacted by landuse and surface water. It was formed by at least three glacial outwash terraces that coalesced in the Cromwell confluence area and include gravel formations from the Upper Clutha and Kawarau catchments. The outwash is generally underlain by relatively impermeable Manuherikia Group mudstone, lignite, and schist. The overlying soils that were formed on the terrace surface are sandy with generally low water retention. The terrace is not crossed by any surface water courses although artificial races and ponds were built across some of its surface. The hydrology of the fringing Kawarau River was substantially altered when Lake Dunstan was filled following completion of the Clyde Dam in 1993. The measured mean rise in water table after this was around 10.5m, hence the aquifer stores a much larger water resource.

Groundwater uses include irrigation, stock and domestic (including town/community) supply. Aquifer pumping tests from completed bores in the Cromwell township area indicate generally high to extremely high Transmissivity. The aquifer is in a dynamic equilibrium with Lake Dunstan, with a modest volume of recharge in the Ripponvale area and discharge of its excess further downstream. Due to the high transmissivity, the aquifer responds very rapidly to groundwater extraction by inducing infiltration from the Lake (ORC, 2014b).

4.2.4.3.2 Groundwater quality monitoring

There is only one groundwater quality SoE monitoring bore in the Cromwell Aquifer Terrace, F41/0300 (150mm diameter). The bore is situated at Sandiflat Road, near the Highlands Motor Sports Park, at NZTM E1297971 N5003508. The bore depth is 48.71m. The bore log describes clay/fine gravels to 1.54m underlain by coarse/fine sandy gravels to 12.64m. There is then boulders to 13.10m underlain by sandy gravels to the well bottom (48.76m) with a horizon of boulders between 30.10 and 30.50m. The bottom sandy gravel horizon, between 30.50 and 48.76m, is described as coarse sandy gravels. The top of the screen leader is located within the coarse sandy gravel horizon, at a depth of 47.61m. The SWL in the bore in December 2019 was 33.3m below MP.

The assessment against the DWSNZ are shown in Figure 40 to

Figure 44. Regarding the DWSNZ, the results indicate good groundwater in the bore. Nitrate concentrations were all below the 11.3mg/L MAV. Nitrate concentrations were between 2.44 and 4.06mg/L during the initial monitoring period (2009 – 2011), with concentrations then continuously falling, reaching around 1.1mg/L in 2019 (Figure 40). Dissolved arsenic concentrations were generally substantially below the DWSNZ MAV of 0.01mg/L, although a sample from March 2009 was close to it at 0.009mg/L (Figure 41). Most of the E. coli results are below the <1 MPN/100mL MAV, although some of the earlier results read <2 and <1.6MPN/100mL, which are potentially related to different analytical Limits of Detection (

Figure 42). This suggests that the risk of faecal contamination is low. Ammonia concentrations were below the aesthetic GV value of 1.5mg/L (Figure 43). Due to the bore's depth of 48.71m it was not assessed for ecosystem impacts. However, due to its depth it is not likely to interact with surface water.

Figure 40: Groundwater nitrate concentrations for the Cromwell Terrace Aquifer

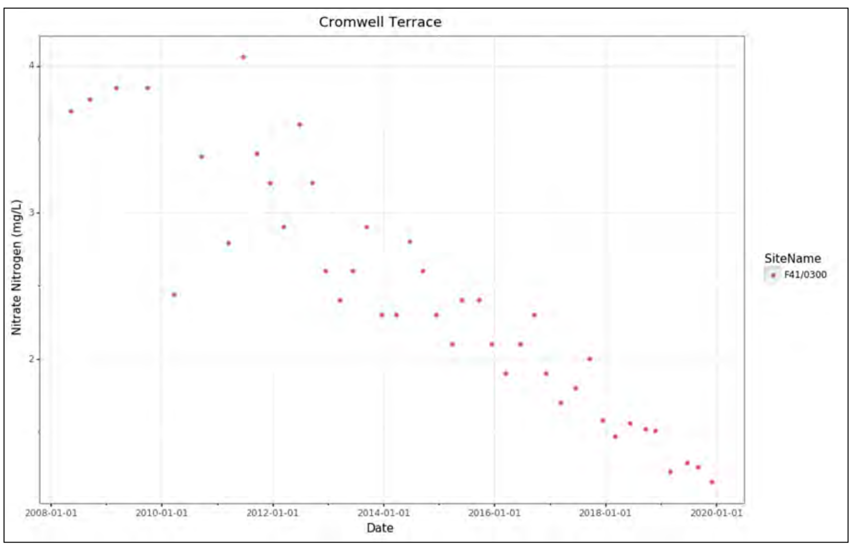


Figure 41: Groundwater dissolved arsenic concentration for the Cromwell Terrace Aquifer

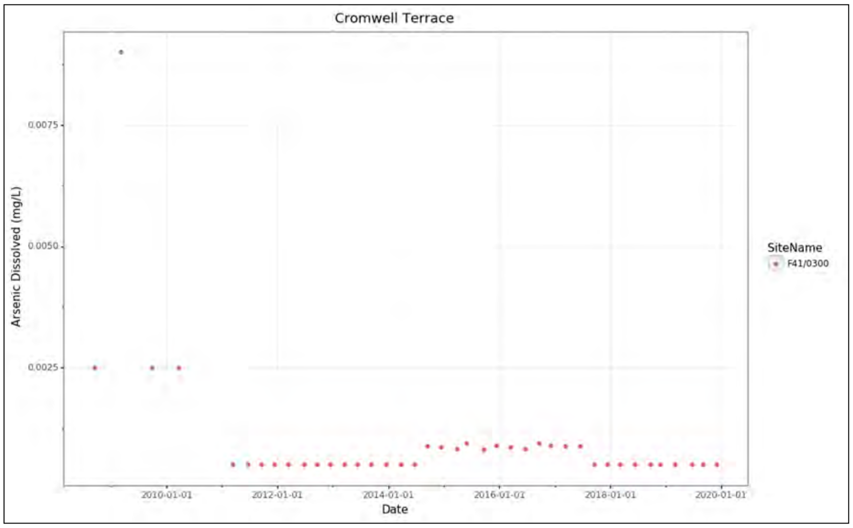


Figure 42: Groundwater E. coli count for the Cromwell Terrace Aquifer

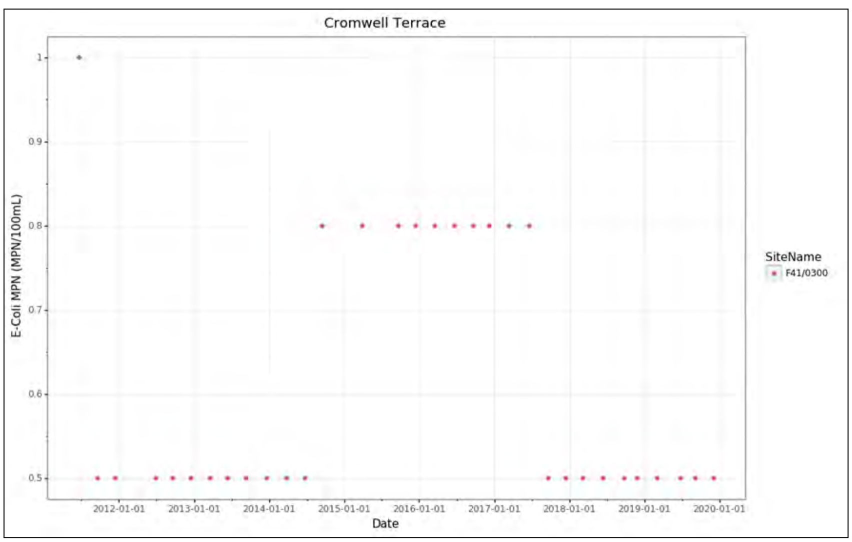


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Figure 43: Groundwater ammonia concentration for the Cromwell Terrace Aquifer

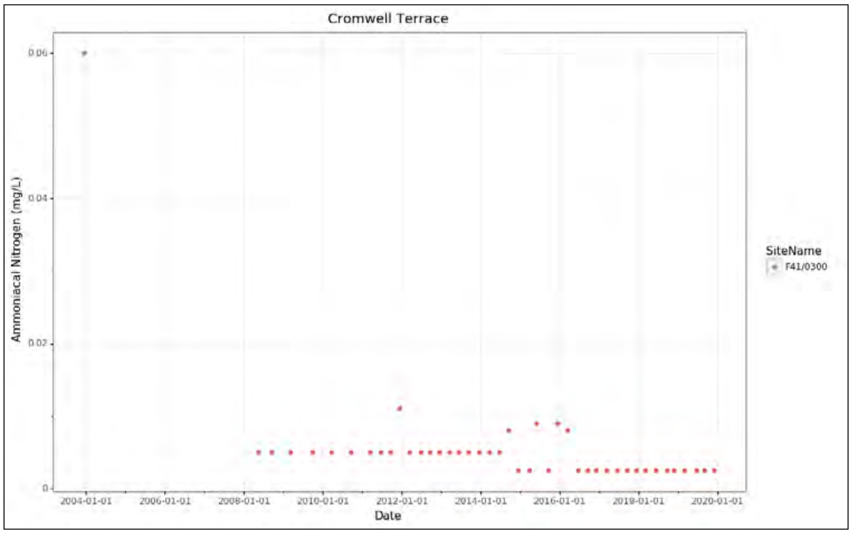
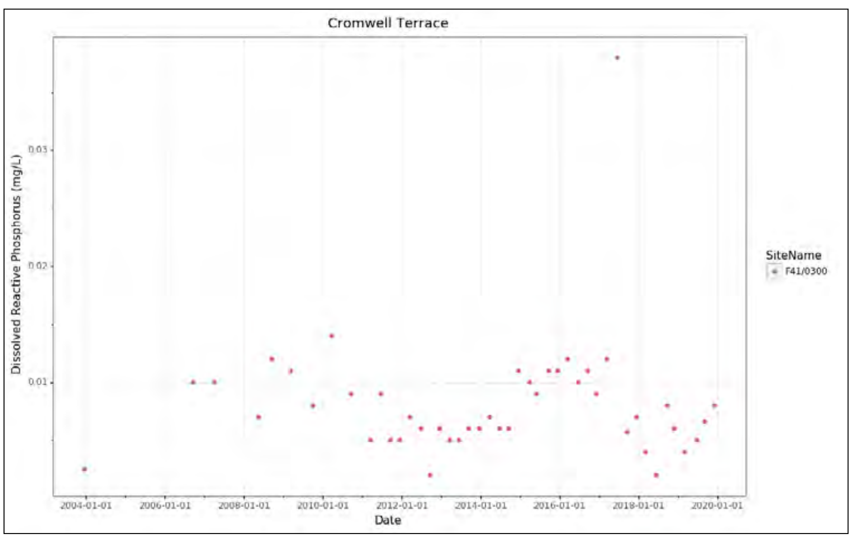


Figure 44: Groundwater Dissolved Reactive Phosphorus concentration for the Cromwell Terrace Aquifer



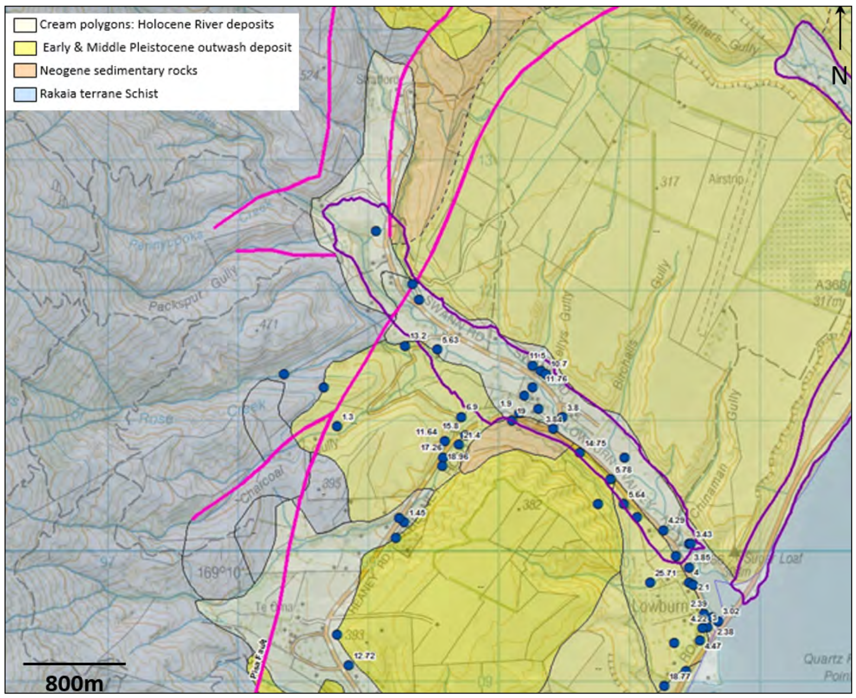
4.2.4.4 Lowburn Alluvial aquifer

4.2.4.4.1 Aquifer information

The Lowburn Alluvial Ribbon aquifer is located north of Cromwell and west of Lake Dunstan. It is bounded to the west by the eastern side of the Pisa Range (Lowburn Face), whose peaks reach elevations of around 1500-1600m. It is bounded to the east by Lake Dunstan. The western boundary of the delineated aquifer zone is located where the Low Burn descends from the Lowburn Face and enters the narrow valley. The aquifer includes the narrow river valley that is approximately 100m lower than the surrounding terraces to the north and south (ORC, 2018a).

The aquifer is located within Holocene river deposits composed of unconsolidated gravel, silt, clay and minor peat of modern-postglacial flood plains. The ranges to the west/southwest of the aquifer are composed of Rakaia Terrane schist whilst the terraces in the north and south are composed of Early/Mid Pleistocene outwash deposits and a small portion of Neogene sedimentary rock near the intersection between Lowburn Valley Road and Heaney Road, Figure 45 (Turnbull, 2000).

Figure 45: geological setting for the Lowburn Alluvial Ribbon Aquifer (from Turnbull, 2000)



The main groundwater uses in the area are irrigation, stock water, and domestic supply. According to the ORC database there are 16 completed bores in the Lowburn Alluvial Ribbon aquifer, whose depth ranges between 2 and 20m. The depth of two bores are not known. There is information regarding the SWL for 12 bores, and it ranges between 1.90 and 14.75m below Measuring Point. Screen depth information is only available for one bore, F41/0449, which is screened between 15.65 and 16.65m, within a horizon of sandy/silty gravels.

4.2.4.4.2 Groundwater quality monitoring

Groundwater SoE monitoring in the Lowburn Alluvial Aquifer is currently conducted in one bore, F41/0162 (125mm diameter), drilled in June 1995. The bore is located at Swann Road, NZTM E1299519 N5011550 (Figure 30). The bore is 16.53m deep, hence one of the deeper ones in the area. The bore log describes topsoil to 0.30m underlain by cobbles and sandy gravels to 3.3m. There is then sandy gravels with some cobbles to the bore bottom at 16.53m. The depth to the top of the screen leader is 15.77m, suggesting that the bore abstracts from an unconfined sandy gravel aquifer. The SWL in the bore ranges between 4.65 and 6.83m below MP. The maximum annual fluctuation is around 1.00-1.50m, with the lowest levels generally observed in December or March. The SWL in December 2019 was 5.1m below MP.

Groundwater quality from bore F41/0162 was assessed against the DWSNZ, Figure 46, Figure 47, and Figure 48. The results indicate good groundwater quality. Most E. coli results are below the <1 MPN/100mL MAV, although some of the earlier results read <2 and <1.6MPN/100mL. This suggests a low risk of faecal contamination, with the exceedances potentially related to different analytical Limits of Detection. There were no arsenic concentrations that exceeded the 0.01mg/L MAV. The nitrate concentration is also much lower than the DWSNZ MAV, ranging between 0.24 and 0.52mg/L. All ammonia concentrations were below the 1.5mg/L GV.

Figure 46: Groundwater E. Coli count for the Lowburn Alluvial Aquifer

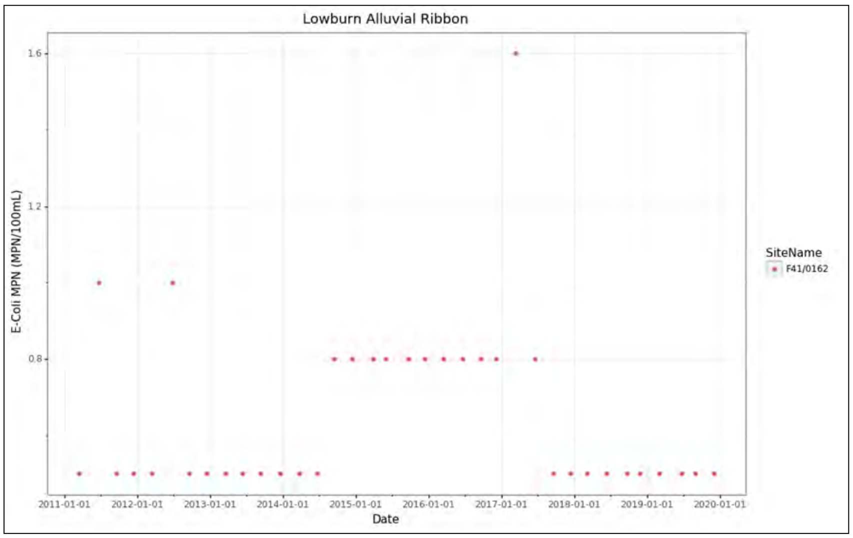


Figure 47: Groundwater dissolved arsenic concentration for the Lowburn Alluvial Aquifer

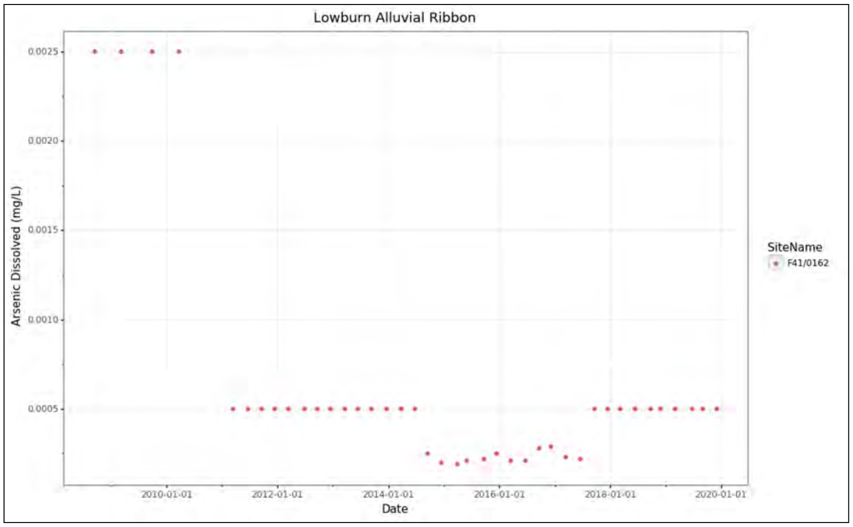


Figure 48: Groundwater nitrate concentration for the Lowburn Alluvial Aquifer

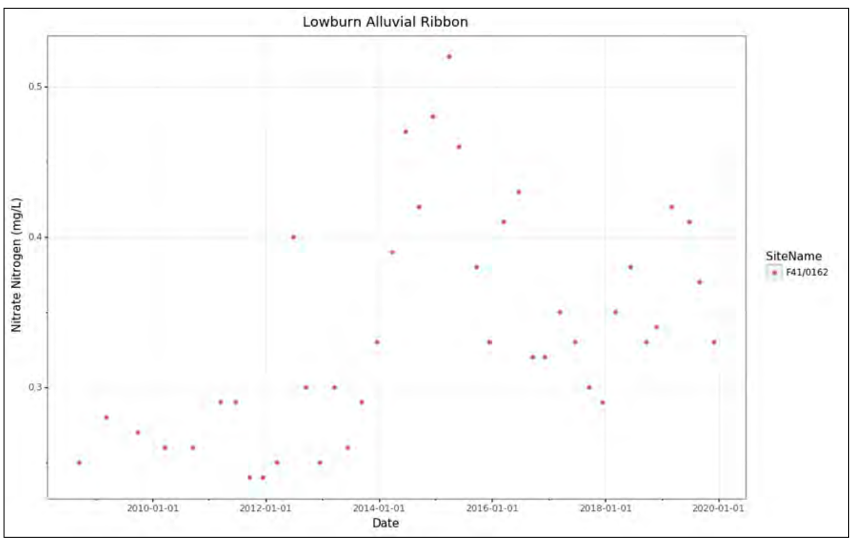
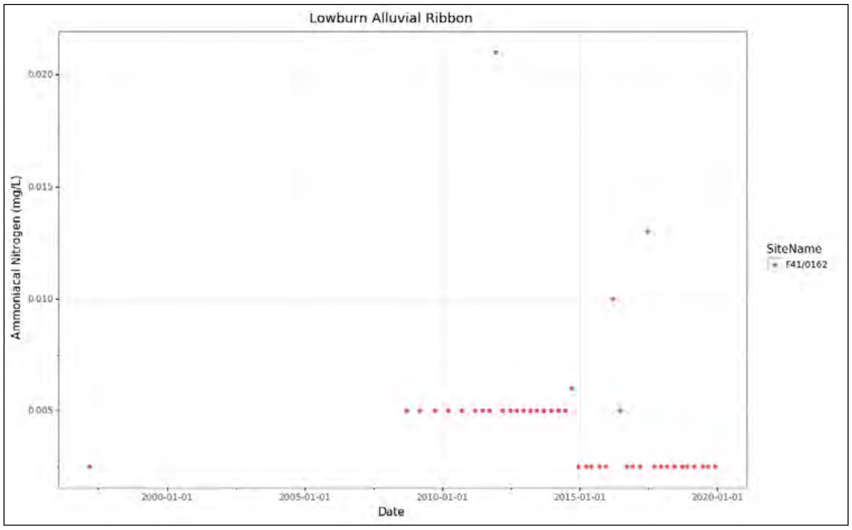


Figure 49: Groundwater ammonia concentration for the Lowburn Alluvial Aquifer



The results were then compared against the RPW Schedule 15 (Table 20) limits and the NPS-FM (Table 21). The Lowburn Alluvial aquifer is located in Group 2 of Schedule 15. The results show that the site is non-compliant with the nitrate limits, which are around five times higher than the threshold. This suggests that interaction of groundwater with surface water, such as the Low Burn, may increase eutrophication and algal growth potential. The results are compliant with the DRP and ammonia limits. Regarding the NPS-FM NOF, all the results sit within the A Band.

Table 20: Schedule 15 comparison results for the Lowburn Alluvial aquifer for 80th percentile for nitrate, DRP, and ammonia.

Bore number				Nitrate (NO_3-N)	Dissolved Reactive Phosphorus (DRP)	Ammoniacal nitrogen (NH_4-N)
Group 2 Sched. 15 limit (mg/L)				**0.075**	**0.010**	**0.100**
F41/0162	Clutha	Dunstan	Lowburn	0.410	0.008	0.010

Table 21: NOF comparison for the Lowburn Alluvial aquifer

	Nitrate		NOF Band	
Bore no.	**Median (mg/L)**	**95th percentile (mg/L)**	**median**	**95th percentile**
F41/0162	0.33	0.47	A	A
	Ammoniacal nitrogen		**NOF Band**	
Bore number	**median (mg/L)**	**Max (mg/L)**	**Median**	**Maximum**
F41/0162	0.005	0.021	A	A
	DRP		**NOF Band**	
Bore number	**Median (mg/L)**	**95th percentile (mg/L)**	**Median**	**95th percentile**
F41/0162	0.00325	0.01095	A	A

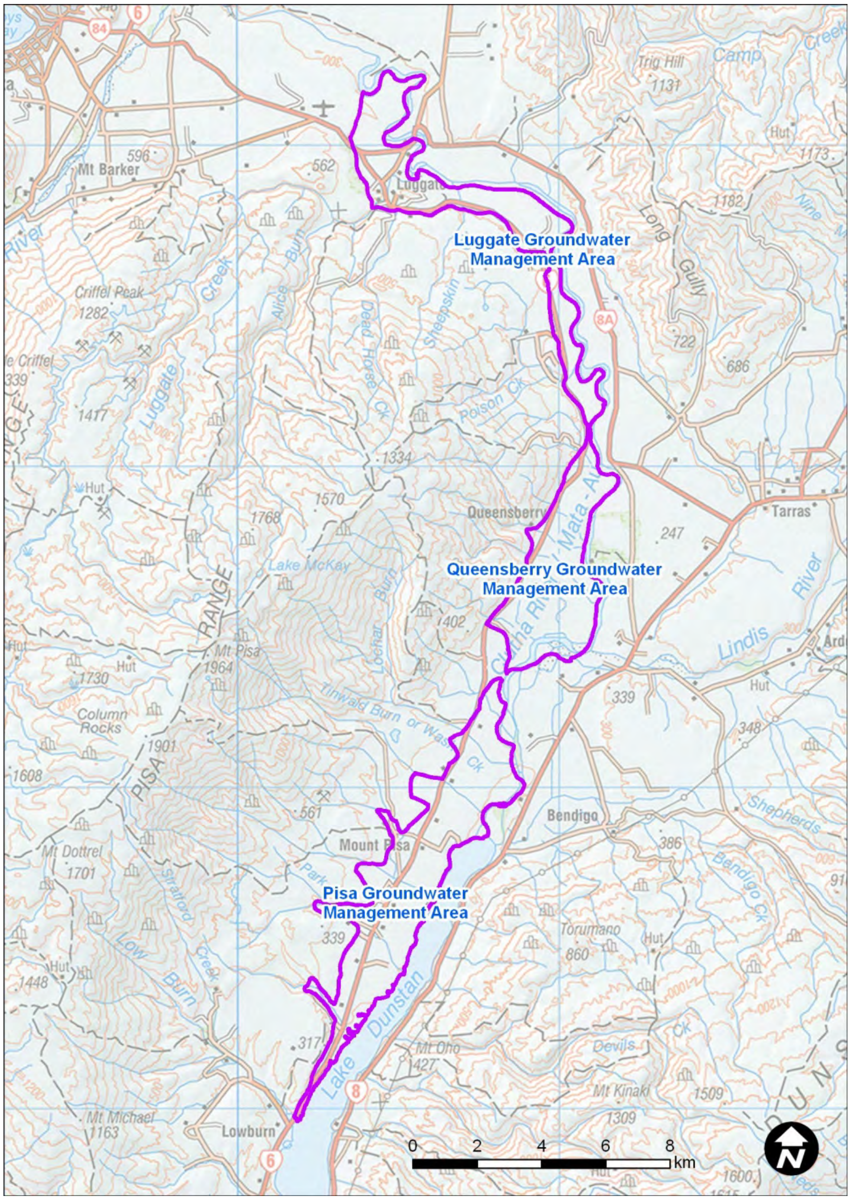
4.2.4.5 West Bank of the Upper Clutha

4.2.4.5.1 aquifer information

The West Bank of the Upper Clutha, situated between Lowburn and Luggate, includes the Pisa, Luggate, and Queensberry Groundwater Management Zones (GWMZ). These were delineated using a 1:250,000 GNS geological map (QMap) for the West Bank of the Upper Clutha (Turnbull, 2000). The GWMZ were identified based on geological classification of Quaternary sediment Q1-Q4 and some Q6 sediment that are located between the Clutha River on the east and the Pisa Range in the west. This work identified three GWMZ where alluvial sediment "pinch" between schist and/or older sediment and the Clutha River. Areas where the sediment extends west into valleys were excluded (ORC, 2018b). The location of these delineated GWMZs is provided in

Figure 50. The Pisa GWMZ is situated between Lowburn to the south, and Kind Creek in the north. The Queensberry GWMZ's northern boundary is around Edward Burn. The Luggate GWMZ is located north of the Burn until the southern boundary of the Wanaka Basin.

Figure 50: Location of GWMZ on the West Bank of the Clutha (from ORC, 2018b)



The database search shows there are 116 bores within the three GWMZ, 113 of which have recorded depths. The bore depths in these GWMZ range between 5.80 and 102m. SWL are recorded in 99 of the bores, with the SWL ranging between 1.25 and 33.4m below MP. Screen depth information is available for 32 bores, with the top of screen depths ranging between 9.67 and 102m, although this lower screen depth is likely to be an error as the maximum recorded bore depth is also 102m. Groundwater uses in the area include irrigation, community, stock, domestic supply and commercial use. This area experiences a rapid expansion of horticulture/viticulture with increasing demand for water applied *via* drip irrigation. This has induced ORC to begin developing a monitoring program, with two bores drilled in the Pisa and Luggate GWMZ in 2017 (ORC, 2018b). There is currently no groundwater monitoring in the Queensberry GWMZ.

4.1.2.5.2 Groundwater quality measurements

There are two SoE bores for monitoring groundwater quality in the West Bank of the Upper Clutha area. Groundwater in the Luggate GWMZ is monitored in bore G40/0411 (150mm diameter), drilled in May 2017. The bore is situated at Pukerangi Drive at NZTM E1309254 N5036692. The bore depth is 17.75m. The log describes silty coarse gravels and cobbles to 2.5m underlain by sandy coarse gravels and cobbles to 5.6m. There is then silty/sandy schist gravel to 9m underlain by schist to 12m. The silt is fractured from 12m to the bottom of the bore at 17.75m. The bore is screened between 12.75 and 17.75m, within the fractured schist. The SWL in November 2019 was 8.112m below MP.

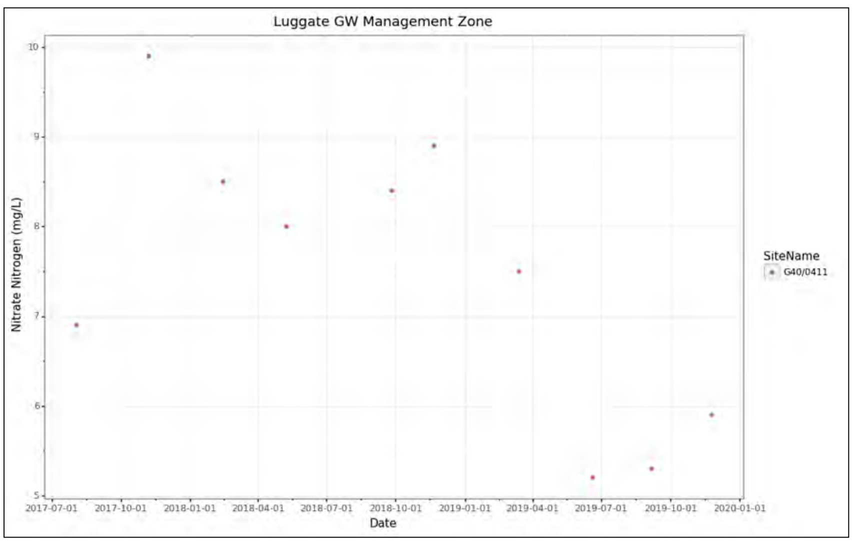
Groundwater in the Pisa GWMZ is monitored in bore G41/0487 (150mm diameter), located at Smiths' Way, NZTM E1304667 N5016105. The bore depth is 28.99m. The bore log describes sandy coarse gravels and some cobbles to 21.4m underlain by sands with finer gravels to 22.5m. There are then silty coarse gravels to 28.8m underlain by brown silts to the bore bottom at 29.4m. The bore is screened at a depth of between 25.99 and 28.99m, within the bottom silty, coarse gravel horizon. The SWL in November 2019 was 20.15m below MP.

Regarding the DWSNZ, groundwater quality in both bores is generally good, with the main issue being elevated nitrate concentrations in bore G40/0411 (Figure 51). Although the concentrations in the bore did not exceed the 11.3mg/L MAV, it ranged between 5.2 and 9.9mg/L, which is close to exceeding the MAV. These high concentrations are potentially due to cultivation of a paddock next to the bore or to septic tanks. The concentrations in bore G41/0487 were substantially lower, ranging between 0.192 and 0.33mg/L. Concentrations in neither bore exceeded the dissolved arsenic MAV of 0.01mg/L (Figure 52). However, due to the prevalence of schist lithology in the area, and the high spatial heterogeneity of dissolved arsenic in groundwater, it is important that bore owners in the area regularly test their bores for arsenic. There was no E. coli detected in neither bore (

Figure 53). Ammonia concentrations in neither of the bores exceeded the DWSNZ GV of 1.5mg/L (

Figure 54).

Figure 51: Groundwater nitrate concentration for the Luggate/Pisa GWMZ



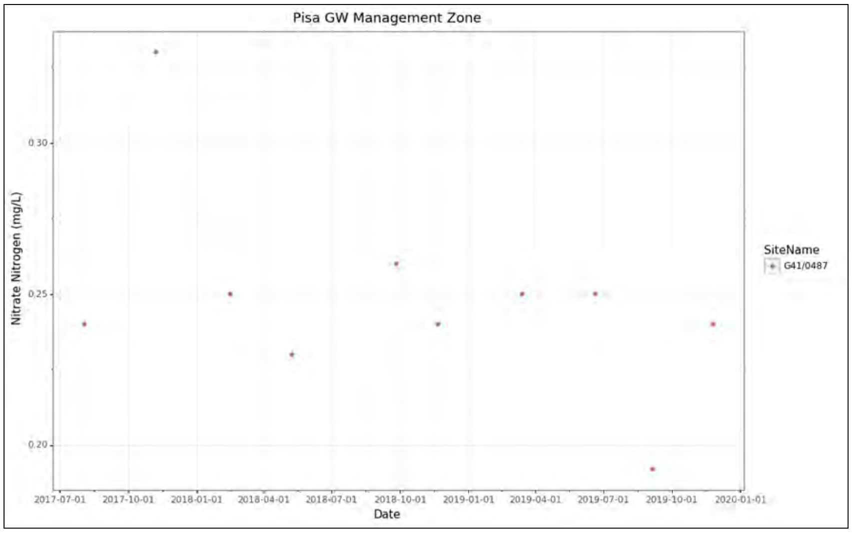
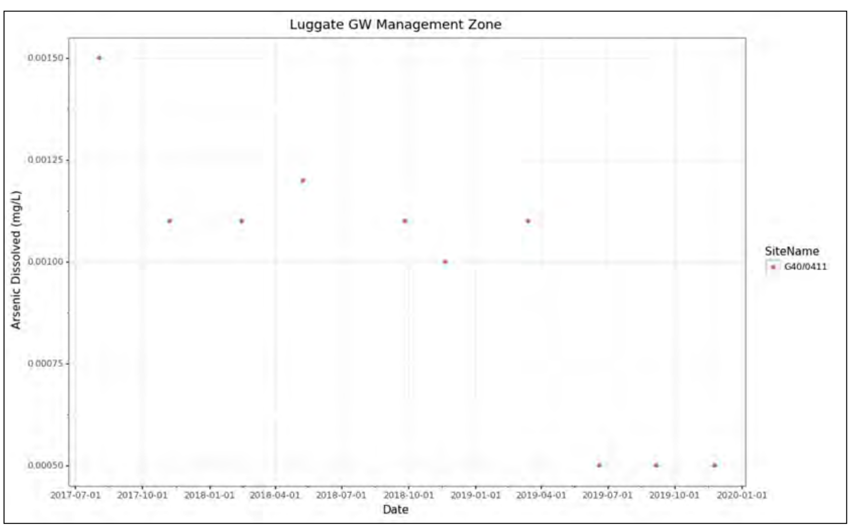


Figure 52: Groundwater dissolved arsenic concentration for the Luggate/Pisa GWMZ



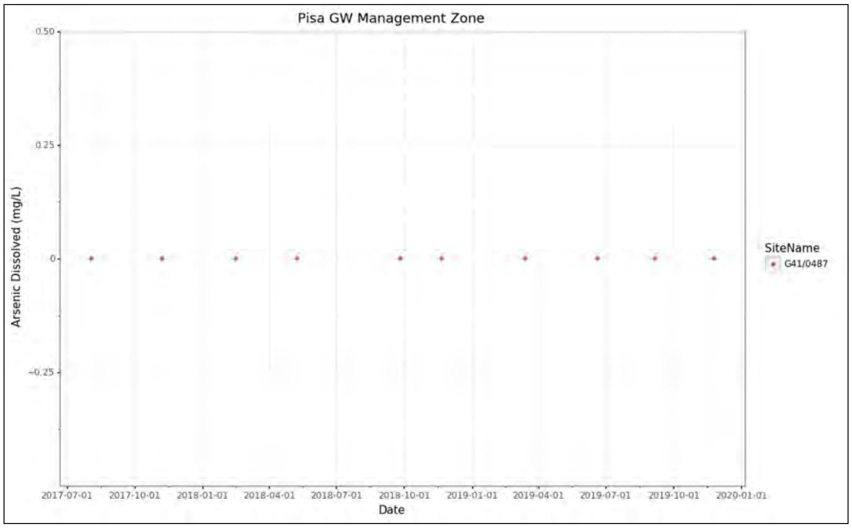
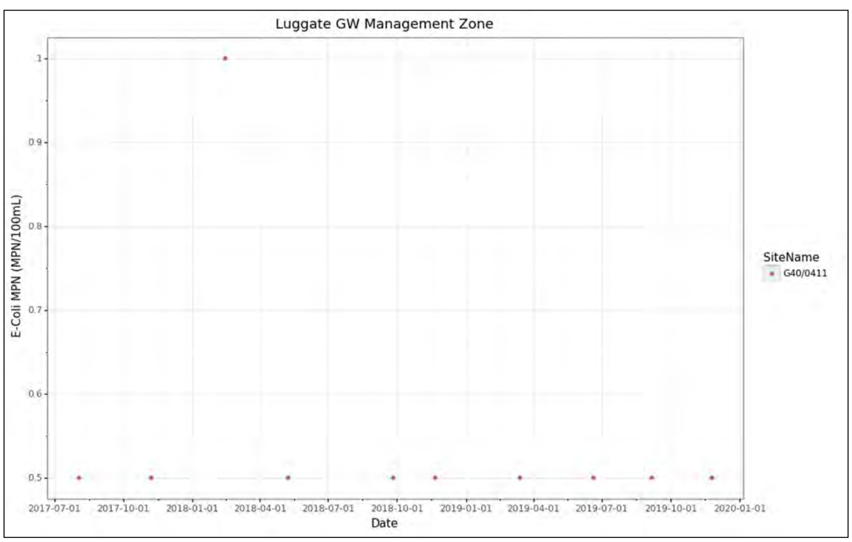


Figure 53: Groundwater E. Coli count for the Luggate/Pisa GWMZ



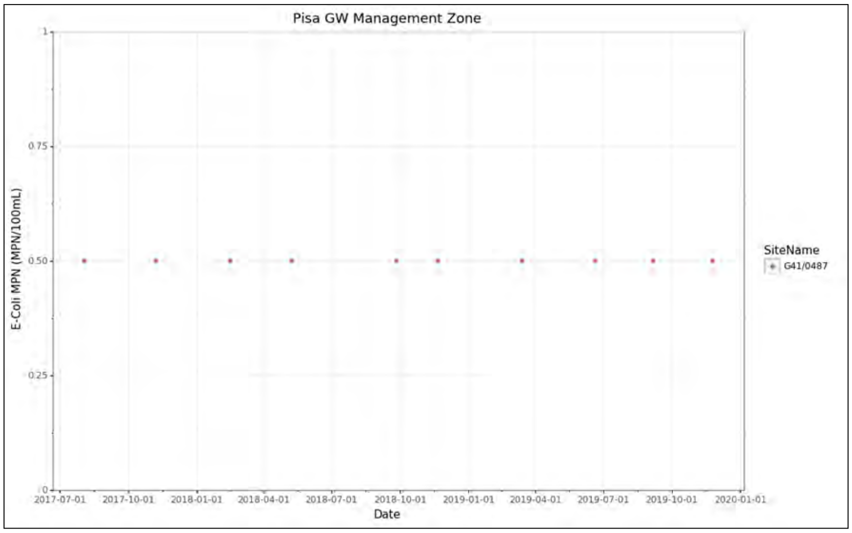
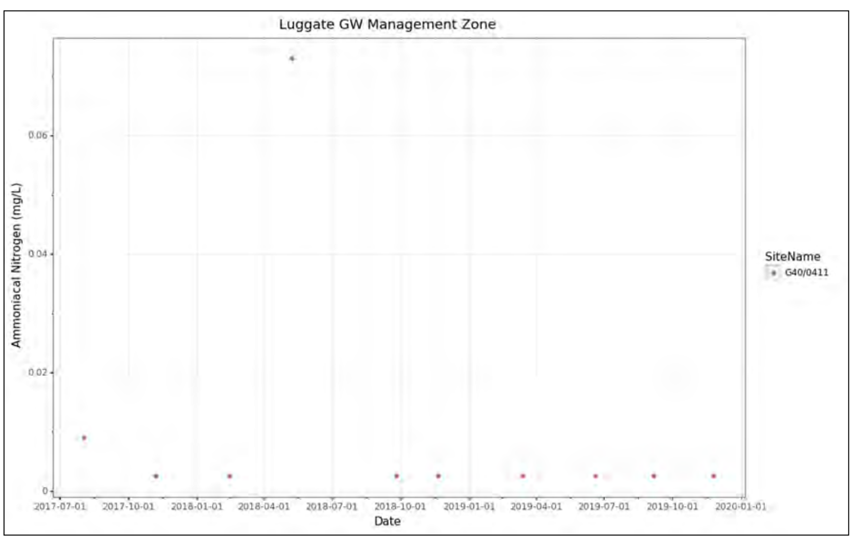


Figure 54: Groundwater ammonia concentration for the Luggate/Pisa GWMZ



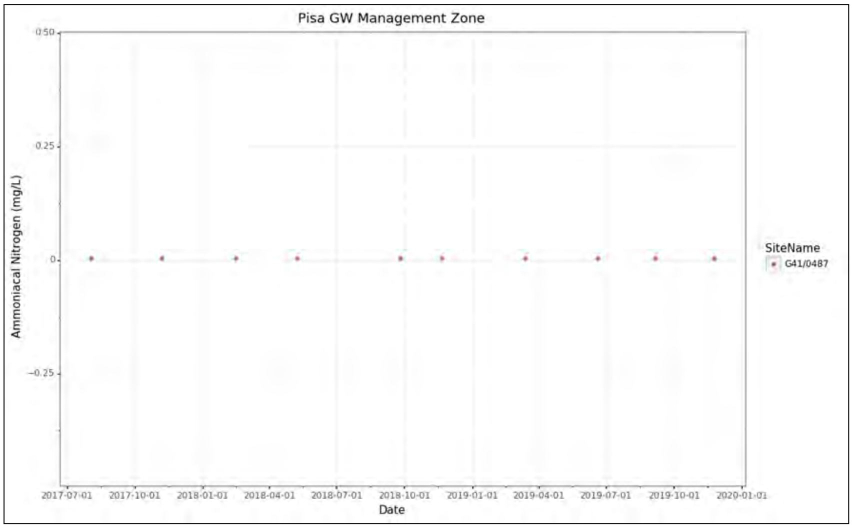
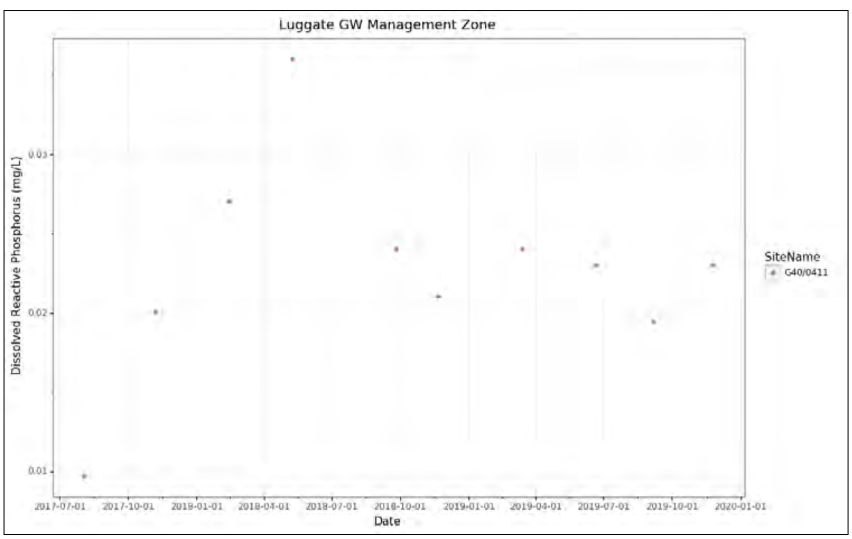
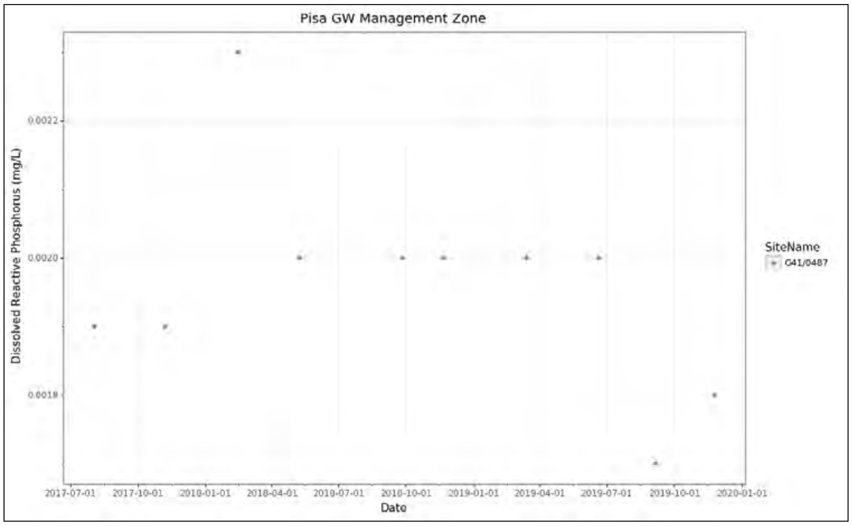


Figure 55: Groundwater Dissolved Reactive Phosphorus concentration for the Luggate/Pisa GWMZ





Comparison of the results against the Schedule 15 limits are provided in Table 22. The results from bore G41/0487 were not analysed as the bore is deeper than 20m. The results for bore G40/0411 (Luggate GWMZ) show non-compliance, as the 80th percentile nitrate and DRP concentrations (

Figure 54 and Figure 55) substantially exceed the Schedule 15 limits. These results indicate potential issues with excessive nitrate and DRP concentrations in case of groundwater discharge to springs/streams, particularly for an unnamed stream situated approximately 265m west of the bore. Conversely, the ammonia concentrations are below the threshold.

Table 22: 80th percentile values for water quality variables & comparison with Schedule 15 limits for the West Bank of the U. Clutha

	Group 2 Sched. 15 limit (mg/L)	**Nitrate (NO_3-N)**	**Dissolved Reactive Phosphorus (DRP)**	**Ammoniacal nitrogen (NH_4-N)**
Bore number	**Aquifer**	**0.075**	**0.010**	**0.100**
G40/0411	Luggate GWMZ	8.340	0.0246	0.006

These results are also reflected in the assessment against the NPS-FM NOF, Table 23. The median and 95th percentile nitrate concentration are in Band D and C, respectively, which are below the National Bottom Line. Band C describes an environment with impacts on growth of multiple species where toxicity starts approaching acute impact levels (i.e. death risk) for sensitive species at higher concentrations (>20mg/L). The median and 95th percentile DRP concentrations are also in Bands D and C, respectively. Band D for DRP describes an environment where ecological communities are impacted by concentrations that substantially exceed natural reference conditions. Combined with other conditions that favour eutrophication, DRP enrichment drives excessive primary production and significant changes in macroinvertebrate and fish communities, as taxa that is sensitive to hypoxia are lost. The classification for median and maximum ammonia concentrations are Band A and B, respectively. At Band B, 95% of the species are protected, with an occasional impact on the 5% most sensitive species starting to occur (MfE, 2020).

Table 23: NPS-FM NOF comparison summary for the W. Bank of the Upper Clutha

	Nitrate		NOF Band	
Bore no.	Median (mg/L)	95th percentile (mg/L)	median	95th percentile
G40/0411	7.75	9.45	D	C
	Ammoniacal nitrogen		NOF Band	
Bore number	median (mg/L)	Max (mg/L)	Median -	Maximum
G40/0411	0.0025	0.073	A	B
	DRP		NOF Band	
Bore number	Median (mg/L)	95th percentile (mg/L)	Median	95th percentile
G40/0411	0.023	0.032	D	C

4.2.4.6 Lower Tarras Aquifer

4.2.4.6.1 Aquifer information

The Lower Tarras aquifer is located on the eastern side of the Upper Clutha, where it is bounded by the Clutha River to the west, SH8/SH8A to the south, east and north and Grandview ridge to the east. There are currently no monitoring bores in the Bendigo and Lindis alluvial aquifer or the Ardgour Valley areas, although it is planned to add them.

The Bendigo-Tarras area has a dry climate, with a mean annual rainfall of between 400 and 500mm. The main water uses in the area are vineyards/cherries irrigation and large central pivots which are increasingly used for pasture irrigation. Flood irrigation is also used for pasture. Groundwater occurs within different geological units including highly permeable sandy gravel glacial outwash deposits on the lower terraces, which are used for irrigation. There are also low yielding, clay rich deposits around Tarras settlement which only contain a limited groundwater resource, and are used for domestic/stock water supply. Bores in the Ardgour Valley abstract from the Lindis alluvial ribbon aquifer, which is highly connected to the Lindis River, hence, takes in this area can deplete its streamflow. Due to these, most of the irrigation production bores are situated in the southern Bendigo area (ORC, 2010a).

The Clutha and Lindis rivers are both significant for the groundwater in the area as they are highly connected with the groundwater system. However, the two contrast in their size and sensitivity to stream depletion, with the Clutha having a mean flow of around 250m^3/second whereas the low Lindis dries out during most summers. Careful groundwater management, which allows resource development in areas where groundwater is buffered by recharge from the Clutha, is therefore required to lessen the impacts on the lower Lindis.

Groundwater in the Bendigo and Tarras basin is found in Quaternary and Tertiary age sediments that rest in a depression formed in the underlying schist. The basin is underlain by Haast schist of the Rakaia Terrane which acts as basement rock to the basin. The basin's shape is controlled by faults and folds through the schist. The basement rocks are overlain by non-marine Miocene quartz conglomerate, sandstone, mudstone and lignites of the Manuherikia Group, which is represented in the Tarras Bendigo area by silt deposits and quartz sands. These are overlain by

Quaternary deposits of sand, silts and gravel. The silty sandy layer is found at the ground surface just north of Tarras (ORC, 2010a).

Bore logs from the area show well sorted gravels in the Clutha Valley to a depth of approximately 50m and thinly layered silts and clay bound sands in the Tarras area. The depth of the aquifer base was refined using geophysics. The depth to the silty mudstone varied from 20-30m in the Ardgour Valley to >120m deep in the Clutha Valley. The data suggests that the underlying silt deposits of the Bendigo area dip to the NE and rise again at the edge of the terrace. These silt deposits underlie the dry Quaternary terraces and restrict horizontal groundwater movement below them. These silt deposits contain the shallow groundwater within the Lindis alluvial ribbon aquifer in the Ardgour Valley.

Piezometric maps show that groundwater generally flows into the aquifer from the Clutha in the northern area of the Tarras/Bendigo allocation zones and returns to the river in the southern areas. The Lindis strongly impacts groundwater flow as water moves into the deeper gravels after exiting the Ardgour Valley at the Lindis Crossing. Water levels in the Lindis Crossing bridge are approximately 7m above the level of the Clutha indicating that groundwater levels drop a significant amount between the bridge and the Lindis/Clutha confluence.

There are four available aquifer pumping test reports from the area. The reported permeability in the more recent alluvium sand and gravels is high, with the reported Transmissivity in the lower terraces ranging between 3,000 and 5,000m^2/day (bores G41/0231, G41/0316, and G41/0286). In contrast to that, the Tarras settlement area was not impacted by fluvial reworking of the glacial sediments and it is underlain by low permeability, clay-rich sediments. Hence, bores in this area are more suitable to supply the low requirements of domestic supplies volumes (ORC, 2010a).

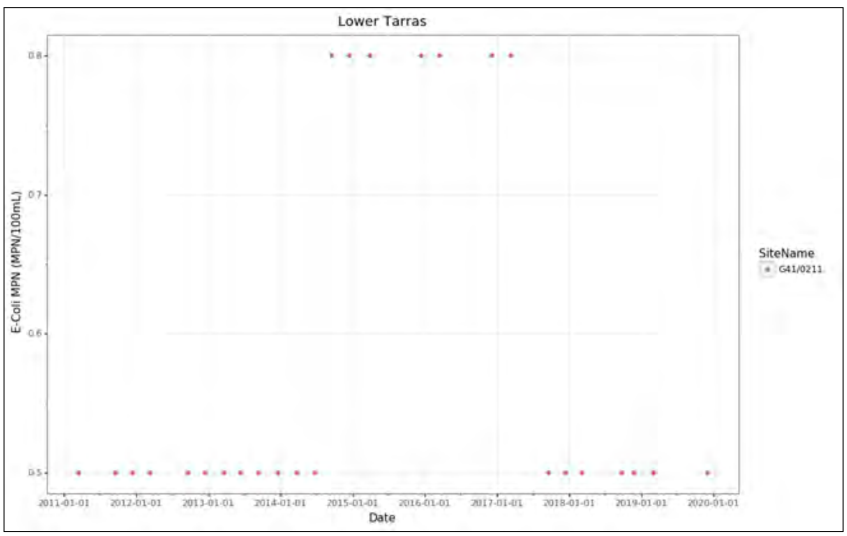
4.2.4.6.2 Groundwater quality results

There are two groundwater SoE monitoring bores in the Lower Tarras area. Bore no. G40/0175 (125mm diameter) was drilled in November 2002. The bore is located at Munro Lane, NZTM E 1316489 N5029566. The bore depth is 12.64m. The bore log describes silty sandy gravels to 6.8m underlain by silts to 7.5m. There is then silty/sandy gravels to the bore bottom at 12.8m. The log also describes grey clay at a depth of 12.8m, suggesting that this is the aquifer depth. The top of the screen leader is located at a depth of 11.44m, and the reported screen length is 1.00m, hence the top of the screen is at a depth of 11.640m the bottom silty/sandy gravels. Water levels in bore G40/0175 fluctuate between 2.00 and 3.00m below MP. However, significantly lower levels were measured in March 2017 (5.92m), December 2017 (6.6m) and March 2018 (7.05m). The drops in the summer (December and March) in 2017 and 2018 was significant, at around 3-4m. However, these drops were not observed during other years of measurement. The SWL in the bore in December 2019 was 2.9m below MP.

Bore G41/0211 (125mm diameter) is located at Maori Point Road, NZTM E1313189 N5027098. The bore was drilled in October 1999. The bore depth is 41.51m. The bore log describes coarse gravels to 15.4m underlain by grey sand to 16.2m. There is then sandy gravels to 22.6m, underlain by cobbley gravel to 22.9m and rock to 23.2m. There is then coarse cobbles to 30.9m underlain by sandy gravels to the bore bottom at 40.90m. This log suggests that the bore abstracts from an unconfined sandy gravels aquifer. The top of the screen leader is at a depth of 40.38m, within a sandy gravels horizon described as slightly silty (between 39.2 and 40.90m). The SWL in the bore ranges between 25.5 and 27.28m below MP. The lowest levels are measured in December/March although in some years water levels recover in March. The highest levels are in June. The normal seasonal fluctuations are usually around 1m. However, there was an anomaly in June 2019 where the levels were higher at 25.50m below MP, with an increase of 1.71m from previous measurement. The SWL in the bore in December 2019 was 27.1m below MP.

The assessment against the DWSNZ for E. coli, dissolved arsenic, and ammonia is shown in Figure 56, Figure 57, Figure 58, and Figure 59. Bore G41/0211 did not have any E. coli exceedances, although the data between September 2014 and March 2017 shows <1.6MPN/100mL. In contrast to that, several of the results in bore G40/0175 exceeded the MAV, notably with counts of 180 MPN/100mL (December 2013) and 4 MPN/100mL (March 2018). These indicate a contamination risk of the bore, likely due to its shallow depth and potential issues with borehead security (Figure 56). No samples in neither bore exceeded the MAV for arsenic (Figure 57) or the GV for ammonia (Figure 58). The nitrate concentrations in both bores are much lower than the DWSNZ MAV of 11.3mg/L. The concentrations in bore G40/0175 range between 0.8 and 1.1mg/L. There is no discernible trend in nitrate concentrations, and they are low although there is intensive grazing around the bore. These results are similar to the nitrate concentrations from bore G41/0211, which range between 0.9 and 1.2mg/L. The data from this bore does not show a trend, although there is some increase over recent years (Figure 59). Very high DRP concentrations, of 2.98mg/L were measured in bore G41/0211 in March 2009. However, this seems to only be a single spike (Figure 60).

Figure 56: Groundwater E. Coli count for the Lower Tarras aquifer



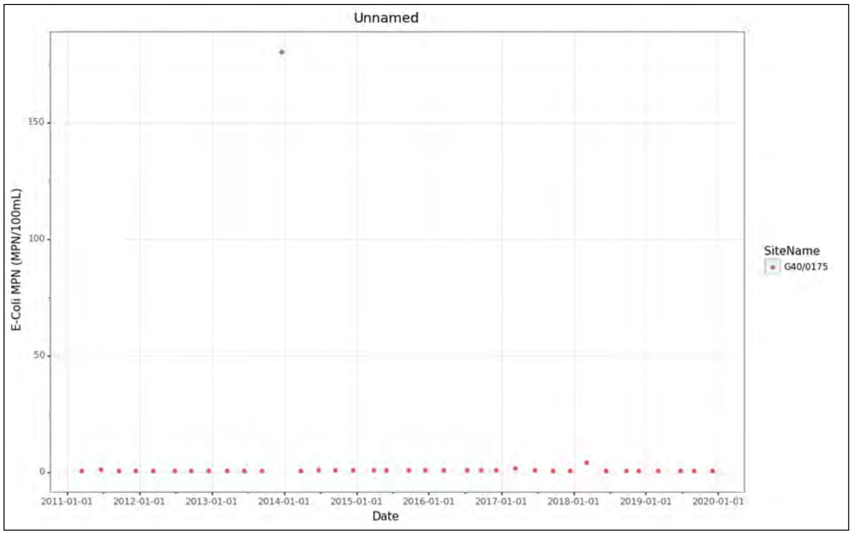
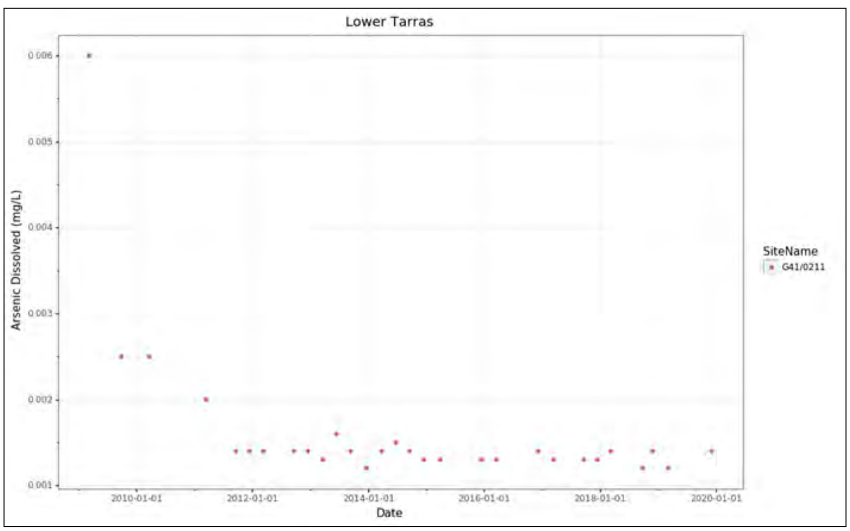


Figure 57: Groundwater dissolved arsenic concentration for the Lower Tarras aquifer



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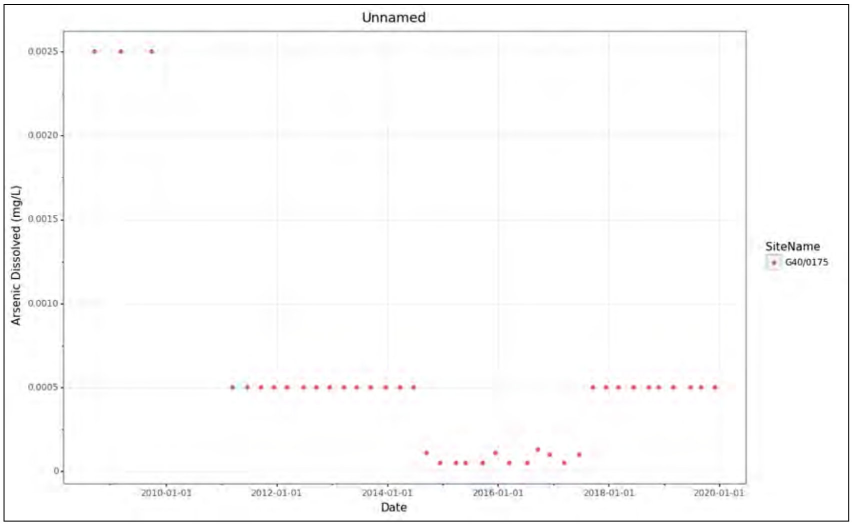
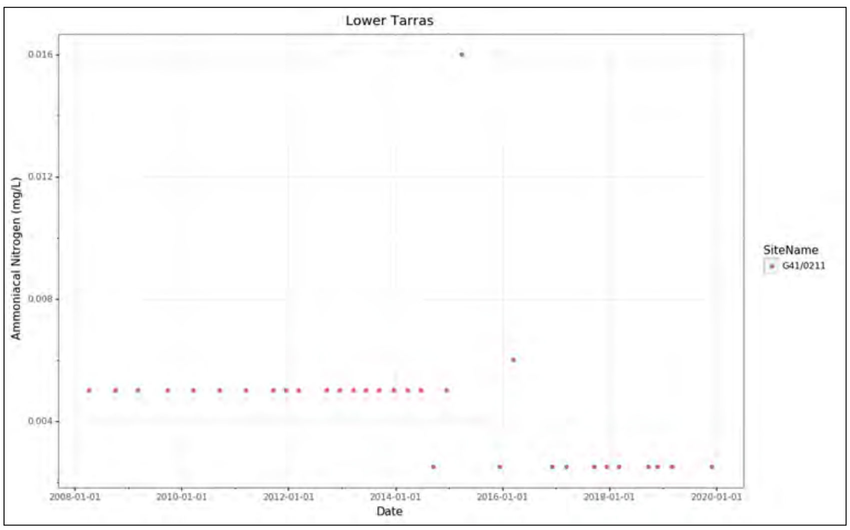


Figure 58: Groundwater ammonia concentrations for the Lower Tarras aquifer



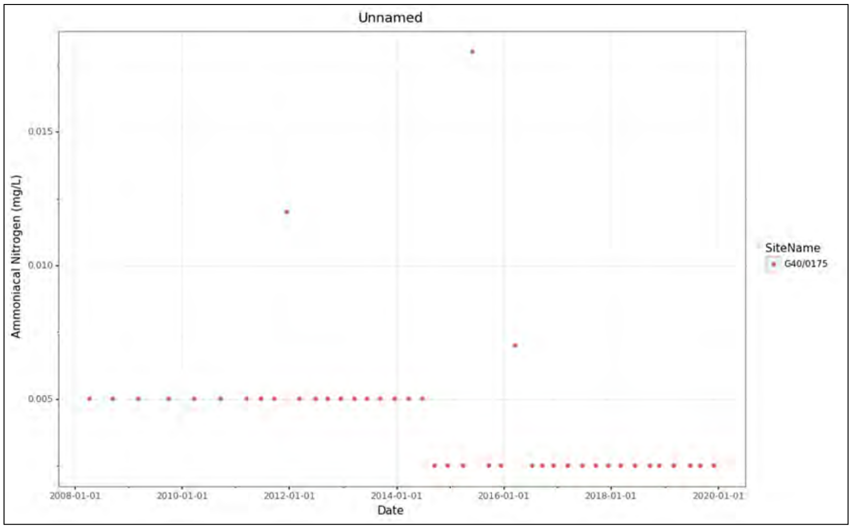
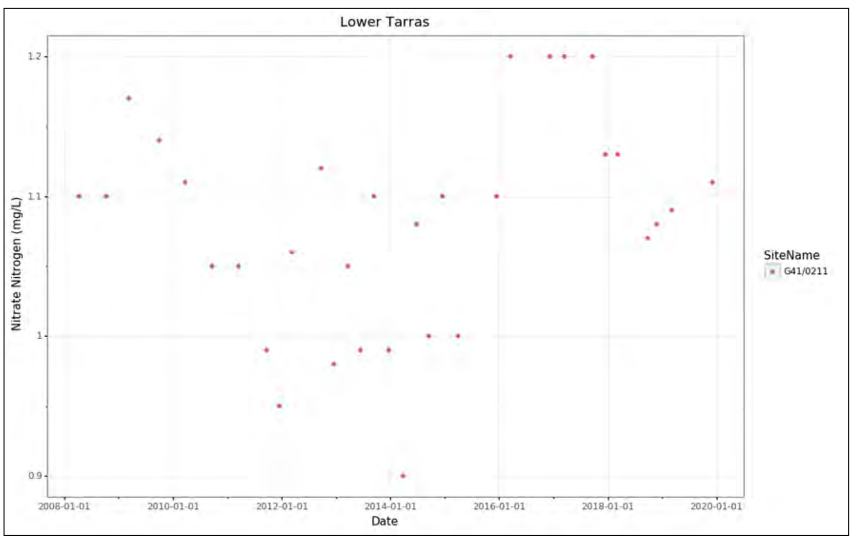


Figure 59: Groundwater nitrate concentration for the Lower Tarras aquifer



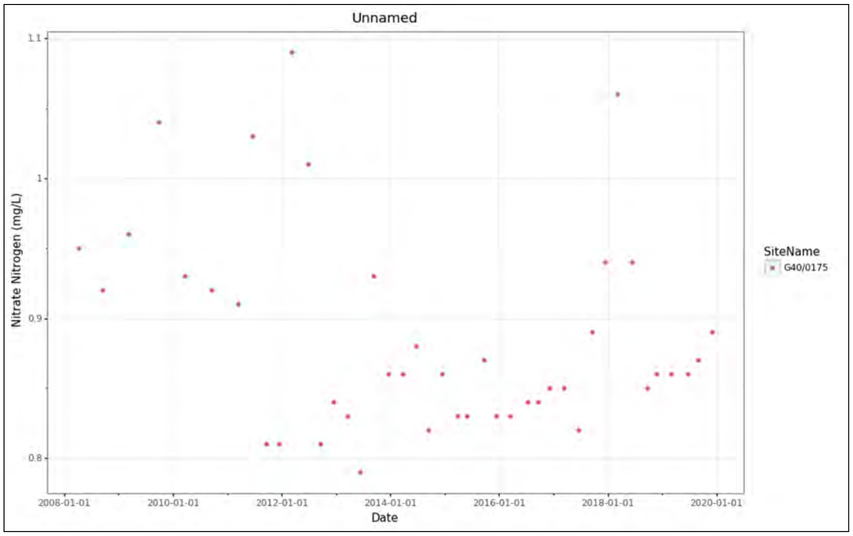
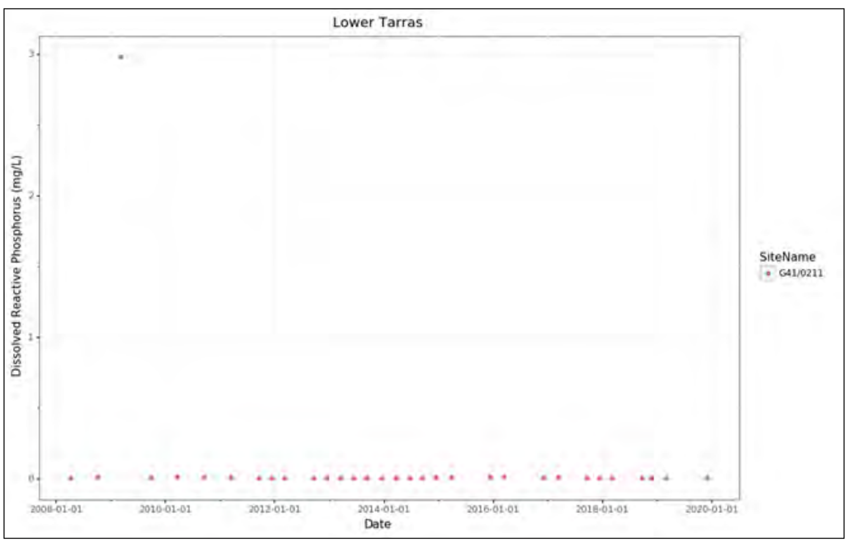
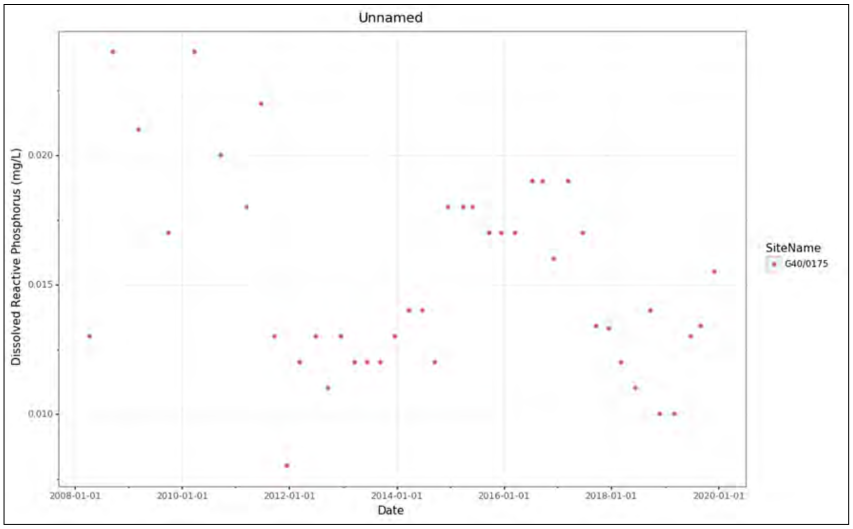


Figure 60: Groundwater Dissolved Reactive Phosphorus concentrations for the Lower Tarras aquifer





Regarding potential impact on surface water ecosystems, nitrate, DRP, and ammonia concentrations for bore G40/0175 were compared against the RPW (Table 24) and NPS-FM thresholds (

Table 25). Due to the depth of bore G41/0211, its results were not used for this analysis. Bore G40/0175 is located in Group 2 of Schedule 15. The results show noncompliance for nitrate and DRP, with nitrate concentrations substantially exceeding the Schedule 15 limits. Conversely, ammonia concentrations are below the limits. These non-compliances suggest potential adverse impacts on surface water quality. The analysis with the NPS-FM thresholds shows that the DRP concentrations are in Band C for the median and B for the 95th percentile.

Table 24: Results for comparison with Schedule 15 limits for nitrate, DRP, and ammonia

Bore number				Nitrate (NO_3-N)	Dissolved Reactive Phosphorus (DRP)	Ammoniacal nitrogen (NH_4-N)
Group 2 Sched. 15 limit (mg/L)				**0.075**	**0.010**	**0.100**
G40/0175	Clutha	Dunstan	Tarras	0.938	0.018	0.010

Table 25: NPS-FM NOF comparison summary for the Lower Tarras aquifer

	Nitrate			NOF Band	
Bore no.	median (mg/L)		95th percentile (mg/L)	median	95th percentile
G40/0175	0.86		1.0395	A	A
	Ammoniacal nitrogen		NOF Band		
Bore number	median (mg/L)	Max (mg/L)	Median -	Maximum	
G40/0175	0.005	0.018	A	A	
	DRP		NOF Band		
Bore number	Median (mg/L)	95th percentile (mg/L)	Median	95th percentile	
G40/0175	0.014	0.02195	C	B	

4.2.5 Manuherikia Rohe

The Manuherikia Rohe encompasses the catchment of the Manuherikia River, which flows for approximately 64km and has a catchment area of 3,033km^2. The catchment includes two major depressions, the Ida and Manuherikia Valleys, which are connected by the Pool Burn Gorge through Rough Ridge. The catchment is one of New Zealand's driest, with a strongly semi-arid, continental climate characterised by warm, dry summers and cold winters. Irrigation water is therefore at a high demand. The headwaters of the river are in the Hawkdun and Saint Bathans Ranges and the Dunstan Mountains. The river flows in a southwest direction and empties into the Clutha at the Alexandra township. The rohe contains SoE monitoring bores within three aquifers: the Manuherikia GWMZ (Section 4.2.5.1), Manuherikia Alluvium aquifer (Section 4.2.5.2), and the Manuherikia Claybound aquifer (Section 4.2.5.3). The Manuherikia Claybound and Alluvium are part of the Alexandra Basin alongside the Earnscleugh and Dunstan Flats. There are no monitoring bores in the Earnscleugh or the Ida Valley aquifer and the Dunstan Flats aquifer only has one monitoring bore that is solely monitored for groundwater levels (G42/0695), although the National Groundwater Monitoring Programme (NGMP) sampling has been undertaken for Geological & Nuclear Sciences (GNS) in the Dunstan Flats in the past.

In relation to the DWSNZ, the results from the SoE monitoring bores generally indicate fair/good groundwater quality. E. coli is the main issue, with exceedances measured in most monitoring bores, albeit at low counts. Nitrate concentrations are below the DWSNZ MAV in all monitoring bores, with concentrations in the Manuherikia Alluvium Aquifer and Manuherikia Claybound Aquifer monitoring bores generally near the reference conditions for low intensity landuse, i.e. <2.5mg/L (Daughney and Morgenstern, 2012). However, increasing concentrations were observed in the Manuherikia GWMZ monitoring bore, where concentrations exceed ½ of the MAV. No elevated arsenic concentrations were detected in any of the monitoring bores in the rohe.

In relation to potential impacts on ecosystem health, the results from the shallow monitoring bores show elevated nitrate and DRP, with concentrations exceeding the Schedule 15 limits. The DRP concentrations for the Manuherikia Alluvium bore are in Band D, below the National Bottom Line. This suggests that interaction of the aquifers with surface water can adversely impact it. The median concentrations for DWSNZ and ecosystem health parameters are shown in Table 26.

Table 26: Median concentrations for DWSNZ/ecosystem health parameters for the Manuherikia rohe

Aquifer	Ammoniacal Nitrogen (mg/L)	Arsenic Dissolved (mg/L)	Dissolved Reactive Phosphorus (mg/L)	E-Coli (MPN/100mL)	Nitrate (mg/L)
Manuherikia Alluvium	0.003	0.000	0.024	0.650	1.100
Manuherikia Claybound	0.005	0.001	0.013	0.500	1.345
Manuherikia GWMZ	0.005	0.001	0.014	0.500	1.600

4.2.5.1 The Manuherikia GWMZ

4.2.5.1.1 Information summary

The Manuherikia GWMZ is bounded to the east by the Hawkdun Range, to the north and west by the Dunstan Mountains, to the south by the Raggedy Range and to the south/west by the Manuherikia Alluvium and Claybound aquifers. The geology of the Manuherikia GWMZ is composed of basement schist geology, where the upper few metres were altered to pale-green colour by water-rock interaction. The schist is overlain by Tertiary sediments of the Manuherikia Group, which consist of terrestrial flood plain, lake, and lake delta sediments that is up to 300m thick. These sediments were deposited in a low-energy environment and comprise of sand, silts, and clay sequences. Thin veneers of Holocene river gravels, associated with modern streams or river drainage, overly the Tertiary sediments. The surface hydrology comprises of the Idaburn catchment, which drains the Ida range in the north and the Poolburn catchment, draining the South Ridge. These streams meet at the Poolburn Gorge, where water flows through the gorge into the Manuherikia River. A groundwater survey has not been conducted in the area to date. However, it is assumed that the groundwater flow direction will follow the topography and flow in a similar direction to the surface hydrology, with groundwater contributing baseflow to the tributaries and streams in the Idaburn and Poolburn catchments (ORC 2018b).

There are 20 completed bores within the Manuherikia GWMZ. Bore depths range between 2.7 and 60.37m. There is SWL information for 19 of the bores, indicating shallow SWL that ranges between 0.77 and 7.5m below MP. Screen depth information is available for six of the bores, with the top of screen depth ranging between 2 and 14.02m, highlighting the shallow aquifer depth. The main groundwater uses are irrigation, stockwater, and domestic/community supply. There are no consented groundwater takes within the GWMZ.

4.2.5.1.2 Groundwater quality monitoring results

Groundwater quality and levels in the Manuherikia GWMZ are monitored in bore G41/0254 (125mm diameter). The bore is located at Donnelly Road, west of Omakau, NZTM E1330618 N5002689. The bore is shallow with a total depth of 6.5m. The bore log describes silty sandy clay to 1.8m underlain by sandy gravels to 3.8m. There is then blue mudstone down to the bore bottom at 6.5m. The top of the screen is located at a depth of 1.82m, within a horizon of sandy gravels. It is not possible to measure the SWL in the bore due to a pump running continuously.

The comparison against the DWSNZ indicates some exceedances of the E. coli MAV, notably 11 MPN/100mL (March 2017) and 6 MPN/100mL (March 2018), Figure 61. None of the results exceeded the dissolved arsenic MAV of 0.01mg/L, with a maximum arsenic concentration of 0.006mg/L in February 2009. Concentrations have then been <0.001mg/L since then (Figure 62). Nitrate concentrations were below the DWSNZ MAV of 11.3mg/L. However, the data shows a pronounced increase in nitrate concentrations, which were around 1.0mg/L at the start of monitoring in 2010. Concentrations then fluctuated between 1.0 and 2.0mg/L until 2014. It then increased steadily, reaching a maximum concentration of 5.3mg/L, over ½ of the MAV, in March 2019 (Figure 63). The ammonia concentrations are below the GV of 1.5mg/L (Figure 64).

Figure 61: Groundwater E. Coli count for the Manuherikia GWMZ

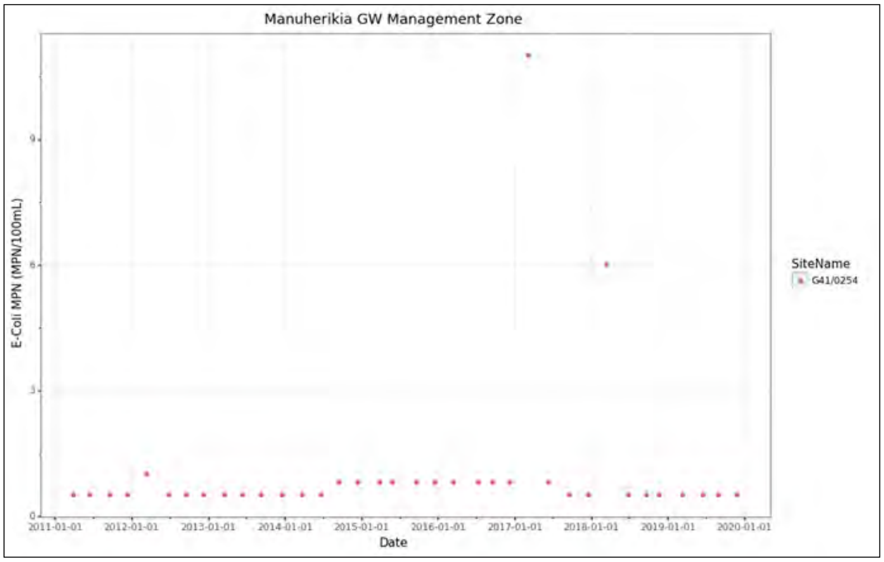


Figure 62: Groundwater dissolved arsenic concentrations for the Manuherikia GWMZ

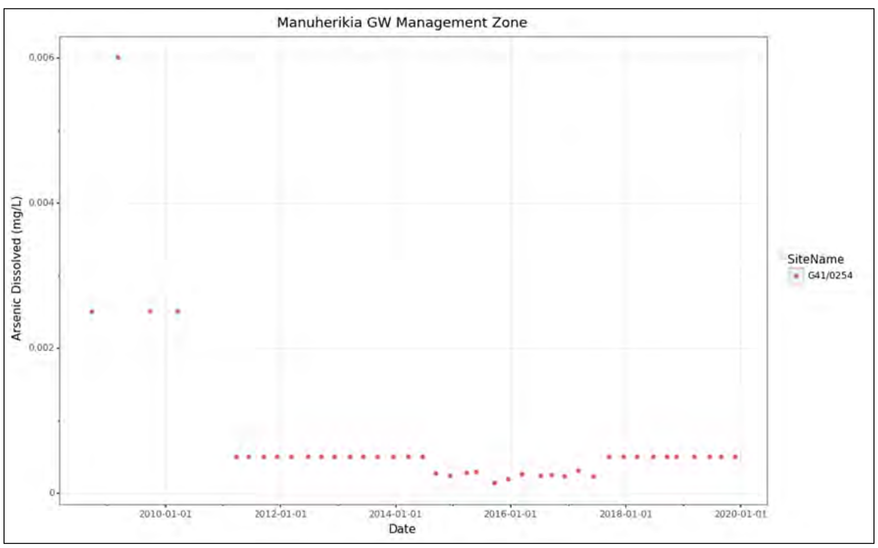


Figure 63: Groundwater nitrate concentrations for the Manuherikia GWMZ

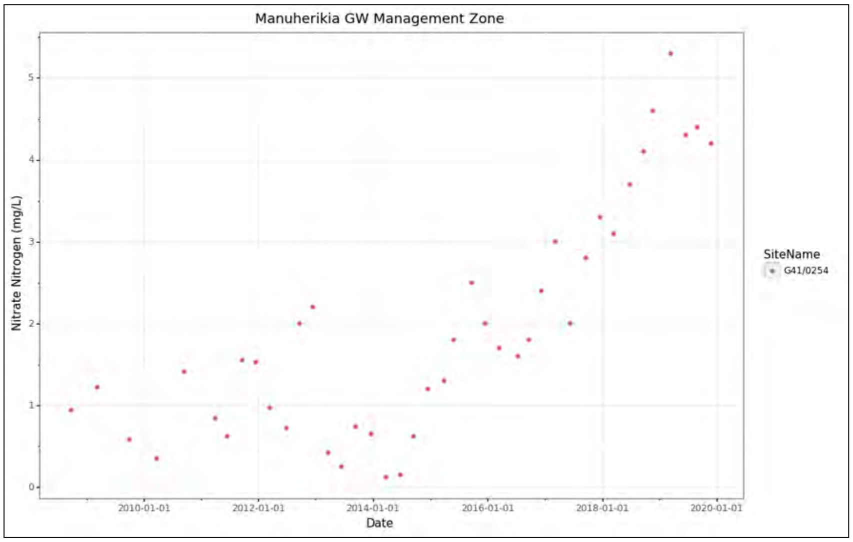


Figure 64: Groundwater ammonia concentrations for the Manuherikia GWMZ

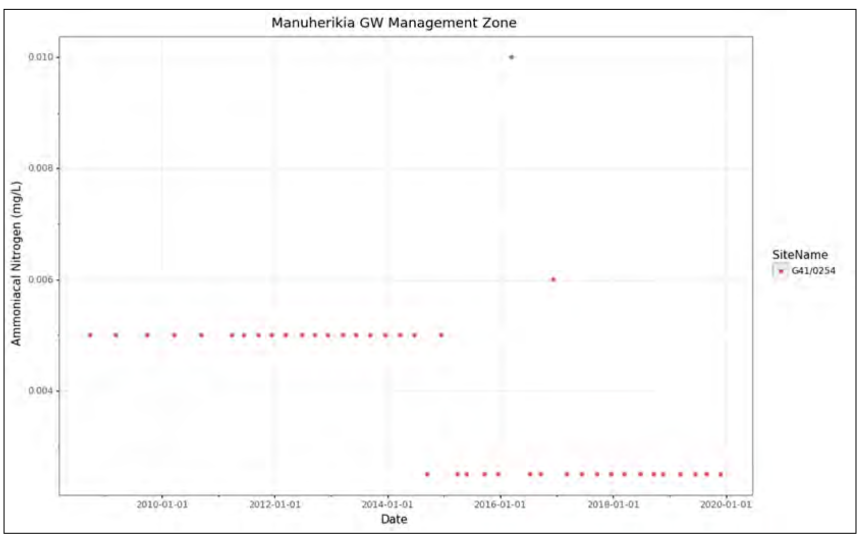
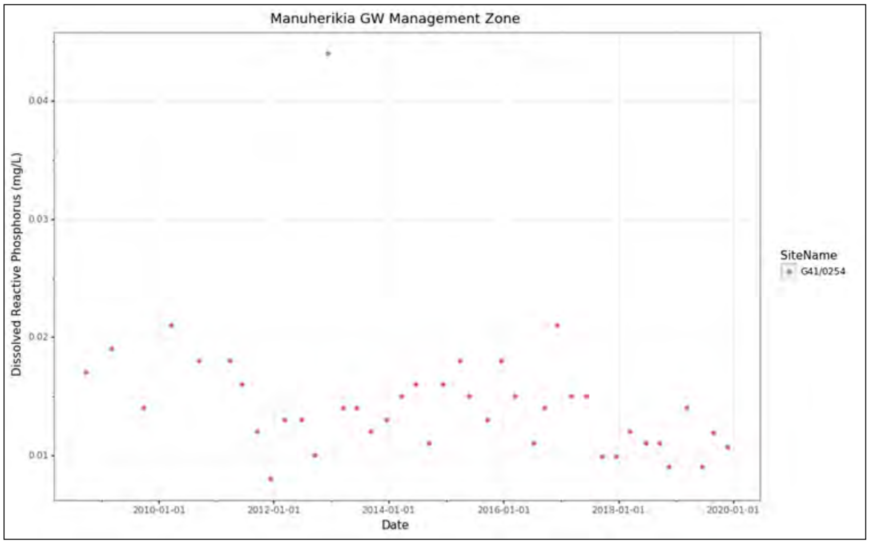


Figure 65: Groundwater Dissolved Reactive Phosphorus concentrations for the Manuherikia GWMZ



Groundwater quality data from bore G41/0254 was then assessed against the RPW (Table 27). The results show potential water quality issues. The 80th percentile nitrate and DRP concentrations exceed the Schedule 15 limits (Figure 65), with nitrate concentration exceeding it by around 40 times. The ammonia concentrations are within the limits.

Compliance with the NPS-FM NOF is shown in Table 28. The median and 95th percentile concentrations for nitrate are in Band B and C, respectively. Nitrate concentrations at Band C will have growth impacts on up to 20% of species, mainly which are sensitive such as fish, although there are no acute effects. The median and 95th percentile concentrations for DRP are in Bands C and B, respectively. DRP concentrations in Band C exceed natural reference conditions and impact ecological communities. If other conditions that favour eutrophication also exist, DRP enrichment can cause increased algal and plant growth, loss of sensitive fish and macroinvertebrate taxa and high respiration and decay rates (MfE, 2020). Both median and maximum ammonia concentrations are in Band A. The elevated nitrate and DRP concentrations can adversely impact surface water quality, particularly a tributary of Thomsons Creek situated approximately 250m away from the bore. The steady increase in groundwater nitrate concentration since 2014 is also concerning.

Table 27: Results for comparison with Schedule 15 limits for nitrate, DRP, and ammonia

Bore number				**Nitrate (NO_3-N)**	**Dissolved Reactive Phosphorus (DRP)**	**Ammoniacal nitrogen (NH_4-N)**
Group 2 Sched. 15 limit (mg/L)				**0.075**	**0.010**	**0.100**
G41/0254	Clutha	Manuherikia	Manuherikia GWMZ	3.100	0.017	0.010

Table 28: NPS-FM NOF comparison summary for the Manuherikia GWMZ

	Nitrate		NOF Band	
Bore no.	Median (mg/L)	95th percentile (mg/L)	Median	95th percentile
G41/0254	1.6	4.4	B	C
	Ammoniacal nitrogen		NOF Band	
Bore number	median (mg/L)	Max (mg/L)	Median -	Maximum
G41/0254	0.005	0.01	A	A
	DRP		NOF Band	
Bore number	Median (mg/L)	95th percentile (mg/L)	Median	95th percentile
G41/0254	0.014	0.021	C	B

4.2.5.2 The Manuherikia Alluvium Aquifer

4.2.5.2.1 Aquifer information

The Manuherikia Alluvium aquifer is defined by the flood plain of the Manuherikia River on its true left bank between the exit from the Ophir Gorge and Alexandra. It is a shallow, unconfined aquifer hydraulically connected to the Manuherikia River and is underlain by Manuherikia Formation consolidated sediments. The depth of the alluvium base is approximately 8m. The water table is shallow and is sloping towards the river. There is no available aquifer pumping test information from this area. The inflows/outflows of the Manuherikia alluvium aquifer are closely tied to the Manuherikia River and to low efficiency irrigation. Water for the irrigation schemes is harvested through the upper and lower Manorburn dams, and is used over the aquifer during the irrigation season. Some groundwater discharge occurs as seepage flow on the western (downhill) side of Fisher Lane, which coincides with the transition from the modern floodplain to the Hawea glacial advance terrace surface sediments. Anecdotally, flow from this spring is likely to be higher once irrigation starts in September (ORC 2012c).

According to the database, there are 35 completed bores within the Manuherikia Alluvium Aquifer. The depths of 34 are reported, which range between 3.68 and 13.46m. The SWL is reported in 32 bores, which ranges between 1.15 and 10.46m. Screen depth information is available for 8 of the bores, with the top of screen depth ranging between 8.49 and 12.96m. This illustrates the shallow aquifer and water table depth.

4.2.5.2.2 Groundwater quality monitoring results

Groundwater quality in the Manuherikia Alluvium aquifer is monitored in bore G46/0152 (150mm diameter), drilled in October 2014. The bore is located at Galloway Road, NZTM E1321034 N4986341. The bore log is mainly composed of sandy and silty gravels. It describes 4.4m of coarse sandy gravel underlain by 0.5m of brown sandy silts. There is then silty coarse gravels to 6.9m underlain by sandy coarse gravels and silt to 10.1m. These are underlain by blue clays down to the bore bottom at 10.50m. The bore is screened between 9.50 and 10.00m, within a horizon of sandy coarse gravels and silts. Groundwater levels in the bore range between 2.7 and 5.8m below MP, with a strong seasonal fluctuation of around 2.5m. It is noted that water levels in the bore are highest during the summer irrigation season and lowest during the winter, highlighting the main role of irrigation recharge, which is the dominant source in this area of low rainfall and high evaporation. There is no noticeable trend of lowering groundwater levels. However, altering flood irrigation to more efficient methods may reduce irrigation recharge, and therefore water levels, in the bore, although this may be potentially offset by a reduction in abstraction (ORC, 2012c).

Groundwater quality results from bore G46/0152 were compared with the DWSNZ. The results show several exceedances of the E. coli MAV, although the counts were low, with a maximum of 4.9MPN/100mL in March 2017 (Figure 66). Nitrate concentrations in the bore are much lower than the DWSNZ MAV of 11.3mg/L, with concentrations ranging between 0.91 and 1.36mg/L (Figure 67). There were no elevated dissolved arsenic concentrations above the MAV (

Figure 68). All ammonia concentrations are below the GV of 1.5mg/L (

Figure 69).

Figure 66: Groundwater E. Coli count for the Manuherikia Alluvium Aquifer

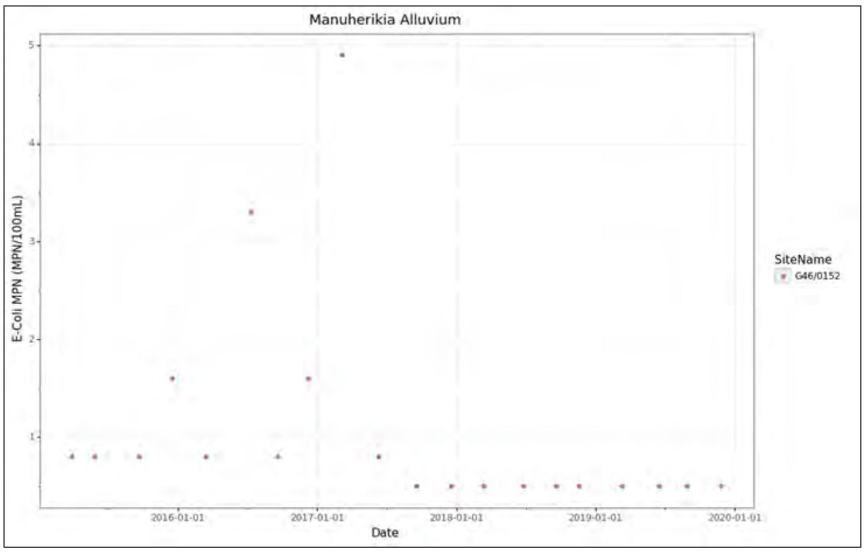


Figure 67: Groundwater nitrate concentrations for the Manuherikia Alluvium Aquifer

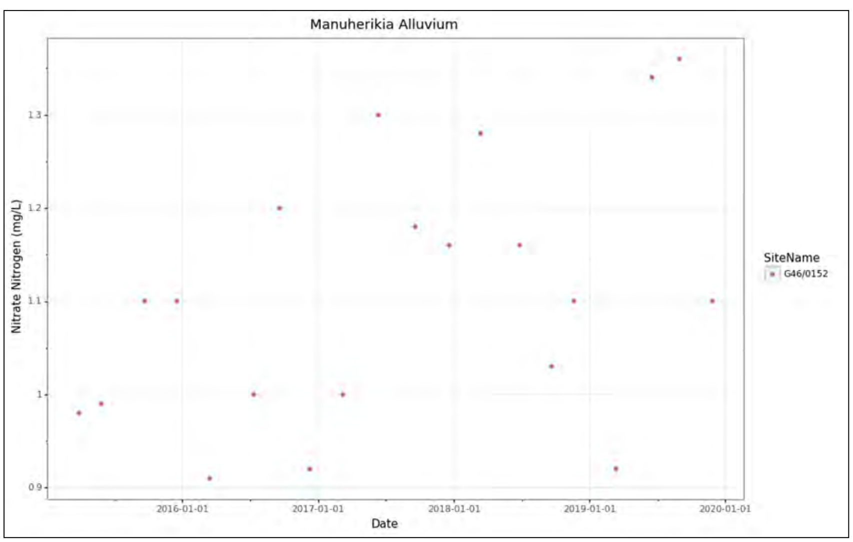


Figure 68: Groundwater dissolved arsenic concentrations for the Manuherikia Alluvium Aquifer

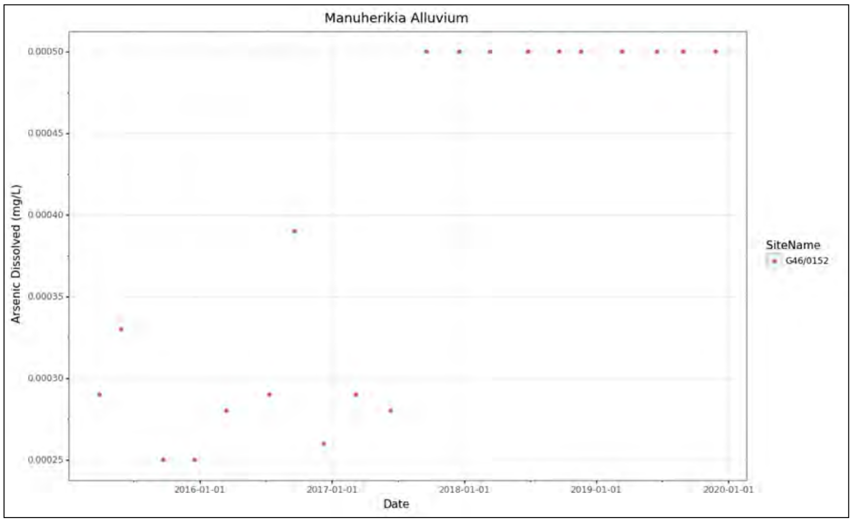


Figure 69: Groundwater ammonia concentrations for the Manuherikia Alluvium Aquifer

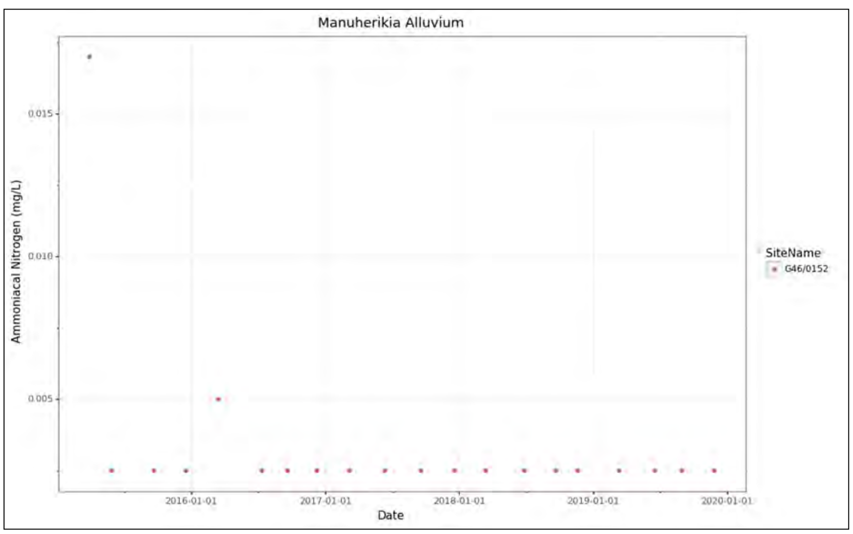
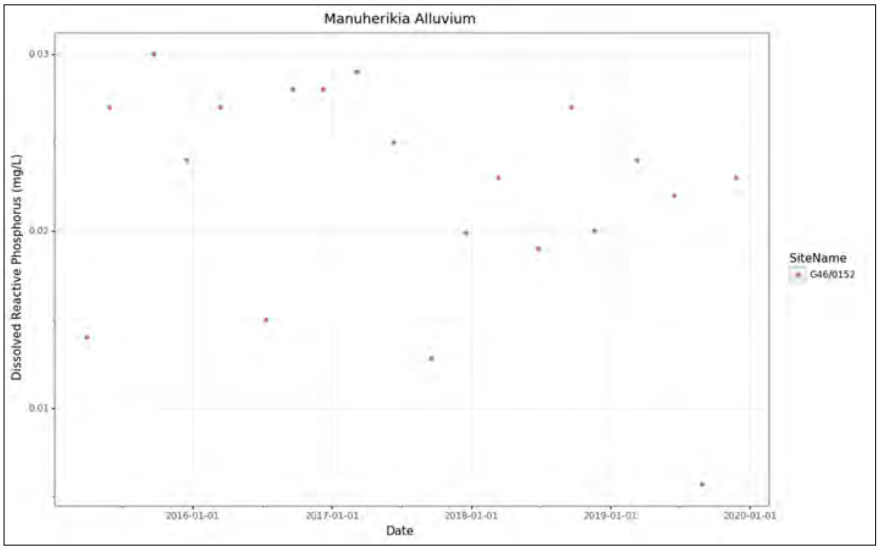


Figure 70: Groundwater Dissolved Reactive Phosphorus concentrations for the Manuherikia Alluvium Aquifer



Bore G46/0152 is located in Group 2 of the RPW's Schedule 15. The 80th percentile concentrations for nitrate, DRP, and ammonia were assessed against Schedule 15 of the RPW, Table 29. The nitrate and DRP concentrations are non-compliant with the Schedule 15 limits, exceeding the threshold by approximately 16 and 2.7 times, respectively (Figure 70). This suggests potential impacts on connected surface water. Conversely, the ammonia concentrations are below the Schedule 15 limits.

Table 29: Results for comparison with Schedule 15 limits for nitrate, DRP, and ammonia

Bore number			Nitrate (NO_3-N)	Dissolved Reactive Phosphorus (DRP)	Ammoniacal nitrogen (NH_4-N)
Group 2 Sched. 15 limit (mg/L)			**0.075**	**0.010**	**0.100**
G46/0152	Manuherikia	Manuherikia Alluvium	1.216	0.027	0.005

The comparison against the NPS-FM NOF is shown in Table 30. The DRP and nitrate data shows some potential concerns. The DRP median concentration is in band D, below the National Bottom Line, where ecological communities are impacted by substantial DRP concentrations above natural reference conditions. Combined with other conditions that favour eutrophication, DRP enrichment stimulates excessive primary production and significant changes in fish and macroinvertebrate communities, as taxa that are sensitive to hypoxia are lost (MfE, 2020). The median nitrate concentrations are in Band B, where there are some growth effects on up to 5% of species, although this band still provides for a good level of protection with some minor effect on growth rate of the most sensitive species (Hickey, 2013; ORC, 2017a). In contrast to these, the ammonia median and maximum concentrations are both in Band A, which provides 99% species protection level with no observed effect on any species (MfE, 2020).

Table 30: NPS-FM NOF comparison summary for the Manuherikia Alluvium Aquifer

	Nitrate		NOF Band	
Bore no.	Median (mg/L)	95th percentile (mg/L)	Median	95th percentile
G46/0152	1.1	1.341	A	B
	Ammoniacal nitrogen		NOF Band	
Bore number	median (mg/L)	Max (mg/L)	Median -	Maximum
G46/0152	0.0025	0.017	A	A
	DRP		NOF Band	
Bore number	Median (mg/L)	95th percentile (mg/L)	Median	95th percentile
G46/0152	0.0235	0.02905	D	B

A

4.2.5.3 The Manuherikia Claybound aquifer

4.2.5.3.1. Aquifer information

The Manuherikia Claybound Aquifer is located north of the Alexandra township. The aquifer is bound to the east by the Manuherikia River channel, north/west by the Dunstan Mountains/Leaning Rock Range, north by McArthur Gully and Springvale Creek, which drain the Leaning Rock Range. It is bound to the south/south west by the Dunstan Flats Aquifer where the boundary is marked along the stream/race that flows along Dunstan Road. Apart from the Manuherikia River, which forms the aquifer's southeastern boundary, the only natural surface water body that crosses it is the Waikerikeri Creek. Due to the combination of the dry climate, high evaporation, and permeable outwash gravels which prevent surface runoff and flow there are no perennial surface water bodies found in the Airport Terrace or Letts Gully parts of the aquifer.

The aquifer can be roughly divided into a northern and southern parts where Springvale Road serves as a boundary. The northern part of the aquifer, to the north of Springvale Road, is drained by the Waikerikeri Creek which flows south from the Dunstan Mountains and empties into the Clutha south of the SH8/Mutton Town Road confluence. There are generally very few bores in this part, apart from a group of bores near the gorge/terrace of the Waikerikeri Creek south of Glen Atholl. The southern part of the aquifer is drained by the Tumatakuru Creek and McArthur Gully which also drain the Dunstan Mountains during rain storms. These creeks flow to the south, where drainage is divided between these and the Waikerikeri Creek by the ridge north of bore G42/0462. Although many of these are likely to be ephemeral, their flowing direction is to the southeast, towards the Manuherikia River.

The area comprises of two distinct groups of formations: The Lindis outwash formation composes the Airport Terrace and Letts Gully Road area, south of Springvale road. The second formation is composed of less distinct landforms such as the older Waikerikeri fans situated to the north. The aquifer was named in 1998 to distinguish it from the high permeability outwash of the Dunstan Flats and the lower permeability outwash of the Lindis advance sediments. The "Claybound" term potentially originated from bore logs north of Springvale Road, where a wide variability of sediment sizes was "lumped" into a single lithological description (i.e. "claybound").

Groundwater exploration north of Springvale Rd encountered pervasively silty, significantly thick weathered gravels and moderate depth to the water table. Pumping tests associated with vineyard development indicated hydraulic conductivity of around 1m/d, which is substantially lower than the Dunstan Flats. This can be potentially attributed to geochemical alteration (weathering) of non-quartz components of the outwash which enriches the weathered material with finer silts/clays and reduces its permeability. In contrast to that, bore logs indicate that the Letts Gully Road area, situated near the Dunstan Flat aquifer and the Clutha River has more permeable sediments with less silt and clay within gravel deposits. The water table is relatively deep in the area, ranging between around 40 and 65m below ground level. However, water tables in bores near the Waikerikeri Creek terrace/Glen Athol are shallower, at around 20m below MP (ORC, 2018b).

According the database there are 111 completed bores within the Manuherikia Claybound Aquifer. Total depth information is available for 95 of those, with bore depths ranging from 1.7 to 70.95m. 58 of these bores (i.e. 61%) are deeper than 30m. SWL information is available for 61 bores, with the reported SWL ranges between 1.07 and 63.23m. Screen depth information is available for 26 bores, and is ranging between 5.05 and 68.38m. The main groundwater uses in the aquifer are domestic, stockwater, community supply and irrigation. Two bores hold a groundwater take consent.

4.2.5.3.2 Groundwater quality monitoring results

Groundwater quality in the Manuherikia Claybound Aquifer is monitored in two SoE bores. Bore no. G42/0123 (100mm diameter) is located at Letts Gully Road, NZTM E1317225 N4987272. The bore depth is 32.40m. There is no lithological log or screen information available for the bore. The data for bore G42/0123 shows that groundwater levels in the bore range between 25.92 and 27.84m below MP with a seasonal fluctuation of between 1.0 and 1.5m. The lowest groundwater levels are generally measured in September and/or December, with a recovery in March, indicating that groundwater levels are strongly impacted by irrigation recharge. The data suggests that the groundwater levels in the bore are falling, with lower recovery in levels than was measured during the start of monitoring. However, this can be due to increased irrigation efficiency, which reduces recharge (ORC, 2012c).

Bore G42/0290 (100mm diameter) is located at Springvale Road, at NZTM E1318011 N4988269. The total bore depth is 16.1m. There is no lithological log or screen information available for this bore. Groundwater levels were quarterly monitored in the bore since March 2015. Groundwater levels in bore G42/0290 range between 15.51 and 16.57m below MP, with a seasonal fluctuation of around 1m. Similar to bore G42/0123 and the data from the Manuherikia Alluvium Aquifer, the lowest levels are also in September with a recovery during December/March, suggesting substantial irrigation recharge. Similar to the data from bore G42/0123, water levels and recovery in this bore also seem to be falling, potentially attributed to more efficient irrigation (ORC, 2012c). It is worthy to note that the Manuherikia Irrigation Scheme water races, which have a known history of leakage, run in proximity to bores G42/0123 and G42/0290.

The comparison of groundwater quality results against the DWSNZ shows that none of the samples in either bore exceeded the dissolved arsenic MAV of 0.01mg/L (Figure 71). There were also no E. coli results which exceeded the MAV (

Figure 72). Nitrate concentrations in both bores are substantially below the 11.3mg/L MAV. The concentrations in bore G42/0290 range between 1.5 and 2.7mg/L. The concentrations in bore G42/0123 range between 0.0 and 1.180mg/L (

Figure 73). These concentrations only slightly exceed the value for natural groundwater in New Zealand (Daughney and Morgenstern, 2012). The ammonia concentrations are below the GV of 1.5mg/L (Figure 74). These results suggest that there are no potential risks to drinking groundwater quality from these bores.

Figure 71: Groundwater dissolved arsenic concentrations for the Manuherikia Claybound Aquifer

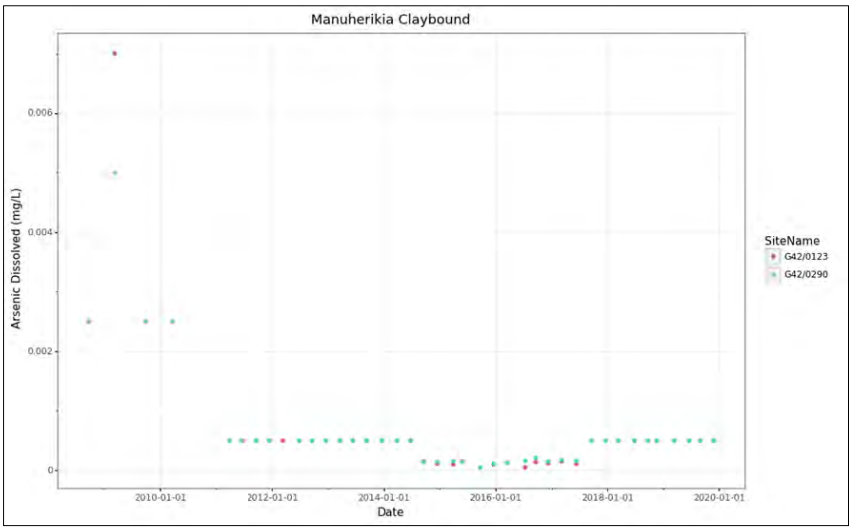


Figure 72: Groundwater E. Coli count for the Manuherikia Claybound Aquifer

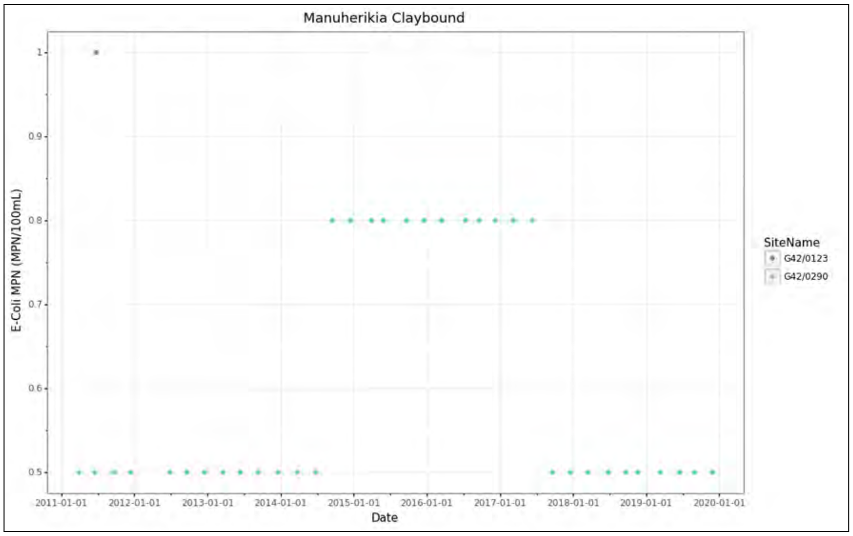


Figure 73: Groundwater nitrate concentrations for the Manuherikia Claybound Aquifer

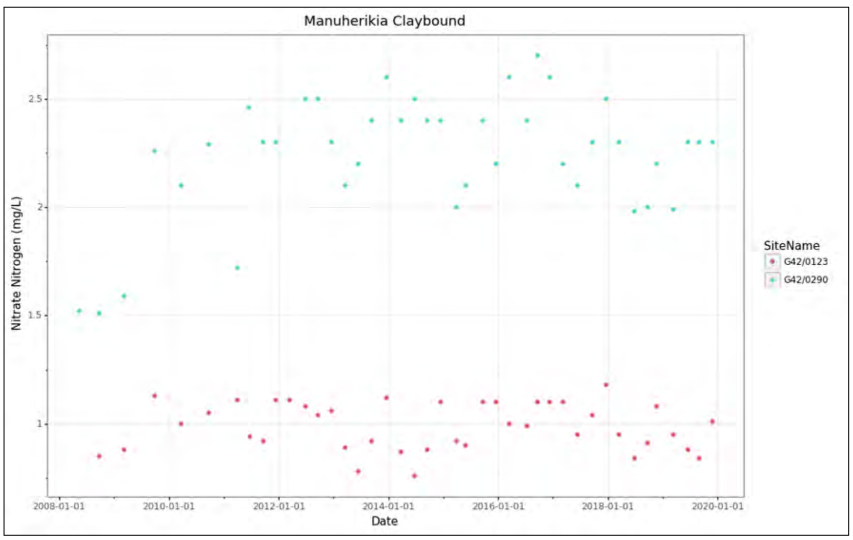


Figure 74:Groundwater ammonia concentrations for the Manuherikia Claybound Aquifer

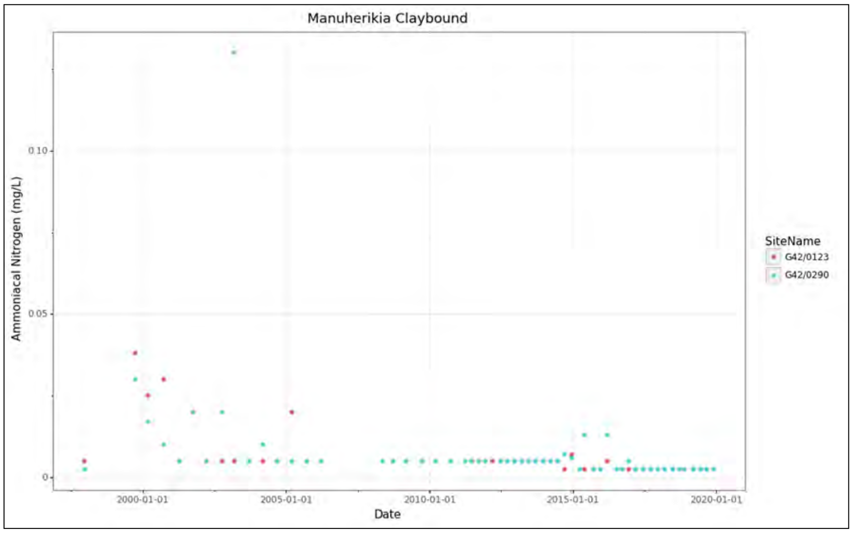
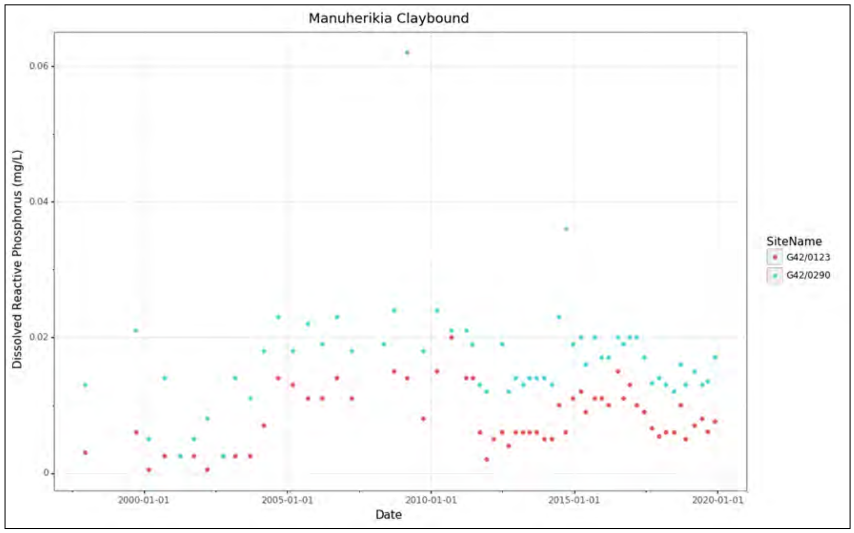


Figure 75: Groundwater Dissolved Reactive Phosphorus concentrations for the Manuherikia Claybound Aquifer



The results were then assessed against the RPW and NPS-FM to determine any potential impacts on surface water quality. Bore G42/0123 was excluded due to its depth. Bore G42/0290 is located in Group 2 of Schedule 15. The results show noncompliance with the limits, with 80th percentile nitrate and DRP concentrations at 32 and twice the limits, Table 31. There were also high DRP results of 0.038 and 0.065mg/L, with most results ranging between 0.01 and 0.0125mg/L (Figure 75). The nitrate and DRP results show an increase between approximately 2000 and 2005, followed by stable concentrations until 2015, where they slightly fell. The 80th percentile ammonia concentrations are within the Schedule 15 limits. The nitrate and DRP concentrations from the bore suggest potential impacts on surface water quality. The bore is located near a surface water feature that flows to the southeast, towards the Manuherikia River.

Table 31: 80th percentile values for water quality variables identified in Schedule 15.

Bore number		Nitrate (NO_3-N)	Dissolved Reactive Phosphorus (DRP)	Ammoniacal nitrogen (NH_4-N)
Group 2 Sched. 15 limit (mg/L)		**0.075**	**0.010**	**0.100**
G42/0290	Manuherikia Claybound	2.460	0.020	0.010

Groundwater quality results were also analysed against the NPS-FM NOF attributes, Table 32. The median and 95th percentile nitrate concentrations are both in Band B, where some growth effects are expected on 5% of the species. The median and 95th percentile DRP concentrations are in Bands C and B, respectively. Band C indicates an impact on ecological communities by DRP concentrations that moderately exceed natural reference conditions. If combined with other factors that increase eutrophication, DRP enrichment can cause increased algal/plant growth, loss of sensitive macro-invertebrates and fish taxa, alongside high respiration and decay rates. The median and maximum ammonia concentrations are in Band A and B, respectively. Band B provides 95% species protection level for toxicity, where impacts on the most sensitive 5% occur occasionally (MfE, 2020).

Table 32: Manuherikia Claybound Aquifer NOF comparison for nitrate, ammonia, and DRP

	Nitrate		NOF Band	
Bore no.	median (mg/L)	95th percentile (mg/L)	median	95th percentile
G42/0290	2.3	2.6	B	B
	Ammoniacal nitrogen		NOF Band	
Bore number	median (mg/L)	Max (mg/L)	Median	Maximum
G42/0290	0.005	0.13	A	B
	DRP		NOF Band	
Bore number	Median (mg/L)	95th percentile (mg/L)	Median	95th percentile
G42/0290	0.017	0.024	C	B

4.2.6 The Lower Clutha Rohe

The Lower Clutha rohe runs from the Roxburgh Dam to the Clutha River mouth south of Balclutha. The region includes the catchments of the Pomahaka (2,060km^2), Waitahuna (406km^2), Waipahi (339km^2), Tuapeka (249km^2), and Waiwera (208km^2) rivers. In contrast to the Upper and Mid Clutha regions, the lower Clutha is dominated by alluvial plains, rolling hill country and lowlands. The Roxburgh and Ettrick rohe are located in Central Otago. The South Otago basin includes four aquifers: the Pomahaka, Clydevale, Wairuna, and Kuriwao, of which the first two contain current SoE monitoring bores (ORC, 2014d). However, aquifers in this area have been reviewed several times and some of these are not found in the RPW. The rohe also includes the Inch Clutha gravel aquifer, located near the Clutha mouth.

Groundwater quality results from the Lower Clutha rohe indicate some significant water quality issues, with elevated E. coli and nitrate concentrations in most bores, notably in the Ettrick and Clydevale basins. Among the identified factors in degraded water quality in southwest Otago are the wide-spread use of artificial paddock drainage and shallow water tables. One of the bores in the Inch Clutha gravel aquifer has elevated arsenic concentrations above the MAV and high DRP concentrations. The results also show issues with elevated nitrates and DRP (Table 33 and

Table 34), with concentrations in most shallow bores exceeding the Schedule 15 limits and NOF bands. Some of these issues are due to shallow monitoring bores that are not properly secured. These results also support surface water quality results from this area, which are generally poor (ORC, 2017a). The median results for the DWSNZ and ecosystem health parameters are shown in Table 35.

Table 33: 80th percentile values for Schedule 15water quality variables for the Lower Clutha rohe

Bore number				Nitrate (NO_3-N)	Dissolved Reactive Phosphorus (DRP)	Ammoniacal nitrogen (NH_4-N)
Group 1 Sched. 15 limit (mg/L)	**FMU**	**Rohe**	**Aquifer**	**0.444**	**0.026**	**0.10**
H46/0118	Clutha	Lower Clutha	Inch Clutha	0.282	0.270	0.013
G44/0127	Clutha	Lower Clutha	Pomahaka Alluvial	5.020	0.015	0.010
G44/0136	Clutha	Lower Clutha	Pomahaka	0.050	0.099	0.016
G43/0224b	Clutha	Lower Clutha	Ettrick	8.340	0.005	0.005
Group 2 Sched. 15 limit (mg/L)				**0.075**	**0.010**	**0.100**
G43/0009	Clutha	Lower Clutha	Ettrick	4.960	0.013	0.010
G43/0072	Clutha	Lower Clutha	Roxburgh	5.320	0.010	0.011

Table 34: Lower Clutha rohe NOF comparison for nitrate, ammonia, and DRP

	Nitrate concentration (mg/L)		NOF Band	
Bore no.	median (mg/L)	95th percentile (mg/L)	median	95th percentile
G44/0127	4.1	5.9455	C	C
G44/0136	0.005	0.05	A	A
G43/0009	4.6	5.52	C	C
G43/0224b	7.9	8.66	D	C
G43/0072	5	5.5	C	C
	Ammoniacal nitrogen		NOF Band	
Bore number	median (mg/L)	Max (mg/L)	Median -	Maximum
G44/0127	0.005	0.056	A	B
G44/0136	0.012	0.023	A	A
G43/0009	0.005	0.38	A	B
G43/0224b	0.0025	0.062	A	B
G43/0072	0.0025	0.113	A	B
	DRP		NOF Band	
Bore number	Median (mg/L)	95th percentile (mg/L)	Median	95th percentile (mg/L)
G44/0127	0.011	0.0325	C	C
G44/0136	0.019	0.1146	D	D
G43/0009	0.009	0.0198	B	A
G43/0224b	0.002	0.03195	A	C
G43/0072	0.006	0.012	B	A

Table 35: Median concentrations for DWSNZ/ecosystem health parameters for the Lower Clutha rohe

Aquifer	Ammonia (mg/L)	Dissolved Arsenic (mg/L)	DRP (mg/L)	E-Coli (MPN/100mL)	Nitrate (mg/L)
Clydevale	0.0200	0.0005	0.0110	0.5000	0.0050
Ettrick	0.0025	0.0005	0.0074	0.5000	4.9000
Inch Clutha	0.0185	0.0025	0.2100	0.5000	0.1000
Pomahaka	0.0120	0.0011	0.0190	0.5000	0.0050
Pomahaka Alluvial Ribbon	0.0050	0.0005	0.0110	0.5000	4.1000
Roxburgh	0.0060	0.0005	0.5000	4.4000	5.0000

4.2.6.1 The Roxburgh basin

4.2.6.1.1 Aquifer information

The Roxburgh basin is located in Central Otago and is defined by an alluvial terrace situated between the Roxburgh township to the south and the Roxburgh dam to the north. The terrace is almost entirely bound by the schist which makes up the Knobbly Range in the east and the Old Man Range in the west. The basin is underlain by fairly impermeable Haast schist and its shape was formed by a series of major north-south trending faults and folds located throughout the basin. Across Central Otago, the basement rocks are, in places where faulting or folding has protected them from erosion, overlain by non marine Miocene quartz conglomerate, sandstone, mudstone, and lignites of the Manuherikia group. Within the Roxburgh area, this group is represented by lignite and fine-grained muddy sediments. These are relatively impermeable and effectively form the base of the water bearing zones in the overlying Quaternary gravels. The aquifer consists of Quaternary glacial outwash, alluvial fans and tailings containing sand, silt, and gravel. These sediments were deposited by the Clutha River following a series of glacial periods and they form the terraces seen today. Adjacent to the foothills are alluvial fan deposits consisting of gravel intercalated with boulder clay. There are also man made tailing (sluicing) deposits of well sorted sands and gravels that make up the terraces' southwestern boundary (ORC, 2014c).

The Clutha River dissects the basin and separates it into two aquifers: Roxburgh East and West, with areas of 13.6km^2 (east) and 0.4km^2 (west), respectively. The shallow geology of the Roxburgh East area is comprised of unconsolidated Pleistocene outwash gravels, moraine, and glacial till. The aquifer boundaries were defined based on topography, and is assumed to be limited to sediments that were accumulated between the Clutha in the west and the mountain ranges to the east. The aquifer sediments are overlain by patches of thin, recent auriferous stream alluvium along the Clutha bank. There are reports of coal seams within the Roxburgh East outwash gravels, although these are more likely to be found in the underlying basement rocks. The aquifer area is surrounded by outcropping schist basement. Two subparallel north-south striking faults were mapped within the schist terrain adjacent to the Roxburgh Dam north of the aquifer area. These faults were not mapped as extending into the aquifer area itself although this possibility cannot be ruled out as the surface expression of these structures may be masked by the unconsolidated Pleistocene deposits (ORC, 2014c).

The Roxburgh West area is located at the western edge of the tectonically formed Roxburgh basin, in a narrow zone between the Clutha and the steep, east-facing slopes of the Old Man Range. The Roxburgh West aquifer consists of Quaternary river alluvium gravels locally intercalated with boulder gravels of alluvial fan origin that overlie schist basement rock. The maximum thickness of the gravel aquifer is around 25-30m. The configuration of the basement rock schist 'bench' is not known, but is assumed to generally slope gently eastward toward the

Clutha. The aquifer thins out towards the west, with only a thin veneer of gravels potentially overlying schist close to the western margin of the aquifer. The Quaternary gravels contain an unconfined aquifer, representing a single hydrologic unit, although there are probably preferential flow paths, e.g. through alluvial fan deposits. The eastern aquifer margin is exposed on the banks of the Clutha (Irricon, 1997). Bore logs from the area indicate that it is dominated by silty/sandy gravels, with some gravel layers reported as containing boulder. There are also minor interlayers of clay and sandy clay. The depth of the unconsolidated deposits, which are likely to represent glacial outwash, exceeds 19.8m in three of the bores. The log for the southernmost bore (G43/0111), located on the Clutha bank, reports shallow schist basement rock at 1.1m. The depth to bedrock increases to the north, reaching 20.3m in bore G43/0126 (ORC, 1999a). Information based on mineral investigations from the early 2000s and more recent 2018 – 2020 exploration by Central Otago District Council points to a central, north-south trending paleo-channel being the primary zone of active groundwater flow in the Roxburgh West aquifer. The deepened outwash sandy gravel within the paleo-channel tends to have elevated hydraulic conductivity and saturated thickness, and hence channelises local groundwater flow.

According to the database there are 29 bores in the Roxburgh aquifer area, although the completion status for most is marked as blank. Depth information is available for 23 bores, with depths ranging between 1.2 and 35m. There is reported SWL for 10 bores, which ranges between 4.75 and 18m. Screen information is only available for one bore, G43/0222, which is screened between 13.24 and 16.14m. The main uses include domestic, irrigation, and industrial.

4.1.5.2 Groundwater quality monitoring

There is currently one groundwater quality SoE bore monitored in the Roxburgh Basin, G43/0072 (150mm diameter). The bore is situated in a paddock 150m west of SH8 at NZTM E1310456 N4954944, approximately 5km north of the Roxburgh township. The total bore depth is 16.8m and there is no bore log or screen information available.

The comparisons of groundwater quality results against the DWSNZ shows that there were no exceedances of the E. coli (

Figure 76) or dissolved arsenic (

Figure 77) MAVs. Groundwater nitrate concentrations range between 3.4 and 5.5mg/L (

Figure 78). These concentrations are lower than the DWSNZ MAV of 11.3mg/L, although the higher concentrations are approximately at ½ of it. There were also no ammonia concentrations that exceeded the GV of 1.5mg/L (

Figure 79). The results suggest that, in relation to the drinking quality standard, there are no groundwater quality issues in the bore although it is prudent to watch the nitrate concentrations.

Figure 76: Groundwater E. Coli count for the Roxburgh Basin

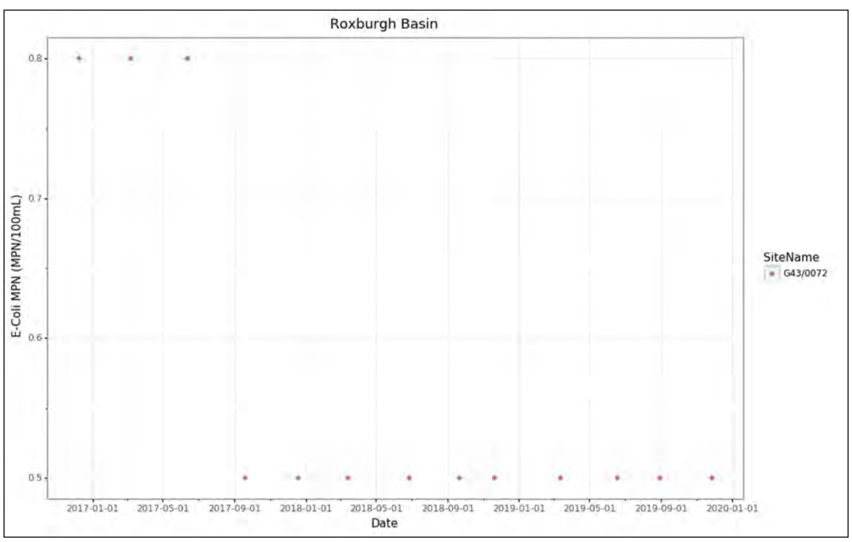


Figure 77: Groundwater dissolved arsenic concentrations for the Roxburgh Basin

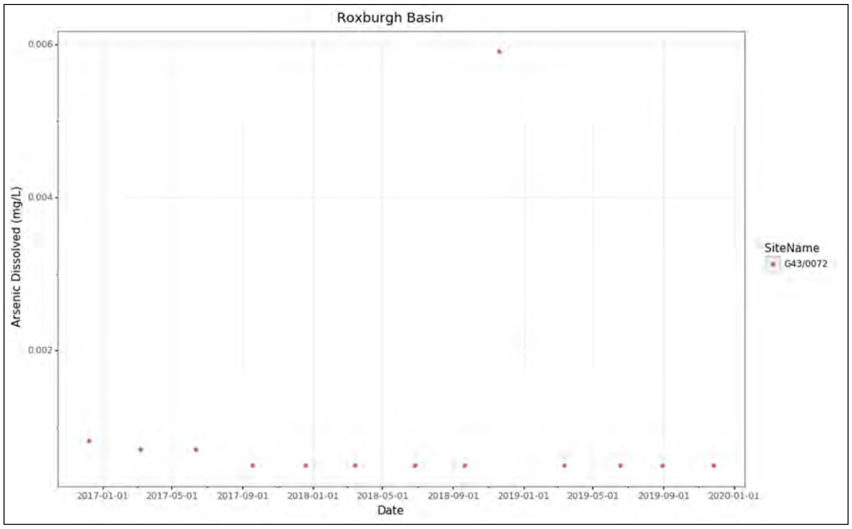


Figure 78: Groundwater nitrate concentrations for the Roxburgh Basin

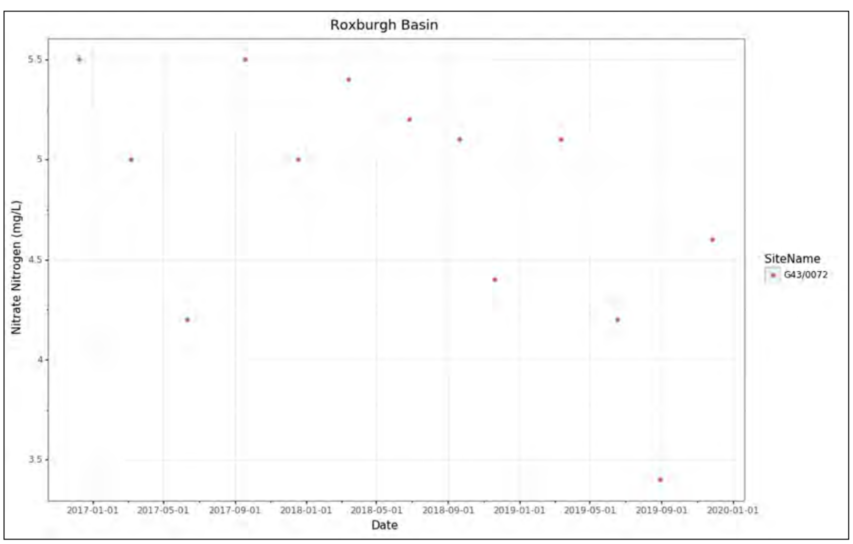


Figure 79: Groundwater ammonia concentrations for the Roxburgh Basin

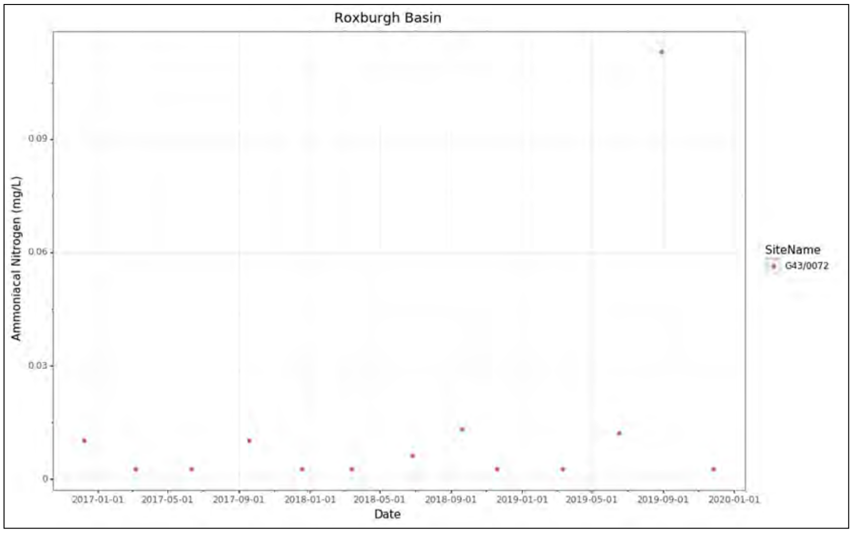
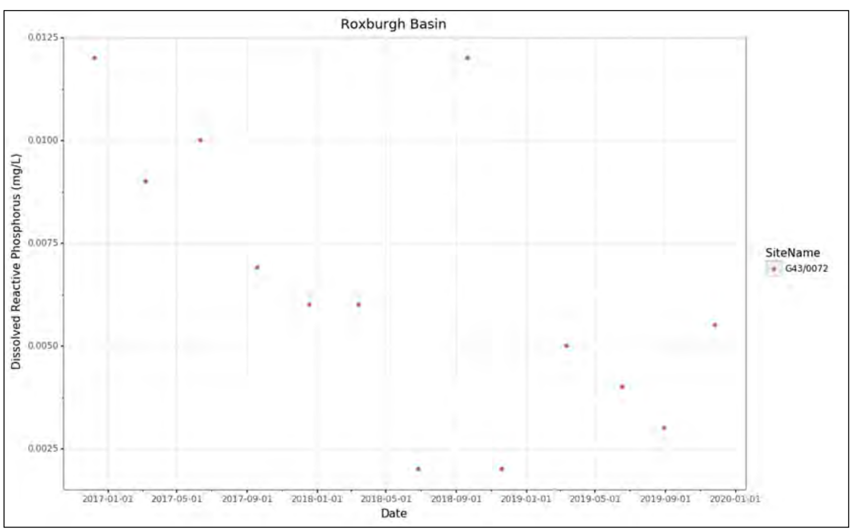


Figure 80: Groundwater Dissolved Reactive Phosphorus concentrations for the Roxburgh Basin



The groundwater quality results were also compared against the RPW (Table 36) and the NPS-FM NOF (Table 37). The Roxburgh monitoring bore, G43/0072, is located in Group 2 of Schedule 15. The results show that the 80th percentile nitrate concentrations are approximately 70 times the Schedule 15 limits. The DRP 80th percentile concentrations is at the Schedule 15 limit (Figure 80). Conversely, ammonia concentrations are below the limit.

Table 36: 80th percentile values for water quality variables identified in Schedule 15.

Bore number				**Nitrate (NO_3-N)**	**Dissolved Reactive Phosphorus (DRP)**	**Ammoniacal nitrogen (NH_4-N)**
Group 2 Sched. 15 limit (mg/L)				**0.075**	**0.010**	**0.100**
G43/0072	Clutha	Lower Clutha	Roxburgh	5.320	0.010	0.011

The results were then assessed against the NPS-FM NOF, Table 37. Both the median and 95th percentile for nitrate are in Band C, with growth effects on up to 20% of species (mainly sensitive ones such as fish), with no acute effects (MfE, 2020). The median and maximum ammonia concentrations are A and B, respectively, with Band B providing 95% species protection level, with an occasional initial impact on the 5% most sensitive species (MfE, 2020). The median and 95th percentile for DRP are in Bands B and A, respectively. Ecological communities are slightly impacted by minor DRP elevation above natural reference conditions in Band B. If there are additional conditions that favour eutrophication sensitive ecosystems may experience additional plant/algal growth, loss of sensitive macroinvertebrate taxa and higher decay and respiration rates (MfE, 2020). These results indicate potential issues with surface water quality, particularly regarding nitrates and DRP.

Table 37: NOF comparison for nitrate, ammonia, and DRP for the Roxburgh basin

	Nitrate		NOF Band	
Bore no.	Median (mg/L)	95th percentile (mg/L)	median	95th percentile
G43/0072	5	5.5	C	C
	Ammoniacal nitrogen		NOF Band	
Bore number	median (mg/L)	Max (mg/L)	Median	Maximum
G43/0072	0.0025	0.113	A	B
	DRP		NOF Band	
Bore number	Median (mg/L)	95th percentile (mg/L)	Median	95th percentile
G43/0072	0.006	0.012	B	A

4.2.6.2 The Ettrick Basin

4.2.6.2.1 Aquifer information

The Ettrick basin is a sedimentary basin beneath the Ettrick Flats on both sides of the Clutha, which includes the lower reaches of the Benger Burn and Ettrick township. The basin area is 14.3km^{2}and is comprised of an unconfined Quaternary alluvium aquifer underlain by a thick mudstone sequence of the Tertiary Manuherikia Group coal measures which lies on the impermeable basement schist rock. The schist bounds the western and southern boundaries (ORC, 1995).

The basin is a sediment-filled topographic depression formed as a result of movement on a normal fault at its western boundary (a “half-graben”). In the case of the Ettrick Basin, the schist hills in the west moved upward while the schist basement rocks below the basin moved down. This early Pleistocene displacement allowed the preservation of the Miocene coal measures. Subsequent Pleistocene glacial outwash sedimentation over time created the Ettrick outwash terraces encountered today.

Bore log data indicate that the unconfined aquifer is between 4 and 30m thick and is comprised of boulders, cobbles, sandy gravels, silty gravels and clay bound gravels, which are interfingered with silt and clay lenses. The aquifer is around 30m thick along the western boundary (adjacent to the schist outcrop) and thins to around 4m in the east as it approaches the Clutha. However, the saturated aquifer thickness is only between 4 and 11m. The aquifer water balance is dominated by the Clutha and Benger Burn. The Clutha is the main discharge zone for the aquifer (i.e. groundwater flows from west to east towards the Clutha). The Clutha probably does not play a major role in groundwater recharge, apart from episodic flood events. However, these are not sufficiently predictable nor regular to be included in the aquifer water balance (ORC, 2014c).

The Benger Burn is another main source of recharge for the aquifer. The Burn is located in the rain shadow of the Umbrella Mountains and the upper Pomahaka, and is generally drier than the catchments to the south and west. However, its annual rainfall of 650-750mm in the hills and 600-650mm on the flats still exceeds the median rainfall of other catchments further north in Central Otago. Due to aspect and higher altitude the upper reaches of the North branch of the Burn receive higher annual rainfall than the South branch. The Burn loses a significant amount of water to the Ettrick Basin aquifer where it first meets the alluvial gravels on the flats. In order to gain a better understanding of natural gains and losses in the lower reaches, two flow stations were installed in the Benger Burn in December 2011: Benger Burn Booths is located us stream within the schist foothills west of the basin. The other station, Benger Burn @ SH8 is positioned downstream, near the Burn/Clutha confluence (ORC, 2014c).

The data shows that, despite a baseflow of 60L/s at the (upper) Booths flow site, there was no surface flow at SH8 during the latter part of the irrigation season. However, although irrigation takes account for some of this loss, it is difficult to determine their impact due to issues with water metering. Furthermore, flow losses of >100L/s were observed during April/May 2013. These are not likely due to irrigation, which usually does not occur during these months. The data also shows gain in flow during winter and spring, likely due to increased flow from the southern branch of the Burn, which enters the main stem between the two gauging stations. Due to a combination of low rainfall and losses to groundwater in its lower reaches, the South Branch does not significantly contribute to surface flows in the Benger Burn during the irrigation season. The difference in the flow between the two sites does not only show changes in flow between the two sites, but also provides insight into the Burn's contribution to the groundwater system. Some of the losses to the aquifer are probably associated with the lower reaches of the South Branch of the Burn, although there is no gauging data to support it. Most of the observed flow losses are probably recharging the aquifer, making the Burn a main source of the Ettrick basin. It is also likely that groundwater takes will further induce the loss of surface water from the Burn during the irrigation season (i.e. aquifer levels will fall and steepen the hydraulic gradient and induce further losses from the stream) [ORC, 2014c].

4.2.6.2.2 Groundwater quality monitoring

Groundwater quality in the Ettrick basin is monitored in two SoE bores. Bore G43/0009 (100mm diameter) is located southeast of the SH8-Clutha Road intersection, at NZTM E1317341 N4939478. The bore depth is 15.2m. There is no available bore log or screen depth information for this bore.

Bore G43/0224b (50mm diameter) is located at Marsh Road, approximately 1.13km west of the Clutha River, at NZTM E1316403 N4941145. The bore was drilled in 2017 as part of ORC's Ettrick

Basin investigation. The bore log describes sand to 1.0m underlain by fine to coarse sand and gravels with a trace of silt to 5m. There is then gravels which coarsen with depth to 21.9m. The gravels are then underlain by mudstone to 22.17m. The bore contains two piezometers, both of which are screened in the gravel horizon. The shallower piezometer, G43/0224a, is screened between 9.73m and 12.73m and the deeper, G43/0224b, is screened between 17.33 and 20.33m. This bore was drilled for an ORC groundwater investigation project, during which it was sampled monthly between February 2017 and June 2018, after which the sampling became quarterly.

Groundwater quality results from the SoE bores were compared against the DWSNZ. The results show several E. coli exceedances in both bores, with a maximum of 18 MPN/100mL (May 2017 and March 2019), Figure 81. Groundwater nitrate concentrations in both bores are below the DWSNZ MAV of 11.3mg/L. However, the concentrations in bore G43/0224b are high, ranging between approximately 6.9 and 9.1mg/L, where the upper end is near the MAV. The concentrations in bore G43/0009 are above the concentrations for natural groundwater (<2.5mg/L, Daughney and Morgenstern, 2012), ranging between 3.62 and 6.5mg/L, which exceed ½ of the MAV of 11.3mg/L (

Figure 82). There were no exceedances of the dissolved arsenic MAV in neither bore (Figure 83: Groundwater dissolved arsenic concentrations for the Ettrick Basin). There are no ammonia concentrations that exceed the GV of 1.5mg/L (

Figure 84).

Figure 81: Groundwater E. Coli count for the Ettrick Basin

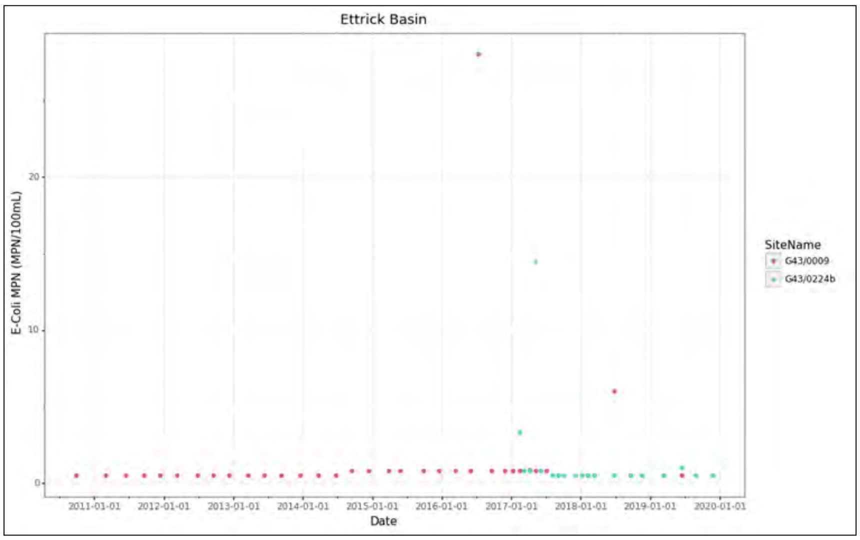


Figure 82: Groundwater nitrate concentrations for the Ettrick Basin

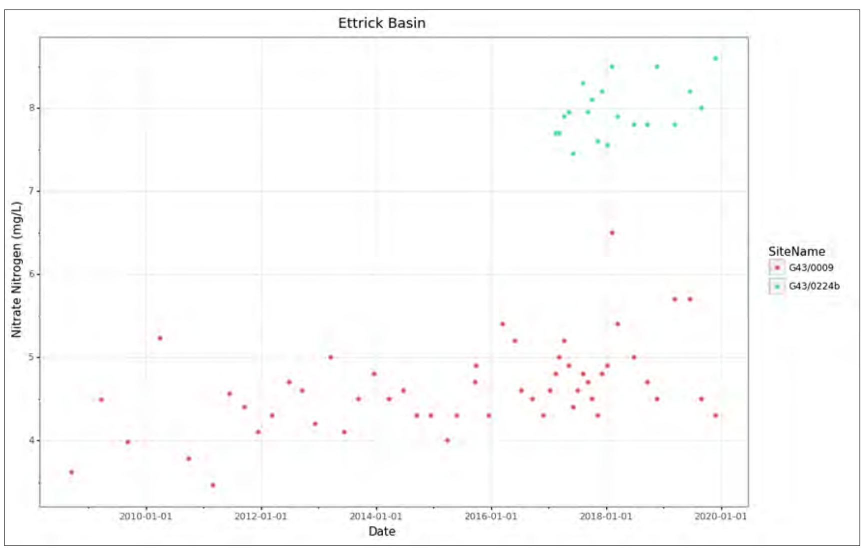


Figure 83: Groundwater dissolved arsenic concentrations for the Ettrick Basin

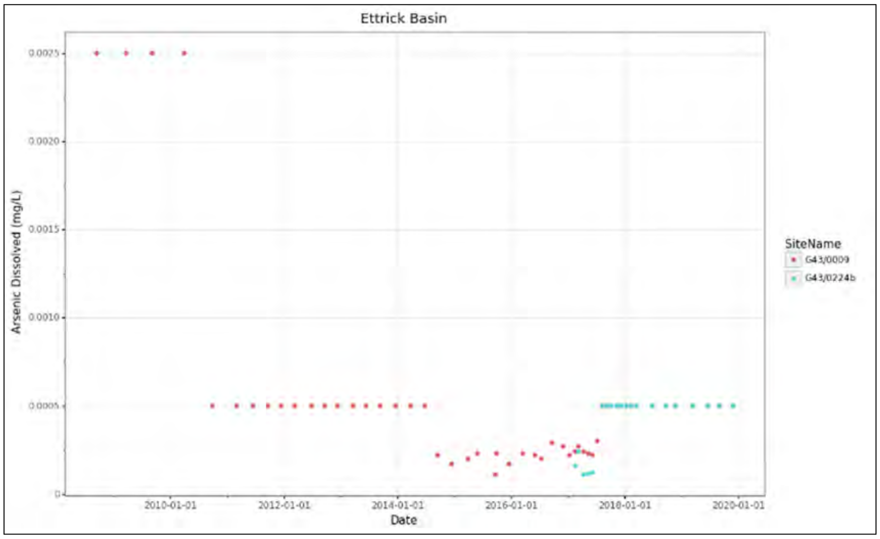


Figure 84: Groundwater ammonia concentrations for the Ettrick Basin

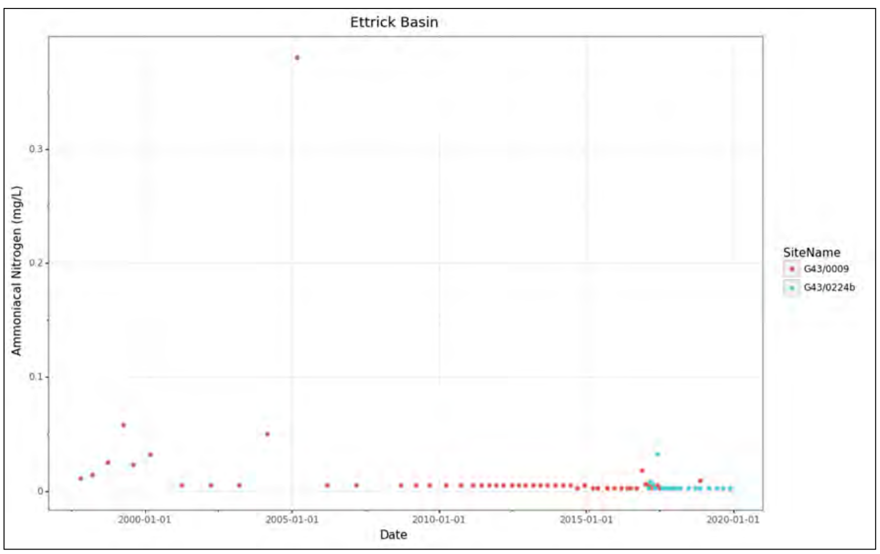
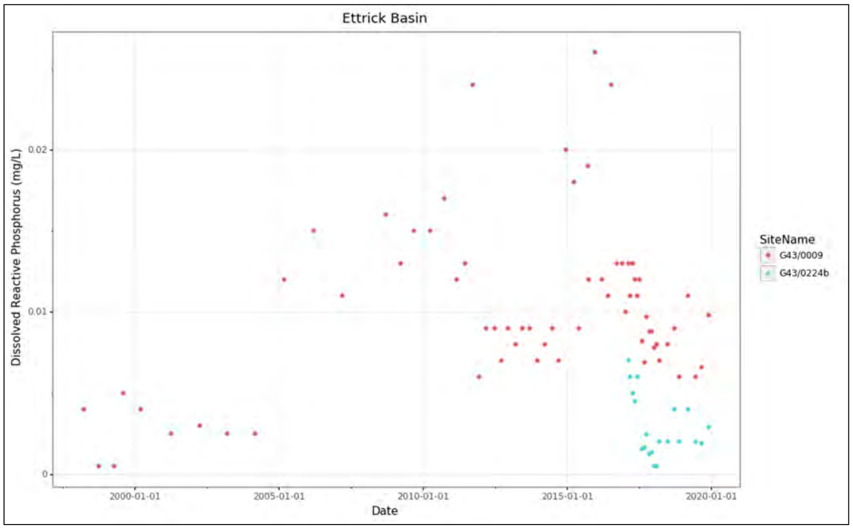


Figure 85: Groundwater Dissolved Reactive Phosphorus concentrations for the Ettrick Basin



The potential impact of groundwater quality in the bores on surface water was analysed against the RPW (Table 38) and (Table 39). Bore G43/0224 is located in Group 1 of Schedule 15 whilst bore G43/0009 is in Group 2. The results show a high degree of non-compliance with the limits for nitrate, with both bores exceeding the respective limits by around 19 times. Bore G43/0009 also exceeds the 80th percentile concentration for DRP (

Figure 85). Conversely, ammonia concentrations in neither bore exceed the limit (Table 38). This indicates potential impact on surface water quality, particularly in relation to eutrophication from nitrate and DRP.

Table 38: 80th percentile values for Schedule 15 water quality variables for the Ettrick Basin

Bore number				**Nitrate (NO_3-N)**	**Dissolved Reactive Phosphorus (DRP)**	**Ammoniacal nitrogen (NH_4-N)**
Group 1 Sched. 15 limit (mg/L)	**FMU**	**Rohe**	**Aquifer**	**0.444**	**0.026**	**0.10**
G43/0224b	Clutha	Lower Clutha	Ettrick	8.340	0.005	0.005
Group 2 Sched. 15 limit (mg/L)				**0.075**	**0.010**	**0.100**
G43/0009	Clutha	Lower Clutha	Ettrick	4.960	0.013	0.010

Potential impacts of nitrate are also highlighted in the assessment against the NPS-FM NOF (Table 39). This shows that the median concentrations in both bores are in Bands C (G43/0009) and D (G43/0224). Band D is below the National Bottom Line. It will impact growth of multiple species and starts approaching acute impact level (i.e. risk of death) for sensitive species. The 95th percentile for both bores is in Band C, where growth effects on up to 20% of the species is expected, though no acute effects (MfE, 2020). Median ammonia concentrations for both bores are in Band A, and both maximum concentrations are in Band B. This band provides 95% species protection level, with initial impact on the 5% most sensitive species occasionally. DRP concentrations in the bores are mixed, with median concentrations in bore G43/0009 in the B Band and in the A band for bore G43/0224. The 95th percentile for bore G43/0009 is in Band A whilst that of bore G43/0224 is in Band C, where ecological communities are impacted by moderate DRP elevated above natural reference condition. If other conditions that favour eutrophication occur DRP enrichment can increase algal/plant growth, loss of sensitive fish & macroinvertebrate taxa, and high respiration/decay rates (MfE, 2020).

Table 39: NOF comparison for nitrate, ammonia, and DRP for the Ettrick basin

	Nitrate		NOF Band	
Bore no.	Median (mg/L)	95th percentile (mg/L)	median	95th percentile
G43/0009	4.6	5.52	C	C
G43/0224b	7.9	8.66	D	C
	Ammoniacal nitrogen		NOF Band	
Bore number	median (mg/L)	Max (mg/L)	Median -	Maximum
G43/0009	0.005	0.38	A	B
G43/0224b	0.0025	0.062	A	B
	DRP		NOF Band	
Bore number	Median (mg/L)	95th percentile (mg/L)	Median	95th percentile
G43/0009	0.009	0.0198	B	A
G43/0224b	0.002	0.03195	A	C

4.2.6.3 The Pomahaka Basin

4.2.6.3.1. Aquifer information

The South Otago basins consist of the Pomahaka, Clydevale, Wairuna and Kuriwao basins. Of these, only the Pomahaka and Clydevale have SoE monitoring bores. The Southern Otago basins are composed of the Cretaceous to Cenozoic sediments deposited upon the Waipounamu Erosion Surface, of a complex fluvio-marine origin. The Hillfoot and Livingstone faults, along with a series of SE trending fault lines, traverse the Clydevale/Wairuna/Kuriwao basins. The basement rock north of the Livingston fault is comprised of fine to medium grained grey sandstone and mudstone whilst the basement south of the fault consists of coarse-grained volcaniclastic sandstone and mudstone. This layer is overlain by carbonaceous clay and deeply weathered clasts of quartz, greywacke, argillite, semischist and schist, which outcrop in the southwest area of the mapped Pomahaka Basin. There are also thin veneers of Quaternary gravel, moraines, and glacial till along the surface water bodies (ORC, 2014d).

The Pomahaka is the largest of the Lower Clutha catchments, with an area of 3,600km^2. The upper reaches are steep and dominated by tussock while the lower reaches mainly flow through pastoral rolling hill country. The headwaters of the river originate in the Umbrella Range and flow in a south west direction to the confluence with the Clutha near Clydevale.

The catchment climate is considered mild, with consistent rainfall throughout the year. The annual rainfall varies from around 700mm in the low latitude parts of the catchment to 1,400mm in the Blue and Umbrella Mountains. The rainfall contributes to higher river flow in the Pomahaka, with the recorded flow at Glenken (the Upper catchment) ranging between 0.8 and 480m^3/second. This includes natural flushing flows, which are important for removing algae and the flushing of nutrients and sediment. Conversely, streams with a low frequency of flushing flows are susceptible to algal proliferations, particularly if they contain high concentrations of nutrients. The Pomahaka experiences around 8 flushing events per year, with this frequency generally exceeding that of streams in North/Central Otago. Soil profiles in the Pomahaka catchment vary with topography and elevation, with the rolling hill country of the lower catchment dominated by insoluble organic, pallic and grey soils. The more mountainous areas of the catchment have primarily semi-arid soils. The Pomahaka River also supports a regionally significant brown trout fishery (ORC, 2017a).

The predominant land cover in the Pomahaka catchment is high producing grassland followed by plantation forestry and native cover. Most of the intensive agriculture within the catchment takes place in relatively flat, rolling country through the middle and lower catchment and the river terraces that border the Clutha River. Land uses in the catchment have significantly changed over recent decades, with the number of dairy farms increasing from 38 to 105 between 1999 and 2008. These conversions typically occur in the middle and lower parts of the catchment, particularly around Tapanui, Heriot and Clydevale. Most farms are located in relatively low-lying areas with poor draining soils, which rely on artificial drainage such as tile drains. However, if not managed properly, tile drains can transmit a significant flow of nitrogen, phosphorus, and bacteria from grazed pastures to waterways. The tile drains also allow riparian zones to be bypassed (ORC, 2017a).

The Pomahaka and Kuriwao basins are referred to as unconfined gravel aquifers. The basins are largely comprised of hard rock and low yielding claybound gravel aquifers. Gravel with properties of an unconfined gravel aquifer exists along surface water bodies that traverse the basins. The unconfined gravel aquifers are more likely to be thin veneers of gravel, i.e. alluvial ribbons, located along the flood plains of the meandering rivers. Although the western side of the mapped Pomahaka Basin comprises of late Quaternary gravels, logs suggest that the gravels are claybound and flow test data suggest that the gravels are low yielding. Some bore logs indicate that a semi-confined gravel lens is also present although this lens may not be continuous. Most bores in this area are located close to streams/creeks. However, due to the low yielding properties of the aquifer, the likelihood of increased groundwater use is low, hence, designating an aquifer zone around the claybound gravels was deemed unnecessary at the time (ORC, 2014d).

The piezometric surface was analysed for both the whole South Otago area and for each individual basin, with water level measurements obtained from bores screened in both alluvium and rock. The regional groundwater flow direction follows the contours of the land, with flow influenced by the Pomahaka and Clutha rivers. The local groundwater flow follows the contours of the land and flows towards discharging rivers and streams. (ORC, 2014d).

The Pomahaka Alluvial Ribbon aquifer is an unconfined aquifer located in South Otago and underlies the townships of Tapanui, Kelso, and Heriot. The aquifer area is around 250km^2 within the Pomahaka River basin with most of the aquifer lying between the river and the Blue Mountains, which form its eastern boundary.

Geologically, the aquifer is hosted in glacial deposits with overlying alluvial sediments and a thin strip of alluvial gravels along the river banks. The boundaries were identified based on topography, with the aquifer extent assumed to be limited to the sediments deposited in the river basin between the surrounding hills and mountain range. The geology of the Pomahaka Basin is dominated by surficial Pleistocene outwash gravels, moraines, and glacial till underlain by weathered and faulted gravels of the Wanganui series. There is also a thin ribbon of recent alluvium deposits along the Pomahaka River. These unconsolidated deposits are underlain by Eocene quartz sands, quartzite, clays, and lignite seams and beds of mudstone, sandstone and conglomerate, which also outcrop southwest of the aquifer area. The regional basement comprises of metamorphic rocks of Permian-Carboniferous age that outcrop north of the Pomahaka area and in the Blue Mountains to the east. It is inferred that the alluvial deposits are in hydraulic connection with the associated water courses whereas the elevated Early Quaternary Gravels are assumed to be in less hydraulic connection. Groundwater outflows from the Quaternary Gravels are likely to initially enter modern river terraces (ORC, 1999b).

Geological maps show the aquifer is divided into two principal basins of $82km^2$ and $124km^2$, with a combined area of $206km^2$. These are referred to as the Kelso and Tapanui basins, for the towns that are located within each of them. The sides and floor of the sedimentary basins are couched in Permian – Mesozoic hard rock. Within the basins, the deepest sediments are mainly fine-grained sandstone, siltstone, claystone and lignite seams of Miocene age. Quaternary sands and gravels cover the basin floor with a thin veneer over the low permeability rocks and sediments of the basement and fine-grained sediments. The reported depth of the Quaternary deposits at the Kelso basin is between 7m and 47m (although these greater depth are rare). Conversely, this information is poorly known for the Tapanui basin. The basement rock divide between the Kelso and Tapanui basins also defines the groundwater yield, with low/insufficient yield from the thin, clay-rich Quaternary gravel deposits, which require deeper drilling into the fractured rock aquifer dominates the Tapanui Basin. Conversely, the Kelso basin tends to have deeper, more permeable gravel and clay-bound gravel deposits hence there is less usage of bores that abstract from fractures. The water table depth tends to be shallowest on younger terrace surfaces close to the main surface water features such as the Pomahaka River and is deepest underneath the Early Quaternary Terrace Gravels towards the margins (ORC, 1999b).

Mapping and bore log information shows that bores located in the northern part of the aquifer were drilled through relatively thin sediments and are penetrating the underlying basement rock, with most bores screened in the rock rather than the shallow sediments. The sediment then becomes thicker to the south, with a maximum thickness of >47m (bore G45/0116, situated west of Kelso).

Aquifer pumping test results indicate a relatively low yield in the area, with Transmissivity (T) values that are more consistent with fine-medium sand than with gravels. This is likely to be explained by the frequent observations of clay and claybound gravels in many bore logs, which may infill pore space within gravel and effectively reduce aquifer hydraulic conductivity and Transmissivity. Mapping of the estimated aquifer Transmissivity suggest that the lowest values are found in the northern edge of the aquifer, where the gravel thickness is likely to be the narrowest. Conversely, higher Transmissivity values, of around $50m^2$/day, are found in the central part of the aquifer, near Kelso, where sediment thickness is greater and probably includes alluvial gravels. There is no information regarding the Transmissivity of bores located in the large area south of Tapanui. There is no information regarding the Storativity and the aquifer Specific Yield. Based on the low Transmissivity of the aquifer, it is likely that the specific yield will be relatively low, at around 0.1. However, it is required to conduct constant discharge pump tests in order to confirm that (ORC, 1999b).

According to the database there are 31 bores within the Pomahaka basin. The bores show a wide range in depth, between 4.4 and 78.5m. There is reported SWL for 26 of the bores, which ranges between 1 and 14.8m. Screen depth is reported for 12 bores, with depths ranging between 2.5 and 77m. Most screens lengths range between 1-3m. The main reported water uses include dairy shed, domestic, stockwater and irrigation (ORC, 1999b).

4.1.5.3.2 Groundwater quality monitoring

There are two groundwater quality monitoring bores in the Pomahaka basin. Bore G44/0127 (100mm diameter) is located approximately 880m northwest of the Paradise Flat/Ardmore Road intersection, at NZTM E1306679 N4910886. The bore depth is 5.2m. The bore log describes clay/topsoil to 1.0m underlain by blue/brown gravels to 4m. There is no information regarding the screen depth, however it is likely to be within the bottom gravel horizon.

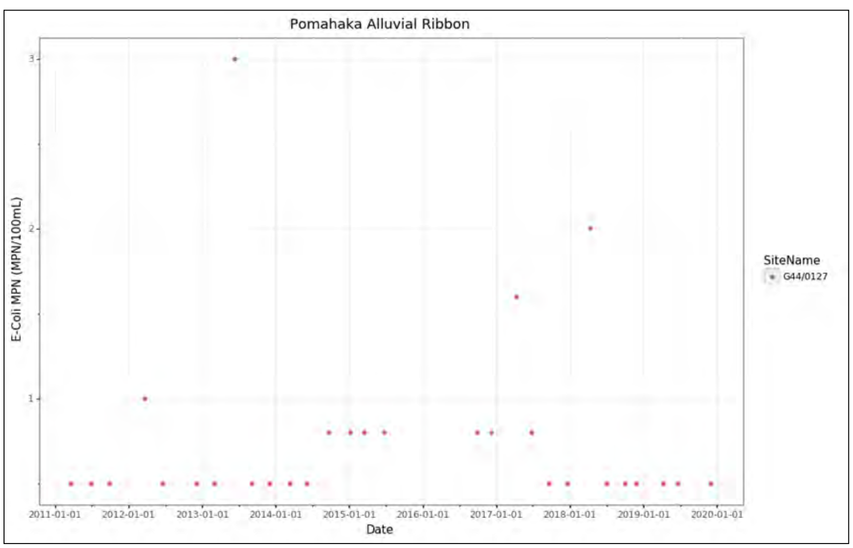
Bore G44/0136 (50mm diameter) is situated in Glencoe, at NZTM E1310773 N4912370. The bore is situated approximately 5.5km west of the foothills of the Blue Mountains, near one of the tributaries of the Pomahaka. The tributary flows in a westerly direction to the south of Pebble Ridge and then flows toward the southwest, entering the Pomahaka south of Kelso. The bore depth is 5.5m. There is no bore log or screen depth information available for it.

The assessment of groundwater quality results against the DWSNZ showed some issues. E. coli in both bores were generally below the MAV, although some exceedances were observed, with a maximum count of 5 MPN/100mL (Figure 86). The last exceedances were measured in April 2018. The results went back down following the exceedance, suggesting it was a single event rather than an occurring trend. This suggests that there is some risk, albeit fairly low, of faecal contamination from the bores. However, the bores are very shallow, with poor borehead protection. Nitrate concentrations in both bores are below the DWSNZ MAV of 11.3mg/L. However, nitrate concentrations in bore G44/0127 range between 2.9 and 6.86mg/L, with the higher end of the results exceeding ½ of the MAV (Figure 87). No dissolved arsenic concentrations exceeded the 0.01mg/L MAV (

Figure 88). There are no ammonia concentrations that exceed the GV of 1.5mg/L (

Figure 89). The results are generally good in relation to the DWSNZ, although there is a degree of risk of faecal contamination and nitrates.

Figure 86: Groundwater E. Coli for the Pomahaka Basin



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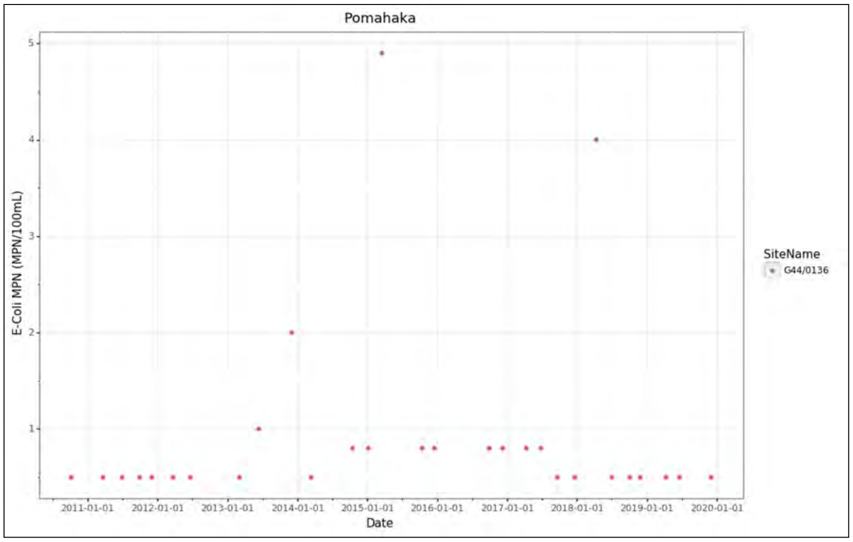
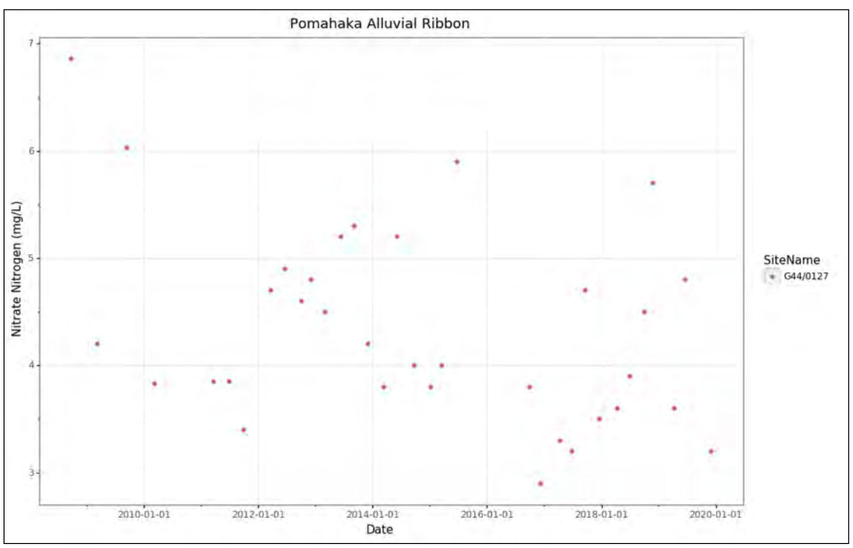


Figure 87: Groundwater nitrate concentrations for the Pomahaka Basin



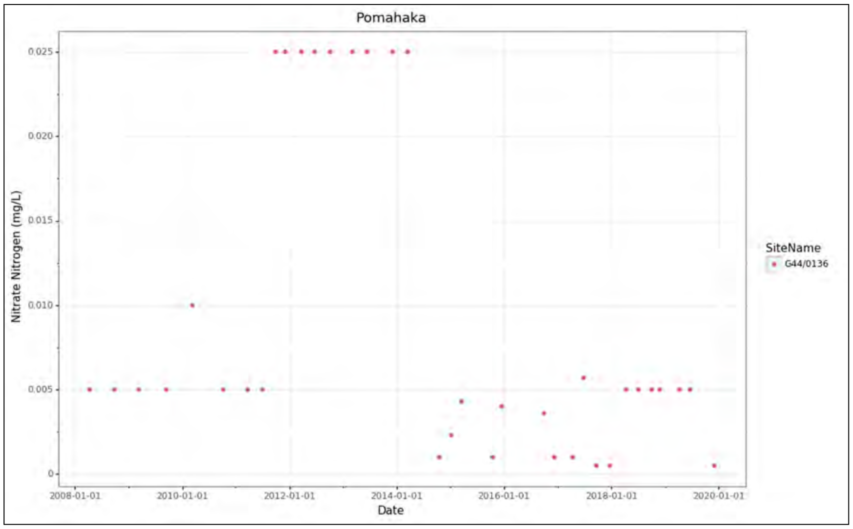
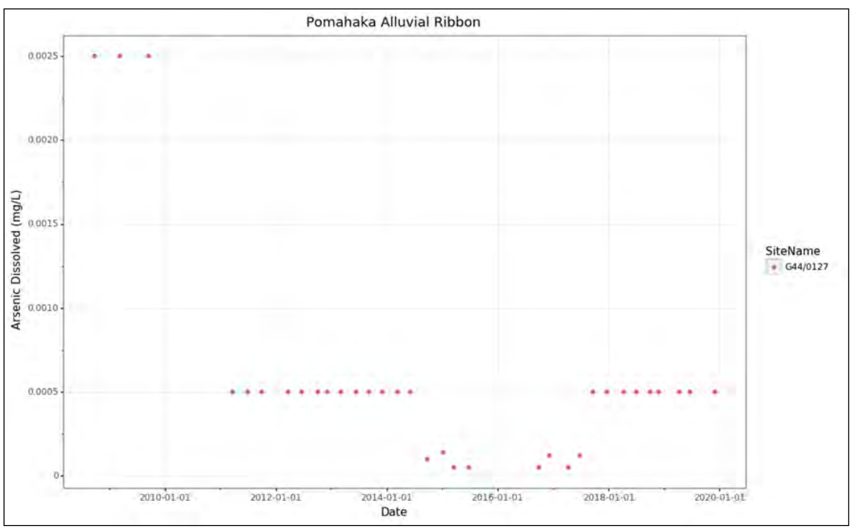


Figure 88: Groundwater dissolved arsenic concentrations for the Pomahaka Basin



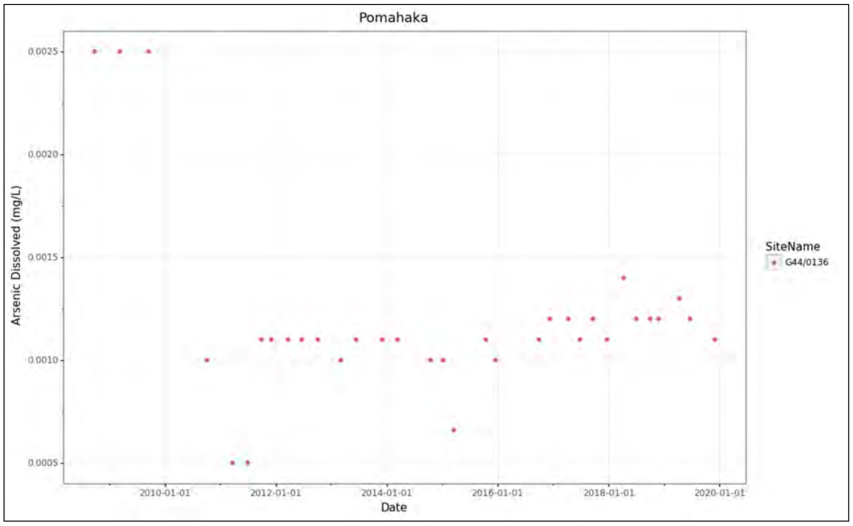
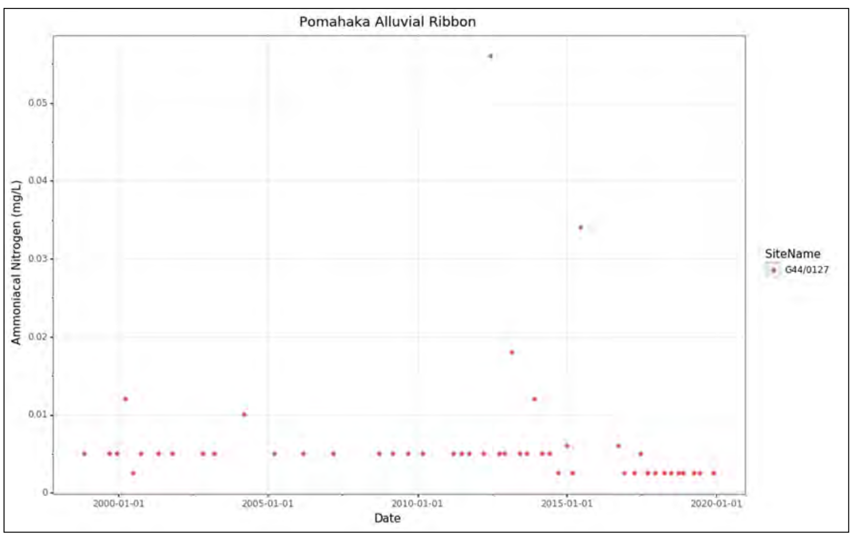


Figure 89: Groundwater ammonia concentrations for the Pomahaka Basin



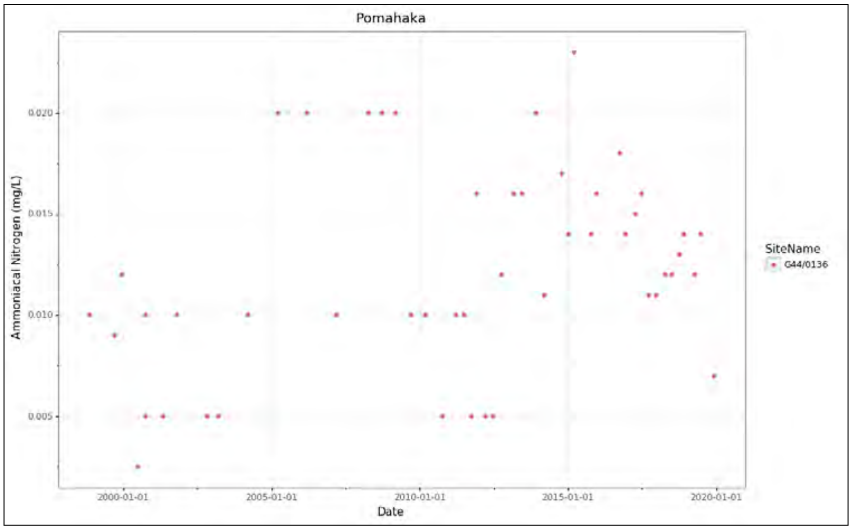
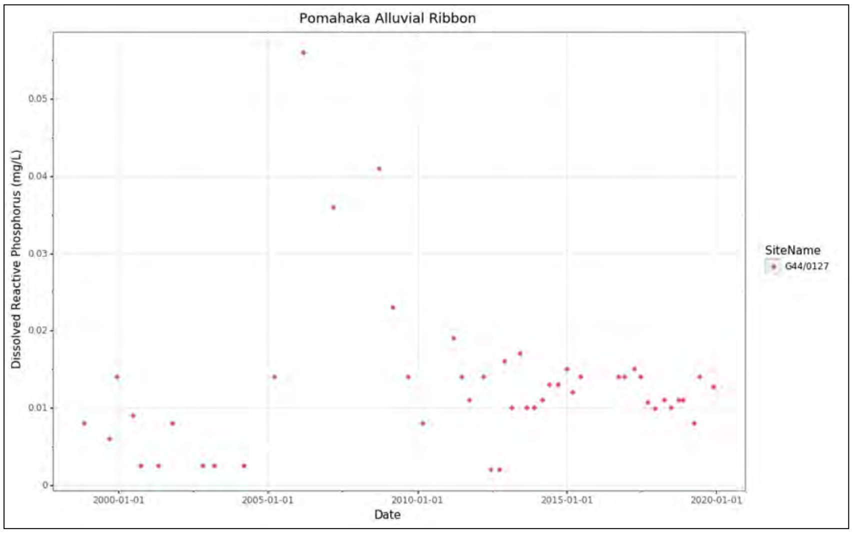
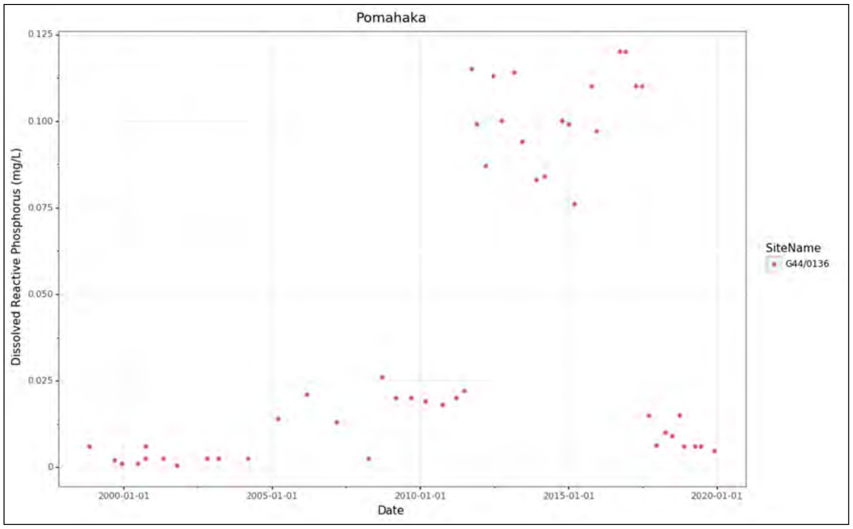


Figure 90: Groundwater Dissolved Reactive Phosphorus concentrations for the Pomahaka Basin





The results were then assessed against the RPW (Table 40) and NPS-FM (Table 41). Bores G44/0127 and G44/0136 are located in Group 1 of Schedule 15. The results show that bore G44/0127 is non-compliant with Schedule 15, with concentrations exceeding the limits by approximately 11 times. The DRP and ammonia are within the limits. The situation is opposite in Bore G44/0136, where DRP concentrations exceed the limits by approximately 4 times, with high increases in concentrations, ranging between 0.075 and 0.125mg/L, between October 2011 and June 2017 (Figure 90). Nitrate and ammonia concentrations are compliant with the Schedule 15 limits.

Table 40: 80th percentile values for Schedule 15 water quality variables for the Pomahaka Basin

Bore number	Nitrate (NO_3-N) [mg/L]	Dissolved Reactive Phosphorus (DRP) [mg/L]	Ammoniacal nitrogen (NH_4-N) [mg/L]
Group 1 Sched. 15 limit (mg/L)	**0.444**	**0.026**	**0.10**
G44/0127	5.020	0.015	0.010
G44/0136	0.050	0.099	0.016

The assessment of groundwater quality against the NOF is shown in Table 41. This shows that bore G44/0136 is in Band A for both nitrate and ammonia. The median and 95th nitrate concentrations for G44/0127 are in Band C, where growth effects on up to 20% of species, mainly sensitive ones such as fish, are expected, although no acute effects. Both median and maximum ammonia concentrations are in Band A for bore G44/0136. The maximum ammonia concentrations for bore G44/0127 are in Band B, which provides 95% species protection level, with a start of occasional impact on the 5% most sensitive species. The results for DRP are poor for both bores, with the median and 95th percentile concentrations for G44/0127 in Band C and those of G44/0136 in Band D. Band C for DRP has moderate DRP concentrations above natural reference conditions that impact ecological communities. Band D is below the National Bottom Line for DRP, where ecological communities are impacted by substantial DRP concentrations above natural reference conditions. For both bands, if combined with other factors that favour eutrophication, DRP enrichment drives excessive primary production and significant changes in macroinvertebrate and fish communities, as sensitive taxa to hypoxia are lost. These results show potential serious problems regarding the groundwater quality results from the Pomahaka bores, particularly regarding DRP and nitrates, with these potential impacts elevated due to the bores' shallow depths (circa 5m).

Table 41: NOF comparison for nitrate, ammonia, and DRP for the Pomahaka basin

	Nitrate		NOF Band	
Bore no.	Median (mg/L)	95th percentile (mg/L)	median	95th percentile
G44/0127	4.1	5.9455	C	C
G44/0136	0.005	0.05	A	A
	Ammoniacal nitrogen		NOF Band	
Bore number	median (mg/L)	Max (mg/L)	Median -	Maximum
G44/0127	0.005	0.056	A	B
G44/0136	0.012	0.023	A	A
	DRP		NOF Band	
Bore number	Median (mg/L)	95th percentile (mg/L)	Median	95th percentile
G44/0127	0.011	0.0325	C	C
G44/0136	0.019	0.1146	D	D

4.2.6.4 The Clydevale aquifer

4.2.6.4.1 Aquifer information

The Clydevale & Wairuna basins are located in the Clutha District. The basins are bounded by the Clutha and Pomahaka Rivers to the east, the Blue Mountains to the west and the catchment boundaries of the Wairuna and Waiwera Streams. The water table is generally shallow and groundwater movement usually follows topography. Rainfall infiltration is the main source of recharge for both basins, with around 2.5-3.5% of rainfall recharging the aquifer, hence most precipitation runs off as surface water. The main groundwater uses in the basins are dairy shed, stock water, and domestic supply (ORC, 2004).

The geology of the basins consists of the following features: massive occurrences of sandstone, mudstone and siltstone are found in the south whilst greywacke and argillite were observed from Clifton and to the north. Haast schist is found north of the area opposite the Tuapeka Mouth. There are also thin veneers of quartzose clay or silt bound gravels that occur opposite of Clydevale and extend towards the Pomahaka/Clutha confluence. There are also some alluvial outwash gravels adjacent to major rivers and in some low lying tributary stream areas. Bore logs confirm the prevalence of low permeability rock, which is different to the heterogenous glacial/post glacial deposits common in Central Otago.

Despite the geological heterogeneity in the basin, the yield from these formations is very low. The hydraulic parameters and bore success rates (i.e. bores that yield satisfactory volumes/rates for either domestic, stockwater, or dairy shed supply) in both aquifers are very low, with the latter generally ranging between 40 – 87%. Due to the low Transmissivity and high drawdown in the aquifers, the radial separation between bores should be >350m, with this distance based on the nominal yield for both basins (0.5L/s). Due to the low permeability of the strata in the area, most bores are deeper than 100m in order to intersect sufficient fracture flow that will permit groundwater abstraction and provide sufficient working drawdown (ORC, 2004).

4.2.6.4.2 Groundwater quality monitoring

There is one monitoring bore within the Clydevale basin area, No. G45/0225 (200mm diameter). The bore is located north of Wairuna Settlement Road near a tributary of the Pomahaka River that flows from Anise Hill towards the northeast at NZTM E1307731 N4897236. The bore log describes yellow clay and sandy silt to 0.7m underlain by brown gravels to 3.8m. There is then grey/blue mudstone to the bore bottom at 5.2m. The bore is screened between 3.2 and 5.2m, within brown gravels. Groundwater quality results from the bore were compared against the DWSNZ. The data indicates several issues, particularly related to elevated E. coli and nitrates. There were several exceedances of the E. coli MAV, with the highest count of 161 MPN/100mL, measured in November 2018. The other exceedances ranged between 3 and 9.8 MPN/100mL (Figure 91). Nitrate concentrations range widely, varying between 1.63 and 12.0mg/L, which exceeds the 11.3 mg/L MAV (June 2019),

Figure 92. The results indicate no samples above the MAV for arsenic (

Figure 93). There are no ammonia concentrations that exceed the GV of 1.5mg/L (

Figure 94).

Figure 91: Groundwater E. Coli count for the Clydevale aquifer

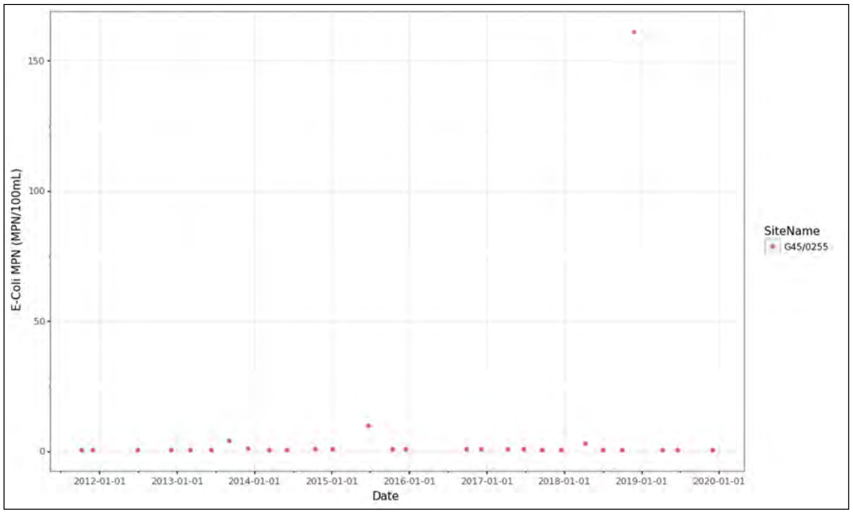


Figure 92: Groundwater nitrate concentrations for the Clydevale aquifer

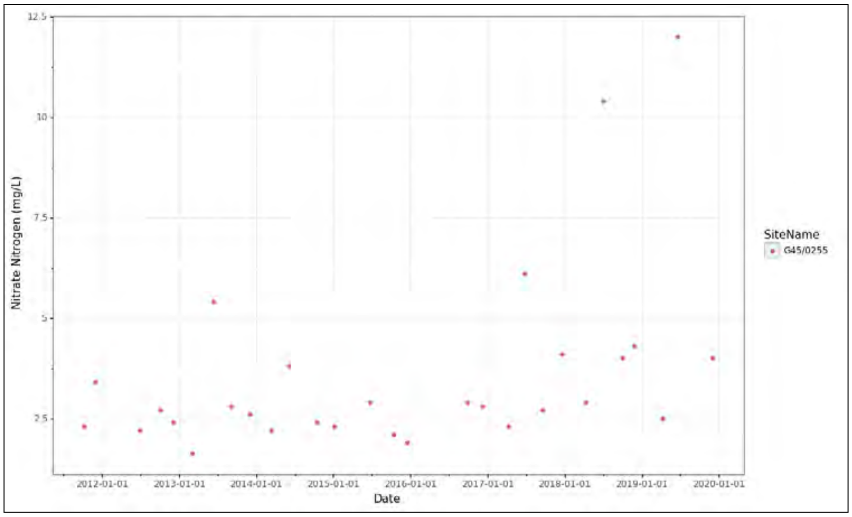


Figure 93: Groundwater dissolved arsenic concentrations for the Clydevale aquifer

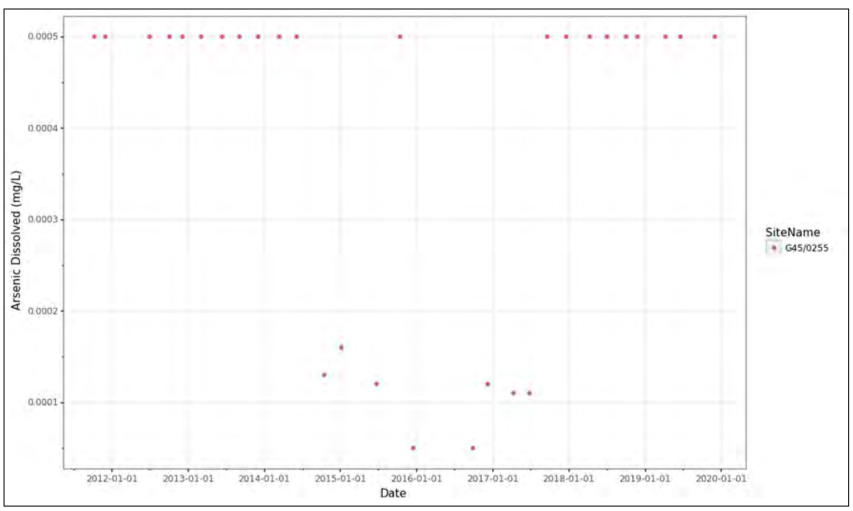


Figure 94: Groundwater ammonia concentrations for the Clydevale aquifer

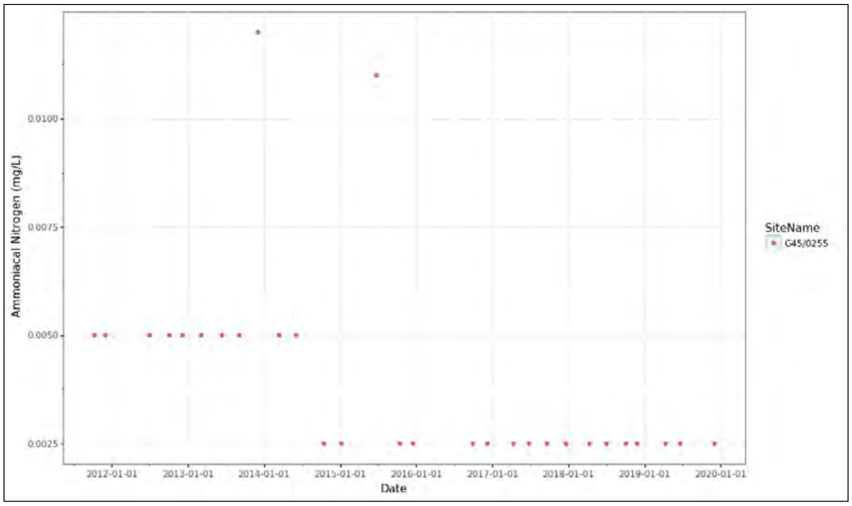
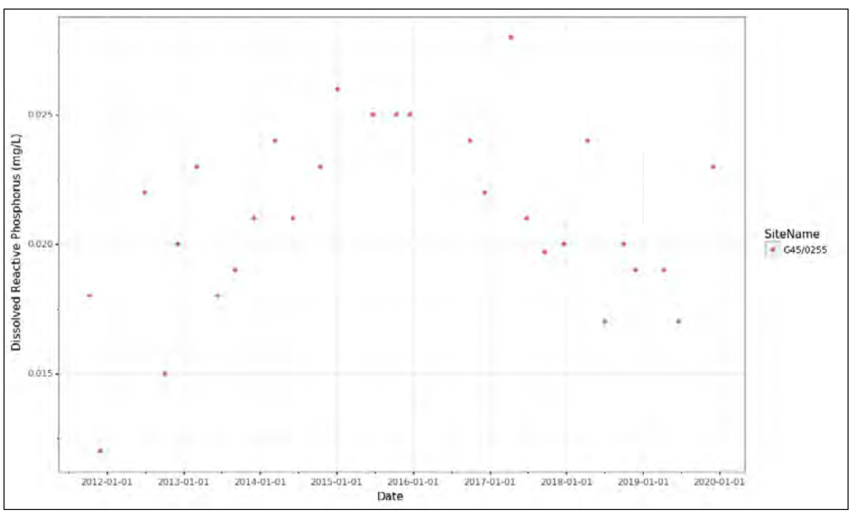


Figure 95: Groundwater Dissolved Reactive Phosphorus concentrations for the Clydevale aquifer



The assessment against the RPW shows that groundwater concentrations in bore G45/0225 comply with the Schedule 15 limits for ammonia and DRP (Table 42). However, the nitrate concentrations substantially exceed the limits. Although compliant with the RPW limits, DRP concentrations are relatively high and are increasing, reaching 0.026mg/L in January 2015. It then flattened at 0.025mg/L until March 2016 where they generally dropped, reaching as low as 0.018mg/L. Despite the lower concentrations, there were also several increases between 2017 and 2019. These increases were close to the maximum concentrations measured prior to 2015 (i.e. around 0.023-0.025mg/L),

Figure 95. These fluctuations and increases are a potential cause for concern. The assessment against the NPS-FM NOF also shows concern regarding DRP, where the median concentration is in Band D. Both

median and 95th percentile nitrate concentrations are in Band C. Conversely, both ammonia concentrations are in Band A (

Table 43).

Table 42: 80th percentile values for Schedule 15 water quality variables for the Clydevale aquifer

Bore number	Nitrate (NO_3-N) [mg/L]	Dissolved Reactive Phosphorus (DRP) [mg/L]	Ammoniacal nitrogen (NH_4-N) [mg/L]
Group 1 Sched. 15 limit (mg/L)	**0.444**	**0.026**	**0.10**
G45/0225	4.04	0.024	0.0118

Table 43: NOF comparison for nitrate, ammonia, and DRP for the Clydevale Aquifer

	Nitrate		NOF Band	
Bore no.	Median (mg/L)	95th percentile (mg/L)	median	95th percentile
G45/0225	2.8	8.68	C	C
	Ammoniacal nitrogen			
Bore number	median (mg/L)	Max (mg/L)		
G45/0225	0.0115	0.012	A	A
	DRP			
Bore number	Median (mg/L)	95th percentile (mg/L)		
G45/0225	0.021	0.0256	D	B

4.1.5.5 Inch Clutha Gravel Aquifer

4.1.4.5.1 Aquifer information

The Inch Clutha Gravel Aquifer is situated in the Lower Clutha Plain, southeast of the Balclutha township. It is located on an alluvial floodplain bounded by gently rolling hills of between 60-100m. The plain is approximately 8km wide and 12km long, with an area of around 90km^2. The gradient across the plain is generally uniform, at <10m above Sea Level. The Clutha River divides into two branches downstream of Balclutha, the Matau and the Koau, which split the area to three blocks: Kaitangata, Inch Clutha and Paretai (although the Paretai block is located in the Catlins FMU). The water table is shallow and requires careful management.

The Lower Clutha Plain (delta) is impacted by tectonic activity with evidence for movement during Quaternary times. Late Cretaceous to early Cenozoic erosion surface is inferred to a depth of around 200m below sea level underneath the delta. However, the extent and thickness of Tertiary sediments within the valley that are concealed beneath the Quaternary sediments is largely unknown. The Quaternary geology of the delta is of an alluvium filled valley formed by the inundation of the meandering Clutha River following changes in sea level. The main controls on the delta's landscape evolution were the position of sea level, and sediment transport by the river and at the coast, which combined to form river terraces of various ages and elevations. Throughout the Quaternary period, climatic fluctuations and the resultant glaciation advance/retreat sequences impacted the Clutha's sediment load flow and gradient. All Quaternary deposits consist of unconsolidated angular to well-rounded gravel and subordinate sand and mud. Post glacial (Holocene) floodplain deposits on the Lower Clutha Plain are fine-grained, well sorted and dominated by fine sand and silt and reworked beach sand mixed with peat near the coast. Near Paretai, there are remnants of older terrace gravels preserved up to 40m above sea level and overlain by around 5m of loess. Alluvial terrace deposits are sourced from locally derived sandstone clasts and are relatively clay rich, hence likely to have reduced permeability. The thickness of the Quaternary strata is unknown, however, it is likely to exceed 25m at the coastal zone. As deltas generally form when sediment-laden fluvial systems deposit bedload when entering an open water body, which leads to up-gradient coarsening where coarser, usually less well sorted, bedload is preferentially deposited (i.e. near the river-sea interface). Due to that, there is potentially a mid zone of permeability in the delta. The depth to the water table is generally shallow and under topographical control, between 0-6m below ground level. Shallower water table sites were measured on the plain itself while wells that are located on terraces have a slightly deeper water table. The aquifer is likely to be composed of sand, gravels, mud and peat. It is likely to form a hydraulically interconnected unit although it is also likely to be heterogenous, with variability in permeability and connectedness to surface water. However, the magnitude of aquifer-river interactions is unknown and there is very little information regarding aquifer properties in the area (ORC, 1998a).

The ORC database shows 9 bores in the Inch Clutha Gravel Aquifer. Total depth information is available for eight of these, ranging between 9 and 155m. Despite this large range the variability in SWL is much narrower, ranging between 1.2 and 13.3m, indicating the shallow water table in the area. Screen depth information is available for 4 bores, which depths ranging between 8 and 18.5m. The screen lengths are approximately 1-2m. Groundwater use in the area is volumetrically low, with the main uses include domestic, stockwater, dairy shed wash and commercial. There are two consented groundwater abstractions in the area.

4.1.4.5.2 Groundwater quality monitoring

Groundwater quality monitoring in the Inch Clutha Gravel Aquifer is monitored in two SoE bores. Bore H46/0118 (1,400mm diameter) is located north of Kaka Point Road, near the Otanomomo settlement, at NZTM E1349089 N4868050. The bore is situated approximately 2.1km west of the Koau Branch of the Clutha River. The bore is actually located in the Catlins FMU and is the only SoE monitoring bore in this FMU. However, as it abstracts from the Inch Clutha Gravel Aquifer, the results were included in this section. The bore depth is 12m. There is no screen depth or log information available for this bore. Bore H46/0144 (100mm diameter) is located east of Kaitangata Highway, at NZTM E1354935 N4870284. The bore depth is 38m. The log describes gravels and clay to 4.5m underlain by grey clay to 20m. There is then 0.50m of fine white quartz underlain by grey clay to the well bottom at 37.8m. There is no screen depth information for this bore. However, the original bore log also states that the grey clays are underlain by gravels and sand at 37.8m to an unknown depth. Based on the provided bore depth of 38m, it is reasonable to assume that the depth of gravels is at least 0.20m. The original log also states that the screen length is 1.5m, although the depth of the screen top is not provided. It is assumed that the uppermost screen depth is around 36.5m, although it may be deeper, which indicates that the total bore depth is greater than 38m. Nevertheless, this information suggests that the bore abstracts from the lower gravel/sands horizon and is confined by >20m of overlying clay layers. SWL data is available in Hilltop between December 2011 and June 2013. However, it is currently not possible to physically measure SWL in the bore. The reported SWL was usually around 1.10m below MP, with one exception of 6.91m in October 2012.

The groundwater quality results from the bores were analysed against the DWSNZ. Bore H46/0144 has issues with elevated dissolved arsenic, with most concentrations after 2010 exceeding the 0.01mg/L MAV, ranging between 0.014 and 0.020mg/L, Figure 96. However, the bore owner confirmed that it is not used for drinking. All E. coli results from both bores were below the MAV (Figure 97). Nitrate concentrations in both bores are much lower than the DWSNZ of 11.3mg/L MAV. Concentrations in bore H46/0118 generally range between 0 – 0.5mg/L, although higher concentrations of between 1.40 and 1.75mg/L were measured between June 2014 and June 2018. The concentrations in bore H46/0144 are lower, ranging between 0 and 0.25mg/L,

Figure 98. Ammonia concentrations in bore H46/0144 range between 1.65 and 2.29mg/L (

Figure 99), which exceed the DWSNZ GV of 1.5mg/L. The results indicate groundwater quality issues regarding elevated arsenic and ammonia concentrations, although the latter can be possibly due to the bore location near a dairy shed.

Figure 96: Groundwater dissolved arsenic concentrations for the Inch Clutha Gravel aquifer

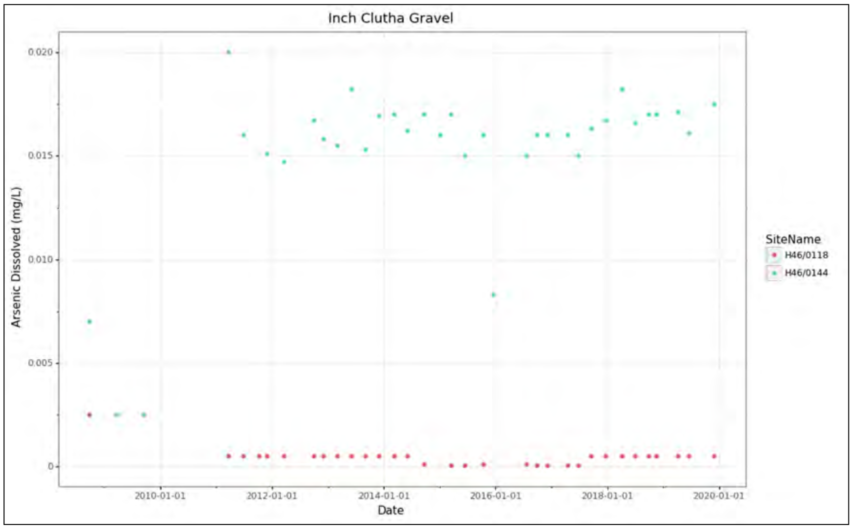


Figure 97: Groundwater E. Coli for the Inch Clutha Gravel aquifer

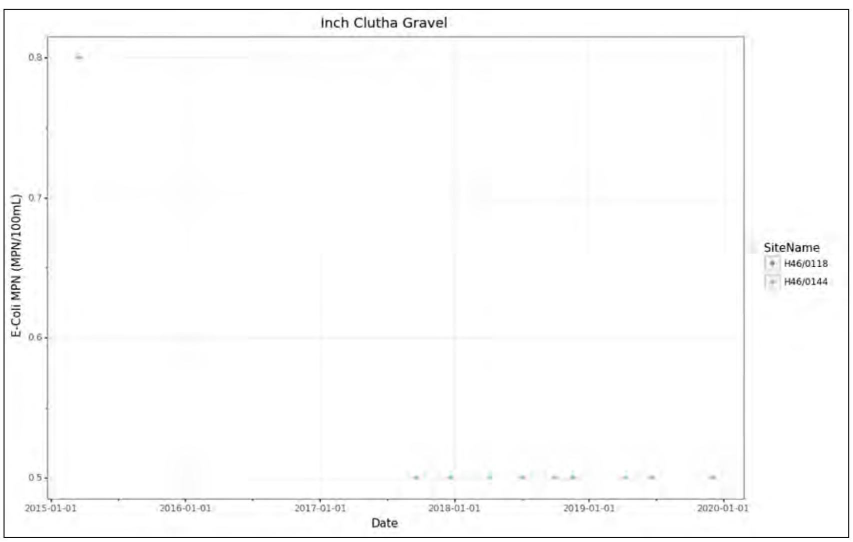


Figure 98: Groundwater nitrate concentrations for the Inch Clutha Gravel aquifer

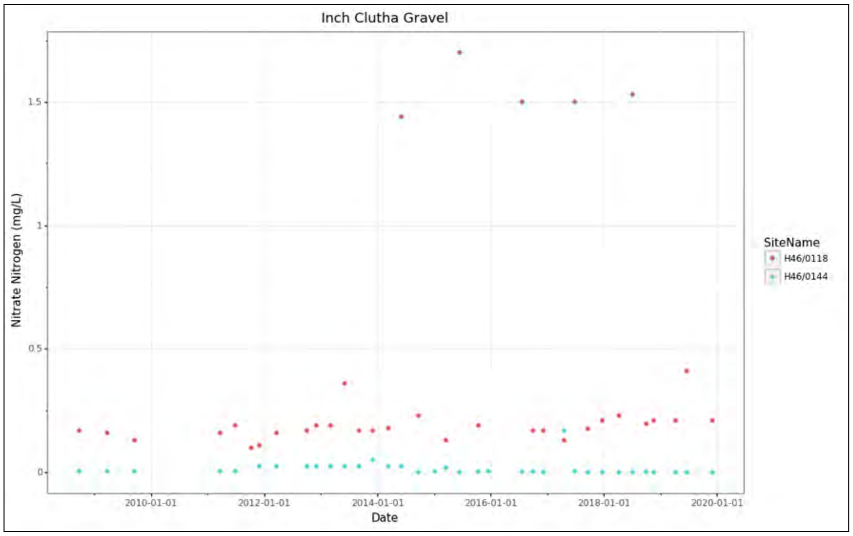


Figure 99: Groundwater ammonia concentrations for the Inch Clutha Gravel aquifer

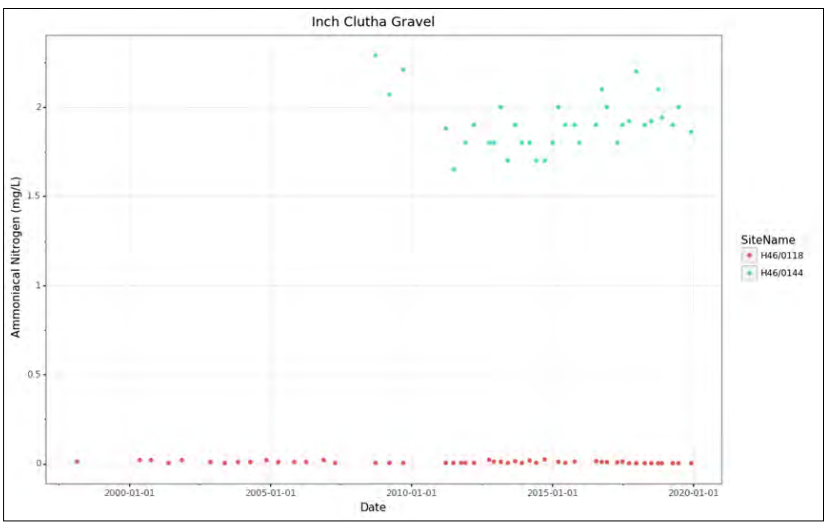
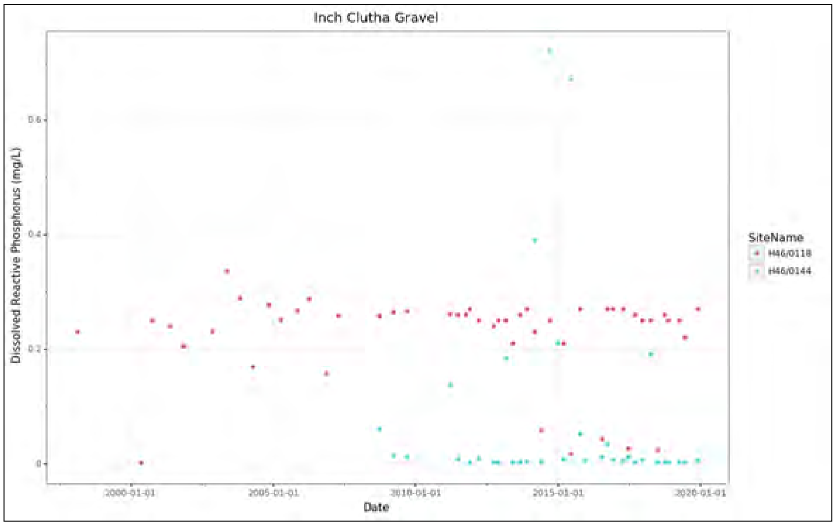


Figure 100: Groundwater Dissolved Reactive Phosphorus concentrations for the Inch Clutha Gravel aquifer



Groundwater quality results from bore H46/0118 were also assessed against the RPW (Table 44) and the NPS-FM NOF (

Table 45). The results from bore H46/0144 were not assessed due to the bore depth. Bore H46/0118 is located in Group 1 of the Schedule 15 receiving water groups. The results show noncompliance with the DRP threshold, with the 80th percentile concentration exceeding the limit by over 10 times (

Figure 100). The nitrate and ammonia concentrations are below the limits.

Table 44: 80th percentile values for Schedule 15 water quality variables for the Inch Clutha Gravel Aquifer

Bore number				**Nitrate (NO_3-N)**	**Dissolved Reactive Phosphorus (DRP)**	**Ammoniacal nitrogen (NH_4-N)**
Group 1 Sched. 15 limit (mg/L)	**FMU**	**Rohe**	**Aquifer**	**0.444**	**0.026**	**0.10**
H46/0118	Clutha	Lower Clutha	Inch Clutha	0.282	0.270	0.013

The results were then assessed against the NPS-FM NOF,

Table 45. The results indicate a similar pattern to the Schedule 15 assessment, with both the median and 95th percentile DRP concentrations in Band D, which is below the National Bottom Line. DRP concentrations at this band are substantially elevated above natural reference conditions and are impacting ecological communities. Combined with other conditions that favour eutrophication, DRP enrichment drives excessive primary production and hypoxia losses

of sensitive taxa, causing significant changes in fish and macroinvertebrates communities. The 95th percentile nitrate concentration is in Band B, where some growth on up to 5% of species occurs (MfE, 2020). The median and maximum ammonia concentrations are both in Band A.

Table 45: NOF comparison for nitrate, ammonia, and DRP for the Inch Clutha Gravel

	Nitrate		NOF Band	
Bore no.	Median (mg/L)	95th percentile (mg/L)	median	95th percentile
H46/0118	0.19	1.5105	A	B
	Ammoniacal nitrogen			
Bore number	median (mg/L)	Max (mg/L)		
H46/0118	0.008	0.023	A	A
	DRP			
Bore number	Median (mg/L)	95th percentile (mg/L)		
H46/0118	0.25	0.283	D	D

4.3 Dunedin & Coast FMU

4.3.1 FMU background information

The Dunedin & Coast FMU contains one groundwater quality monitoring bore, H45/0314, located in the Tokomairiro Plain GWMZ. The median results for DWSNZ and ecosystem health parameters from the FMU are shown in Table 46.

Table 46: Median concentrations for DWSNZ/ecosystem health parameters for Dunedin & Coast FMU

	Arsenic Dissolved (mg/L)	E-Coli (MPN/100mL)	Nitrate Nitrogen (mg/L)	Ammoniacal Nitrogen (mg/L)	Dissolved Reactive Phosphorus (mg/L)
Tokomairiro Plain GWMZ	0.002	0.650	0.001	0.064	0.014

4.3.2 Tokomairiro Plain GWMZ

The Tokomairiro plain is an alluvial basin located approximately 60km southwest of Dunedin on SH1. The plain is approximately 4km wide and 14km long with an area of around 65km^2. It is bounded in the east and west by hills rising to around 350m. The climate is similar to Dunedin and the Taieri Plain with warm summers, cool winters, and a relatively even rainfall distribution of around 650-750mm/year. The prevailing wind direction is from the southwest.

The elevation of the plain is between 35-40m above sea level at Milburn (north) and Moneymore (south), with drainage from these points towards the centrally located Milton (via the east/west branches of the Tokomairiro River) and then southeast to the coast via the Tokomairiro River valley. There are also numerous tributaries that traverse the plain, with the area between Clarksville and Milton being prone to flooding and requires drainage management.

The main impediment to agricultural development has previously been the poorly drained yellow grey soils. Tile drainage has been an important aspect of development, which still continues as new drains and maintenance of the existing drain network. Landuse has been intensive sheep farming with some cropping. Some farms then converted to dairy in the 1990s, which accounted for around 25% of the plain's area (ORC, 1998b). Milton town is on reticulated water supply, sourced from the East branch of the Tokomairiro River, which replaced groundwater. However, residents remarked regarding the taste which may indicate high iron/manganese concentrations in the former groundwater source. Rural properties across the plains are supplied via the North Bruce scheme, apart from those who opted out, who generally still use groundwater and some rainwater collection. The scheme supply is deemed sufficient for sheep farming. However, it is not for dairying, which needed to be supplemented, usually using private, individual private bores (ORC, 1998b).

The Tokomairiro Basin is located within the easternmost fault angle depression or graben of the Otago basin and has a complex structural history, being dissected by several faults. The basement rock throughout the Tokomairiro Basin is composed of Otago Schist (part of the Haast Schist) overlain by Tertiary sediments where they have resisted erosion. Although the Tertiary deposits elsewhere can potentially include aquifers, they are unlikely to form variable aquifers in the Tokomairiro Basin. The Tertiary sediments are overlain by Quaternary sediments, which appear to be continuous, with most of the wells in the area abstract from the shallower Quaternary sediments.

Three Quaternary sediments were mapped at Milburn. These include fan gravel, well-bedded pebbly gravels with grey reddish silts that dip up to 20° to the northwest. Alluvial deposits form the low terrace of the surface of the Tokomairiro catchment are differentiated from the more recent alluvium occurring in the incised valleys and streams. The older deposits, which are exposed on the banks of the Tokomairiro River, consist of slightly weathered, unconsolidated sand, silt and gravel. Much of the area is blanketed by 3-4m of loess, principally composed of silt sized quartz grains, which was deposited very recently during the last Glacial Advance (<30,000 years).

There are generally no springs or artesian flowing wells on the plain. That, and the generally consistent depth of the water table suggest an unconfined aquifer. However, there are several bores that exhibit a degree (although for some it may just be seasonally) of artesian flow, indicating that stratified, semi confined or perhaps confined conditions may occur in some parts of the plain and at greater depths. This is similar to the pattern observed in the Lower Taieri plain which has a similar geological history. Groundwater flow is determined by the surface drainage patterns and generally follows the surface topography. Groundwater from Milburn-Back Road area flows west to the North Branch of the Tokomairiro whilst groundwater in the Moneymore area flows north to the west branch of the Tokomairiro near the Clarksville-Milton reach. Groundwater will therefore naturally seep into the Tokomairiro throughout most of its length across the plain. There is no aquifer pump test information available from the area (ORC, 1998b).

According to the database there are 169 bores in the Tokomairiro Plain basin. There is total depth information for 103 bores, with depths ranging between 1.9 and 70m. The SWL information is for 22 bores, and ranges between 0.1 and 16.14m, which is similar to the information provided in ORC (1998b). Screen depth information is available for 5 bores and it ranges ranging between 0.8 and 44.11m. Screen lengths are usually around 1m. Bore logs are available for 15 bores. The main groundwater uses include stock water, domestic, irrigation, commercial and investigation.

4.3.2.1 Groundwater quality monitoring

Groundwater quality in the Tokomairiro Plain GWMZ is monitored at bore H45/0314 (125mm diameter). The bore is located west of the intersection between Limeworks Road and SH1 near Milburn, at NZTM E 1368244 N4892910. The bore depth is 11.28m. The bore log describes 2.1m of clay underlain by claybound gravels to 18.7m underlain by mudstone to 19.7m. However, the recorded bore depth is 11.28m. There is no screen depth information for this bore but it is likely to be screened within the clay bound gravel horizon, at a likely depth of around 9-10m.

Groundwater quality results from bore no. H45/0314 were compared against the DWSNZ. None of the results exceeded the E. Coli (Figure 101) or dissolved arsenic (Figure 102) MAVs. Nitrate concentrations are low, with a maximum of 0.0065mg/L, which is substantially lower than the 11.3mg/L MAV,

Figure 103. The ammonia concentrations are also below the GV,

Figure 104. These results do not suggest that there are any groundwater quality issues in this bore.

Figure 101: Groundwater E. Coli count for the Tokomairiro GWMZ

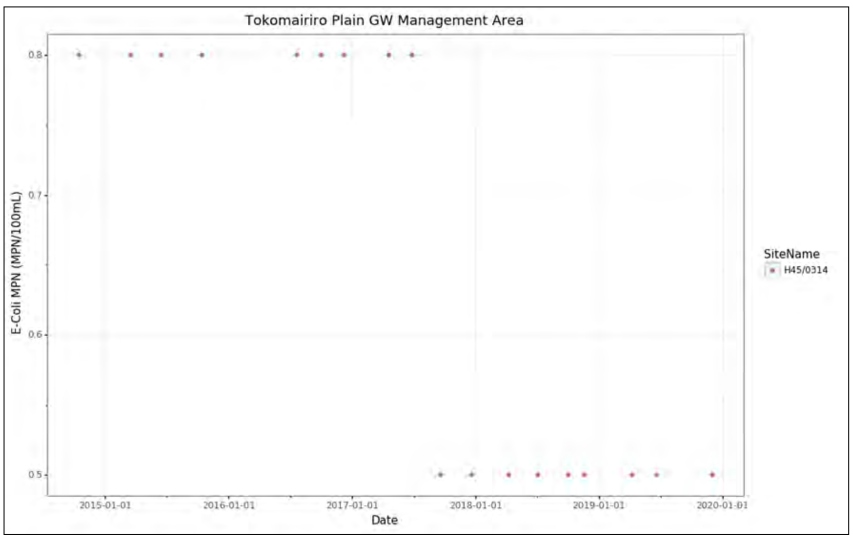


Figure 102: Groundwater dissolved arsenic concentrations for the Tokomairiro GWMZ

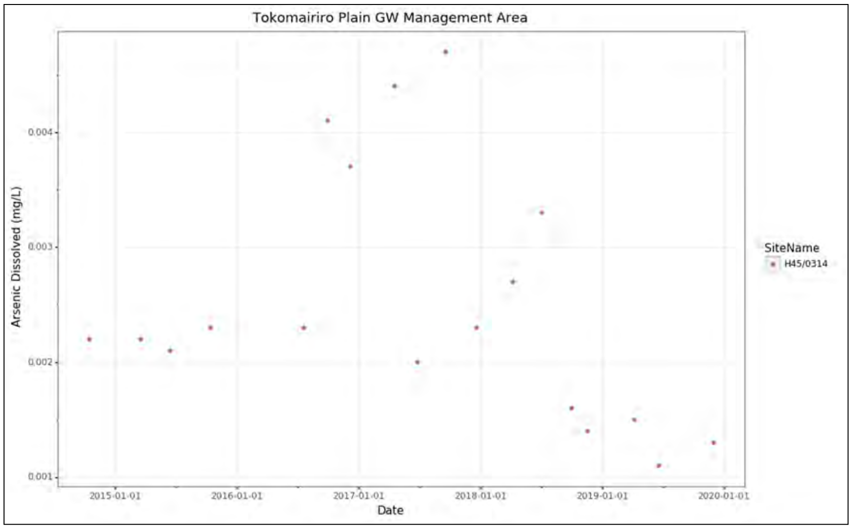


Figure 103: Groundwater nitrate concentrations for the Tokomairiro GWMZ

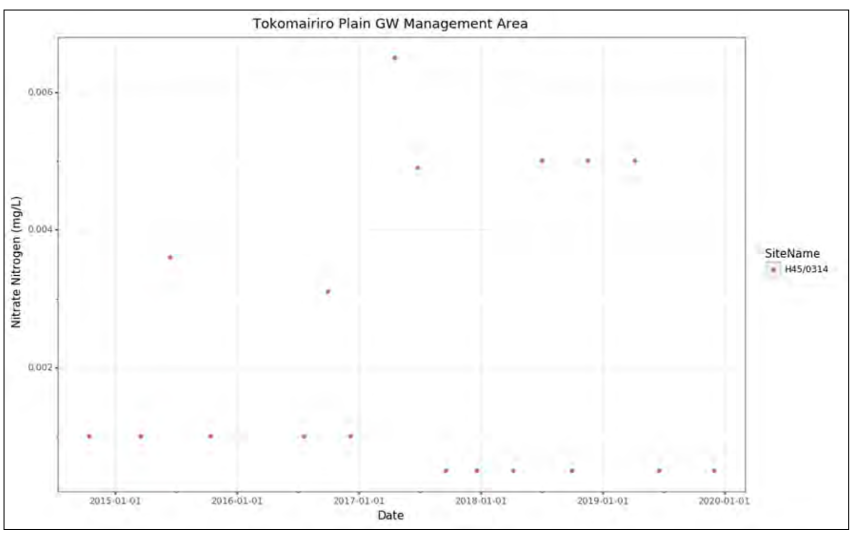


Figure 104: Groundwater ammonia concentrations for the Tokomairiro GWMZ

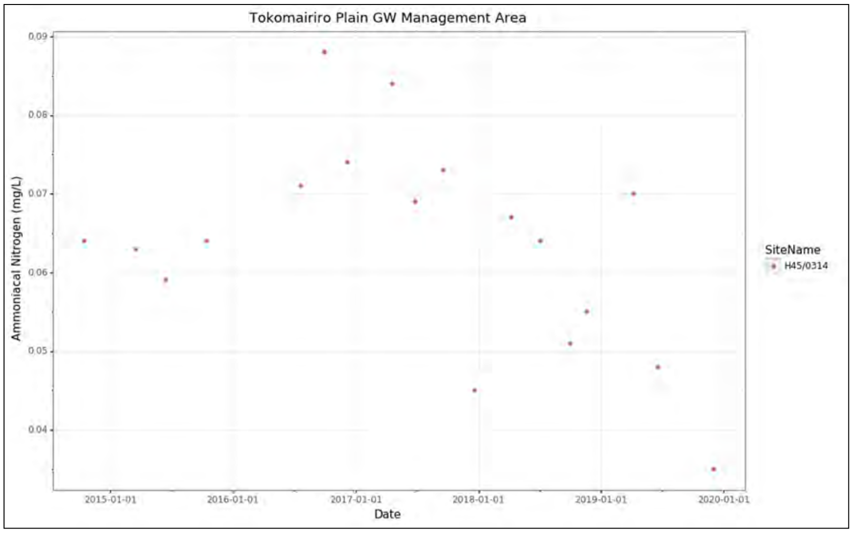
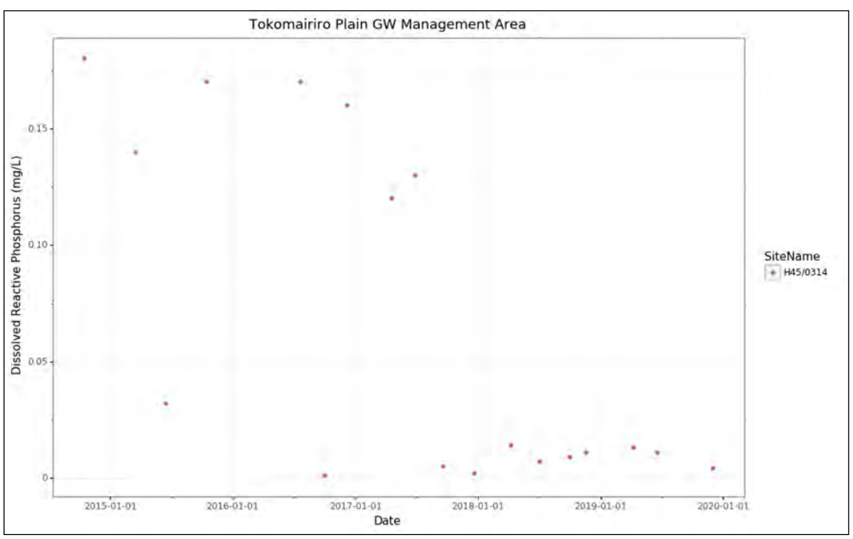


Figure 105: Groundwater Dissolved Reactive Phosphorus concentrations for the Tokomairiro GWMZ



The results were then assessed against the Schedule 15 limits (Table 47) and the NPS-FM NOF (Table 48). Bore H45/0314 is located in Group 1 of the Schedule 15 receiving water group. The results indicate potential issues with DRP, with the 80th percentile concentrations exceeding the limit by over five times. The DRP results were high, ranging between 0.0175 and 0.125mg/L between 2014 and 2017. Concentrations than fell after June 2017, ranging between 0.001 and 0.014mg/L,

Figure 105. This decline is potentially associated with a change in land use. The nitrate and ammonia concentrations are below the Schedule 15 thresholds.

Table 47: 80th percentile values for Schedule 15 water quality variables for the Tokomairiro GWMZ

Bore number				**Nitrate (NO_3-N)**	**Dissolved Reactive Phosphorus (DRP)**	**Ammoniacal nitrogen (NH_4-N)**
Group 1 Sched. 15 limit (mg/L)	**FMU**	**Rohe**	**Aquifer**	**0.444**	**0.026**	**0.10**
H45/0314	Dunedin & Coast		Tokomairiro	0.006	0.152	0.072

The results were then compared against the NPS-FM NOF, Table 48. The median and 95th percentile DRP concentrations are in Band C and D, respectively. DRP concentrations at Band D are substantially elevated above natural reference conditions and are impacting ecological communities. Combined with other conditions that favour eutrophication, DRP enrichment drives excessive primary production and hypoxia losses of sensitive taxa, causing significant changes in fish and macroinvertebrates communities. The median and maximum ammonia concentrations are both in Band B, where an adverse toxicity impact on the 5% most sensitive species begins to take place. This band provides a 95% species protection level (MfE, 2020). The median and 95th percentile nitrate concentrations are in both in Band A. These results indicate potential issues, particularly regarding DRP although concentrations appear to fall from the 2017 peak. Elevated ammonia concentrations seem to also present an issue, although to a lesser degree. It is therefore important to maintain a watch on groundwater quality at this site.

Table 48: NOF comparison for nitrate, ammonia, and DRP for the Tokomairiro GWMZ

	Nitrate		NOF Band	
Bore no.	Median (mg/L)	95th percentile (mg/L)	median	95th percentile
H45/0314	0.001	0.01	A	A
	Ammoniacal nitrogen		NOF Band	
Bore number	median (mg/L)	Max (mg/L)	Median	Maximum
H45/0314	0.064	0.088	B	B
	DRP		NOF Band	
Bore number	Median (mg/L)	95th percentile (mg/L)	Median	95th percentile

H45/0314	0.0135	0.1715	C	D

4.4. The Taieri FMU

4.4.1 Background information

The Taieri FMU contains the catchment of the Taieri River, with an area of 5,650km^2. This FMU includes the Maniototo Tertiary Aquifer, Strath Taieri Basin, and the Lower Taieri Basin (Figure 106). Background information on the FMU is provided in Section 4.4.1. Groundwater quality results for the FMU is provided in Section 4.4.2. Descriptions of the different aquifers and their groundwater quality results are provided for the Maniototo Tertiary Aquifer (Section 4.4.3), Strath Taieri aquifer (Section 4.4.4), and the Lower Taieri aquifer (Section 4.4.5).

The Taieri River is Otago's second largest, with a total length of 318km, the 4th longest in New Zealand. The Taieri originates in the Lammerlaw, Lammermoor and the Rock and Pillar Ranges in Central Otago. It then meanders in a north easterly direction across the Upper Taieri River Scroll Plain, a large natural wetland located in the centre of the Maniototo and Styx basins. This unique area contains nationally and regionally significant landscape and biodiversity values.

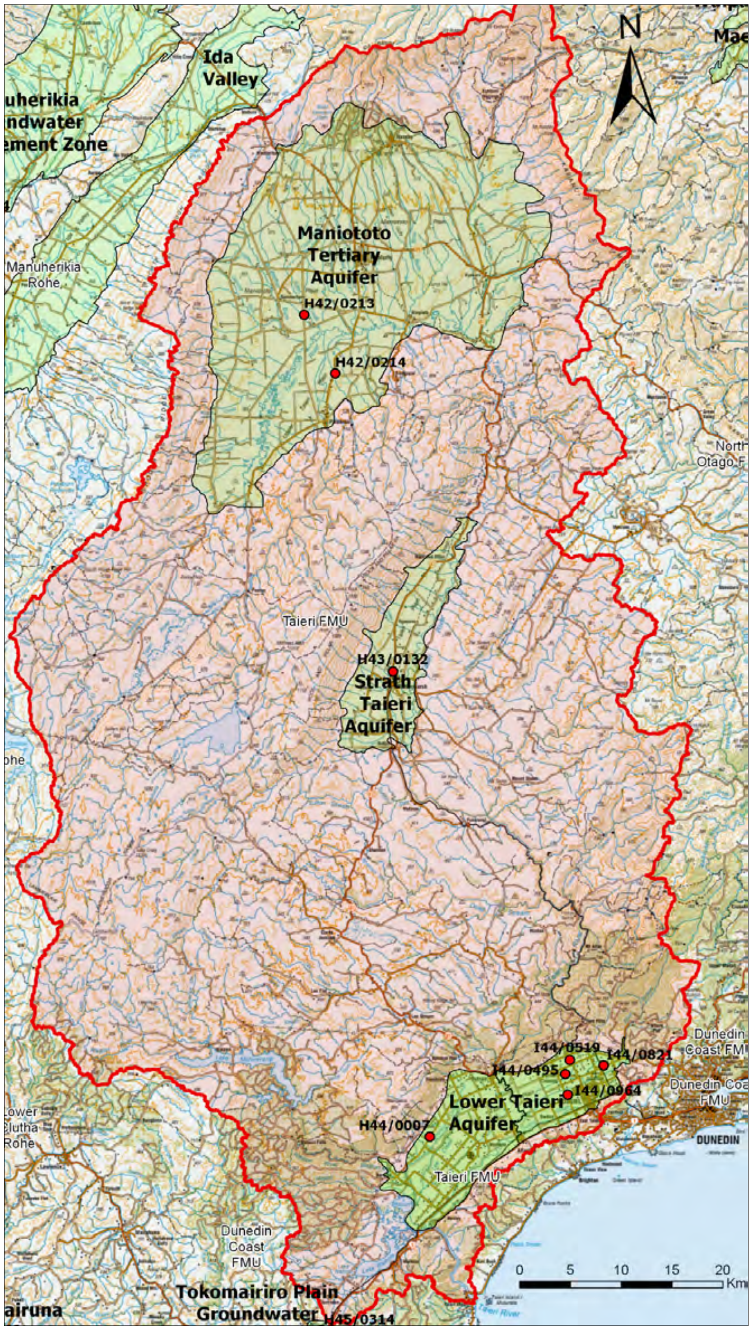
The Upper Taieri has two major catchments whose sizes exceed 1,000km^2: the Logan Burn and the Kye Burn. The Logan Burn originates in the Rock and Pillar and Lammermoor Ranges. The Rock and Pillar Range is located to the east. It is about 20km in width and it extends north east from the Lammermoor range for around 45km. The highest peak on the Rock and Pillar, Summit Rock, is 1,450m above sea level (asl). This prominent feature divides the Upper and Strath Taieri, where the Taieri River collects tributaries from the ridge's western, northern, and eastern slopes. The Kye Burn originates in the Ida Range and Kakanui Mountains. These ranges contain the highest elevations in the catchment (Mount Ida, 1691masl and Mt. Pisgah, 1,643masl, respectively) and are snow capped for several months of the year.

Many of the tributaries from the surrounding ranges flow into the Taieri River through gorges and down alluvial fans located on the Maniototo Plain. The tributaries from Rough Ridge in the west include the Linn Burn and Totara Creek. Tributaries from the Rock and Pillar Range in the south include the Logan Burn, Sow Burn, and Pig Burn. Tributaries from the Ida Range in the north include the Kye Burn, Wether Burn, and the Hog Burn. The tributaries from the Kakanui Mountains in the northeast include the Swin Burn. From the Maniototo, the Taieri flows through an incised gorge and crosses the Taieri Plain, where it joins the catchments of Lakes Waipori and Waihola, becoming tidal before flowing through another gorge and into the sea at Taieri Mouth, approximately 30km south of Dunedin (ORC, 2017a).

Rainfall throughout the Taieri catchment is highly variable and is especially low in Central Otago due to the Alps' rain shadow effect. The predominantly dry climate, combined with significant areas of low relief typical of the Upper Taieri, Maniototo, and the Strath Taieri Plains increases the need for irrigation. This intensifies landuse (e.g. arable cropping) and raises the pressure on water resources and quality. Rivers located in dry areas have low water yields, which reduces their dilution and flushing capacity. Land use intensification in these catchments can therefore increase their susceptibility to elevated nutrients and water quality degradation (ORC, 2017a). The Upper Taieri is one of the driest, coldest, and hottest areas in New Zealand, with a high temperature range of between 30 and -15°C in the summer and winter, respectively, recorded near Naseby and in the north of the Taieri catchment. The mean annual rainfall is highly variable, with a minimum of 396mm (Patearoa) and a maximum of 758mm (Dansey's Pass). The lowest rainfall is usually during winter and early spring, and the highest rainfall in December.

The region is dominated by catchments that receive very low mean annual rainfall (<500mm), with REC of predominantly cool/dry low elevation rivers and cool/dry hill rivers. The predominant land cover through the region is high producing grassland. The upper reaches of the Logan Burn and Kye Burn are steep and have moderate to severe physical limitations for arable cropping. These areas are dominated by low producing grassland and native cover. The ranges in the Upper Taieri catchment are also dominated by native cover. Land use intensity on low producing grassland have low nutrient leaching levels, which provide for good water quality.

Figure 106: Location of the Taieri FMU (red), aquifers (green) and SoE monitoring bores (red dots)



4.4.2 Summary of groundwater quality results

The median groundwater quality results for the DWSNZ and ecosystem health parameters for the FMU are shown in Table 49. The results indicate potential risk for faecal contamination, with bores in all three of the FMU's aquifers exceeding the E. coli MAV. There are also elevated nitrates in some bores, which exceed ½ of the MAV. Conversely, nitrate concentrations in other bores were within natural reference conditions. Elevated arsenic was measured in one sample in the Strath Taieri in 2009. However, it is likely that this was a single incident, potentially due to sampling or analytical error, and does not indicate continuous risk. The assessment against surface water quality limits is summarised in Table 50 and Table 51. This indicates potential issues, with exceedances of the Schedule 15 limits for nitrates in all aquifers, nitrates and DRP in two aquifers and ammonia in one. . It is likely that some of these elevated results are due to monitoring bores being shallow, insecure, and located near high risk land uses (e.g. dairy farms or septic tanks). The potential impact on surface water quality is enhanced due to bores' shallow depth and proximity to surface water bodies.

Table 49: Median concentrations for DWSNZ/ecosystem health parameters for the Taieri FMU

Aquifer	Ammonia (mg/L)	Dissolved Arsenic (mg/L)	DRP (mg/L)	E-Coli (MPN/100mL)	Nitrate Nitrogen (mg/L)
Lower Taieri	0.009	0.001	0.015	0.500	1.530
Maniototo Tertiary	0.050	0.001	0.049	0.800	1.715
Strath Taieri	0.005	0.001	0.039	0.500	1.460

Table 50: NOF comparison for nitrate, ammonia, and DRP for the Taieri FMU

	Nitrate Nitrogen (mg/L)		NOF Band	
Bore no.	50% (mg/L)		95%ile	Band
H43/0132	1.46	B	1.7	B
I44/0519	2.4	C	3.3	B
H42/0213	0.0495	A	0.2215	A
H42/0214	4	C	5.865	C
	Ammoniacal Nitrogen (mg/L)		NOF Band	
Bore no.	50%	max	Median	95th percentile
H43/0132	0.005	0.049	A	A
I44/0519	0.019	5.43	A	D
H42/0213	0.235	0.55	B	C
H42/0214	0.0025	0.25	A	B
	Dissolved Reactive Phosphorus (mg/L)		NOF Band	
Bore no.	Median	95th percentile	Median	95th percentile
H43/0132	0.039	0.054	D	C
I44/0519	0.0025	0.0111	A	A
H42/0213	0.1125	0.1984	D	D
H42/0214	0.0425	0.04915	D	C

Table 51: Schedule 15 comparison results for the Taieri FMU

Bore number			Nitrate (NO_3-N)	Dissolved Reactive Phosphorus (DRP)	Ammoniacal nitrogen (NH_4-N)
Group 2 Sched. 15 limit (mg/L)	**FMU**	**Aquifer**	**0.075**	**0.010**	**0.100**
I44/0519	Taieri	Lower Taieri	2.900	0.006	0.102
H42/0213	Taieri	Maniototo Tertiary	0.109	0.143	0.386
H42/0214	Taieri	Maniototo Tertiary	4.320	0.047	0.007
H43/0132	Taieri	Strath Taieri	1.600	0.048	0.010

4.4.3. The Maniototo Tertiary aquifer

4.4.3.1 Aquifer information

The Maniototo is a low-lying basin in Central Otago. It is surrounded by the Kakanui and Ida ranges to the north and east, the Rock and Pillar range to the south and the Rough Ridge range to the west. The elevation of the basin ranges between 300 and 600m above sea level and the surrounding ranges rising over 1000m. The defined aquifer area is 785km^2, making it the largest in Otago.

The Maniototo is drained by the Taieri River, which flows through the southern part of the basin and captures all surface drainage from the surrounding ranges. The river emerges from a rock gorge into the basin south of Patearoa. It then exits the basin south of Kokonga where it enters another rocky gorge. The topography between these two points is flat and the river is meandering, forming many oxbow lakes and marshes. Much of this land is included within the Upper Taieri Wetlands Complex, listed in the RPW as a regionally significant wetland.

The rainfall in the northern part of the basin, along the Ida Range and Kakanui Mountains, receives higher rainfall than the southern part. The surrounding ranges receive significantly higher rainfall than the basin, with a total of >2,000mm/year. Rainfall is concentrated in the summer months and some precipitation falls as snow during the winter. However, the annual Potential Evapotranspiration (PET) exceeds rainfall, often by >400-600mm. PET has a strong seasonal trend which reflects the hot summers and cool winters. The main land use in the basin is sheep and beef grazing. Due to the dry climate, irrigation is used to support pasture growth for stock grazing. However, dairy farming has increased in recent years, particularly in the southern part of the basin. There is also forestry in the northern part, west of Naseby (ORC, 2014e).

The Upper Taieri/Maniototo area contains several important wetlands. The Upper Taieri Wetlands Complex includes three sub areas located on the Taieri River floodplain: the Styx (Paerau) basin Wetlands, the Maniototo Basin Wetlands, and Taieri Lake Wetlands. The Styx Basin wetland consist of a scroll plain landform of meanders, oxbows, old braids backwater and cut offs that stretch from near Paerau to Canadian Hut. It includes the 136ha Serpentine Wildlife Management Reserve. The Maniototo Basin Wetlands, downstream of the Styx Wetlands, are of similar landform and includes the 37.5ha Eden Creek Wildlife Management Reserve and the 44ha Halls Road Wildlife Management Reserve. The Taieri Lake Wetlands lie adjacent to the Taieri River, downstream of the Maniototo Wetlands. They encompass part of the 187ha Taieri Lake Recreation Reserve. The Belmont Inland Saline Management Area is a 20.4ha salt pan south of the Puketoi Road/ Puketoi Runs Road intersection.

The Maniototo Basin is underlain by greywacke of the Rakaia Terrane, typically composed of quartzofeldspatic sandstone and mudstone. The basin's shape was formed by a series of northeast trending folds and faults, some of which are still currently active. The basin geology consists of sedimentary rock of Miocene and Pliocene age (the Manuherikia and Hawkdun groups) overlain by Quaternary sediments. The Manuherikia group sediments were deposited in deltaic, fluvial and lake margin setting (i.e. low energy environment) and comprise of quartz, conglomerate and sandstone with minor sandstone and lignite seams. The Hawkdun Group overlies the Manuherikia group and hosts the well indurated Maniototo Conglomerate that covers most of the area northeast of Ranfurly. The Quaternary sediments were deposited by fan or alluvial processes. The older Pleistocene materials that make up the terraces are composed of weathered gravel and sand with some loess cover. The more recent Holocene alluvium were deposited along river and stream valleys and are comprised of unconsolidated sands and gravels. The sediment thickness in the Maniototo basin was not determined in detail but data suggests that the depth to the (greywacke) basement ranges between 88 and >250m. Most of the sediments described in the logs are composed of mudstone or siltstone with thinner units of sandstone, conglomerate, and some lignite measures (ORC, 2014e).

The aquifer systems in the Maniototo are complex and can be divided to two main categories: shallow unconfined aquifer in the Quaternary sediments (Pleistocene and Holocene) and a deeper confined aquifer in the Cenozoic sediments (Neogene and Paleogene). The Pleistocene sediments are older and form the basin terraces whilst the younger Holocene alluvium deposits are located in flat valley bottoms adjacent to surface water bodies. Both are comprised of unconsolidated sands and gravels although they are also likely to contain lenses of finer material. These sediments form a permeable, unconfined aquifer that can be high yielding and normally consist of a shallow water table.

The deep confined aquifers of the Cenozoic sediments have a deep water table and are at times artesian. These sediments are comprised of siltstone/mudstone with minor sandy layers. Most of the artesian bores are found in the southern part of the basin, near the entrance of the Taieri River to the basin, in the central part, near the Eden Creek/Taieri confluence, and east of that area, near the crossing of the Taieri and Ranfurly Patearoa Road (near the Ewe Burn). There is also one artesian bore in the Kye Burn area (ORC, 2014e).

Groundwater flow direction is generally to the southeast, broadly following surface topography, and discharging into the Taieri River as baseflow. Previous studies on some of the streams that flow into the Taieri showed that some tributaries like the Kye Burn and Sow Burn lose groundwater for a reach as the streams come out of the hillside and flow over the alluvial gravels. Flow is then re-established before the streams discharge into the Taieri River. This illustrates the importance of groundwater to the basin's hydrology, particularly during low flows (ORC, 2014e).

The catchment is considered fully allocated for surface water, although some storage potential may be available. Irrigation in the basin has grown significantly and the currently maximum take from the basin is around 1.41 million m^3/year. Some of the bores are screened in the shallow Pleistocene/Holocene sediments whilst others are from deeper confined Paleogene or Neogene sediments. Irrigation takes from the deeper confined aquifer were only developed since 2003. The confined aquifers are likely to abstract from discontinuous lenses of sand and gravel. The discontinuous nature of these lenses makes it difficult to determine whether groundwater users are abstracting from the same aquifer, which makes aquifer management difficult. Additionally, there is also the risk of abstracting from a perched/very limited aquifer which can be overused and depleted. Although the unconfined aquifers are separated from the confined ones by low permeability aquitard materials, abstraction from the lower, confined aquifer may still impact the unconfined aquifer and surface water by inducing leakage (i.e. from the overlying aquifer, surface water, or at the margins of water bearing layers where the aquitard may thin out) [ORC, 2014e].

Available aquifer and hydrogeological properties information for the Maniototo is limited. The ORC database holds pumping test information for two bores: H42/0190 (86m deep, abstracting from the confined aquifer) and bore H42/0203 (5.5m deep, unconfined). The estimated Transmissivity ranges between 400-500m^2/d. There are also specific capacity tests from 10 drilling logs, with inferred Transmissivity ranging between 4 and 618m^2/day for the confined aquifer and between 3 and 465m^2/day for the unconfined aquifer (ORC, 2014e). However, although these can provide an estimate of the aquifer permeability, they also strongly depend on bore construction, pumping duration and flow rate. The lack of such data highlights the need to obtain this information during consent application process.

Groundwater samples indicate similar composition to that of the Kye Burn, suggesting that groundwater are derived from the same source as the Kye Burn and that groundwater contributes to the Burn's baseflow. However, the data suggests potential for cation exchange processes, which, coupled with the mixing of shallow and deeper groundwater, will continue to provide additional variation of these parameters. Water mixing can be due to bore construction across different strata, upwelling of deeper groundwater from the hills as it discharges to the Kye Burn (and the Taieri) and the proximity of bores to geological faults. Some bores that abstract from the Tertiary sediments, which are usually deeper than 30m, may also represent older groundwater with longer residence time (ORC, 2014e).

The main sources of groundwater recharge in the basin are rainfall, irrigation excess and surface water recharge. Rainfall recharge was assessed by ORC (2011). The mean annual recharge for the 38 year model period is 40.6mm, or 31.6million m^3/year. The data shows strong variability with variation of between 2 and 160mm recharge/year, which reflects variation in the timing and depth of annual rainfall. The rainfall recharge is around 6% of the annual rainfall and the highest recharge is on average during the winter months. Irrigation returns were not included in the model (ORC, 2011).

The Maniototo Basin is fully drained by the Taieri. The total volume of groundwater abstractions minus any losses to groundwater through evapotranspiration is likely to result in net flow loss for the Taieri after a sufficiently long duration for a steady state condition to occur. Hence, any groundwater takes in the basin can potentially decrease baseflow to the Taieri. After pumping starts, the stream depletion rate can slowly increase. The duration of reaching maximum depletion rate can range between hours and decades and it depends on the aquifer properties and the distance of the bore from the stream. This is the time lag or lag effect. In some circumstances, stream depletion can continue to increase even after pumping stops (ORC, 2014e).

For the shallow Quaternary unconfined aquifers in the Maniototo, stream depletion is a function of the distance from the stream and the hydraulic conductivity of the aquifer and stream bed. For the Neogene/Palaeogene confined aquifers, the limited hydraulic connection with the surface water due to the aquitard between the aquifer and stream bed may further increase the lag effect. Hence, takes from the confined aquifer, even close to the stream may have a significant time lag. Therefore, despite any provisions designed to consider surface water depletion by groundwater takes in the RPW, these will not be effective in addressing the potential for long term baseflow depletion for the Taieri, which is significantly over-allocated. Any further groundwater abstraction from the Maniototo Basin is therefore likely to contribute to further worsen the situation

According to the database there are 201 bores in the Maniototo basin. Total depth information is available for 143 of these, with recorded depths ranging between 0.25 and 205m. The SWL information is available for 64 of the bores, with the reported SWL ranging between 0.04 and 34.6m. There is screen information for nine of the bores, with the reported top of screen depth ranging between 2.6 and 41.41m. Bore logs are available for 34 of the bores. The main groundwater uses include domestic, irrigation, stock water, exploration and monitoring.

4.3.1.2 Groundwater quality measurements

Groundwater quality in the Maniototo is monitored in two bores, both of which were drilled in October 2014. Bore H42/0213 (150mm diameter) is located south of the Maniototo Road-Gimmerburn-Waipiata Road intersection, at NZTM E1366536 N4993063. The bore depth is 5.6m. The bore log describes coarse brown gravels to 3.8m underlain by blue clay and silts to the bore bottom at 5.6m. The bore is screened between 2.6 and 5.6m, within the gravels and clay/silts horizon. The bore is located very close to Eden Creek. The SWL in this bore ranges between 0.6 and 1.38m below MP, with an annual fluctuation of around 0.35m. The lowest levels are usually measured in late summer (March) and the highest in spring or early summer. There does not appear to be a continuous decline in water levels.

Bore H42/0214 (150mm diameter) is located east of the Sow Burn at the Patearoa-Ranfurly/Greer Road intersection, NZTM E1369602 N4987279. The bore depth is 9m. The bore log describes top soil to 0.4m underlain by alternating horizons of gravels and sand to 5m, whose depths range between 0.5 and 2.0m. There is then silt/silty clay to 7m. These are underlain by silty clay with minor angular quartz gravel underlain by silty fine sand with some clay and gravels down to the well bottom at 9m. The bore is screened at a depth of between 6.0 and 9.0m, within silty clay, where the bottom 1.5m also have some gravel and sands. The overlying silt/clay layer is likely to provide some degree of confinement. Groundwater levels in the bore range between 1.20 and 2.19m below MP. The annual range in water levels in the bore is usually between 0.70 and 0.80m although the range in 2018 was lower at around 0.20m. The lowest water levels are usually in late summer and the highest during spring/early summer. Due to their shallow depths, levels in the bores are likely to be strongly responsive to rainfall.

Groundwater quality results from the bores were assessed against the DWSNZ. The results indicate a high potential for faecal contamination and elevated nitrates. The exceedance of the E. Coli MAV in bore H42/0213 included high counts of 450 (March 2016) and 1,300 (December 2018) MPN/100mL. The results from bore H42/0214 also show some E. Coli exceedances, albeit at a lower count, with a maximum of 79MPN/100mL (December 2018),

Figure 107. Nitrate concentrations in both bores are lower than the MAV of 11.3mg/L. However, concentrations in bore H42/0214 range between 3.6 and 6.8mg/L, with the upper ends of this range exceeding ½ of the MAV. The concentrations in bore H42/0213 are much lower, ranging between 0.002 and 0.230mg/L, Figure 108. Dissolved arsenic concentrations in neither of the bores exceeded the MAV of 0.01mg/L, Figure 109. Ammonia concentrations in both bores are lower than the GV of 1.5mg/L, Figure 110.

Figure 107: Groundwater E. Coli count for the Maniototo Tertiary Aquifer

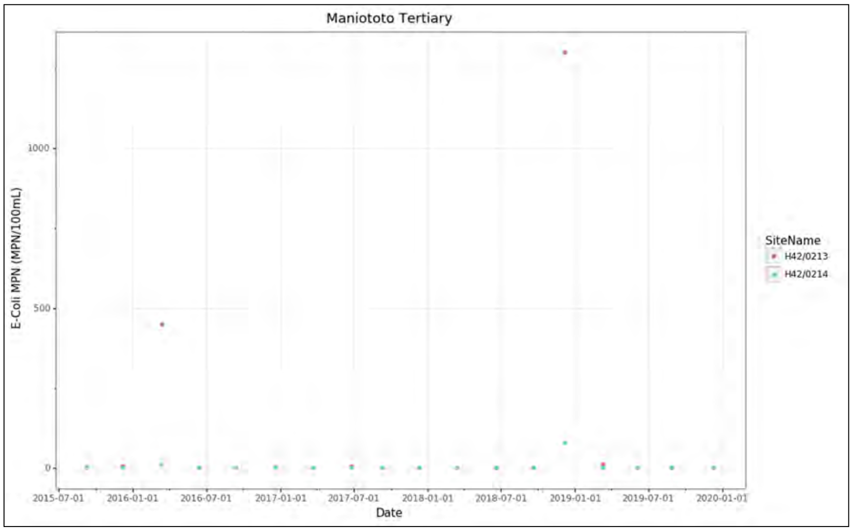


Figure 108: Groundwater nitrate concentrations for the Maniototo Tertiary Aquifer

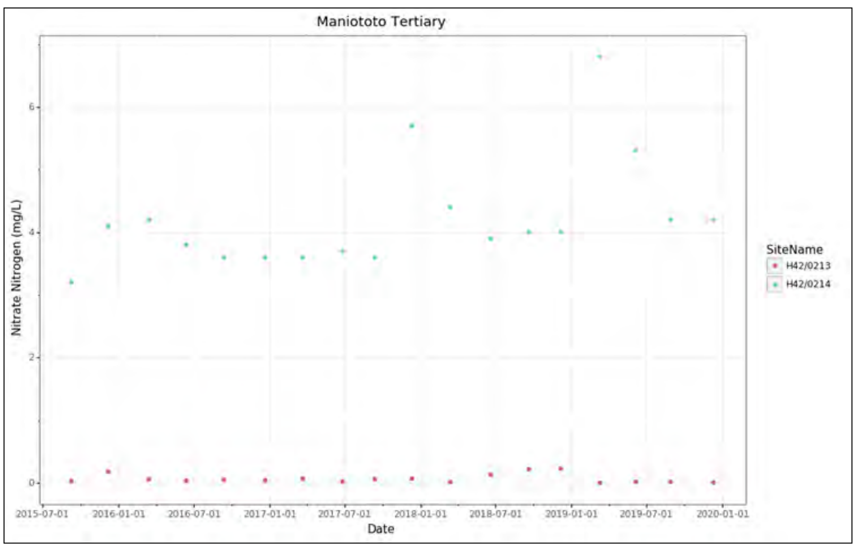


Figure 109: Groundwater dissolved arsenic concentrations for the Maniototo Tertiary Aquifer

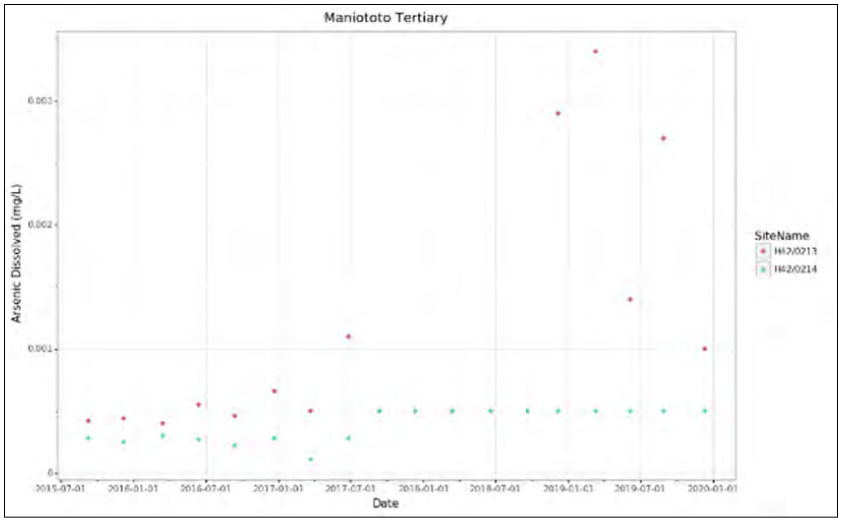


Figure 110: Groundwater ammonia concentrations for the Maniototo Tertiary Aquifer

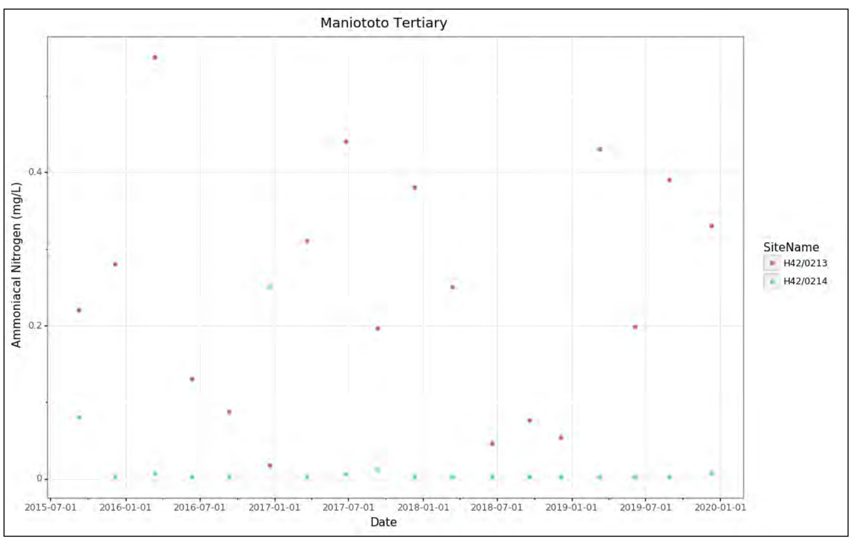
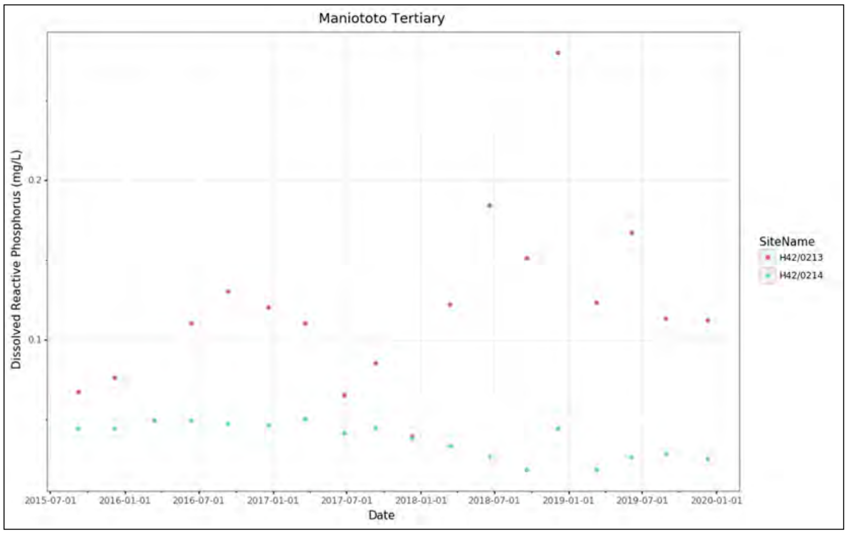


Figure 111: Groundwater Dissolved Reactive Phosphorus concentrations for the Maniototo Tertiary Aquifer



The results were then assessed against the Schedule 15 limits (Table 52) and the NPS-FM NOF (Table 53). Both bores are located in Group 2 and are shallow, hence, interaction with surface water can adversely impact surface water quality. The results indicate potential water quality issues, with the 80th percentile nitrate and DRP concentrations in both bores exceeding the Schedule 15 limits. The nitrate concentrations in bore H42/0214 exceed the limit by around 57 times and by around two times in bore H42/0213. The DRP concentrations in bore H42/0213 and H42/0213 exceed the limit by approximately 14 and 4 times, respectively,

Figure 111. Ammonia concentrations in bore H42/0213 exceed the limit by 3.86 times. The concentrations in bore H42/0214 are below the threshold.

Table 52: 80th percentile values for Schedule 15 water quality variables for the Maniototo Tertiary Aquifer

Bore number				**Nitrate (NO_3-N)**	**Dissolved Reactive Phosphorus (DRP)**	**Ammoniacal nitrogen (NH_4-N)**
Group 2 Sched. 15 limit (mg/L)	**FMU**	**Rohe**	**Aquifer**	**0.075**	**0.010**	**0.100**
H42/0213	Taieri		Maniototo Tertiary	0.109	0.143	0.386
H42/0214	Taieri		Maniototo Tertiary	4.320	0.047	0.007

The results were also compared against the NPS-FM NOF, Table 53. The assessment shows poor results, particularly for DRP, with the median concentration for both bores in Band D and the 95th percentile concentration in Band D for bore H42/0213 and Band C for bore H42/0214. DRP concentrations at Band D are substantially elevated above natural reference conditions and are impacting ecological communities. Combined with other conditions that favour eutrophication, DRP enrichment drives excessive primary production and hypoxia losses of sensitive taxa, causing significant changes in fish and macroinvertebrates communities. The median and 95th percentile nitrate concentrations for bore H42/0214 are in Band C, with growth effects on up to 20% of (mainly sensitive) species but no acute effects. The concentrations for bore H42/0213 are both in Band A. The median and maximum ammonia concentrations for bore H42/0213 are in Bands B and C, respectively. Ammonia concentrations in Band C provide 80% species protection level, with a start of regular impact (reduced survival rate) of the 20% most sensitive species. The maximum concentration for bore H42/0214 was in Band B which provides 95% species protection level and a start of impact on the 5% most sensitive species.

Table 53: NOF comparison for nitrate, ammonia, and DRP for the Maniototo Tertiary Aquifer

	Nitrate Nitrogen (mg/L)		NOF Band	
Bore no.	Median (mg/L)	95th percentile	95%ile	Band
H42/0213	0.0495	0.2215	A	A
H42/0214	4	5.865	C	C
	Ammoniacal Nitrogen (mg/L)		NOF Band	
Bore no.	Median (mg/L)	Max.	Median	max
H42/0213	0.235	0.55	B	C
H42/0214	0.0025	0.25	A	B
	DRP (mg/L)		NOF Band	
Bore no.	Median	95th percentile	Median	95th percentile
H42/0213	0.1125	0.1984	D	D
H42/0214	0.0425	0.04915	D	C

4.3.2 The Strath Taieri basin

4.3.2.1 Aquifer information

The Strath Taieri basin is located between the Rock and Pillar Range to the west and the Taieri Range to the east. The basin length is approximately 20km and it is around 10km wide, with an area of approximately 200km^2. The basin floor elevation ranges between 200-300masl with the Rock and Pillar rising to a maximum elevation of 1,450m at Summit Rock, around 5km west of the basin. The hills to the east are lower and gentler, with the Taieri Ridge, located along the north eastern side of the basin, reaching 708m and the hills to the southeast/South range between 300-500m.

Surface water drainage consists of the Taieri River, which flows through the basin, and numerous tributaries that drain the adjacent hills. The Taieri enters the basin from a rocky valley to the north and, after meandering along the east side of the basin, turns to the southeast and flows into the Taieri Gorge. The dominant tributary drainage is from west to east with several streams coming off the Rock and Pillar and flowing across the basin into the Taieri. Some of these disappear into alluvial soils before emptying into the Taieri. However, the larger streams are perennial.

The Strath Taieri is characterised by warm summers and cold winters. The mean annual rainfall on the valley floor is around 600-700mm. However, evaporation is also high, at around 500mm/year, which makes the valley prone to drought during dry years. Conversely, the Rock and Pillar range has much higher annual rainfall, at around 1800mm, with evaporation of around 400mm. Hence, even though the valley floor may be dry, flow will remain in many streams that drain the Rock and Pillar range.

The Strath Taieri is a tectonic basin that was formed by the faulting/folding of the Otago Schist basement rocks. The schist age is late Palaeozoic to Mesozoic. During the late Mesozoic-early Cenozoic it was eroded to a relatively flat surface, or a peneplain. This surface was formed in Central Otago during the late Cenozoic either by faulting, folding or both forming a series of northeast trending ridges and valleys that include the Rock and Pillar Range, the Taieri Ridge and the Strath Taieri basin (ORC, 1997c).

The Central Otago ridges, which include the Rock & Pillar and the Taieri Ridge, are asymmetric, with shallower slopes on the west side and steeper slopes in the east. The valleys, including the Strath Taieri basin, are asymmetric in the opposite sense, hence the basement is likely to be deepest along the west side of the valley (i.e. near the steep ridge). The basin was filled with sediment that eroded off the surrounding ridges, mainly the Rock and Pillar. The sediments are predominantly sand and gravels, which become coarser toward the western side of the basin, near the steep slope of the Rock and Pillar. Another source of sediment was deposition from the Taieri River. These fluvial sediments are finer, i.e. fine sands and silts, which were deposited in the slow moving meanders of the river. The resulting soil profile is likely to be a complex system of interlayered lenses of gravel, sand, silty sand and silt (ORC, 1997c).

The areal extent of the sediment is generally between Sutton in the south and approximately 4km north of the Old Rock and Pillar railway station. It is bounded from the east and west by the Taieri River and the Rock and Pillar range, respectively. The sedimentary cover outside of this area is very thin or absent and schist tors are common. To the east, alluvial fans along the base of the Rock and Pillar rise to around 300-400m above sea level, while in the north of the basin sediments do not extend far beyond the old Rock and Pillar station.

The soil throughout the basin area is generally silty sand and gravel, where lenses of finer material are interlayered with coarser material. When holes are dug below the water table the water seems to enter the hole from preferential flow paths as opposed to flow uniformly around the hole. There are also numerous iron pans and minor perched water table observed in an exploration trench west of Middlemarch. Silty soil dominates some areas, where it is difficult to obtain water, at least in shallow wells. Anecdotal information suggests that it is difficult to obtain water on the east side of the railway tracks in Middlemarch township. This area appears to be formerly boggy, with heavy, low yielding soils. These areas can be the remnants of former oxbow lakes or meanders formed during previous flow of the Taieri and deposited finer sediment (ORC, 1997c).

It appears that the Strath Taieri basin contains a single unconfined aquifer that consists primarily of silty gravel. It also contains iron pans and silt lenses that form perched water tables, locally confined aquifer conditions, and channels of preferential groundwater flow. This suggests a fairly heterogenous aquifer with potential for depletion of perched wells. The water table is shallow across much of the valley, at <5m below ground level, but is deeper to the west and locally deeper beneath localised pockets of silt.

The groundwater system in the Strath Taieri is similar to those in the Maniototo, with an unconfined sedimentary aquifer receiving direct rainfall recharge that is augmented by leakage from streams around the basin's edges. Groundwater in the basin generally flows to the east/southeast, parallel to the direction of surface water, before discharging into the Taieri. The horizontal hydraulic gradient, i.e. the slope of the water table, ranges from 0.006 (0.6%) in the southern part to around 0.016 (1.6%) in the northern part of the basin. The hydraulic gradient is around half the gradient of the land surface, hence the water table is deeper in the western part of the valley (i.e. near the steeper side of the Rock and Pillar). Similar to the Maniototo, allocation issues arise due to the close groundwater-surface water interaction, with surface water being fully allocated in the area (ORC, 2006).

According to the ORC database there are 101 bores (completed/blanks status) in the Strath Taieri basin. There is depth information available for 63 of these, with the recorded depths ranging between 2.3 and 103.70m. There is reported SWL data for 20 bores, with the SWL ranging between 0.8 and 35.35m. Screen depth information is available for three of the bores, with recorded top of screen depth ranging between 4.39 and 21.7m. The main groundwater uses in include domestic, stockwater, irrigation and commercial supply. Bore logs are available for 14 bores in the basin. Four of the bores have abstraction consents.

4.3.2.2 groundwater quality monitoring

Groundwater quality monitoring in the Strath Taieri basin is monitored in one bore, H43/0132 (155mm diameter). The bore is located at Swansea Street, Middlemarch, at NZTM E1375278 N4957866. The bore depth is 9.10m. There is no lithological log or screen information available for this bore.

Groundwater quality results from the bore were analysed against the DWSNZ. The results show several exceedances of the E. coli MAV, notably with readings of 80 MPN/100mL (December 2011), 30 MPN/100mL (September 2016), and 9 MPN/100mL (December 2013), Figure 112. This indicates some contamination issues with the bore, although the exceedances are also likely to be due to poor bore security. The dissolved arsenic results show one exceedance, with a concentration of 0.03mg/L (March 2009), which is three times higher than the MAV,

Figure 113. However, all the other arsenic results are substantially lower than the MAV, suggesting that the exceedance was an isolated event, potentially due to analytical error. Nevertheless, it is important to keep monitoring arsenic concentrations in this bore. All nitrate concentrations are below the MAV of 11.3mg/L, with most samples ranging between approximately 1.0 and 1.7mg/L. The maximum concentration was 4.7mg/L (December 2012), which is slightly below ½ of the MAV, Figure 114. Ammonia concentrations were below the aesthetic GV of 1.5mg/L, Figure 115. These results indicate some issues with faecal contamination and potential issues with elevated arsenic. However, the latter is likely to have been a single incident.

Figure 112: Groundwater E. Coli count for the Strath Taieri basin

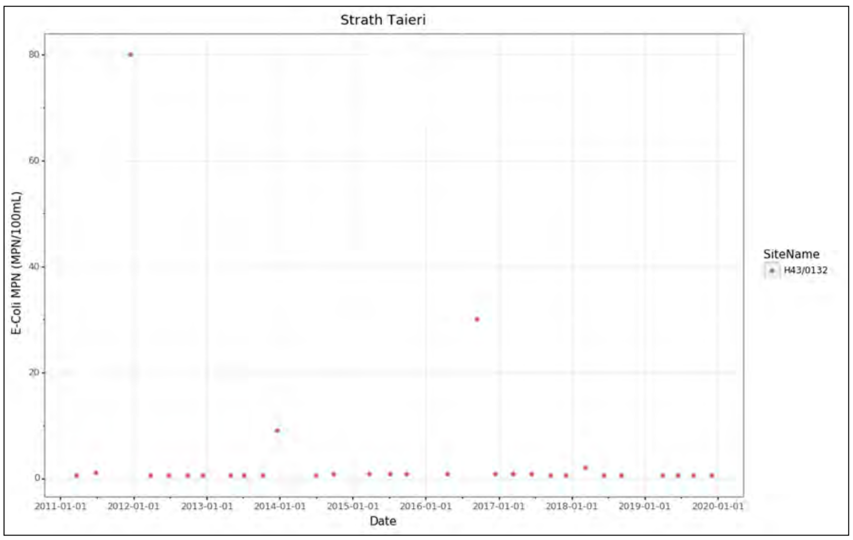


Figure 113: Groundwater dissolved arsenic concentrations for the Strath Taieri basin

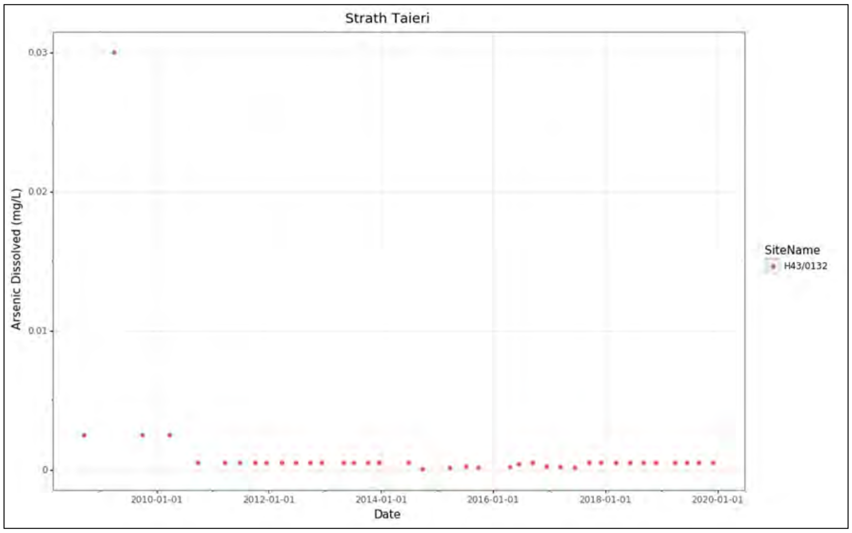


Figure 114: Groundwater nitrate concentrations for the Strath Taieri basin

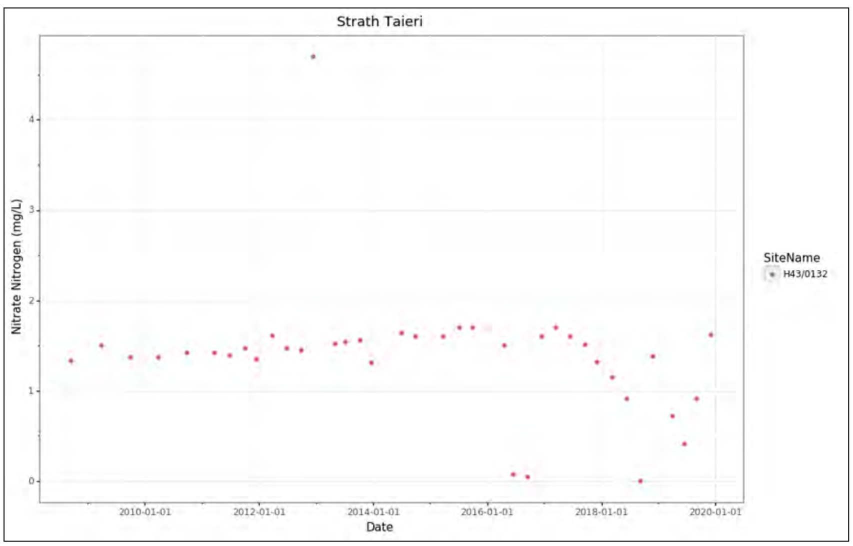


Figure 115: Groundwater ammonia concentrations for the Strath Taieri basin

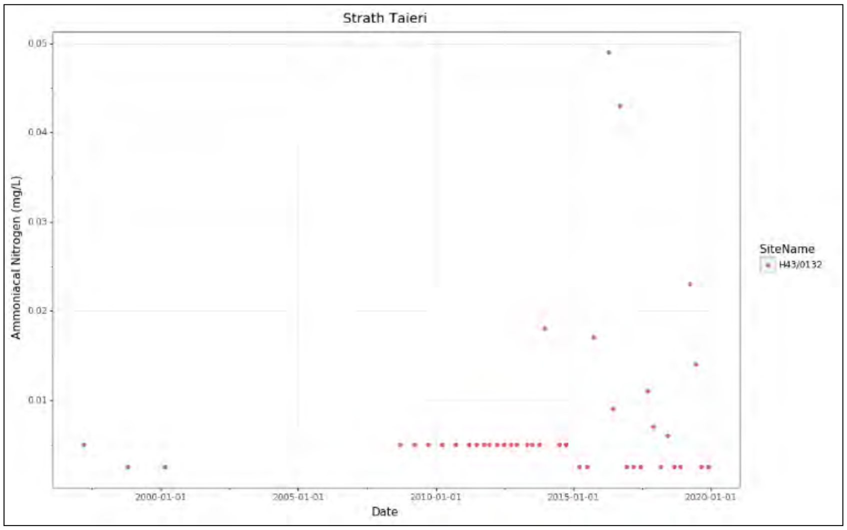
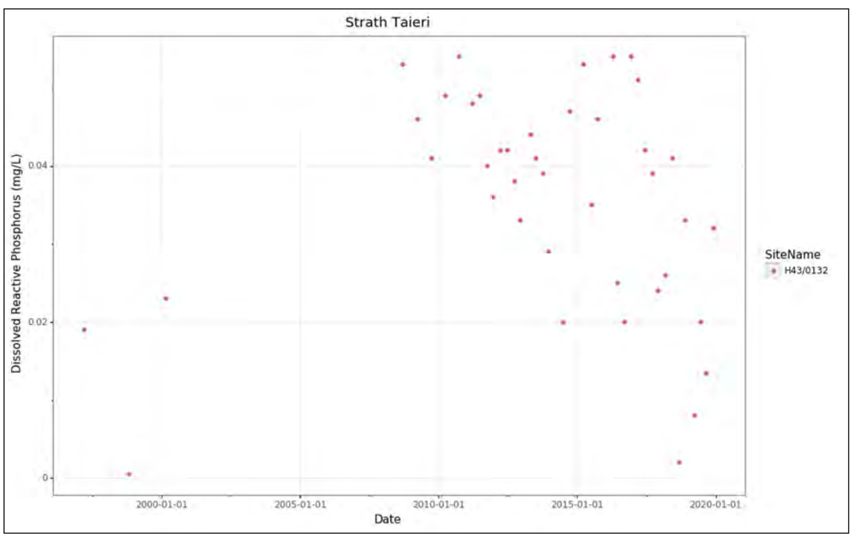


Figure 116: Groundwater DRP concentrations for the Strath Taieri basin



The results were then analysed against Schedule 15 of the RPW (Table 54) and the NPS-FM NOF (Table 55). The results show that the 80th percentile DRP concentrations exceed the limits by around four time. Groundwater DRP concentrations fluctuated over the monitoring period, falling from around 0.058mg/L in 2008 to around 0.02 in July 2014. It then rose again, reaching 0.054mg/L in April 2016. It then fell to around 0.02mg/L in September 2016 followed by an increase to 0.051mg/L in March 2017. It then continued fluctuating between approximately 0.04 and 0.01mg/L (Figure 116). Nitrate concentrations are over twice the Schedule 15 limit. The ammonia concentrations are below the limit. These results indicate potential water quality issues through the elevated nitrate and DRP concentrations. This risk is further exacerbated due to the bore's shallow depth and proximity to Dewer Stream.

Table 54: 80th percentile values for Schedule 15 water quality variables for the Strath Taieri Aquifer

Bore number			Nitrate (NO_3-N)	Dissolved Reactive Phosphorus (DRP)	Ammoniacal nitrogen (NH_4-N)
Group 2 Sched. 15 limit (mg/L)	**FMU**	**Aquifer**	**0.075**	**0.010**	**0.100**
H43/0132	Taieri	Strath Taieri	1.600	0.048	0.010

The assessment against the NPS-FM shows similar results, with the median and 95th percentile DRP concentration in Bands D and C, respectively. This indicates that DRP concentrations are substantially elevated above natural reference conditions. Combined with additional factors that favour eutrophication, DRP enrichment drives excessive primary production and significant changes in fish and macroinvertebrate communities as taxa that are sensitive to hypoxia are lost. The median and 95th percentile nitrate concentrations are in Band B, where some growth effect on up to 50% of species is occurring (MfE, 2020).

Table 55: NOF comparison for nitrate, ammonia, and DRP for the Strath Taieri Aquifer

	Nitrate		NOF Band	
Bore no.	Median (mg/L)	95th percentile (mg/L)	median	95th percentile
H43/0132	1.46	1.7	B	B
	Ammoniacal nitrogen		NOF Band	
Bore number	median (mg/L)	Max (mg/L)	Median	Maximum
H43/0132	0.005	0.049	A	A
	DRP		NOF Band	
Bore number	Median (mg/L)	95th percentile (mg/L)	Median	95th percentile
H43/0132	0.039	0.054	D	C

4.3.3 The Lower Taieri basin

4.3.3.1 Aquifer information

The Lower Taieri groundwater Basin forms a distinct hydrological unit, surrounded on all sides by low permeability rock. Its only connections to the wider Taieri catchment are the Taieri River, Silver Stream, Waipori River and the Henley Gorge section of the Taieri River. The area has been extensively drained since European settlement in the mid 1800s, transforming its former predominant marsh/wetland character to grazed pasture. These changes have substantially altered the Lower Taieri's hydrology, including an increase in the demand for using groundwater to supplement the existing surface water resources. The understanding and usage of groundwater in the basin has increased over recent years. For instance, the town supply for Mosgiel, alongside many rural dwellings, are sourced from groundwater. Groundwater also significantly impacts the local ecology of the modified Lower Taieri by supporting seepage to drains, lakes and wetlands (ORC, 2010c)

The Lower Taieri plain lies in a north east trending tectonic depression that is around 40km long and 5-10km wide. It extends from Abott's Hill in the northeast for around 30km to lakes Waipori and Waihola in the southwest with a total area of around 210km^2. The plain ranges in elevation from 40m ASL at the northern end to around sea level at Waipori and Waihola lakes in the southern end. The southern end of the basin is separated from the Tokomairiro Basin by a low bedrock divide near Milburn.

The Quaternary geology of the Lower Taieri reflects the depositional and tectonic influences of the last 2 million years. The basin's origin is tectonic, since the western and eastern basement blocks become up-thrust relative to the basin floor through the tectonic action of faults at the margins. The basin floor has also subsided and the outlet to the sea was only kept open through the down cutting processes of the Taieri River as the seaward hills were upfaulted. The basin floor is currently inferred to be around 300m below sea level and the basin was consequently filled with Tertiary and Quaternary sediments since the reactivation of the eastern bounding Titri Faulting.

The resulting basin is filled with sediment from both the Quaternary and older Tertiary periods (65 – 2 million years BP). Following the post glacial sea level rise between 4000-8000 years BP, the basin was rapidly inundated by the sea and estuary water. All the West and much of East Taieri became a coastal embayment or estuary as far up the basin as the Mosgiel outskirts. This newly embayment/estuary was filled with silty sediments, which resulted in the deposition of a consistently silty/clayey sand lower permeability layer in the shallow basin sediments, commonly termed the "Waihola Silt-Sand". This horizon thickens up to 25m in the southwest towards the basin exit. Groundwater in the gravels underneath this Waihola Silt-Sand is semi-confined. Hence, this Waihola Silt-Sand deposit is significant in dividing the groundwater system into vertically segregated compartments. These are underlain by gravel-dominated Quaternary sediments, identified based on available bore logs that tap the top of the semi-confined aquifer alongside deeper bores. Information suggests that there are two aquifers beneath the Waihola Silt-Sand: the "confined Mosgiel-Momona aquifer" and the "Henley Deep aquifer". The base of the Henley Deep aquifer is deeper than 154.3m BGL (the bottom of the Waipori 99-1 bore). The confined Mosgiel-Momona Aquifer was also encountered in an investigation bore at the airport (I44/0921). Although the drilling stopped at the top of the Henley Deep Aquifer, a marker horizon of the Waipori (lignite) aquitard common to the Henley and the Mosgiel-Momona aquifers was logged at the same stratigraphic level as in bore Waipori 99-1. The lignite divided the confined Mosgiel-Momona and the Henley Deep aquifers.

The Quaternary sediments in the Mosgiel area are more variable than those in the West Taieri area. The Waihola Silt-Sand extends into the East Taieri, perhaps as far as Riccarton Road, though not as far as Mosgiel. Logs from the Mosgiel-Wingatui areas show rapid transitions from one lithology to the next and generally poorer sorting, with logs with indefinite descriptions (e.g. silty sandy clay-bound gravel) more common in the Mosgiel District. These poor sorting and high sediment variability is inferred to be due to the proximity of mixed sediment sources, e.g. the Silver, Mill and Owhiro Streams, hill slope outwash channels, and flood flows.

The main surface water bodies of the Lower Taieri plain are the Taieri River, Silver Stream and the Waipori River, which enter the plains from schist rock gorges. Other prevailing hydrological features are Lakes Waipori and Waihola, the intervening wetland complex and drainage creeks and channels.

The climate of the Taieri Plain is sub humid, with precipitation of around 700-800mm on the plain and up to 1200 in the Maungatua Range. Precipitation distribution is relatively even with winter being the driest. Potential evapotranspiration at the airport was around 780mm/year.

The Lower Taieri plains are mainly covered with grass paddocks, except for the two small wetlands in East Taieri and the Waipori-Waihola Wetland complex. Most of the area outside the wetlands (i.e. under artificial drainage) is used for cattle grazing with some market garden and berry cropping around Outram. Farming ranges from large commercial dairies to small life style blocks. There are also some processing, manufacturing and service industries on the plains alongside urban/semi urban areas in Mosgiel, Kinmont, East Taieri, Allanton and Outram.

The main groundwater uses are domestic, stock, dairy shed and irrigation supplies. Irrigation is relatively low and most abstraction takes are for insurance against dry years. The highest takes by volume are for the Mosgiel town supply followed by abstraction and re-injection of groundwater used in 'ground source' heat exchanges at Dunedin Airport.

Groundwater is found throughout the Quaternary sequences, however, higher volumes and yields tend to be correlated with coarser deposits (sands, sandy gravel and coarse gravels). The Lower Taieri basin is characterised by larger sediment grain size segregation (i.e. better sorting) in West Taieri and higher variability and poorer sorting in East Taieri.

The Mosgiel and North Taieri areas are underlain by an unconfine aquifer, in contrast to the semi-confined conditions found further down gradient on the plains. This is supported by the following observations: High – moderate nitrate concentrations at depth, indicating the infiltration of soil drainage, a consistently downward vertical groundwater pressure gradient, and an absence of laterally continuous and recognisable confining layer. The water bearing layers in East Taieri tend to be more highly stratified with short pumping tests suggesting a degree of semi confined conditions. However, regarding longer term behaviour, the groundwater response is closer to a stratified, unconfined aquifer. There are several areas with flowing artesian conditions at the East Taieri and the lower West Taieri Drainage area. A reduction in flowing artesian conditions may be the impact of land drainage, causing long term drawdown. The mapping of bore depths suggests that most bores are <40m deep, but there are also deeper ones. The greatest depths to groundwater are found in deeper bores in North Taieri and the shallowest depth to water is beneath lower lying, drained areas (ORC, 2010c).

Water level surveys indicate elevated groundwater heads in the North Taieri area, north of Mosgiel, which decline with distance to the southwest. This is similar to the surface topography of the Taieri plains, with ground level of around 30m amsl north of Mosgiel which grades down to a couple of metres of sea level in the southwest (Henley). Several distinct transitions were noted within this pattern (ORC, 2010c):

- the abstraction from the Mosgiel bores over many decades seems to have induced the formation of a hollow in the groundwater surface, where groundwater converges from upgradient recharge areas.
- School Swamp at East Taieri functions as a discharge zone for this part of the groundwater system and a similar convergence of local groundwater level contours.
- The Taieri River appears to control the shape of the groundwater level surface
- The West Taieri Drainage scheme produces a large scale deflection of the groundwater level surface.
- The Lake Waipori/Waihola Wetlands Complex is a strong local control on adjacent groundwater levels.

There are several aquifer tests available from the Lower Taieri basin. The first is a 72 hours test for the Wingatui bore (I44/0089) when it was pumped at 26L/s in July 1947. The test data was re-analysed recently by ORC using steady drawdown-distance data and the Transmissivity was calculated for the screened water bearing layers (18-53m depth). The derived Transmissivity was around 380-400m^2/day.

The Outram bridge well field unconfined aquifer has very high Transmissivity, ranging between approximately 14,500 and 17,000m^2/day. However, these parameters solely relate to the DCC Outram well field, which is believed to be a restricted zone of higher permeability. Exploratory drilling and geophysics indicated that the higher permeability conditions declined rapidly approximately 200-300m downstream of the Outram Bridge. The transmissivity of water supply bores in Mosgiel, derived from pumping tests conducted between 1970 and 1990, ranges between 80 and 1,250m^2/day. This indicates a high range in transmissivity values. However, there is a bias in the results, as only the most efficient/high yielding bores were tested, hence this range over represents higher permeability zones of the groundwater system. The tests estimated a Storativity of around $1x10^{-4}$m and estimated leakage of around $2x10^{-4}$/day, indicating semi-confined conditions. Estimated aquifer parameters are also available for the West Taieri area, where bores seem to penetrate through the Waihola Silt-Sand aquitard and into the top of the Mosgiel-Momona Confined Aquifer. The transmissivity ranges between 740 to 1,530m^2/day and the Storativity is around $1.2x10^{-4}$ to $3x10^{-4}$. The Mosgiel-Momona confined aquifer, where bores are around 30m deep, had Transmissivity ranges between 1200 and 1,600m^2/day. However, more closely supervised tests on fully penetrating bores derived T range between 650 to 850m^2/day and a Storativity range of $9x10^{-3}$ to $7x10^{-4}$. It is inferred that the lower and narrower range in aquifer Transmissivity results for the deeper bores is a partial consequence of the newer test bores being fully penetrating. Furthermore, these latter tests also indicate a much lower variability in hydraulic properties in the West Taieri aquifer area than in the Mosgiel area, which is consistent with observations of the sedimentary geology (ORC, 2010c).

The main sources of groundwater recharge are rainfall and recharge from surface water (The Taieri River, Silver Stream, Waipori River. An investigation of groundwater-surface interaction between Silver Stream and the aquifer indicated that water from the Silver Stream recharges the shallow groundwater between Puddle Alley and Wingatui at around 30L/s during low flows. Due to the downward hydraulic gradient shallow groundwater slowly flows downward to lower water bearing units in the groundwater system. The Silver Stream therefore provides a partial recharge source to the deeper water supply aquifer, albeit mixing with water of other origin that have taken much longer time (e.g. years) to reach that greater depth. The direction and magnitude of groundwater recharge to the aquifer may change due to changes in the flow rate/stage height of the Silver Stream (including freshes and floods that produce bank storage) and the shallow groundwater level in the water bearing layer in closest contact with the stream. This indicates that the Silver Stream is in dynamic equilibrium with the adjoining groundwater, which is occasionally perturbed by low and high flow events. The outputs of groundwater from the basin include discharge into wetlands like the School Swamp and Lake Waipori Wetlands Complex, drains, or groundwater abstraction from bores (ORC, 2010c).

The Lower Taieri basin has several anthropogenic groundwater quality issues. The main one is elevated nitrate concentrations, which are restricted to the stratified unconfined water bearing layers in the north of the basin near Mosgiel and North Taieri where there are oxidised geochemical conditions. Elevated iron and manganese concentrations are another main limitation for groundwater quality in the Lower Taieri. Salinity is an issue in a small area of the West Taieri, particularly within the West Taieri Drainage Scheme perimeter. The Lower Taieri River at Henley Ferry and distributary branches of lakes Waihola and Waipori are tidal, where surface water saline intrusion penetrates these water bodies for up to 15km upstream from the Taieri mouth. Groundwater salinity is also impacted by the Holocene marine and estuarine sediments of the Waihola Silt-Sand formation, which were deposited under saline/brackish conditions (ORC, 2010c).

4.3.3.2 Groundwater quality monitoring

Groundwater quality in the Lower Taieri basin is currently monitored in five bores, whose depths range between 17.50 and 40.50m. The bore details are summarised in Table 56. Four of the bores are located within approximately 3.5km north and west of Mosgiel. The remaining bore is located at Maungatua Road, on the northwestern part of the plain. Screen depth information is not available for any of the bores. Bore logs are available for two bores, I44/0821 and I44/0964. The bore log for I44/0821 (27.38m depth) is mainly composed of clay truncated by thin layers of gravels. The log describes clay and thin gravel layers to 21.7m underlain by gravels to 22.9m. There is then clay to the bottom of the bore at 53.1m with thin layers of gravel, all <1.2m thick, at 42.0, 48.0m and 51.9m. There is no screen information available for this bore. However, considering the recorded total bore depth of 27.38m, it is likely screened within the gravels/heavy clay bound gravels at a depth of approximately 22m. This lithology, particularly the substantial upper clay layer, suggests that the bore abstracts from a confined/semi confined aquifer. Groundwater levels in bore I44/0821 were monitored manually since January 2017. Water level in the bore ranges between 9.286 and 10.665m below MP with an annual range of between 0.301 and 1.379m. The highest water levels are in winter/early spring. There does not appear to be a declining trend in water levels in this bore.

The bore log for bore no. I44/0964 (40.5m deep) is composed of alternating horizons of gravels and clay. The log describes 0.4m of top soil underlain by brown gravels to 3.80m. There is then alternating horizons of clay and gravel to 6.4m, mainly underlain by clay with some gravel layers <1.2m thick, to 24.8m. The lithology then changes below this depth and becomes more gravel-dominated, with brown sandy gravels down to 33.3m underlain by clay to 34.9m. There is then alternating horizons of gravels and clay, approximately 2m thick, down to the bore bottom at 40.60m. The recorded bore depth is 40.50m. The original bore log indicates that the top of the screen leader is 1.80m long and that the screen length is 1.500m. Based on a total bore depth of 40.50m, the top of the screen is at a depth of 39.00m, within a horizon of clay, although this might be an error in the bore log. This information suggests that the bore abstracts from a semi confined/unconfined aquifer overlain by a shallow unconfined aquifer.

Table 56: Summary of groundwater quality monitoring bores details for the Lower Taieri

Bore no.	**Depth (m)**	**Diam. (mm)**	**Eastings**	**Northings**	**Screen top (m)**	**Screen Bottom (m)**	**Log avail.**
H44/0007	24.4	100	1378924	4912001	n.a.	n.a.	No
I44/0495	22.9		1392261	4918203	n.a.	n.a.	No
I44/0519	17.5		1392705	4919569	n.a.	n.a.	No
I44/0821	27.38	100	1396046	4919018	n.a.	n.a.	Yes
I44/0964	40.5	100	1392510	4916131	n.a.	n.a.	Yes

The assessment of groundwater quality results against the DWSNZ indicate a high risk of faecal contamination, with E. coli exceedances in three of the monitoring bores. The highest ones were in bore H44/0007, ranging between 8 and 340MPN/100mL. The exceedances in bore I44/0519 ranged between 2 and 280 MPN/100mL and those in bore I44/0495 ranged between 1.6 and 22 MPN/100mL (Figure 117). These indicate a high risk of faecal contamination, which is not surprising considering the bores are located near risky land uses (i.e. dairy sheds, septic tanks) and many suffer from poor borehead protection. Groundwater nitrate concentrations in all five bores are below the DWSNZ MAV of 11.3mg/L (Figure 118). However, concentrations over ½ the MAV (i.e. over 5.5mg/L) were measured in bores no. I44/0821 and I44/0964, although the high concentrations in the latter bore are likely due to a single event. The concentrations in bore I44/0821 range between approximately 5.10 and 6.92mg/L and those in in bore I44/0964 generally range between approximately 1.2 and 1.6mg/L. However, a much higher concentration of 6.00mg/L was measured in October 2011, although this is likely to have been due to a single event, as concentrations in the following sample were much lower. Some of the concentrations in bore I44/0519 are above the 2.5mg/L nitrate threshold for low intensity land use (Daughney & Morgenstern, 2012), with this level exceeded in most samples after 2017. The maximum concentration was 3.70mg/L, measured in November 2018. Although these are still substantially lower than the MAV, the data suggests an increase in nitrate concentrators, with these observations further corroborated by the risky land uses in the area. Conversely, nitrate concentrations in the other bores (H44/0007, I44/0495) are below 1.0mg/L. Dissolved arsenic concentrations in all bores ranged between 0.0001 and 0.005mg/L, which are below the DWSNZ MAV of 0.01mg/L (Figure 119). Ammonia concentrations in bore I44/0519 range between 0.005 and 5.43mg/L, which substantially exceed the aesthetic GV of 1.5mg/L. The data shows two exceedances of the GV, with measurements of 2.16mg/L (October 2004) and 5.43mg/L (July 2005),

Figure 120. These exceedances are likely due to poor bore security and/or contamination from a nearby septic tank. Apart from these, concentrations were below 0.65mg/L. As the bore is situated approximately 400m west of Mill Stream, this may potentially hamper surface water quality.

Figure 117: Groundwater E. Coli count for the Lower Taieri Aquifer

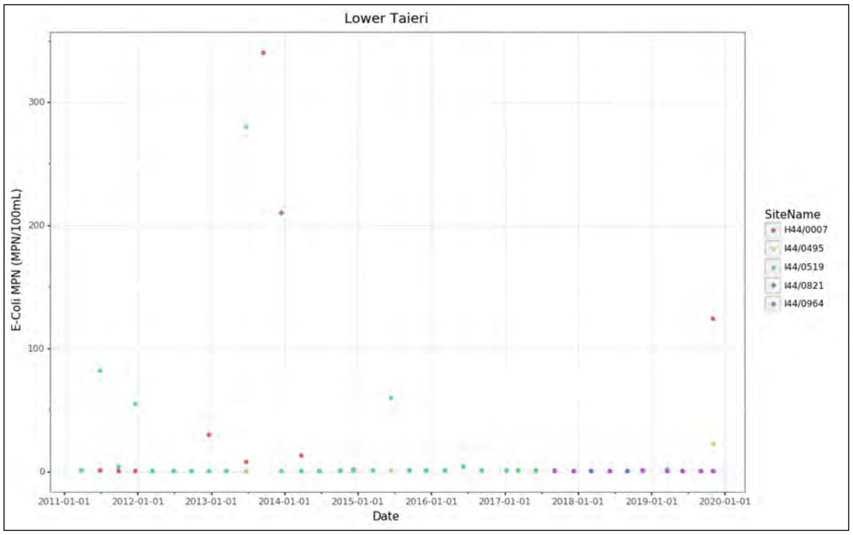


Figure 118: Groundwater nitrate concentrations for the Lower Taieri Aquifer

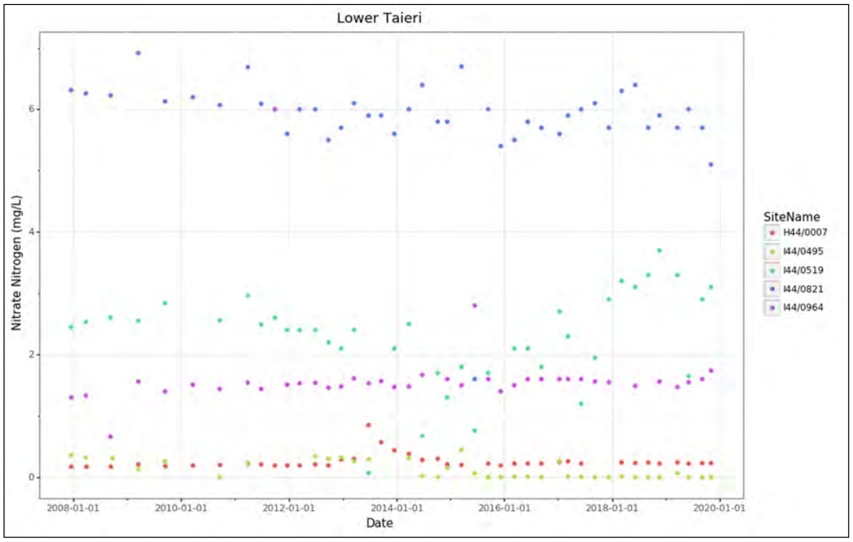


Figure 119: Groundwater dissolved arsenic concentrations for the Lower Taieri Aquifer

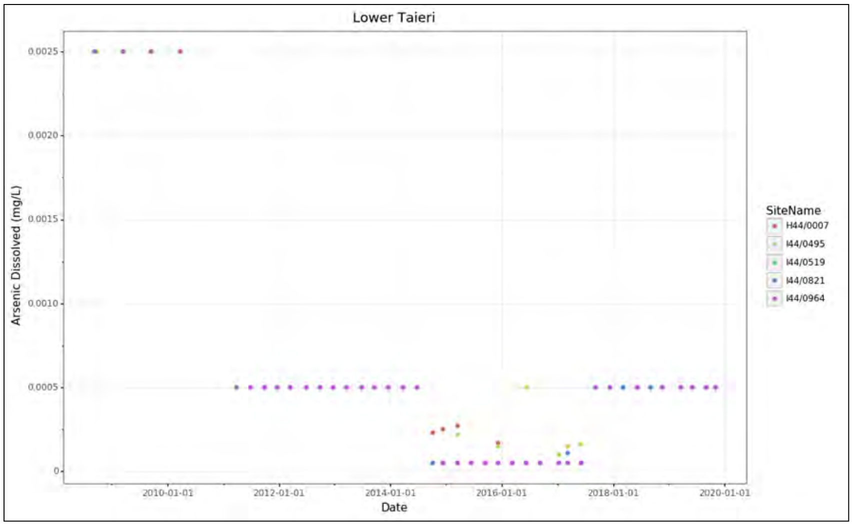
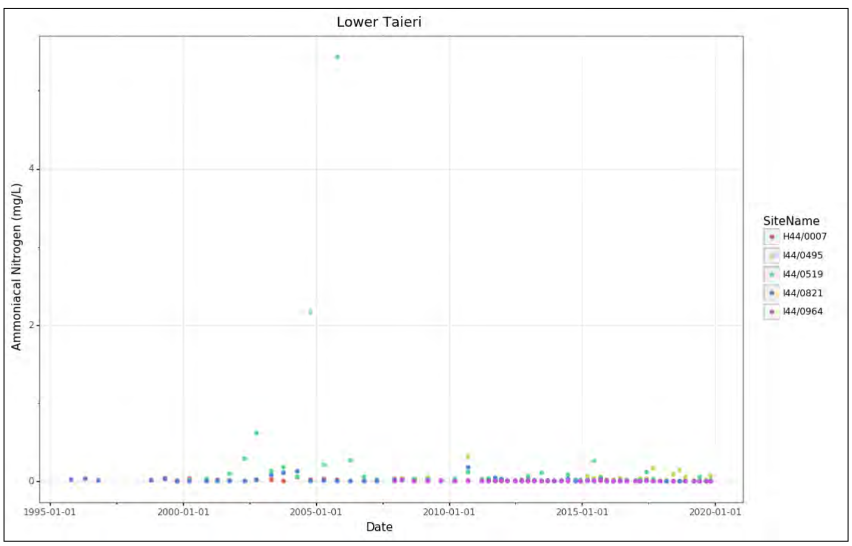


Figure 120: Groundwater ammonia concentrations for the Lower Taieri Aquifer



The results were then assessed against the RPW (Table 57) and NPS-FM NOF (Table 58). Bore I44/0519 is the only bore shallower than 20m. The results indicate potential water quality issues, with both the 80th percentile nitrate and ammonia concentrations exceeding the Schedule 15 limits. The nitrate 80th percentile concentrations exceed the threshold by 39 times. The ammonia concentrations only slightly exceeded the limits. The DRP concentrations were below the threshold.

Table 57: 80th percentile values for Schedule 15 water quality variables for the Lower Taieri Aquifer

Bore number			Nitrate (NO_3-N)	Dissolved Reactive Phosphorus (DRP)	Ammoniacal nitrogen (NH_4-N)
Group 2 Sched. 15 limit (mg/L)	**FMU**	**Aquifer**	**0.075**	**0.010**	**0.100**
I44/0519	Taieri	Lower Taieri	2.900	0.006	0.102

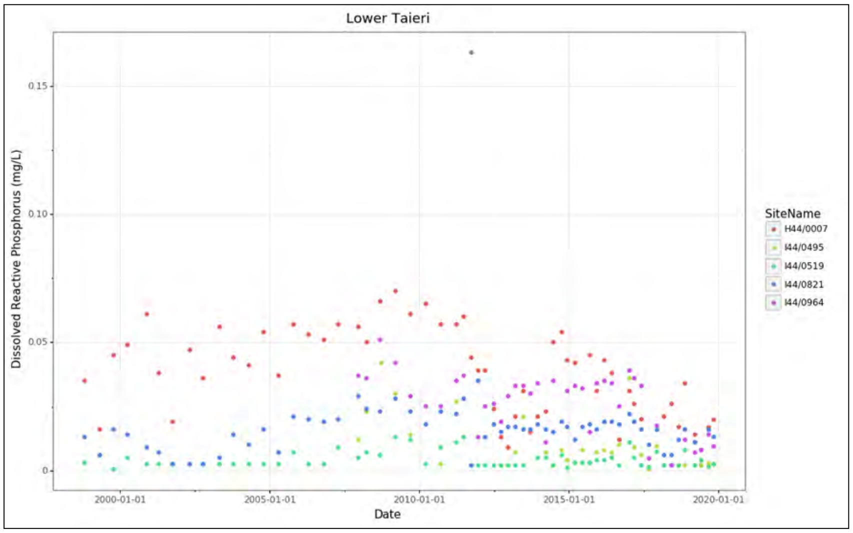
The assessment against the NPS-FM shows that the median and 95th percentile nitrate concentration are in band C and B, respectively (Table 58). At Band C growth effects on up to 20% of species (mainly sensitive species, such as fish) is expected but no acute effects. The ammonia maximum concentration in Band D, where ammonia toxicity starts to approach acute impact level (i.e. risk of death) for sensitive species (MfE, 2020). However, the median ammonia concentration is in Band A, suggesting the issues are related to single incidents rather than a persisting issue.

Table 58: NOF comparison for nitrate, ammonia, and DRP for the Lower Taieri Aquifer

	Nitrate Nitrogen (mg/L)		**NOF Band**	
Bore no.	Median (mg/L)	95th percentile	**median**	**95th percentile**
I44/0519	2.4	3.3	C	B
	Ammoniacal Nitrogen (mg/L)		**NOF Band**	
Bore no.	Median (mg/L)	max	**Median**	**95th percentile**
I44/0519	0.019	5.43	A	D
	Dissolved Reactive Phosphorus (mg/L)		**NOF Band**	
Bore no.	Median (mg/L)	95th percentile	**Median**	**95th percentile**
I44/0519	0.0025	0.0111	A	A

Although groundwater quality from most of the Lower Taieri SoE bores was not assessed against the RPW and NPS-FM, the DRP results from some bores shows some potential issues. The median DRP concentrations in bores H44/0007 (0.039mg/L), I44/0964 (0.031mg/L) and I44/0821 (0.016mg/L) are high. Concentrations also show fluctuations over time, potentially due to changes in land use and/or septic tank density and efficiency (Figure 121).

Figure 121: Groundwater Dissolved Reactive Phosphorus concentrations for the Lower Taieri Aquifer



4.5 The North Otago FMU

The North Otago region covers an area of around 2,202 km^2 (220,208Ha) from around Waikouaiti in the south to the Waitaki River in the north. The location of the FMU is shown in Figure 122. It encompasses parts of the lower Waitaki Plains, Kakanui, Waianakarua, and Shag catchments. The FMU also contains several aquifers: the North Otago Volcanic Aquifer (NOVA), Lower Waitaki Plains aquifer, Kakanui-Kauru Alluvium aquifer, and the Shag Alluvium aquifer (. It also includes the Papakaio aquifer, which is currently not been monitored, although it is planned to monitor it in the future.

The North Otago region is dominated by catchments that receive very low rainfall (<500mm/year) and are predominantly cool/dry low elevation rivers and cool/dry hill rivers. The predominantly dry climate and extensive areas of low relief topography of the lower river catchments is extensively used for cropping and irrigation. These activities increase the pressure on groundwater and surface water resources. The main land cover throughout North Otago is high producing grassland, which reflect areas actively managed and grazed for dairy, beef, lamb, wool, and deer farming. This land cover dominates the Shag and Kakanui catchments. Conversely, the Upper catchments of the Kakanui, Shag, and Waianakarua are mountainous and less suitable for intensive grazing. These areas are dominated by low producing grassland, forestry and native cover. Those low intensity land uses typically leach low nutrient levels and generally provide good water quality. Low yielding rivers (located on dry areas) have reduced dilution and flushing capacity, which tend to be more susceptible to elevated nutrients should land use in these upper catchments intensify (ORC, 2017a).

Figure 122: Location of the North Otago FMU (red), aquifers (green) and SoE monitoring bores (red dots)

Groundwater quality results from the different aquifers in the North Otago FMU were assessed against the DWSNZ surface water quality standards (i.e. the RPW and NPS-FM), with the latter being critical due to the strong groundwater-surface water interaction in many North Otago catchments. The results indicate significant groundwater quality issues, especially the elevated nitrate concentrations, which are the highest in Otago, and E. coli exceedances. Nitrate concentrations in monitoring bores in the NOVA and Kakanui-Kauru aquifers substantially exceed the 11.3mg/L MAV, with concentrations in some bores exceeding 32.2mg/L. Additionally, nitrate concentrations in some bores in the Lower Waitaki aquifer are over ½ of the DWSNZ MAV. Potential faecal contamination is also a concern, with elevated E. coli measured in some bores in each of the FMU's aquifers, with a maximum count 6,200 MPN/100mL (bore J43/0006). In contrast to these issues, there were no elevated dissolved arsenic concentrations in any of the bores.

Table 59: Median concentrations for DWSNZ/ecosystem health parameters for the N. Otago FMU

Aquifer	Ammonia (mg/L)	Arsenic Dissolved (mg/L)	Dissolved Reactive Phosphorus (mg/L)	E-Coli (MPN/100mL)	Nitrate Nitrogen (mg/L)
Kakanui-Kauru Alluvium	0.0025	0.0005	0.01	0.5	2.95
Lower Waitaki Plains	0.026	0.00011	0.0065	0.8	4.735
NOVA	0.005	0.0005	0.017	0.5	10
Shag Alluvium	0.005	0.0005	0.0085	0.65	0.75

The potential impact on surface water quality was assessed by comparing nutrient concentrations in shallow bores to the RPW (Table 60) and NPS-FM NOF limits (Table 61). The results indicate potential adverse impacts on surface water quality, particularly due to the strong groundwater-surface water interaction in the FMU. The results show elevated nitrate and DRP, with concentrations in all bores substantially exceeding the Schedule 15 limits. The assessment against the NPS-FM also illustrates these issues, with most concentrations in the C and D bands. All of these indicate significant groundwater quality issues in this FMU, which has the most degraded groundwater quality in the region.

Table 60: Schedule 15 comparison for the North Otago FMU

Bore number		Nitrate (NO_3-N)	Dissolved Reactive Phosphorus (DRP)	Ammoniacal nitrogen (NH_4-N)
Group 2 Sched. 15 limit (mg/L)	**Aquifer**	**0.075**	**0.010**	**0.100**
J41/0008	NOVA	27.660	0.057	0.010
J41/0762	Kakanui	4.940	0.011	0.016
J41/0764	Kakanui	3.400	0.011	0.006
J41/0771	Kakanui	11.000	0.010	0.012
J42/0126	Kakanui (township)	21.600	0.026	0.010
J43/0006	Shag	1.116	0.011	0.010
J41/0317	Lower Waitaki	5.800	0.032	0.010
J41/0442	Lower Waitaki	1.072	0.005	0.005
J41/0586	Lower Waitaki	7.280	0.009	0.005

Table 61: NOF comparison for nitrate, ammonia, and DRP for the North Otago FMU

	Nitrate		NOF Band	
Bore number	Median (mg/L)	95th percentile	Median	95th percentile
J41/0008	26	28.2	D	D
J41/0317	4.735	6.66	C	C
J43/0006	0.75	1.604	A	B
J42/0126	20	22	D	D
J41/0762	4.3	5.88	C	C
J41/0764	2.1	3.9	B	C
J41/0771	7.2	12	D	D
J41/0442	0.82	1.385	A	A
J41/0586	6.3	7.495	C	C
	Ammonia		NOF Band	
Bore number	Median (mg/L)	Max. (mg/L)	Median (mg/L)	Max. (mg/L)
J41/0008	0.005	0.065	A	B
J41/0317	0.005	0.034	A	A
J43/0006	0.005	0.025	A	A
J42/0126	0.005	0.01	A	A
J41/0762	0.007	0.043	A	A
J41/0764	0.0025	0.026	A	A
J41/0771	0.0025	0.034	A	A
J41/0442	0.0025	0.0086	A	A
J41/0586	0.0025	0.013	A	A
	Dissolved Reactive Phosphorus (mg/L)		NOF Band	
Bore no.	Median	95th percentile	Median	95th percentile
J41/0008	0.048	0.062	D	D
J41/0317	0.026	0.039	C	D
J43/0006	0.0085	0.01375	A	B
J42/0126	0.0184	0.029	B	D
J41/0762	0.009	0.012	A	B
J41/0764	0.01	0.012	A	C
J41/0771	0.009	0.011	A	B
J41/0442	0.005	0.006	A	A
J41/0586	0.0065	0.01	A	B

4.5.1 the North Otago Volcanic Aquifer

4.5.1.1 Aquifer information

The North Otago Volcanic Aquifer (NOVA) serves as an important water source for parts of the Waitaki District that are underlain by the volcanic sediments. The main groundwater uses include domestic, stock take, and irrigation, which mainly rely on the shallow volcanic sediments. Groundwater also provides important baseflow which sustains some creeks during dry weather. The aquifer mapped zone extends over much of the land that is underlain by volcanic sediments.

The aquifer is located beneath downlands and tablelands west/south of Oamaru. The main surface water drainage overlying the aquifer include Waiareka Creek (in the Kakanui catchment), Awamoa Creek and Oamaru Creek (which drain individually to the coast). Landon Creek is located in the far north of the area but is mainly ephemeral.

Broadly, the sediments that make up the NOVA comprise the following strata and geological materials:

- Waiareka Tuffs: marine tuff beds, columnar jointed basalt intrusions, pillow lavas siltstone with volcanic ash inclusions and occasionally diatomite.
- Totara & McDonald limestone: marine carbonate sediments including massive fine-grained limestone and calcareous siltstone often with significant volcanic association.
- Deborah volcanics – marine tuffs, pillow lava, columnar jointed basalt, crystal breccia, ash bed and siltstone with significant volcanic influences.

It is important to recognise that the boundaries between these strata are seldom precise and that they were all deposited in a setting of varying sea floor depths close to a subsurface volcanic eruption that ultimately extended above sea level for a brief period. Under the base of the volcanic sequences there are marine sediments without volcanic influences which are deposited in deep water. These sediments are fine-grained, very silty and have low permeability. The volcanic sequences are overlain by deeper water fine marine sediments (the Gee Greensand and the Rifle Butts formation) that also have low permeability. The sedimentary thickness of the volcanic sequences exceeds 500m in places (e.g. beneath the northern part of Oamaru, which include 245m of Deborah Volcanics, 30m of limestone and 235m of Waiareka Volcanics). To the west of the Waiareka Creek catchment, the volcanic sequence is due to sedimentary and erosion processes. There are also several recognised fault/fold structures that deform the volcanic aquifers (ORC, 2008).

The North Otago climate is temperate and is impacted by strong oceanic influences of air streams from the Pacific, the southwest and the northwest, which are tempered by passing over elevated parts of the South Island interior. This variability in air stream direction strongly impacts temperature, evaporation and rainfall patterns. It is also impacted by non seasonal factors such as El Niño Southern Oscillation (ENSO) and the Pacific Decadal Oscillation which can change air streams' balance, climate, and hydrology. The mean annual rainfall near the centre of the aquifer is around 580mm and is lower, around 450mm/year in the east end of the aquifer (Grandview). The PET usually exceeds rainfall, which induces significant soil moisture deficits in late spring, summer and most of autumn in most years. Due to that, soil moisture surplus and aquifer recharge occurs tends to be confined to the winter and early spring, which leaves relatively low potential for aquifer recharge.

The main land use in the area is pastoral and arable farming. There is also market gardening concentrated in the east of the area, within an approximate triangle located between Alma, Oamaru and Kakanui townships. The Waiareka Valley has undergone a significant transformation in 2007 through the large Downlands Irrigation Scheme which uses surface water from the Waitaki River. This has helped to overcome the area's soil moisture deficits which allowed the intensification and expansion of irrigated pasture (mainly dairying, which has replaced sheep) and arable cropping (ORC, 2008).

The groundwater flow pattern within the NOVA is fairly simple. The highest water table is under the higher tablelands within the NOVA whilst the lowest levels were found along the axis of the Waiareka Valley and the Kakanui Estuary. Groundwater flow patterns broadly follow surface topography, flowing from higher elevation ridges and tablelands toward the ocean and surface water (i.e. the Waiareka Creek, Oamaru Creek, or the Kakanui Estuary). On the north side of the Kakanui Estuary, the Waiareka Aquifer appears to recharge in the rolling land along the aquifer's western boundary and flow east into the Waiareka Creek, a significant receptor for groundwater within the Waiareka Aquifer. This is balanced by southwestern flow into the east bank of the

Waiareka Creek. Groundwater flow divides between the Waiareka Creek and the Ocean along a line situated approximated near Weston and Kakanui.

The piezometric map shows steep gradients in areas of low recharge, which can infer a low to moderate hydraulic conductivity. Reported Transmissivity from several aquifer pumping tests is low, ranging between 5.4 and 80m^2/day. The drawdowns in the volcanic aquifer bores are relatively high, indicated by the reported low Transmissivity and the low specific capacity of around 0.5 to 1.5L/s/m of drawdown. This low permeability indicates that groundwater was only used due to the lack of any other feasible supply option.

In general, most of the information on the landward portions of the NOVA suggests that it behaves as an unconfined aquifer with artefacts of fracture/fissure flow evident in pumping test analysis. The aquifer displays unconfined recharge and flow towards the nearest down gradient perennial water body. However, there are a few exceptions such as areas where the aquifer is overlain by the fine marine sediments of the Gee Greensand and Rifle Butts Formation which seem to form a semi-confining layer atop the volcanic aquifer. These two formations are overlying the Deborah Volcanics for much of the coastal zone and presumably thicken out to sea, hence, for much of its potential contact with the ocean the NOVA is largely semi confined or confined.

Due to the fracture/fissure occurrence of groundwater in the volcanic aquifer the drawdown response in pumping tests shows a dual confined/unconfined signature, hence the initial drawdown curve is consistent with that of a confined aquifer. However, subsequently, the drawdown rate is more consistent with that of an unconfined aquifer. Storativity was only obtained from one test where an observation bore was used (J41/0714). The initial Storativity (S) coefficient was $4x10^{-4}$, which is analogous to the S coefficient for a confined aquifer. However, this was not sustained for more than a few hours and an analysis of long term drawdown data from the bore showed a shift to a storage coefficient of $1x10^{-2}$ (1%) although the inconsistency of aquifer tests to provide accurate storage data is known. Independent comparison of recharge-inducing rainfall events and water table rise in the Webster well (J41/0178) suggested an average unconfined storage of 0.10, or 10%, which is consistent with more recent Specific Yield (Sy) estimation of 0.09 or 9% (ORC, 2008).

The only reliable indication of significant interaction of the NOVA with adjoining aquifers is between the NOVA and the Kakanui Alluvial Aquifer, in the area between Gemmells Crossing and the Kakanui Estuary. In contrast, groundwater levels in the Waiareka Aquifer are significantly higher than the adjoining and overlying alluvial aquifer, with the flow gradient dominated by upward flow from the NOVA into the base of the Alluvium. Based on that, it is expected that the volcanics contribute groundwater to the alluvium aquifer. This was supported by elevated Electrical Conductivity and sodium concentrations in the alluvium (ORC, 2008).

4.5.1.2 Groundwater quality measurements

Groundwater quality in the NOVA is monitored in three bores, whose details are summarised in Table 62. Most of the monitoring bores are located in areas of cropping, which increases the potential for elevated nutrient concentrations. Bore no. J41/0008 (1000mm diameter) is situated at Fortification Road, Whitecraig, NZTM E1434870 N5000331. The bore’s depth is 20m. There is no bore log or screen information for the bore. Although this bore has been monitored since January 1986, the bore head security is very poor and has a high contamination potential. The SWL in the bore was monitored since July 2015. Water levels range between 5.025m and 7.98m below MP. The seasonal variation in water levels is between approximately 1.3 and 2.0m.

Bore J41/0249 (250mm diameter) is located north of Woolshed Road at NZTM N1430982 N5000848. The bore depth is 90m. The bore log describes topsoil and clay to 2.6m underlain by brown, fractured rock to 24.2m. There is then fractured blue rock to 90.0m, underlain by

Waiareka Volcancics rock to 91.0m. Both fractured rock units are described as water bearing. The log states that the casing depth is 5.5m. Based on that, it is assumed that the remainder of the bore is open hole and that it abstracts from the fractured rock units. The SWL in the bore was monitored since April 2016, although there is a gap in monitoring between March 2017 and April 2019. The highest water level in the bore, 1.993m below MP, was measured in November 2019 and the lowest, 5.266m below MP, was measured in April 2019. The data suggests that the highest water levels are in winter/early spring and the lowest during summer. However, it also includes a high variability, of around 3.273m, in groundwater levels during 2019, which can potentially be attributed to pumping from the bore or measurement error. Due to that, and to the short availability of data (considering the gap between 2017 and 2019), it is difficult to assess whether the water levels in the bore follow a trend.

Bore J42/0126 (250mm diameter) is located at Fenwick Street, Kakanui township, NZTM E1434931 N4994910, approximately 1km north of the Kakanui River mouth. The bore depth is 10.9m. The bore log describes topsoil and yellow clay to 4.2m underlain by sand and gravels to 7m. There is then 1m of rock followed by sand, silts and weathered rock fractures to 18m underlain by broken rock to the bottom of the bore at 18.8m. The bottom of the bore, at a depth of 10.9m, is located within a horizon of sandy silts and weathered rock. There is no information regarding the screen depth, however, it is likely to be screened in the bottom sandy silts/weathered rock layer, at an approximate depth of around 8.0m. This suggests that the aquifer is relatively shallow, with a basement depth of around 18m. Groundwater levels were monitored in this bore since July 2015. The highest water level, 2.285m, was measured in April 2016 and the lowest, 14.12m, measured in July 2015. Water levels in the bore generally range between approximately 2.285 and 4.45m below MP, with two measurements of substantially lower levels of 14.12m (April 2016) and 9.362m (December 2017) below MP. The reasons for the lower readings are unclear, but it can be due to the bore pumping or measurement error. Interestingly, lower SWL at the same time were also measured in bore J41/0008, which increases the likelihood of it being related to dry conditions and associated higher pumping from the bore.

Groundwater levels in the NOVA is monitored for the Deborah (Webster bore, J41/0178, since August 1986) and the Waiareka (Isbister bore, J41/0198, since December 1997) bores. The Waiareka bore has shown a steady decline since around September 2002, falling from an elevation of approximately 123.2m to 121.45 in mid 2008. This level restricts takes by 50%. The Deborah bore has declined from a max. of around 130.8m in August 2000 to around 128.15m in June 2006, which is within a 50% restriction zone. However, the water levels in the bores have recovered and have been above the restriction level since mid 2007 although it appears that they were dipping back into it in mid 2008 (ORC, 2008).

Table 62: Summary of monitoring bore details for the NOVA

Well Number	Depth (m)	Diam. (mm)	Drill Date	Eastings	Northings	use	Bore Log?
J41/0008	20	1000	1/01/1972	1434870	5000331	Irrigation	No
J41/0249	90	250	1/01/1985	1430982	5000848	Irrigation	Yes
J42/0126	10.9	250	1/04/1995	1434931	4994910	Irrigation	Yes

Groundwater quality results from the NOVA SoE monitoring bores were compared against the DWSNZ. The results indicate significant issues with elevated nitrate concentrations, which are the highest in Otago. Nitrate concentrations in bores J41/0008 and J42/0126 substantially exceed the 11.3mg/L MAV, with concentrations in bore J42/0126 ranging between 17.0 and 22.0mg/L and those in bore J41/0008 ranging between 9.0 and 32.2mg/L. The concentrations in bore J41/0249 range between 3.29 and 6.20mg/L, with the upper end of these exceeds ½ of the MAV, Figure 123. Monitoring of E. Coli in the NOVA only started in 2017. This has indicated some issues in bore J41/0008, with two exceedances of

27MPN/100mL (June 2018) and 4 MPN/100mL (September 2019). There were no exceedances in bores J41/0249 and J42/0126,

Figure 124. Arsenic concentrations in all bores were below the MAV of 0.01mg/L,

Figure 125. Ammonia concentrations in all monitoring bores were below the GV of 1.5mg/L,

Figure 126.

Bore J41/0008 is also sampled as part of the Institute for Environmental Research (ESR)'s National Pesticides in Groundwater Survey, which is conducted every four years. Glyphosate was measured in the bore during the 2018 survey, with this bore being the only one in New Zealand where glyphosate was detected. Furthermore, DDT was also detected in the bore, which indicated that the contamination source was from the surface and close to the borehead (ESR, 2019). Considering the very poor borehead security, these results are unsurprising.

Figure 123: Groundwater nitrate concentrations for the NOVA

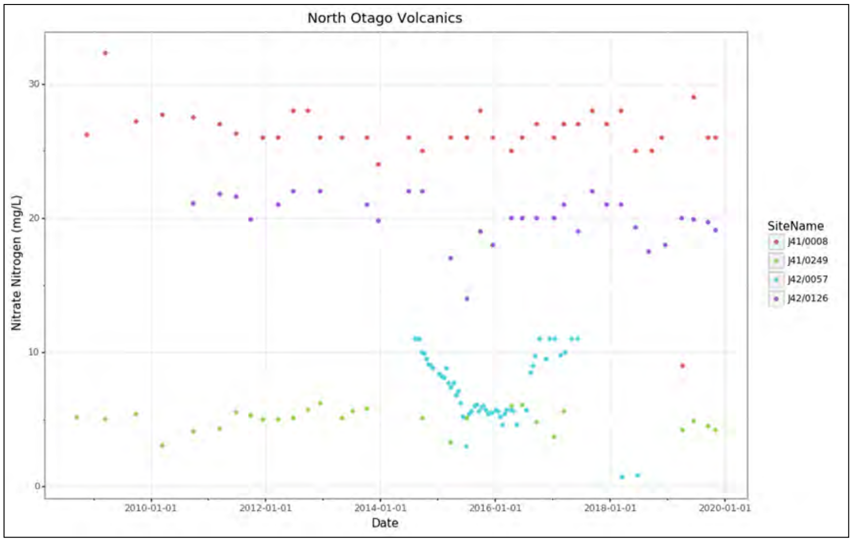


Figure 124: Groundwater E. Coli count for the NOVA

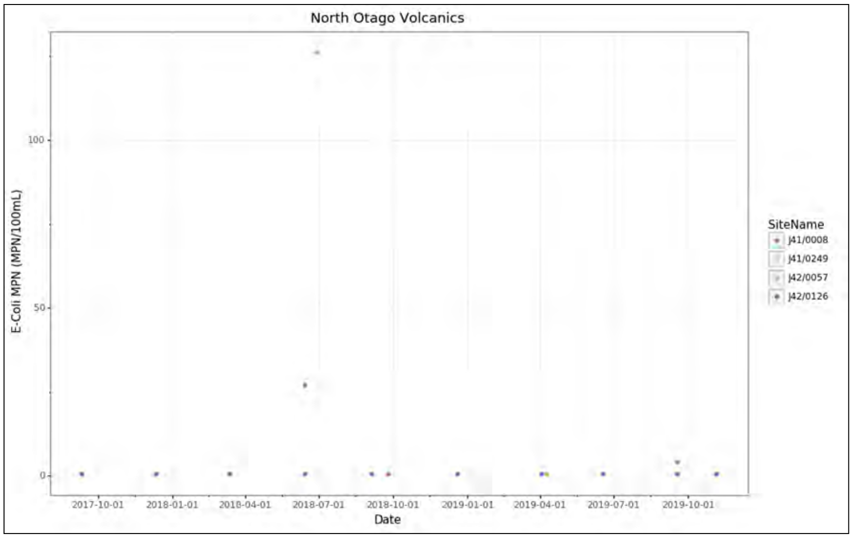


Figure 125: Groundwater dissolved arsenic concentrations for the NOVA

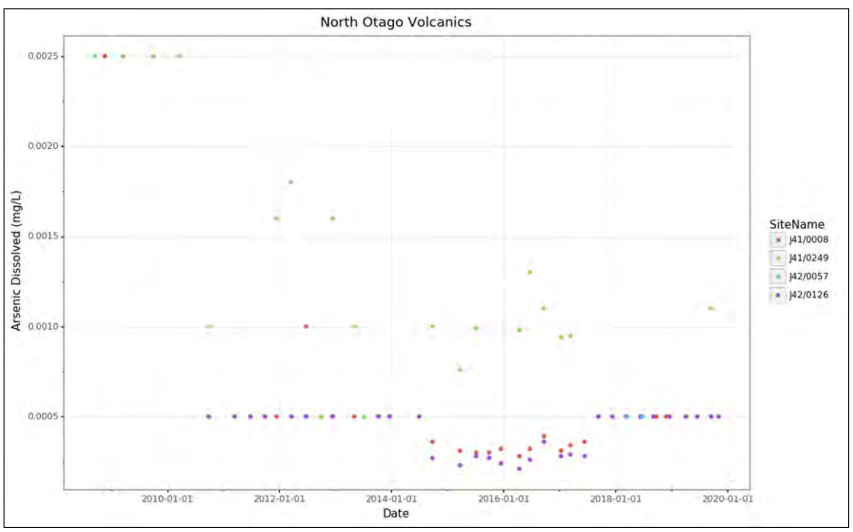


Figure 126: Groundwater ammonia concentrations for the NOVA

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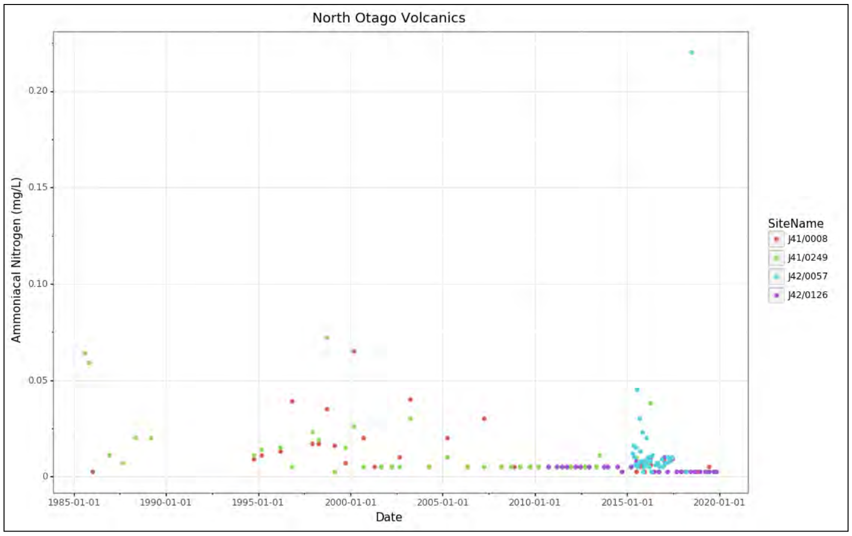


Table 63: 80th percentile values for Schedule 15 water quality variables for the NOVA

Bore number			Nitrate (NO_3-N)	Dissolved Reactive Phosphorus (DRP)	Ammoniacal nitrogen (NH_4-N)
Group 2 Sched. 15 limit (mg/L)	**FMU**	**Aquifer**	**0.075**	**0.010**	**0.100**
J41/0008	N. Otago	NOVA	27.660	0.057	0.010
J42/0126	N. Otago	NOVA	21.600	0.026	0.010

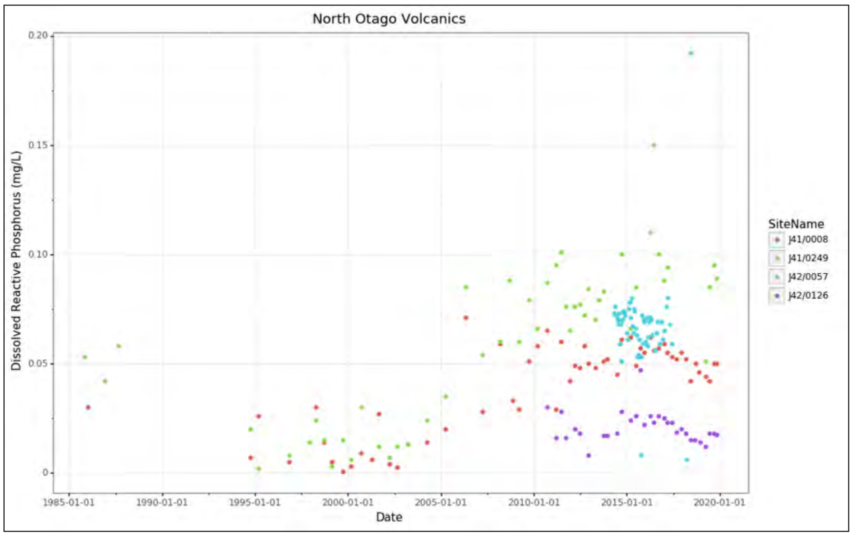
Groundwater quality results were then analysed against the RPW (Table 63) NPS-FM NOF (Table 64). Due to their shallow depths, only bores J41/0008 and J42/0126 were included in this assessment. Both bores are located in Group 2 of Schedule 15 of the RPW. The results further indicate severely elevated nitrate concentrations, with the 80th percentile concentrations in bore J41/0008 and J42/0126 exceed the threshold by 369 and 288 times, respectively. The DRP concentrations also exceed the limits by around 6 (J41/0008) and 3 (J42/0126) times. The ammonia concentrations are below the limit.

These results are also mirrored in the assessment against the NPS-FM, with the median and 95th percentile nitrate concentrations from both bores in Band D, substantially elevated above the median (6.9mg/L) and 95th percentile (9.8mg/L) National Bottom Lines for nitrate. These highly elevated nitrate concentrations impact on the growth of multiple species and exceed the concentration for acute impact level (i.e. risk of death) for sensitive species of 20mg/L (MfE, 2020). Therefore, interaction of these bores with surface water can severely hamper surface water quality.

Alongside nitrates, DRP concentrations in bore J41/0008 are also high (Figure 127), with both the median and 95th percentile concentrations placed in Band D, exceeding the median (0.018mg/L) and 95th percentile (0.054mg/L), below the National Bottom Lines. These concentrations are substantially elevated above natural reference conditions. Combined with other conditions that favour eutrophication, DRP enrichment drives excessive primary production and significant changes in macroinvertebrates and fish communities as taxa that is sensitive to hypoxia are lost. The DRP 95th percentile and median DRP concentrations are in

Bands C and B, respectively. DRP concentrations in Band C are moderately elevated above natural reference conditions. If other conditions that favour eutrophication exist, DRP enrichment can cause increased algal and plant growth, loss of sensitive macroinvertebrate & fish taxa and high rates of decay and respiration (MfE, 2020).

Figure 127: Groundwater Dissolved Reactive Phosphorus concentrations for the NOVA



The median and maximum ammonia concentrations in bore J41/0008 are in Bands A and B, respectively. Ammonia concentrations in Band B provide 95% species protection level, with concentrations starting to impact occasionally on the 5% most sensitive species (MfE, 2020). Both median and maximum concentrations in bore J42/0126 are in Band A.

Table 64: NOF comparison for nitrate, ammonia, and DRP for the North Otago Volcanic Aquifer

	Nitrate		NOF Band	
Bore number	Median (mg/L)	95th percentile	Median	95th percentile
J41/0008	26	28.2	D	D
J42/0126	20	22	D	D
	Ammonia		NOF Band	
Bore number	Median (mg/L)	Max. (mg/L)	Median (mg/L)	Max. (mg/L)
J41/0008	0.005	0.065	A	B
J42/0126	0.005	0.01	A	A
	Dissolved Reactive Phosphorus (mg/L)		NOF Band	
Bore no.	Median	95th percentile	Median	95th percentile
J41/0008	0.048	0.062	D	D
J42/0126	0.0184	0.029	B	C

4.5.2 Kakanui-Kauru Alluvial Aquifer & Shag alluvial aquifers

4.5.2.1 Aquifer information

The Kakanui River catchment area is 894km^2. The catchment is bordered by Pisgah Spur and the Kakanui Mountains to the south and west and is separated from the Waitaki catchment, situated to the north, by rolling hill country. The main tributaries of the Kakanui are the Kauru River (catchment area of 143km^2), Island Stream (122km^2) and the Waiareka Creek (213km^2) (Ozanne and Wilson, 2013).

From its source in the Kakanui Mountains, the Kakanui River flows in a northeast direction through gorges incised in downlands or rolling country for around 40km before emerging onto plains at Clifton. It then flows to the southeast at a gentler gradient through highly developed pastures, where it merges with the broad, gravel-bedded Kauru River. The Kakanui water is heavily used for irrigation. Land use has intensified in the Kakanui catchment over the past 20 years, with increasing concerns regarding the intensification and subsequent water quality degradation. The lower Kakanui and Waiareka Creek are dominated by mixed sheep/beef/dairy/cropping and, recently dairy farming, increased by the introduction of the North Otago Irrigation Company (NOIC) water to the Waiareka Creek catchment. In contrast to that, the landuse in the upper Kauru and upper Kakanui is lower intensity sheep/beef farming and native vegetation. There is strong groundwater-surface water interaction in the alluvial gravels of the Kauru and the main stem of the Kakanui, particularly upstream of Gemmels Crossing, which strongly affects water quality. Conversely, groundwater-surface water interaction in Waiareka Creek is low.

The Shag is a medium sized river with a catchment size of around 550km^2. The headwaters of the Shag are located on the south western slopes of Kakanui Peak in the Kakanui Mountains. From there, the Shag flows in a southeasterly direction for 90km past the township of Palmerston, before entering the Pacific Ocean south of Shag Point. The river supports high ecological values including high diversity of native fish, waterfowl, and regionally significant fisheries. The catchment is dominated by extensive agriculture and forestry with some short rotation cropping in the lower catchment. Parts of the catchment are utilised for the Oceana Gold hard rock goldmine at Macraes Flat, which includes open pit and underground mines. The existing mine operation discharges water and associated contaminants to the Deepdell Creek catchment. These operations are covered by numerous resource consents that include extensive monitoring and reporting. These are available through Oceana Gold (ORC, 2017a).

4.5.2.2 Groundwater quality measurements

There are three SoE monitoring bores in the Kakanui-Kauru Alluvium aquifer. The bores were installed in January 2014, as part of the Kakanui monitoring programme, three of which were left as SoE monitoring bores after the sampling for the programme has ended. Bore J41/0762 (Kakanui bore 3, 100mm diameter) is located at NZTM E1425455 N5007458. The bore depth is 3.3m. The log is composed of sandy gravel and minor silt. Bore J41/0764 (Kakanui bore 5, 100mm diameter) is situated at NZTM E1425354 N5004854. The total bore depth is 9.6m. The log describes coarse gravel to 9.6m underlain by sandy clay to 9.8m. Bore J41/0771 (Kakanui bore 10, 100mm diameter) is situated at NZTM E1429017 N5001748. The total bore depth is 4.1m. The log describes silty sand to 0.4m underlain by sandy gravel and cobbles to 3.3m. There is then 0.2m of clay/sand underlain by stiff clay to the bore bottom at 4.1m. This information indicates that the bores abstract from a shallow unconfined aquifer. It also indicates that the aquifer is very shallow, with basement depth of less than 10m.

Water level measurements in J41/0764 began in May 2015, with water levels ranging between 4.368 and 5.985m. The annual variability in water levels ranges between approximately 0.40 and 1.70m. Static Water Level measurements in bore J41/0762 began in May 2015, with levels ranging between 1.096 and 2.79m below MP. The seasonal variation in groundwater ranges between approximately 0.30 and 1.20m.

Groundwater in the Shag Alluvium Aquifer is monitored in bore J43/0006 (300mm diameter). The bore is situated at Mill Road, Palmerston NZTM E1421870 N4962122. The bore is 9.1m deep. The log describes topsoil and clay to 0.61m underlain by claybound gravel to 1.22m. There is than gravel to 9.14m, with the layer between 1.22 and 3.05 containing traces of clay and the layer between 3.05 and 9.14 described as gravel and sand. There is then sandstone to 10.14m. Screen information is not available for the bore, although it is likely to be screened within the bottom gravel/sand layer. Water levels are not monitored in bore J43/0006, potentially due to continuous pumping.

The comparison of groundwater quality against the DWSNZ indicate issues with elevated E. coli and nitrates. High E. coli exceedances were measured in the bores, which included the highest count in Otago (6,200MPN/100mL) in bore J43/0006 (September 2010) and a count of 291MPN/100mL (December 2018) in bore J41/0762, Figure 128. Some of the Kakanui bores also have substantial issues with elevated nitrate, with maximum concentrations in bores J41/0762 and J41/0771 exceeding the DWSNZ MAV of 11.3mg/L,

Figure 129. Nitrate concentrations in the bores also show strong fluctuations, potentially related to changes in land use. The maximum concentrations in J41/0764 are 4.50mg/L which exceed the reference for groundwater under low intensity landuse (Daughney and Morgenstern, 2012). The concentrations in bore J43/0006 are lower, with a maximum of 2.64mg/L, which slightly exceeds the low landuse reference conditions. There are no exceedances of the arsenic MAV in the bores (

Figure 130). Ammonia concentrations in the bores do not exceed the GV of 1.5mg/L (

Figure 131).

Figure 128: Groundwater E. Coli count for the Kakanui/Shag Alluvium Aquifers

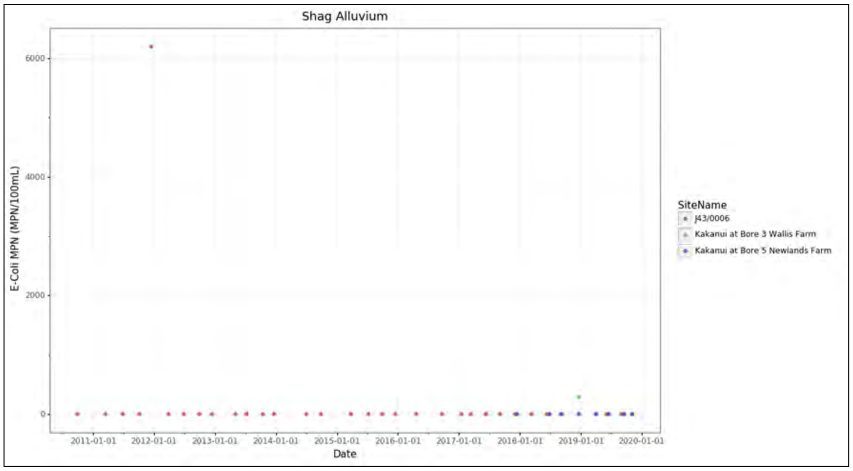


Figure 129: Groundwater nitrate concentrations for the Kakanui/Shag Alluvium Aquifers

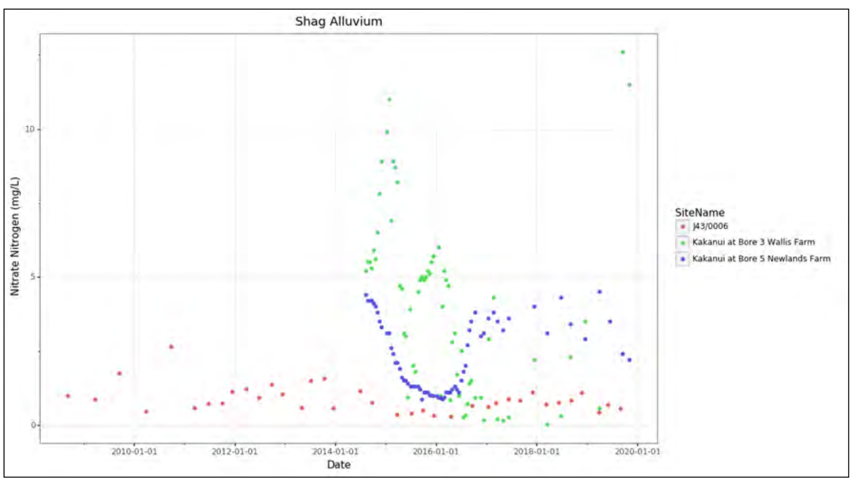


Figure 130: Groundwater dissolved arsenic concentrations for the Kakanui/Shag Alluvium Aquifers

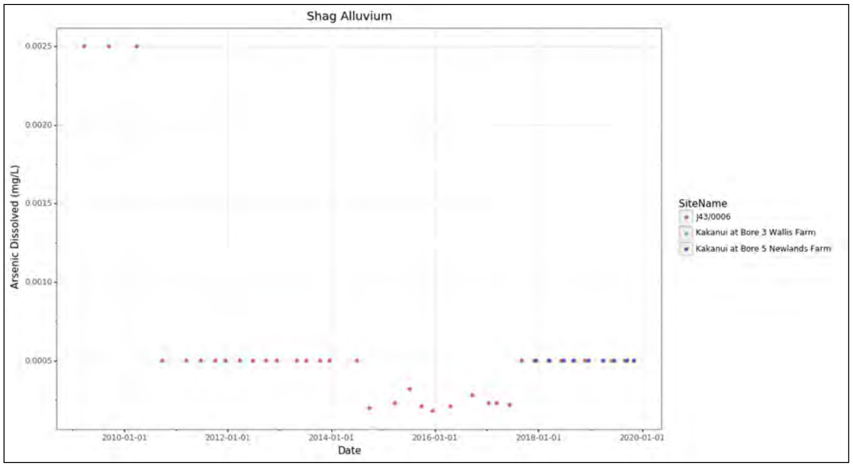
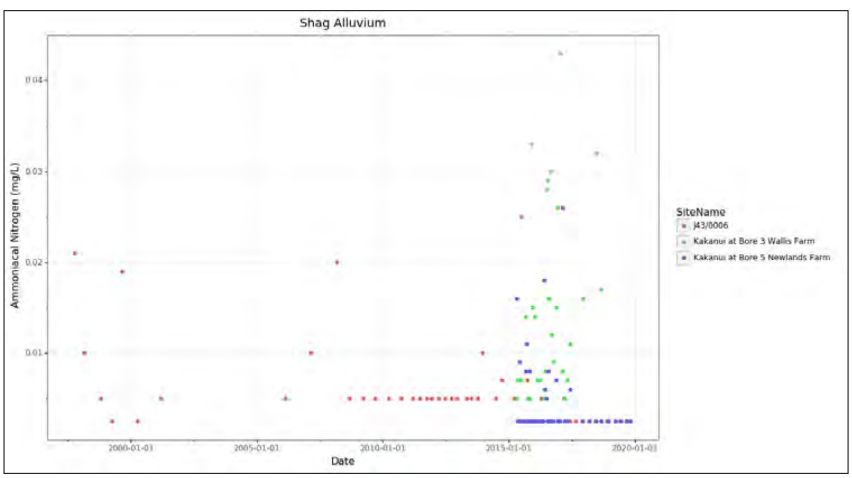


Figure 131: Groundwater ammonia concentrations for the Kakanui/Shag Alluvium Aquifers



Nutrient concentrations from the bores were then assessed against the RPW and NPS-FM NOF. The bores are located in Group 2 of Schedule 15 of the RPW. The results indicate substantial potential water quality issues, with the 80th percentile nitrate concentrations exceeding the Schedule 15 limits by between approximately 147 (J41/0771) and 15 (J43/0006) times, Table 65. DRP concentrations in all bores also exceed the threshold, although the concentrations are closer to the limits (Figure 132). The ammonia concentrations are below the limits.

Table 65: 80th percentile values for Schedule 15 water quality variables for the Kakanui-Kauru Alluvial Aquifer

Bore number	Nitrate (NO_3-N)	Dissolved Reactive Phosphorus (DRP)	Ammoniacal nitrogen (NH_4-N)
Group 2 Sched. 15 limit (mg/L)	**0.075**	**0.010**	**0.100**
J41/0762 Kakanui bore 3	4.940	0.011	0.016
J41/0764 Kakanui bore 5	3.400	0.011	0.006
J41/0771 Kakanui bore 10	11.000	0.010	0.012
J43/0006	1.116	0.011	0.010

The comparison of nitrate concentrations from the bores against the NPS-FM NOF also indicates some issues, particularly for the Kakanui bores, with median and 95th percentile concentrations for bore 10 in Bands D and those for bore 3 in Band C. Nitrate concentration in Band D is below the National Bottom Line, indicating impacts on growth of multiple species which begins to approach acute impact level (i.e. death risk) for sensitive species at concentrations that exceed 20mg/L. The concentrations for bore J43/0006 are lower, with the median and 95th percentile in bands A and B, respectively.

The DRP concentrations are dominated by spiking concentrations, with the 95th concentrations in bands C and B. Ecological communities where DRP concentrations are in band C are impacted by moderately elevated above natural reference conditions. If other conditions that favour eutrophication also exist, DRP enrichment can increase algal and plant growth, loss of sensitive macroinvertebrate and fish taxa and high decay and respiration rates.

Figure 132: Groundwater Dissolved Reactive Phosphorus concentrations for the Kakanui/Shag Alluvium Aquifers

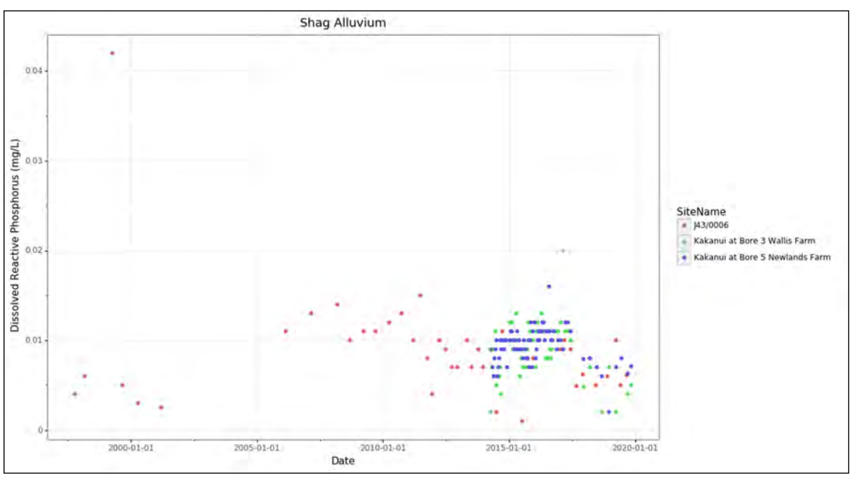


Table 66: NOF comparison for nitrate, ammonia, and DRP for the Kakanui-Kauru Alluvial Aquifer

Nitrate			NOF Band	
Bore number	Median (mg/L)	95th percentile	Median	95th percentile
J43/0006	0.75	1.604	A	B
J41/0762	4.3	5.88	C	C
J41/0764	2.1	3.9	B	C
J41/0771	7.2	12	D	D
Ammonia			NOF Band	
Bore number	Median (mg/L)	Max. (mg/L)	Median (mg/L)	Max. (mg/L)
J43/0006	0.005	0.025	A	A
J41/0762	0.007	0.043	A	A
J41/0764	0.0025	0.026	A	A
J41/0771	0.0025	0.034	A	A
Dissolved Reactive Phosphorus (mg/L)			NOF Band	
Bore no.	Median	95th percentile	Median	95th percentile
J43/0006	0.0085	0.01375	A	B
J41/0762	0.009	0.012	A	B
J41/0764	0.01	0.012	A	C
J41/0771	0.009	0.011	A	B

4.5.3 The Lower Waitaki Aquifer

4.5.3.1 Aquifer information

The Lower Waitaki Plains aquifer is located approximately 20km north of Oamaru. The aquifer area is around 19,793ha and it has a triangle shape, stretching from a narrow point at Black Point in the west to its widest margin along the North Otago coast (Figure 122). The Plains' alluvial sand and gravel formation hosts an unconfined aquifer, with potentially local semi confined conditions associated with silt and clay lenses. Three main soil types were identified for the area:

- Well drained soils mainly composed of sandy loams (potentially gravelly and stony), covering approximately half of the plains in the north along the Waitaki River margin (e.g. Rangitata sandy loam on the lower terraces near the river, and Stewart silty loam on the higher terraces);
- Moderately well drained soils mainly composed of silty loams (intermediate soils such as Ngapara and Darnley silty loams) covering the southern half part of the Plains;
- Imperfectly drained soils mainly made of silty loams (heavier soils such as Pukeuri silty loam), encountered in a limited number of locations across the Plains (e.g. Hilderthrope and Pukeuri).

Soil maps indicate that most of the soils along the river terraces and in the northern half of the Plains are free-draining, suggesting that these are suitable for intensive pastoral farming and less suitable for cropping/horticulture. Based on that, the upper part of the Plains are mainly used for dairying whilst cropping is practiced on the heavier soils in the southern part of the valley.

Dairy farming composes the main land use on the Plains, with its expansion linked to the Lower Waitaki Irrigation Scheme. The scheme abstracts water from the Waitaki River, on the upper edge of the Waitaki Plain, where a managed race delivers water through the lower Plains and down to Oamaru. The water uses include agricultural, commercial, and domestic uses. The scheme's peak daily distribution volume is around 1.2million m^3, of which approximately 1.123 million m^3 is used for irrigation (ORC, 2016c).

The geology of the Lower Waitaki Plains is mainly composed of Holocene and late Pleistocene unconsolidated gravels and sands, which were deposited during successive phases of glacial advance/retreat. The more recent sediments were deposited adjacent to the Waitaki River and the coastline. The Plains' alluvium overlies consolidated Tertiary sedimentary rocks (i.e. the Rifle Butts Formation) which consist of various conglomerates, sandstones, siltstone and mudstone. Available bore logs indicate that the depth to the Tertiary sediment basement ranges between 13 and 45.80m, with the aquifer deepening towards the west. The basement sediments comprise of sandstone, siltstone, and mudstone. The morphology of the Plains is impacted by the local fault system.

Groundwater levels have been monitored in the Dennisons bore J41/0377 since March 1997. The seasonal fluctuation in water levels is around 1.5m, although a range of 2.0m was also observed in some years (e.g. 2011). The highest water levels occur in March/April, following recharge from irrigation during the summer, although some episodic high levels were occasionally measured during winters (e.g. July 2013, 2017). These are likely connected to high flow from the Waitaki River or hillside catchments. Water levels then recede during the winter months, with the lowest levels usually observed in September and October. An upward trend was observed between 1997 and 2002, following the aquifer's equilibration to the new recharge dynamics posed by the irrigation scheme. There is currently no stage monitoring on the lower Waitaki River, and the nearest groundwater level monitoring bore is around 9km away from the river, hence, groundwater-river interaction is not directly investigated (ORC, 2016c).

Piezometric maps suggest that groundwater flow direction generally follows topography, with the highest hydraulic heads near Black Point and the lowest at the coast. The flow direction in the upper part of the aquifer is from the southwest towards the northeast/Waitaki River. Groundwater in the lower part flows from the west towards the east/southeast and the ocean. The hydraulic gradient is shallower along the western parts of the foot hills (aquifer recharge area) and steeper in the southeast near the coast (discharge area). The mean gradient is around 1:270m, similar to the land surface gradient. The data also indicated that the depth to groundwater ranges between approximately 1 and 15m below ground level, with the shallowest water tables measured near the Waitaki River and the deepest near the coast and away from the river (i.e. to the east and south). The measurements also indicated the expansion of the shallow water table towards the central part of the plains during the summer, following recharge by irrigation returns. A large part of the Lower Waitaki Plain is listed as a Groundwater Protection Zone in the RPW. This is likely due to the high permeability of the soil in the area (ORC, 2016c).

4.5.3.2 Groundwater quality monitoring

Groundwater quality in the Lower Waitaki Plains aquifer is monitored in five bores, the details of which are summarised in Table 67. Bore J41/0317 (150mm diameter) has been monitored since June 1993 whilst the other four bores were added following an ORC investigation of the area in 2016.

Bore J41/0317 (150mm diameter) was drilled in June 1983. The bore is located at Steward Road approximately 1km west of SH1, NZTM E1448327 N5020845. The total bore depth is 16.5m. There is no bore log or screen information for this bore.

Bore J41/0442 (150mm diameter) was drilled in June 1997. The bore is located at Jardine Road, Oamaru, NZTM E1435789 N5022981. The total bore depth is 11.4m. The bore log describes tight silty gravel/pebbles to 3.9m underlain by tight sandy gravels/pebbles/cobbles to 7.3m. There is then silty gravel/pebbles to 10.4m underlain by silty clay to the bore bottom at 11.4m. The bore is screened at a depth of between 8.4 and 10.4m, within a horizon of silty gravel/pebbles. The SWL in the bore in November 2019 was 4.07m below MP.

Bore J41/0586 (125mm diameter) was drilled in July 2003. The bore is located at Ferry Road, Oamaru, NZTM E1444388 N5022051. The total bore depth is 10.9m. The bore log describes coarse, cobbley gravels to 11.6m underlain by clay to the bore bottom at 12.7m. The bore is screened between 10.30 and 10.90m, within a layer of cobbley gravels. The SWL in December 2019 was 3.190m below MP.

Bore J41/0576 (200mm diameter) was drilled in December 2003. The bore is located at MacDonalds Road, Oamaru (Hilderthorpe) at NZTM E1447793 N5017591. The total bore depth is 23.0m. The bore log describes 1.0m of topsoil underlain by grey gravels to the bore depth at 23.0m. The bore is screened in the gravels, at a depth of between 21.0 and 23.0m. There is no SWL information for the bore (likely due to the inability to measure it through the borehead setup). The SWL at the time of drilling was 7.4m below MP. The bore log indicates that it abstracts from an unconfined gravel aquifer at least 23m deep.

Bore J41/0571 (150mm diameter) was drilled in August 2002. The bore is located at Hilderthorpe-Pukeuri Road, Oamaru, NZTM E1446095 N5014890. The total bore depth is 23.5m. The bore log describes top soil and clay to 1.3m underlain by small sandy gravels to 11.1m. There is then weathered gravels to the bore bottom at 23.5m. The length of the leader and screen are 2.040m, with a leader length of 0.700m, indicating that the bore is screened at a depth of 22.16m, within the weathered gravels horizon. This indicates that the bore abstracts from an unconfined gravel aquifer. The SWL in December 2019 was 7.18m below MP.

This information indicates that the bores abstract from an unconfined gravel aquifer. The aquifer and SWL are deeper in bores J41/0571 and J41/0576, situated in the eastern, lower part of the plains, than in the other SoE monitoring bores which are situated in the upper part of the Plains. This is consistent with previous findings (ORC, 2016c).

Table 67: Summary of groundwater quality SoE bore details for the Lower Waitaki Plains Aquifer

Well Number	Depth (m)	Diam. (mm)	Drill Date	Easting NZTM	Northing NZTM	Screen Top (m)	Screen Bottom (m)	Bore Log?
J41/0317	16.5	150	1/01/1983	1448327	5020845	N.A.	N.A.	No
J41/0442	11.4	150	3/06/1997	1435789	5022981	8.4	10.4	Yes
J41/0586	10.9	125	25/07/2003	1444388	5022051	10.3	10.9	Yes
J41/0576	23	200	5/12/2003	1447793	5017591	N.A.	N.A.	Yes
J41/0571	23.5	150	12/08/2002	1446095	5014890	N.A.	N.A.	Yes

Groundwater quality results from the Lower Waitaki SoE bores was assessed against the DWSNZ. The results indicate some groundwater quality issues. Exceedances of the E. coli MAV were measured in all bores, with the most exceedances observed in the long term monitoring bore, J41/0317 (

Figure 133). E. coli has been monitored in this bore since September 2012. The highest exceedance was 150MPN/100mL (September 2016). Most of the exceedances were measured during spring/summer, likely associated with the higher water table during these seasons due to irrigation recharge (ORC, 2016c). The monitoring of E. coli in the other bores began in March 2017. Exceedances of the MAV were noted in all four bores, with E. coli counts ranging between 1.6 and 9 MPN/100mL (

Figure 133). This indicates high potential risk for faecal contamination in the Lower Waitaki aquifer.

Groundwater nitrate concentrations in the Lower Waitaki bores suggest potential issues, with most bores having relatively high concentrations (Figure 134). Nitrate concentrations in bore J41/0317 were monitored since November 2008. Concentrations range between 2.8 and 8.6mg/L, which exceeds ½ of the DWSNZ MAV of 11.3mg/L. The data also shows high fluctuations and increasing concentrations, particularly since March 2015. The concentrations in bores J41/0576 and J41/0586 range between approximately 5.3 and 7.9mg/L, which also exceeds ½ of the MAV. Concentrations in these bores, and in bore J41/0571, have also generally increased since the start of monitoring in June 2016. Although groundwater nitrate concentrations were below the MAV, their increase still indicate issues with potential nitrate contamination. Dissolved arsenic concentrations in all bores were below the 0.01mg/L MAV (

Figure 135). All ammonia concentrations were below the aesthetic GV of 1.5mg/L (
Figure 136).

Figure 133: Groundwater E. coli count for the Lower Waitaki Aquifer

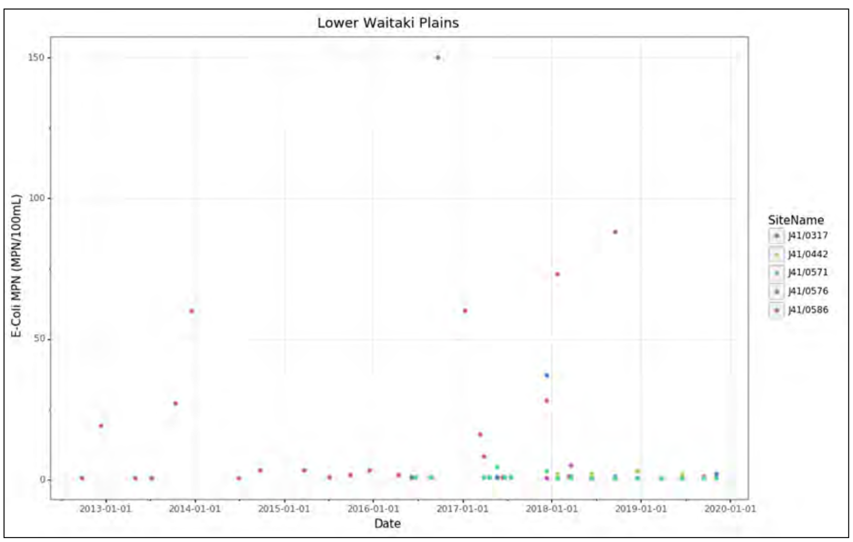


Figure 134: Groundwater nitrate concentrations for the Lower Waitaki Aquifer

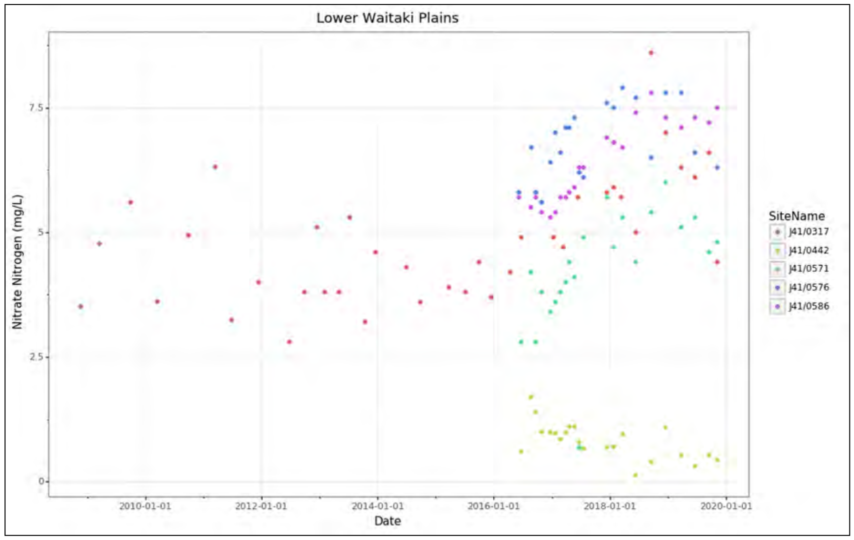


Figure 135: Groundwater dissolved arsenic concentrations for the Lower Waitaki Aquifer

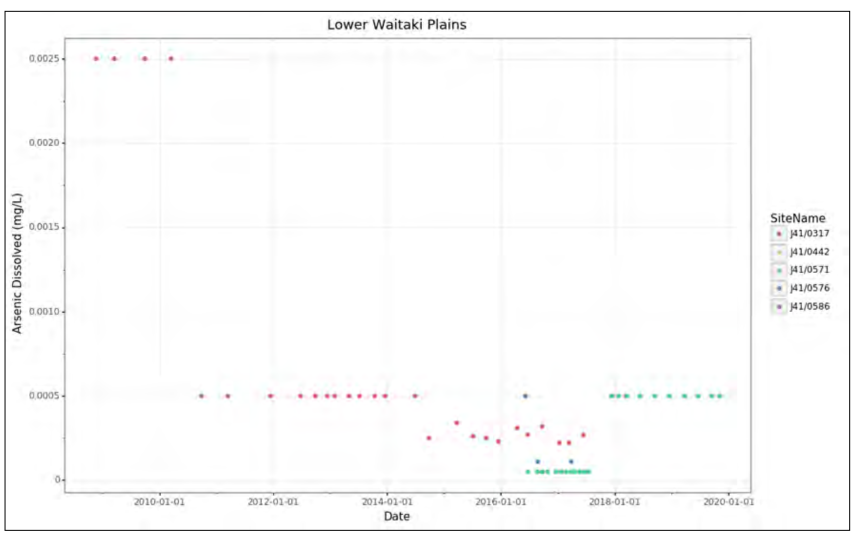
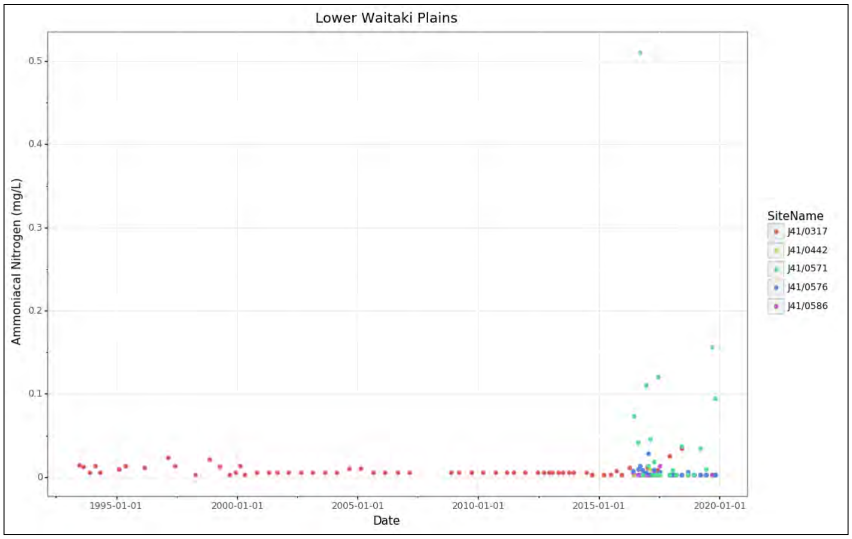


Figure 136: Groundwater ammonia concentrations for the Lower Waitaki Aquifer



Potential impacts of groundwater quality on surface water systems was assessed by comparing nutrient concentrations from shallow bores (<20m) against the RPW and the NPS-FM NOF. Bores shallower than 20m in the Lower Waitaki aquifer include J41/0317, J41/0442, and J41/0586, all of which are located in Group 2 of Schedule 15. The 80th percentile nitrate concentrations in all bores exceed the Schedule 15 limit of 0.075mg/L, with concentrations in the bore exceeding the limit by between 14 (J41/0442) and 97 times (J41/0586). DRP concentrations in bore J41/0317 exceed the limit by more than three times, with maximum concentrations of 0.144mg/L (Figure 137). Conversely, DRP concentrations in the other bores are below the limit. Ammonia concentrations in all three bores are also below the Schedule 15 limit (Table 68).

Figure 137: Groundwater Dissolved Reactive Phosphorus concentrations for the Lower Waitaki aquifer

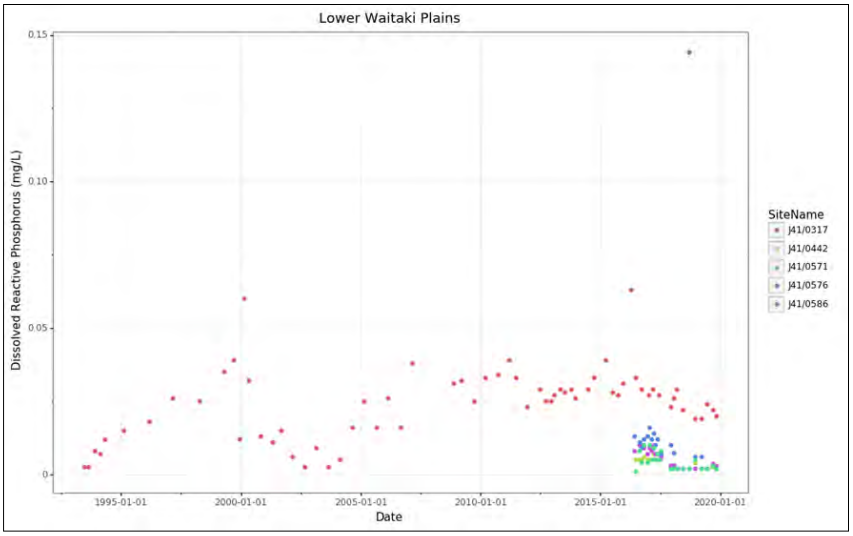


Table 68: 80th percentile values for Schedule 15 water quality variables for the Lower Waitaki Aquifer

Group 2 Sched. 15 limit (mg/L)	Nitrate (NO_3-N)	Dissolved Reactive Phosphorus (DRP)	Ammoniacal nitrogen (NH_4-N)
Bore number	**0.075**	**0.010**	**0.100**
J41/0317	5.800	0.032	0.010
J41/0442	1.072	0.005	0.005
J41/0586	7.280	0.009	0.005

The assessment against the NPS-FM NOF further highlights the elevated nitrates in the Lower Waitaki groundwater, with the median and 95th percentile concentrations in bores J41/0317 and J41/0586 in Band C, where there are growth effects on up to 20% of species, mainly of which are sensitive such as fish, though no acute effects are expected. The median and 95th percentile nitrate concentrations for boreJ41/0442 are in Band A (Table 69).

The DRP assessment for bore J41/0317 also shows potential issues, with the median and 95th percentile DRP concentrations in Bands C and D, respectively. Band D is below the National Bottom Line, where ecological communities are impacted by DRP concentrations that substantially exceed natural reference conditions. If combined with other conditions that favour eutrophication, DRP enrichment can drive excessive primary production and significant changes to macroinvertebrate and fish communities, as species that are sensitive to hypoxia are lost. The 95th percentile DRP concentration for bore J41/0586 is in Band B, where ecological communities are slightly impacted by minor DRP exceedance of natural reference conditions. If other conditions that favour eutrophication occur, sensitive ecosystem may experience additional algal and plant growth, loss of sensitive macroinvertebrate taxa and higher rates of respiration and decay (MfE, 2020). Ammonia concentrations for all bores are in Band A.

Table 69: NPS-FM NOF comparison for nitrate, ammonia, and DRP for the Lower Waitaki Aquifer

	Nitrate Nitrogen (mg/L)		**NOF Band**	
Bore no.	Median (mg/L)	95th percentile	**median**	**95th percentile**
J41/0317	4.735	6.66	C	C
J41/0442	0.82	1.385	A	A
J41/0586	6.3	7.495	C	C
	Ammoniacal Nitrogen (mg/L)		**NOF Band**	
Bore no.	Median (mg/L)	max	**Median**	**95th percentile**
J41/0317	0.005	0.034	A	A
J41/0442	0.0025	0.0086	A	A
J41/0586	0.0025	0.013	A	A
	Dissolved Reactive Phosphorus (mg/L)		**NOF Band**	
Bore no.	Median (mg/L)	95th percentile	**Median**	**95th percentile**
J41/0317	0.026	0.039	C	D
J41/0442	0.005	0.006	A	A
J41/0586	0.0065	0.01	A	B

5. Discussion & Recommendations

This report highlights a wide variability in groundwater quality across Otago, with some areas having substantial issues (e.g. North Otago, Lower Clutha) whilst others generally have good groundwater quality (e.g. the Upper Lakes). The report also highlights other issues regarding the condition and suitability of the monitoring network. In order to help improve groundwater quality in Otago, the following recommendations are based on this report:

- Ensure groundwater users maintain good borehead security to prevent contaminant migration into bores. It is also recommended to tighten the rules regarding bore security in the Regional Plan/consent conditions.
- Publish the groundwater quality monitoring results on the ORC website with suitable symbology that clearly indicates when parameters exceed the DWSNZ MAVs.
- Encourage bore owners to regularly test their bore water, especially in areas of high risk (i.e. Central Otago/Upper Lakes for arsenic and areas of intensive farming/On Site Waste Management Systems for E. coli and nutrients).
- Many of the areas where the SoE data shows degraded groundwater quality (e.g. North Otago, Lower Clutha) are used for intensive farming. Some of these are situated on permeable substrate (e.g. the Lower Waitaki and Kakanui-Kauru). It is recommended to review the regulatory/planning regimes around high risk land uses (e.g. intensive farming, On Site Waste Management Systems), particularly in vulnerable catchments.
- Many SoE bores are situated on private land and require maintenance and better head protection. Furthermore, many of the bores' locations are based on previous availability rather than their representation of aquifers. Due to these issues, it is recommended to implement a dedicated programme to replace unsuitable bores with new, dedicated ones. The new bores will ideally be emplaced on TLA reserve land in order to ensure long term access. When suitable existing bores are identified on private land, it is recommended that access for monitoring is ensured by signing a formal agreement with the land owners. It is also recommended to have an ongoing maintenance programme

for the bores, where they are pumped, surveyed, and the head security is confirmed on a regular basis.

6. Conclusions

This report summarises the results from ORC's groundwater quality SoE monitoring programme. The groundwater SoE quality network currently consists of 54 monitoring bores, situated on both public and private land with varying degree of borehead security. Although bores are located in each FMU, their distribution is not even, with the Catlins and Dunedin & Coast FMUs having only one monitoring bore each. Furthermore, some of the aquifers in the region are currently not monitored. This report assesses groundwater quality results from the start of monitoring in each currently active SoE bore until the end of 2019. Groundwater quality in the SoE bores is monitored quarterly for microbiological parameters, major ion geochemistry, and metal concentrations. The sampling follows the National Environmental Monitoring Standards [NEMS] (2019) and the samples are analysed in an accredited laboratory.

This report summarises the state of groundwater quality in Otago in relation to drinking water quality. This is assessed by comparing groundwater E. coli, dissolved arsenic, and nitrate concentrations against the DWSNZ thresholds. The report also assesses the impact on surface water quality by comparing groundwater nutrient concentrations in shallow bores against the RPW and NPS-FM NOF. However, as these standards do not currently include limits for nutrients in groundwater, this approach only provides an overview, rather than a direct analysis.

The E. coli assessment was based on the percentage of samples in each SoE bore that exceeded the DWSNZ MAV. The data shows that E. coli was detected in 75% of the bores in the region at a point during the monitoring period and that exceedances were detected in each of Otago's FMU/rohes. This indicates that potential faecal contamination is a significant water quality issue across Otago. The proportion of E. coli exceedance across Otago (75%) is similar to that of the Clutha, North Otago and Taieri FMUs. However, a wider variability was observed within the different rohes of the Clutha FMU, with higher proportions in the Manuherikia and Lower Clutha rohes, indicating a higher contamination risk in these rohes. Conversely, the proportion of exceedance in the Upper Lakes rohe was lower than the regional, whilst that of the Dunstan rohe was similar to it. The data from the Catlins and Dunedin & Coast FMU is highly skewed due to each FMU having only one monitoring bore. An assessment of E. coli exceedance and bore depth shows that the highest proportion of E. coli exceedance was in bores shallower than 10m (92%) and the lowest (40%) in bores deeper than 60m. This data indicates that groundwater and bores in Otago are vulnerable to faecal contamination. Elevated E. Coli can also be a local issue and is strongly dependent on bore security, hence, the SoE data does not present a complete mapping of this risk. Nevertheless, it is strongly recommended that bore owners ensure adequate borehead security and regularly test their groundwater.

Arsenic in groundwater can originate from anthropogenic (e.g. sheep dips, treated timber posts) and geological sources such as schist lithology, reduced peat deposits, and volcanic rocks. Exposure to elevated arsenic can lead to a range of cancers. The spatial distribution of maximum arsenic concentrations in Otago groundwater shows that concentrations exceeded the MAV in only seven SoE monitoring bores, five of which are located in the Upper Clutha/Wakatipu Basin area, which are underlain by schist lithology known to contain arsenic. No arsenic concentrations above the MAV were detected in any bores in the North Otago, Dunedin & Coast, or Catlins FMUs. Nevertheless, due to the abundance of arsenic-containing schist lithology, particularly in the Upper Clutha area, and the high spatial variability of arsenic in groundwater, it is strongly recommended that bore owners regularly test their water.

Nitrate (NO_3-N) is a key nutrient required for the growth of plants and algae. However, excess nitrate can adversely impact water quality (e.g. eutrophication) and also cause health concerns. Groundwater nitrate concentration data shows that none of the aquifers in Otago has a median nitrate concentration above the DWSNZ MAV of 11.3mg/L. However, it did highlight a variable degree of nitrate contamination in relation to the MAV, with the median concentration in some aquifers, particularly in North Otago and the Lower Clutha, closer to the MAV. Conversely, the median nitrate concentrations in many aquifers are low, suggesting either low impact from landuse (i.e. concentrations below <2.5mg/L, [Daughney and Morgenstern, 2012]) or denitrification. However, the potential for denitrification was not addressed in this report.

The potential impacts of groundwater quality in Otago on ecosystems was investigated by assessing groundwater nutrient concentrations (nitrate, DRP, and ammonia) in bores shallower than 20m against the RPW Schedule 15 limits and the NPS-FM NOF. The results show that groundwater concentrations of nitrate and DRP usually exceed the surface water limits. Conversely, most ammonia concentrations were below the limit. However, it is important to note that, due to the absence of standards for groundwater nutrient limits, this assessment is only an overview.

The groundwater quality assessment for each FMU/aquifer shows that, similar to surface water, groundwater quality across the region is also highly variable. The results from the Clutha FMU show high variability, with good groundwater quality in some rohe (i.e. the Upper Lakes, Dunstan) and degraded quality in others, particularly the Lower Clutha. The main issues are elevated E. coli and dissolved arsenic concentrations in some bores, with elevated nutrient concentrations also common. The results from the Upper Lakes and Dunstan rohes generally show compliance with the DWSNZ, although elevated E. coli counts were measured in some bores. Elevated dissolved arsenic concentrations were also measured in some bores, although their source is likely to be the prevalent schist lithology. Nitrate concentrations are generally below the DWSNZ for nitrates. However, nutrient concentrations usually exceed the RPW and NPS-FM surface water limits, with particularly high DRP and nitrate concentrations in Kingston and Glenorchy. These are likely due to high septic tanks density and to shallow, poorly-secured boreheads. These nutrients can potentially adversely impact water quality in Lake Wakatipu, although groundwater (and nutrient) fluxes into the Lake are likely to be substantially lower than the surface water inflows. Groundwater quality in the Manuherikia rohe is generally fair although E. coli exceedances were measured in most bores, albeit at low counts. Nitrate concentrations are below the DWSNZ MAV in all monitoring bores, with concentrations in the Manuherikia Alluvium Aquifer and Manuherikia Claybound Aquifer monitoring bores generally near the low intensity landuse reference value. However, increasing nitrate concentrations were observed in the Manuherikia GWMZ monitoring bore, where concentrations exceed ½ of the MAV. No elevated arsenic concentrations were measured in any of the monitoring bores in the rohe. The results from the shallow monitoring bores show that nitrate and DRP concentrations exceed the surface water limits. Groundwater quality results from the Lower Clutha rohe indicate significant water quality issues, with elevated E. coli and nitrate concentrations in most bores, notably in the Ettrick and Clydevale basins. The results also show elevated nutrient concentrations, with some of these issues due to shallow monitoring bores and poor bore security. These results also support the reported poor surface water quality results from this area (ORC, 2017a).

Groundwater results from the Taieri FMU indicate potential risk of faecal contamination, with E. coli exceedance measured in all the FMU's aquifers. The pattern of nitrate concentrations is mixed, with elevated concentrations over ½ of the MAV in some bores and concentrations around the low intensity landuse value in others. The assessment against surface water quality standards indicates potential issues, with exceedances of the nutrient limits in most aquifers. It is likely that some of these elevated results are due to monitoring bores being shallow, insecure, and located near risky land uses (e.g. dairy farms and/or septic tanks). Nevertheless, these can potentially adversely impact surface water quality and ecosystem health.

The results indicate that the North Otago FMU has the most degraded groundwater quality in Otago, with high E. coli exceedances and elevated nitrate concentrations, particularly in the NOVA. Potential faecal contamination is also a concern, with elevated E. coli measured in some SoE bores in each of the FMU's aquifers. Conversely, there were no elevated dissolved arsenic concentrations in any of the bores. The results also indicated high nitrate and DRP concentrations which substantially exceed the surface water limits. Understanding the potential impact on surface water quality is imperative due to the prevalence of groundwater-surface water interaction in this FMU.

Based on this report, the following actions are recommended:

- Ensure bore owners practice good bore security to prevent contaminant migration to bores and encourage frequent groundwater testing. This includes improving ORC's regulatory and education regimes.
- Publishing the SoE groundwater quality monitoring results on the ORC website with suitable symbology to clearly indicate when parameters exceed the DWSNZ MAVs.
- Review the legislation and management of known high risk activities to water quality in areas of poor groundwater quality.
- Embark on a programme to replace unsuitable SoE bores with new dedicated ones. It is also recommended to have an ongoing maintenance programme for the bores.

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Appendix 1: List of monitoring bores for the SoE network

Bore number	Depth (m)	Diameter (mm)	Eastings (NZTM)	Northings (NZTM)	FMU	Rohe
F40/0025	40	150	1294352	5042604	Clutha / Mata-Au	Dunstan Rohe
F40/0045	60	100	1295870	5040239	Clutha / Mata-Au	Dunstan Rohe
F40/0206	45	150	1297955	5042689	Clutha / Mata-Au	Dunstan Rohe
F41/0104	60	100	1267649	5008496	Clutha / Mata-Au	Dunstan Rohe
F41/0162	16.53	125	1299519	5011550	Clutha / Mata-Au	Dunstan Rohe
F41/0203	4.1	50	1272318	5010248	Clutha / Mata-Au	Dunstan Rohe
F41/0300	48.71	125	1297971	5003508	Clutha / Mata-Au	Dunstan Rohe
F41/0437	24.85	0	1264923	5010849	Clutha / Mata-Au	Dunstan Rohe
F41/0438	6	0	1269859	5012093	Clutha / Mata-Au	Dunstan Rohe
G40/0175	12.64	125	1316489	5029566	Clutha / Mata-Au	Dunstan Rohe
G40/0411	17.75	150	1309254	5036692	Clutha / Mata-Au	Dunstan Rohe
G41/0211	41.51	125	1313189	5027098	Clutha / Mata-Au	Dunstan Rohe
G41/0487	28.99	150	1304667	5016105	Clutha / Mata-Au	Dunstan Rohe
G43/0009	15.2	100	1317341	4939478	Clutha / Mata-Au	Lower Clutha
G43/0072	16.8	150	1310456	4954944	Clutha / Mata-Au	Lower Clutha
G43/0224b	12.73	50	1316402	4941149	Clutha / Mata-Au	Lower Clutha
G44/0127	5.2	100	1306679	4910886	Clutha / Mata-Au	Lower Clutha
G44/0136	5.5	50	1310773	4912370	Clutha / Mata-Au	Lower Clutha
G45/0225	128	200	1307731	4897236	Clutha / Mata-Au	Lower Clutha
H46/0144	38	100	1354935	4870284	Clutha / Mata-Au	Lower Clutha
G41/0254	6.5	125	1330618	5002689	Clutha / Mata-Au	Manuherikia
G42/0123	32.4	100	1317225	4987272	Clutha / Mata-Au	Manuherikia
G42/0290	16.1	100	1318011	4988269	Clutha / Mata-Au	Manuherikia
G46/0152	10	150	1321034	4986341	Clutha / Mata-Au	Manuherikia
E41/0182	10.1	25000	1235134	5023214	Clutha / Mata-Au	Upper Lakes
E41/0183	10.2	25000	1235510	5023479	Clutha / Mata-Au	Upper Lakes
E41/0184	10	25000	1235260	5023606	Clutha / Mata-Au	Upper Lakes
E41/0185	10	25000	1235380	5023306	Clutha / Mata-Au	Upper Lakes
F42/0113	4.4	75	1264431	4971121	Clutha / Mata-Au	Upper Lakes
G40/0367	17.1	150	1305561	5047533	Clutha / Mata-Au	Upper Lakes
G40/0415	30.07	250	1305860	5052754	Clutha / Mata-Au	Upper Lakes
G40/0416	30.5	200	1302748	5052499	Clutha / Mata-Au	Upper Lakes
H45/0314	11.28	125	1368244	4892910	Dunedin Coast	
J41/0008	20	1000	1434870	5000331	North Otago	
J41/0249	90	250	1430982	5000848	North Otago	
J41/0317	16.5	150	1448327	5020845	North Otago	
J41/0442	11.4	150	1435789	5022981	North Otago	
J41/0571	23.5	150	1446095	5014890	North Otago	
J41/0576	23	200	1447793	5017591	North Otago	

J41/0586	10.9	125	1444388	5022051	North Otago	
J41/0762	3.3	0	1425455	5007458	North Otago	
J41/0764	9.6	0	1425354	5004854	North Otago	
J41/0771	4.1	0	1429017	5001748	North Otago	
J42/0126	10.9	250	1434931	4994910	North Otago	
J43/0006	9.1	300	1421870	4962122	North Otago	
H42/0213	5.6	150	1366536	4993063	Taieri	
H42/0214	9	150	1369609	4987274	Taieri	
H43/0132	9.1	155	1375279	4957869	Taieri	
H44/0007	24.4	100	1378924	4912001	Taieri	
I44/0495	22.9	0	1392261	4918203	Taieri	
I44/0519	17.5	0	1392705	4919569	Taieri	
I44/0821	27.375	100	1396046	4919018	Taieri	
I44/0964	40.5	100	1392510	4916131	Taieri	
H46/0118	12	1400	1349089	4868050	The Catlins	

Appendix 2: SoE groundwater quality monitoring parameters and analytical methods

Parameter	Method	Limit of Detection
Total anions & cations for anion/cation balance	Sum of cations as mEquiv/L calculated from Sodium, Potassium, Calcium and Magnesium. Iron, Manganese, Aluminium, Zinc, Copper, Lithium, Total Ammoniacal-N and pH	0.07meq/L (anions) 0.05meq/L (cations)
pH	pH meter. Analysed at Hill Laboratories - Chemistry; 101c	0.1 pH units
Total Alkalinity	Titration to pH 4.5 (M-alkalinity), autotitrator. APHA 2320 B (modified for Alkalinity <20) 23rd ed. 2017.	1.0g/m^3 as CaCO3
Carbonate Alkalinity	Calculation: from alkalinity and pH, valid where TDS is not >500 from alkalinity and pH, valid where TDS is not >500 mg/L and alkalinity is almost entirely due to hydroxides, carbonates or bicarbonates. APHA 4500-CO2 D 23rd ed. 2017.	1.0g/m^3 as CaCO3
Bicarbonate Alkalinity	Calculation: from alkalinity and pH, valid where TDS is not >500 from alkalinity and pH, valid where TDS is not >500 mg/L and alkalinity is almost entirely due to hydroxides, carbonates or bicarbonates. APHA 4500-CO2 D 23rd ed. 2017.	1.0g/m^3 as CaCO3
Hydroxide Alkalinity	Calculation: from alkalinity and pH, valid where TDS is not >500 from alkalinity and pH, valid where TDS is not >500 mg/L and alkalinity is almost entirely due to hydroxides, carbonates or bicarbonates. APHA 4500-CO2 D 23rd ed. 2017.	1.0g/m^3 as CaCO3
Free Carbon Dioxide Calculation	Calculation: from alkalinity and pH, valid where TDS is not >500 from alkalinity and pH, valid where TDS is not >500 mg/L and alkalinity is almost entirely due to hydroxides, carbonates or bicarbonates. APHA 4500-CO2 D 23rd ed. 2017.	1.0g/m^3 at 25 °C
Total Hardness	Calculation from Calcium and Magnesium. APHA 2340 B 23rd 1-6	1.0g/m^3 as CaCO3
Electrical Conductivity (EC)	Conductivity meter, 25°C. APHA 2510 B	0.1mS/m
Approx. Total Dissolved Salts	Calculation: from Electrical Conductivity.	2g/m^3
Dissolved Arsenic	Filtered sample, ICP-MS, trace level. APHA 3125 B 23rd ed.	0.0010g/m^3
Dissolved Cadmium	Filtered sample, ICP-MS, trace level. APHA 3125 B 23rd ed. 2017	0.00005g/m^3
Dissolved Calcium	Filtered sample, ICP-MS, trace level. APHA 3125 B 23rd ed. 2017	0.05g/m^3

Dissolved Chromium	Filtered sample, ICP-MS, trace level. APHA 3125 B 23rd ed. 2017	0.0005g/m^3
Dissolved Iron	Filtered sample, ICP-MS, trace level. APHA 3125 B 23rd ed. 2017	0.02g/m^3
Dissolved Magnesium	Filtered sample, ICP-MS, trace level. APHA 3125 B 23rd ed. 2017	0.02g/m^3
Dissolved Manganese	Filtered sample, ICP-MS, trace level. APHA 3125 B 23rd ed. 2017	0.0005g/m^3
Dissolved Potassium	Filtered sample, ICP-MS, trace level. APHA 3125 B 23rd ed. 2017	0.05g/m^3
Dissolved Sodium	Filtered sample, ICP-MS, trace level. APHA 3125 B 23rd ed. 2017	0.02g/m^3
Chloride	Filtered sample. Ion Chromatography. APHA 4110 B (modified)	0.5g/m^3
Fluoride	Direct measurement, ion selective electrode. APHA 4500-F- C	0.05g/m^3
Total Nitrogen*	Alkaline persulphate digestion, automated Cd reduction/sulphanilamide colorimetry. APHA 4500-N C & 4500-NO3- I (modified) 23rd ed. 2017.	0.010g/m^3
Total Ammoniacal-N	Phenol/hypochlorite colorimetry. Flow injection analyser. (NH4-N = NH4+-N + NH3-N). APHA 4500-NH3 H 23rd ed. 2017.	0.005g/m^3
Nitrite-N Trace	Automated Azo dye colorimetry, Flow injection analyser. APHA 4500-NO3- I (modified) 23rd ed. 2017.	0.0010g/m^3
Nitrate-N	Calculation: (Nitrate-N + Nitrite-N) - NO2N. In-House. 0.0010 g/m3	0.0010g/m^3
Nitrate-N + Nitrite-N Trace	Total oxidised nitrogen. Automated cadmium reduction, flow injection analyser. APHA 4500-NO3- I (modified) 23rd ed. 2017.	0.0010g/m^3
Total Organic Nitrogen (TON), trace level	Calculation: TN - (NH4N + NO3N + NO2N)	0.012g/m^3
Dissolved Reactive Phosphorus (trace)	Filtered sample. Molybdenum blue colorimetry. Flow injection analyser. APHA 4500-P G 23rd ed. 2017.	0.0010g/m^3
Total Phosphorus	Total phosphorus digestion, ascorbic acid colorimetry. Discrete Analyser. APHA 4500-P B & E (modified from manual analysis and also modified to include a reductant to reduce interference from any arsenic present in the sample) 23rd ed. 2017. NWASCO, Water & soil Miscellaneous Publication No. 38, 1982	0.004g/m^3
Sulphate	Filtered sample. Ion Chromatography. APHA 4110 B (modified) 23rd ed. 2017.	0.5g/m^3
Escherichia coli	MPN count using Colilert (Incubated at 35°C for 24 hours), Colilert 18 (Incubated at 35°C for 18 hours), APHA 9223 B 23rd ed. 2017.	1 MPN/100mL

7.3. SoE Monitoring Bi-annual Update

Prepared for:	Data and Information Committee
Report No.	SPS2108
Activity:	Environmental: Water
Author:	Eike Breitbarth, Manager Environmental Monitoring
Endorsed by:	Gwyneth Elsum, General Manager Strategy, Policy and Science
Date:	1 March 2021

PURPOSE

[1] This paper informs council about the hydrological data capture and quality produced from the environmental monitoring network operated by the ORC Environmental Monitoring team.

EXECUTIVE SUMMARY

[2] This report summarizes the capture and data quality of State of the Environment (SoE) and project monitoring in Otago. The Environmental Monitoring (EM) team currently maintains a hydrological network of 273 sites, of which there are 169 SoE sites and 104 project sites. The monitoring network includes surface water hydrography, water temperature, rain fall, and ground water. Monitoring of the trophic lakes, water quality other than temperature, biodiversity, air quality, and climate are not included in the report.

[3] This paper and attached report inform council about the performance of hydrological network operated by the EM team. The report is not advising about environmental parameters such as river levels and flow or water quality and thus is not describing the state of the environment in Otago or is indicative of any environmental changes.

[4] For the period July 2020 to 1 December 2020, 98.3% of hydrological network data capture was archived. Data quality is categorized into quality code (QC) levels, as defined by the National Environment Monitoring Standards (NEMS). QC levels range from QC0 (missing data) to QC600 (highest standard). Quality code targets depend on the monitoring type, with SoE surface hydrology targeted at QC600, while groundwater and project sites are generally targeted at QC500. Of all SoE site data archived (including groundwater, rainfall, and water temperature), a total of 49% were of the highest quality standard (QC600), with 41% at QC500 level, while for project sites 40% were at QC600 and 49% at QC500, respectively. In summary, the report details that over the assessed 6-month period data capture and quality were of a high standard.

RECOMMENDATION

That the Committee:

1) ***Receives** this report.*

BACKGROUND

[5] Environmental monitoring is a fundamental building block of the ORC and forms the basis for environmental analysis, planning, and decision making. Data produced are of crucial importance to a wide range of stakeholders involving sectors such as irrigation, farming, source water protection for drinking water, and public health. River level and flow measurements, as well as rain sensor data are further elemental to flood prediction and flood monitoring. These data are used by the ORC Natural Hazards team and Civil Defence.

[6] Continuous data are publicly available through the ORC's Water Info website (https://www.orc.govt.nz/managing-our-environment/water/water-monitoring-and-alerts) and is easily accessed through an interactive map. The webpage also displays any alerts (e.g., low flow or flooding) and informs about rating changes and site maintenance. A further flood alert is available through region-specific Twitter alerts. Water quality (including contact recreation) and air quality data are publicly available through the LAWA website (https://www.lawa.org.nz/explore-data/otago-region/). Reports of historic data are frequently produced by the EM data team on request.

[7] The monitoring network and its maintenance operate 365 days/year and relies strongly on continuous on-line field measurements, that are telemetered back to the office. This is complemented by manual in-field validation measurements for e.g., water flow, rainfall, and water quality. Further, a wide range of parameters such as water temperature or also level in some groundwater bores are downloaded from deployed sensors during field visits and verified during additional manual measurements. The technical maintenance of the field infrastructure and telemetry network is carried out by EM staff.

[8] The monitoring network is differentiated into standard SoE sites and project sites. Project sites are installed based on requests from other teams (primarily the Science team) and are designed for temporary investigations. However, these sites frequently become a permanent part of the network.

[9] Quality coding of the data depends on the installation type (instrumentation) and is verified by the EM data team constantly. Quality coding standards are set by the National Environment Monitoring Standards (NEMS, http://www.nems.org.nz/) and are observed NZ wide. Quality codes are QC600 and QC500, which both describe a high level of accuracy and differ operationally. Further codes are QC400 (poor), QC300 (synthetic), QC200 (raw data), and QC0 (missing data). Until telemetered data are verified by the EM data team, all data are coded as QC200 (raw data).

DISCUSSION

[10] The report refers to the period of July - December 2020, covering data capture and quality analysis for surface water hydrography, rainfall, groundwater, and water temperature. Please see attachment for data plots.

[11] Surface Water Hydrography:

A key component of surface SoE reporting are data on river level and flow, which are produced from telemetered sites continuously measuring the water level in the rivers. Data capture was 98.5% for SoE sites and 98.6% for project sites. The quality control target for SoE surface water measurements is QC500 or better, depending on site and installation type. Of the QC500 sites, 97% of the captured data was at QC500 level. Of the OC600 sites, 66% of the captured data was at target level, while 27% were at OC500 level.

[12] Rainfall:
For the SoE rainfall sites targeted at QC600, 82% of the captured data were coded to OC600. Of the QC500 sites, only 55% achieved the set data quality target, while 35% of the captured data remains unverified (QC200) and 10% of the data are missing. These are largely from alpine sites that are inaccessible during winter and are subjected to snow fall.

[13] Groundwater:
The groundwater sites deliver 99.7% data capture, of which 81% comply with the set target of QC500 and 18% are classed as QC400 (poor). The manually measured and project sites reach 96.5% and 98.8% data capture, respectively. There, 95% correspond to the QC500 standard and only 4% are archived as QC400.

[14] Water quality:
Water temperature data capture was 99.4% for telemetered SoE sites, and 98.8% for manually downloaded field deployed temperature loggers. 79% of the SoE temperature data where at QC600 level and 15% at OC500. A 96.6% capture was achieved for project sites. Here data verification returned 89% at satisfactory levels of QC500 or higher.

[15] General trend in data quality:
Data capture and quality produced of the ORC environmental monitoring network are of a high standard overall. Comparing the 2020-2021 quarter 1 vs quarter 3, a slight downward shift by 6% in the proportion of SoE hydrological surface water site QC600 and QC500 data quality was observed though. Data quality at QC600 was decreasing from 56% to 50% and QC500 data were increasing from 34 to 40% of the total capture, respectively. While the ratio is variable to some extend due to disruptive events such as COVID and new junior staff hiring that require training, a general trend was observed since 2016 with the proportion of the SoE surface water QC600 data decreasing from 66% to 50% and the QC500 proportion increasing from 27% – 40%.

[16] It should be noted, that QC500 is a high level of data quality. However, for surface water level, the reduction from QC600 to QC500 is defined as data “do not meet operational standards/best practice at the time of acquisition, and/or undergone minor modifications” (NEMS, http://www.nems.org.nz/assets/Documents/NEMS-14/Water-Level-v3.0.pdf) and the measurement resolution drops from +/-3mm to +/-10mm.

[17] This change is noteworthy, as it can be indicative of need for reviewing operational processes, the network structure, technologies used, and resourcing. A SoE monitoring network review is planned in order to accommodate increasing monitoring demands by the recently revised National Policy Statement – Freshwater Management (NPS-FM) and the aforementioned revisions tie into that.

CONSIDERATIONS

Policy Considerations

[18] The SoE network monitoring included in this report includes sites used for the development of the new Land and Water Plan.

Financial Considerations

[19] nil

Significance and Engagement

[20] The EM team is an essential service provider to ORC internal and external stakeholders, as well as to the public in general, and to Civil Defence. Data produced are of direct importance for guidance and decision making for public health and safety, environmental and cultural values, and the Otago economy.

[21] The information in this paper does not trigger ORC's Significance and Engagement Policy.

Legislative Considerations

[22] nil

Risk Considerations

[23] Data reported to the highest quality standard is essential for economic and environmental decision making. Highly accurate river level and flow data are crucial for irrigation take allocations. These data are frequently scrutinized and challenged by different stakeholders and thus a decrease in data quality may negatively affect the credibility of the ORC. Flood monitoring and modelling/prediction strongly depend on uninterrupted accurate data flow. Compromises in data quality and data capture can have adverse effects on Civil Defence decisions.

NEXT STEPS

[24] The ORC SoE monitoring network will be reviewed in order to implement the upcoming monitoring requirements of the recently revised National Policy Statement – Freshwater Management (NPS-FM). Structure and management of the network will be reviewed for technology and future proofing, internal operation processes, and resourcing, with the goal to achieve a continuously high level of service.

[25] An update of data capture and data quality of State of the Environment and project hydrological monitoring will be provided at the next Data & Information Committee meeting.

ATTACHMENTS

1. SoE Monitoring Bi-annual update - graphs [**7.3.1** - 15 pages]

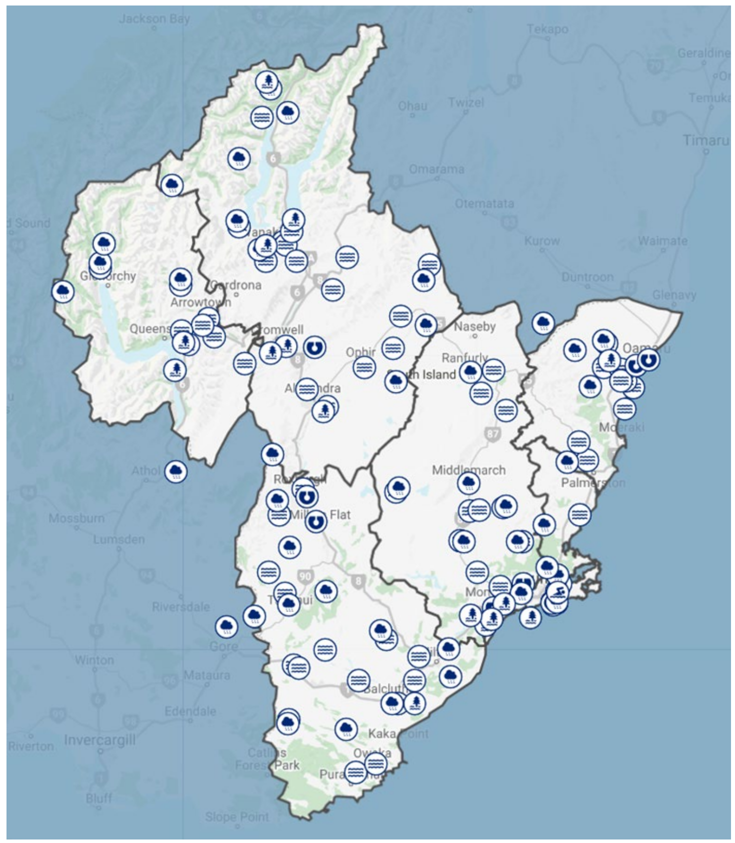
Data capture - ORC environmental monitoring network

(July 2020 – December 2020)

98.29 % Hydrological network data capture achieved (SOE and Project Data)

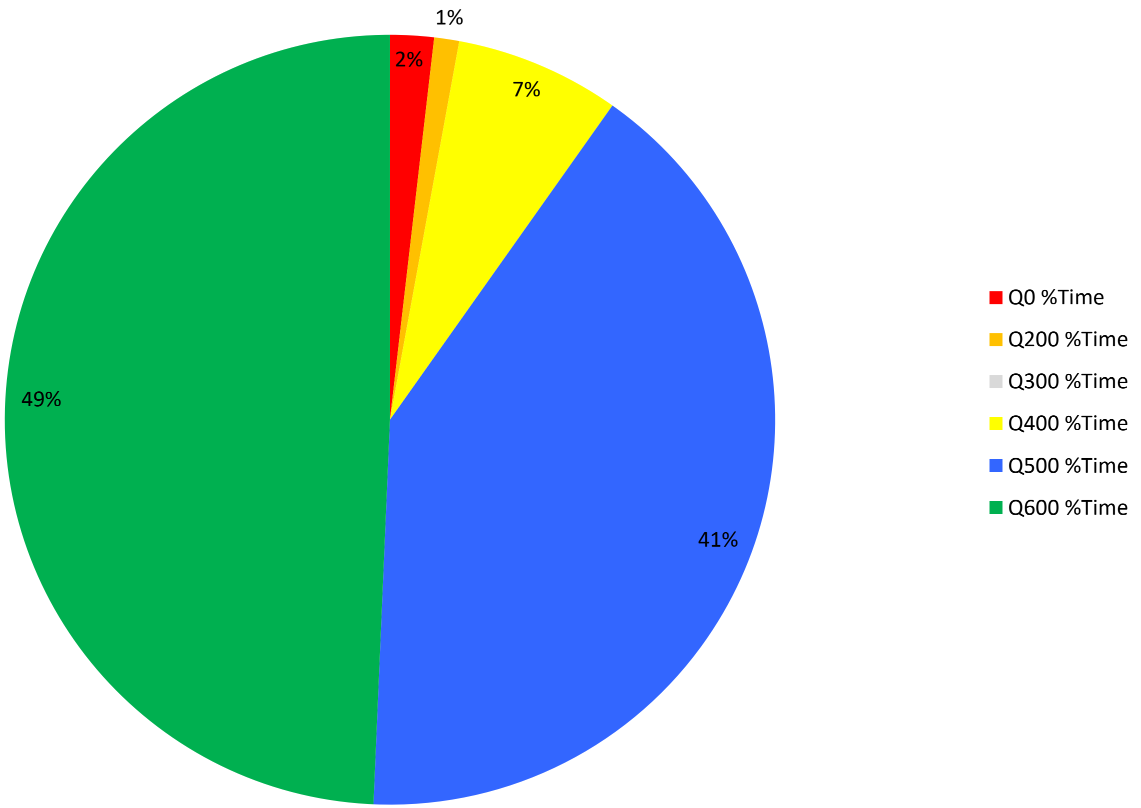
	No. of Sites	% record missing
Surface Water		
SOE Telemetered	77	1.53
Project	40	1.44
Groundwater		
SOE Telemetered	23	0.30
SOE Manual	6	3.50
Project	16	1.23
Rainfall		
SOE Telemetered	32	1.64
Water Temperature		
SOE Telemetered	7	0.61
SOE Manual	24	1.16
Project	48	3.33
Total	273	1.71

Sate of the Environment (SoE) – data



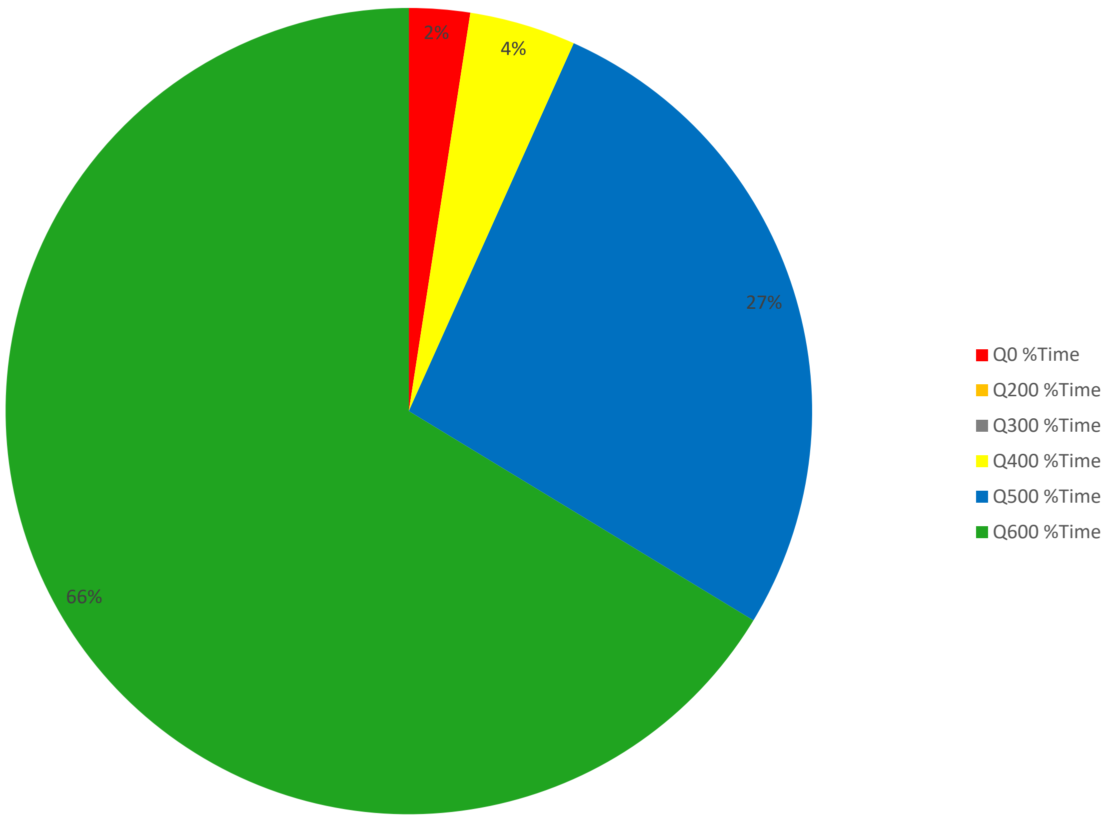
[ORC SOE network]

QC for all SOE Data Sources



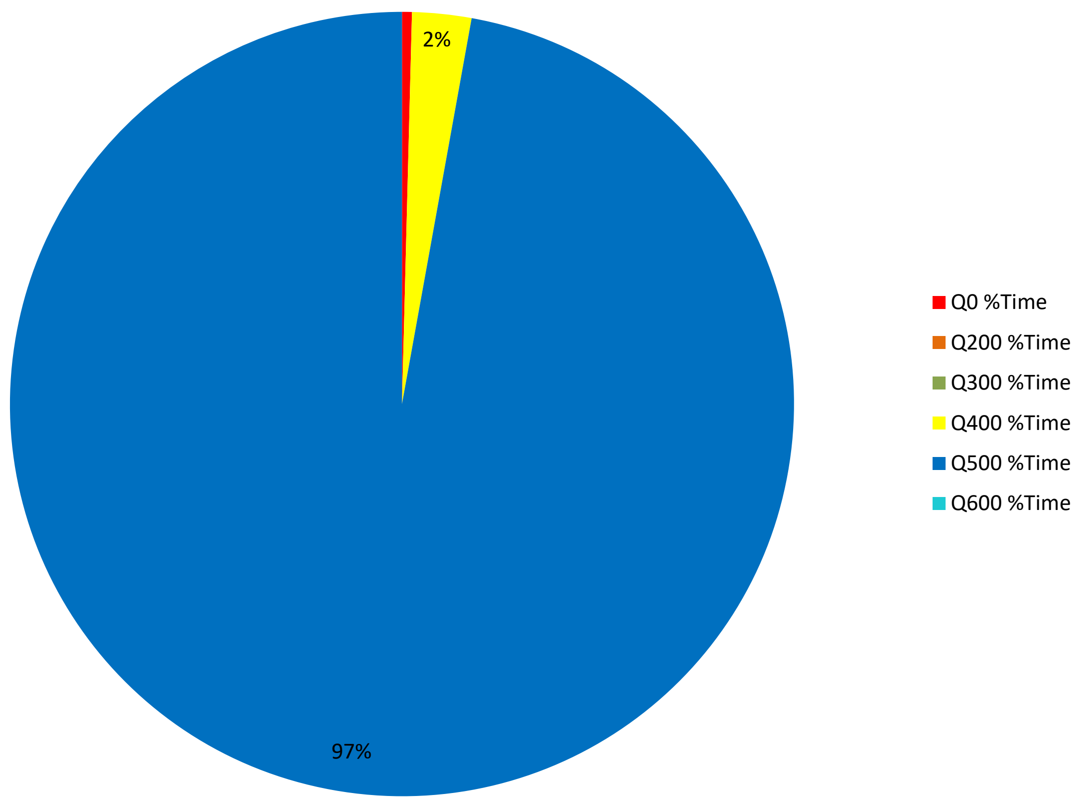
3

SOE Water Level QC – Max QC600

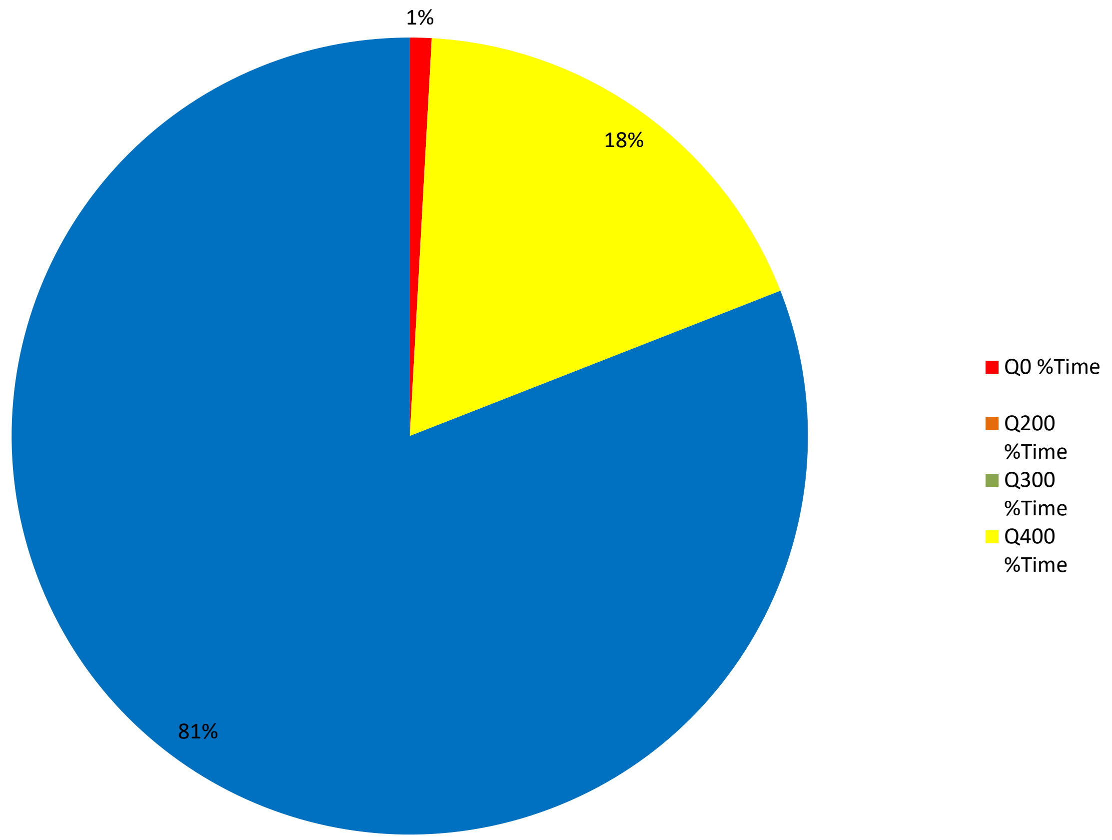


4

SOE Water Level QC – Max QC500

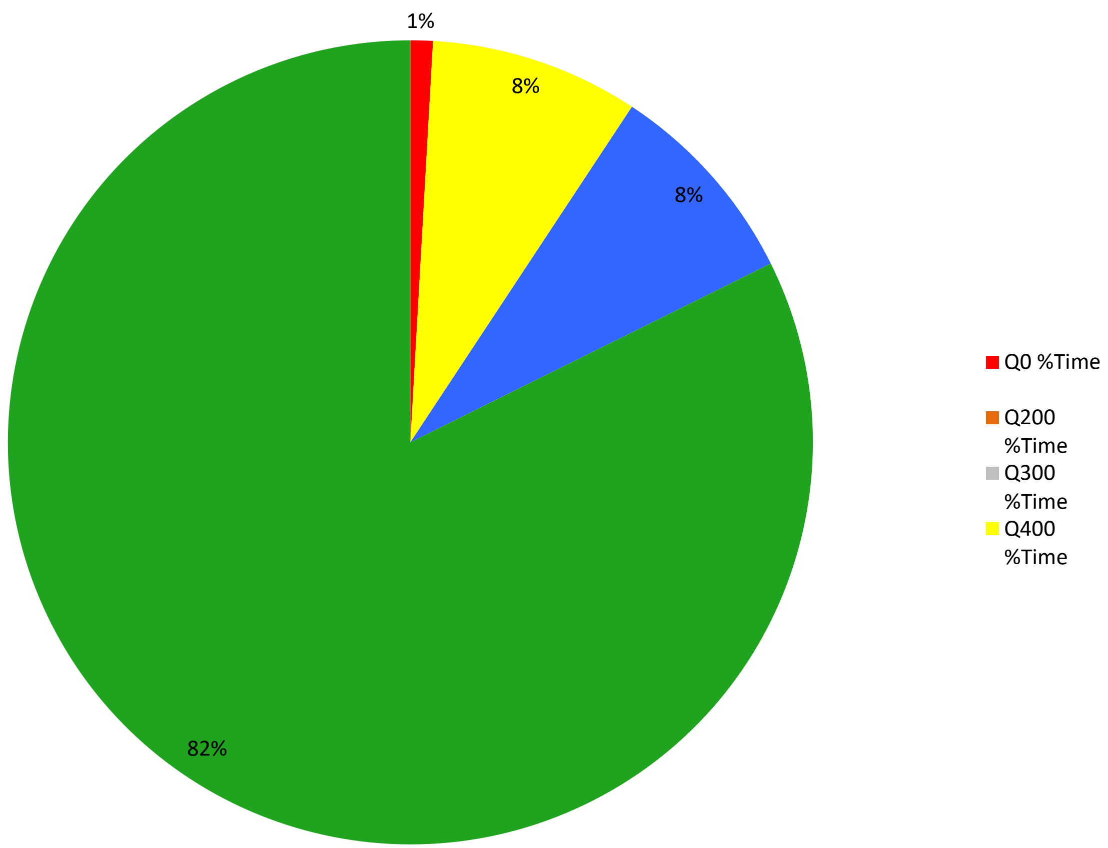


SOE Groundwater QC



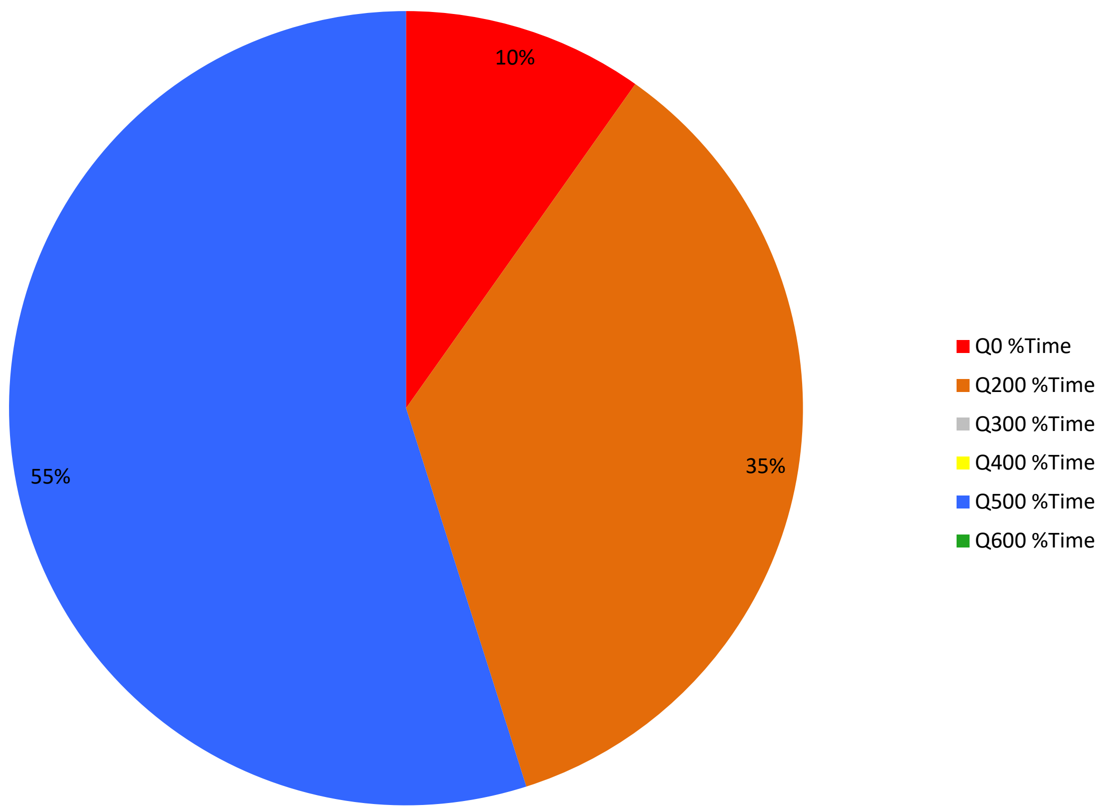
6

SOE Rainfall QC – Max QC600



7

SOE Rainfall QC – Max QC500



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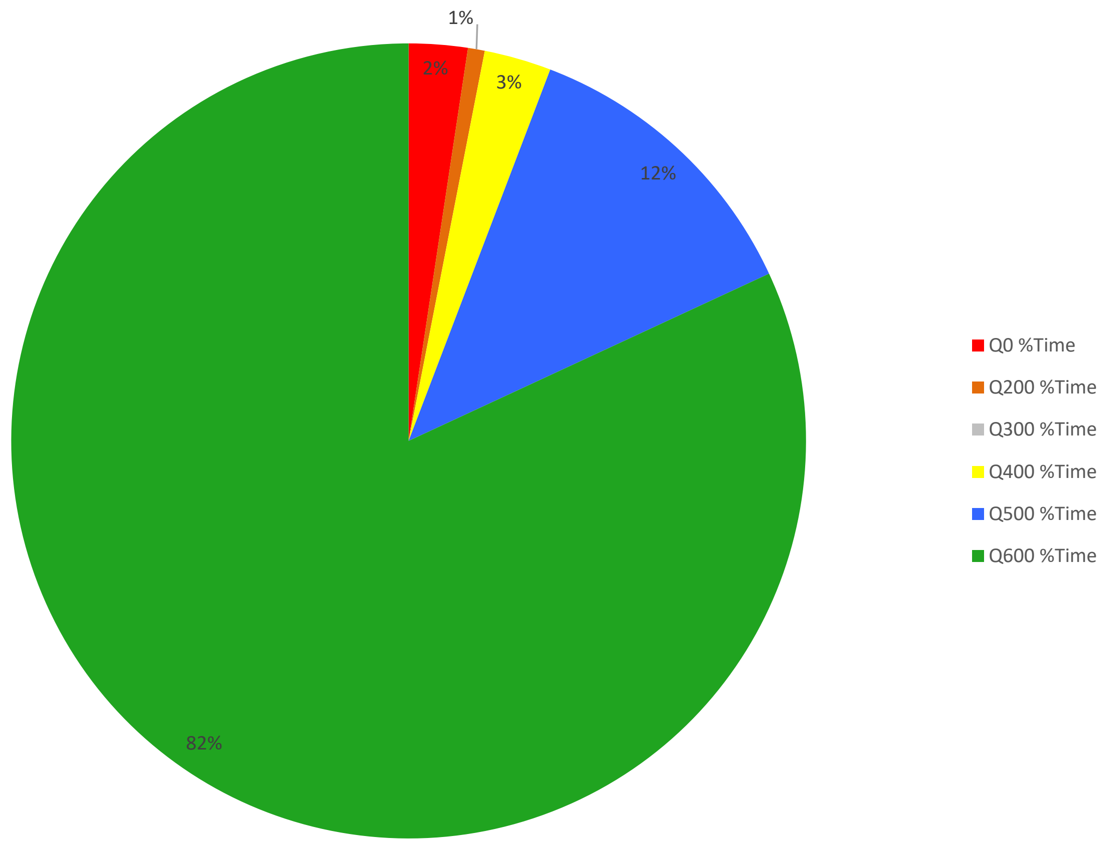
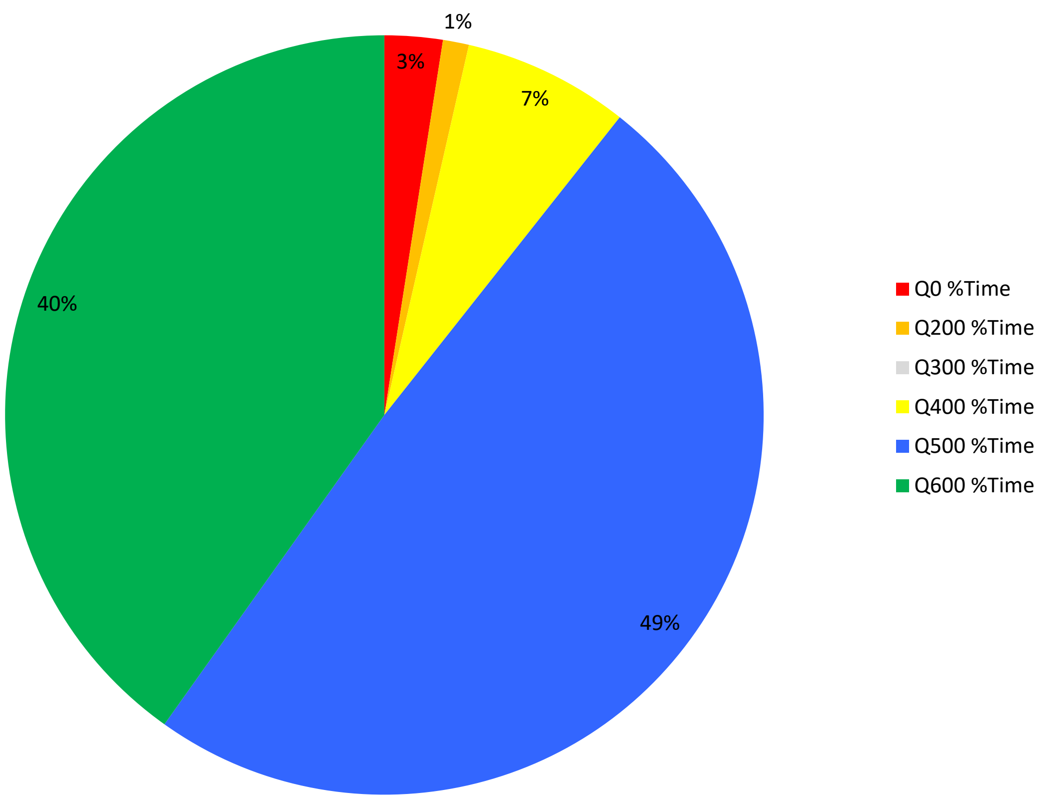
SOE Water Temperature QC



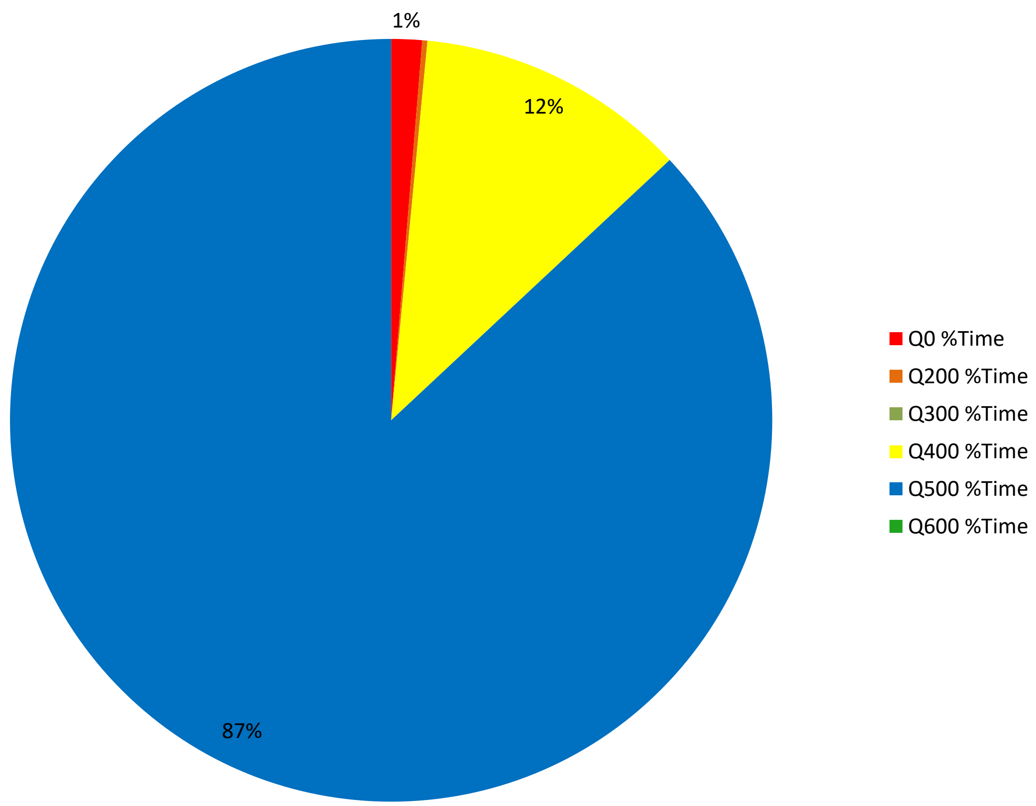
9

Project site data

QC for all Project Data Sources

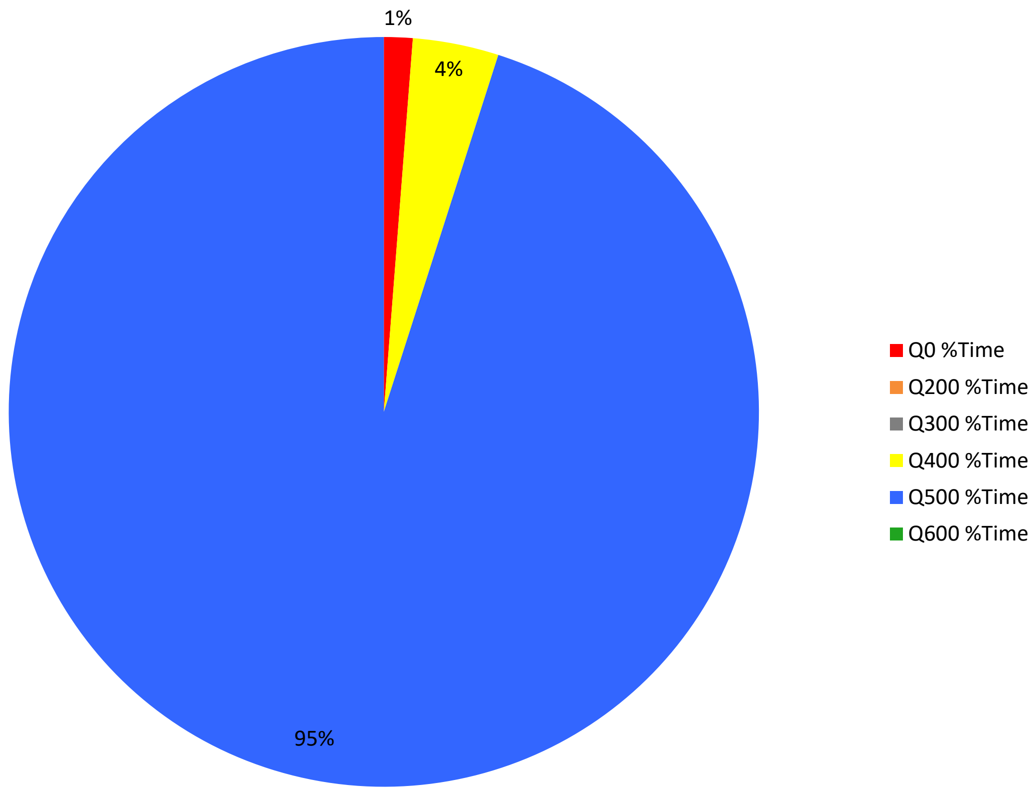


Project Water Level QC



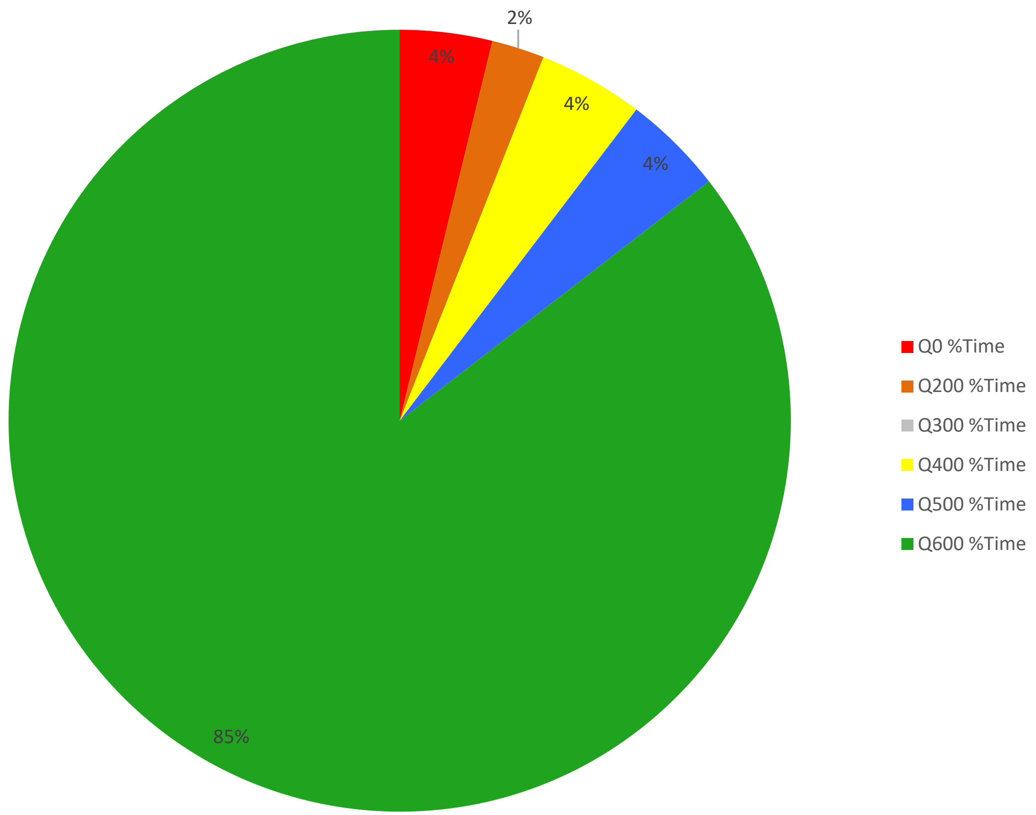
12

Project Groundwater QC



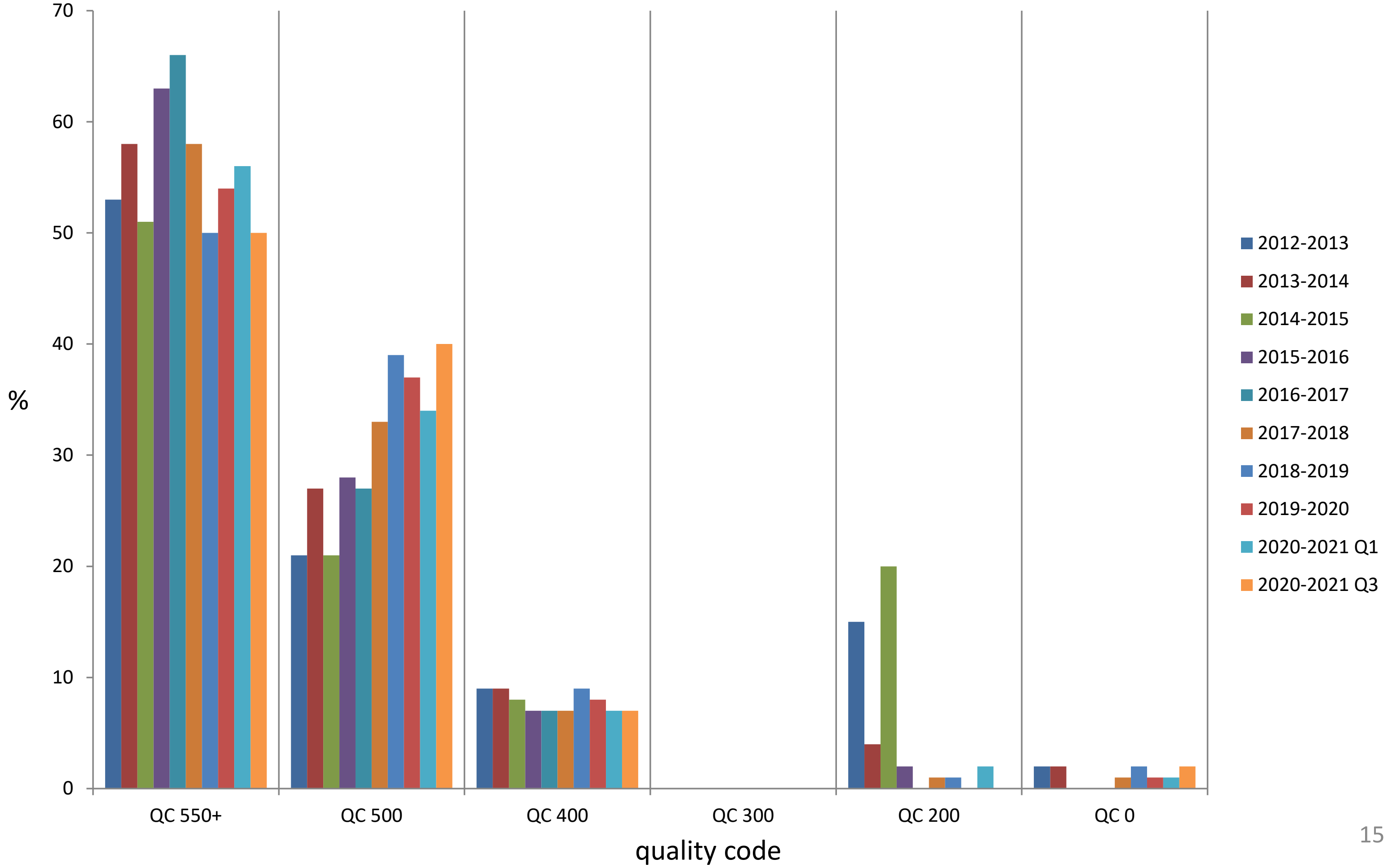
13

Project Water Temperature QC



14

Overall Comparison 2012-2021



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Data and Information Committee 2021.03.10

7.4. Annual Air Quality Report 2020

Prepared for:	Data and Information Committee
Report No.	SPS2107
Activity:	Governance Report
Author:	Sarah Harrison, Air Quality Scientist
Endorsed by:	Gwyneth Elsum, General Manager Strategy, Policy and Science
Date:	10 March 2021

PURPOSE

[1] This annual report discusses the results of State of the Environment monitoring for air quality for the year 2020. Also included are a summary of Arrowtown PM_{10} spatial and temporal trends, an outline of the monitoring projects required to inform the future Regional Air Plan review, and an analysis of Otago's air quality data during the 2020 COVID-19 lockdown.

EXECUTIVE SUMMARY

[2] Otago has several towns – Alexandra, Arrowtown, Clyde, Cromwell and Milton, where air quality is considered degraded during winter. Under the Resource Management Act (RMA, 1991) and the National Environmental Standards for Air Quality (NESAQ, 2004, revised 2011) regional councils are required to monitor and improve air quality where necessary. The main pollutant of concern in Otago is particulate matter, a product of combustion, and in some Otago towns in excess of 90% of PM_{10} (particulate matter with a diameter of less than 10 microns) is produced by home heating emissions from solid fuel burners in winter (Environet, 2019). Long term exposure to PM_{10} and $PM_{2.5}$ (particulate matter with a diameter of less than 2.5 microns), contribute to the risks of developing, and exacerbating existing cardiovascular and respiratory conditions, which makes fine particulates a serious threat to human health (WHO, 2006).

[3] Otago Regional Council (ORC) has a State of the Environment (SOE) monitoring network to monitor PM_{10} and report exceedances of the NESAQ (50 $\mu g/m^3$, 24-hour average). This network is currently being upgraded to include monitoring $PM_{2.5}$, in preparation for the NESAQ update incorporating limits for $PM_{2.5}$.

[4] During winter 2020 the NESAQ for PM_{10} was exceeded 80 times across six of the seven monitored towns in Otago. In the past, ORC has implemented a work programme (Air Quality Strategy (2018) to help Otago residents meet the Regional Air Plan rules in order to improve air quality in targeted towns. Analysis of long-term trends have shown that overall concentrations are decreasing in some airsheds, including Arrowtown, but significant decreases in emissions are still required to meet the NESAQ for PM_{10}.

[5] ORC air quality programmes include a Regional Air Plan review and the NESAQ update. These programmes are proposed for LTP planning years one to five.

RECOMMENDATION

That the Council:

1) ***Receives*** *this report*

STATE OF THE ENVIRONMENT

[6] Otago has a network of seven air quality monitoring stations in the following locations: Alexandra, Arrowtown, Clyde, Cromwell, Central Dunedin, Milton and Mosgiel. All these sites monitor PM_{10}, and Central Dunedin also monitors $PM_{2.5}$. The $PM_{2.5}$ data will be analysed and presented in the next annual report.

[7] Under the RMA regional councils are required to monitor air quality and work towards meeting the standards of the NESAQ. The NESAQ is currently under review to include $PM_{2.5}$ standards, which are based on the current World Health Organisation recommended guidelines. The relevant standards and guidelines are given below (table 1).

[8] Table 1. Standards and guidelines for PM_{10} and $PM_{2.5}$.

Pollutant	Averaging Time	NESAQ Standard		NESAQ Guideline		WHO Guideline	
		Value (µg/m³)	Allowable exceedances	Value (µg/m³)	Allowable exceedances	Value (µg/m³)	Allowable exceedances
PM_{10}	24-hour	50	1 per year			50	NA
	Annual			20	NA	20	NA
$PM_{2.5}$	24-hour					25	3
	Annual					10	NA

[9] A summary of the key SOE monitoring indicators for 2020 are given below (Table 2).

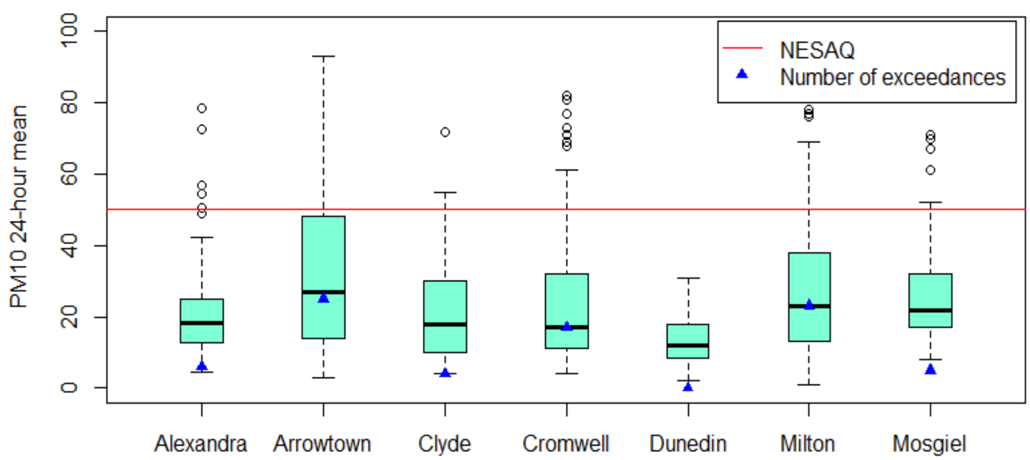
[10] Table 2. Key PM_{10} indicators for 2020 for Otago towns.

Site	Maximum daily concentration (µg/m³)	Winter Mean (µg/m³)	Average highest 10 days (µg/m³)	Number of exceedances (n)
Alexandra	79	21	54.2	6
Arrowtown	93	33	82.5	25
Clyde	72	23	51.4	4
Cromwell	82	29	72.0	17
Dunedin	40	13	29.3	0
Milton	96	32	74.8	23
Mosgiel	71	25	55.5	5

[11] With the exception of the Dunedin site, all sites exceeded the NESAQ limit for PM_{10} at least four times during 2020. Arrowtown and Milton had the highest number of exceedances, with 25 and 23 respectively, and both sites had the highest maximum concentrations with 93 µg/m³ and 96 µg/m³ respectively (table 1).

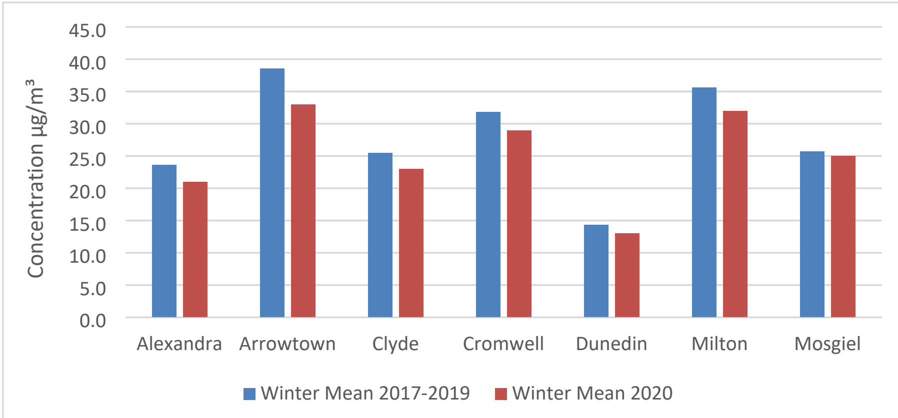
[12] Figure 1 below shows the wintertime (May-August inclusive) 24-hour average values of PM_{10} and the number of exceedances for each site. The exceedances of the NESAQ are shown to be mostly outliers at Alexandra, Clyde and Mosgiel (Figure 1).

[13] Figure 1. Winter PM_{10} daily concentrations and number of exceedances comparison. The box shows the median (horizontal bar) and interquartile range; whiskers are 1.5 times the interquartile range and more extreme (outlier) values are presented outside the whiskers. The NESAQ limit (red line) for PM_{10} is 50 µg/m³ (24-hour average).

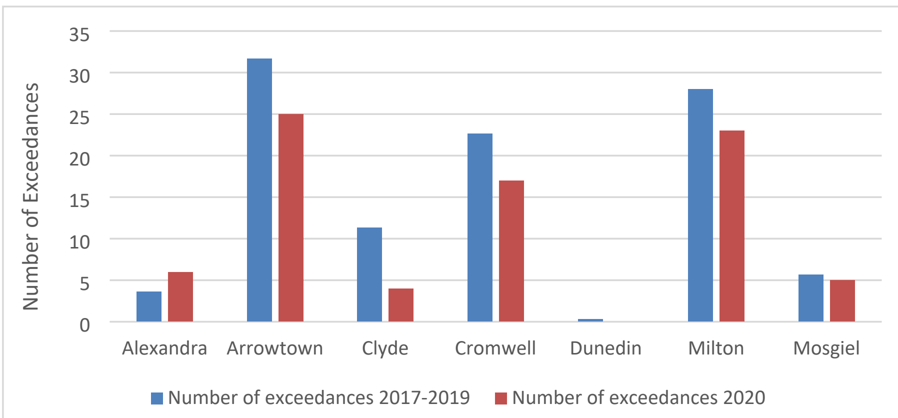


[14] When comparing data to previous years, the winter mean is a more appropriate indicator, as exceedances only occur in winter. Figures 2 and 3 below show how 2020 compares with the average of the previous three years. At all monitored sites, the mean winter concentrations have shown improvement. The least improvement has occurred in Dunedin and Mosgiel. For most sites the number of exceedances has shown improvement, except for Alexandra, which had six exceedances in 2020 compared to previous three year's average of four (Figure 3). Winter 2020 was one of the warmest on record, driven by warmer sea temperatures due to La Nina, and the prevalence of high pressures and north-easterlies causing sunny and warm conditions (NIWA, 2020).

[15] Figure 2. Mean winter PM_{10} concentrations comparison for Otago towns.



[16] Figure 3. Average annual number of PM_{10} exceedances (2017-2019) compared to exceedances in 2020 for Otago towns.

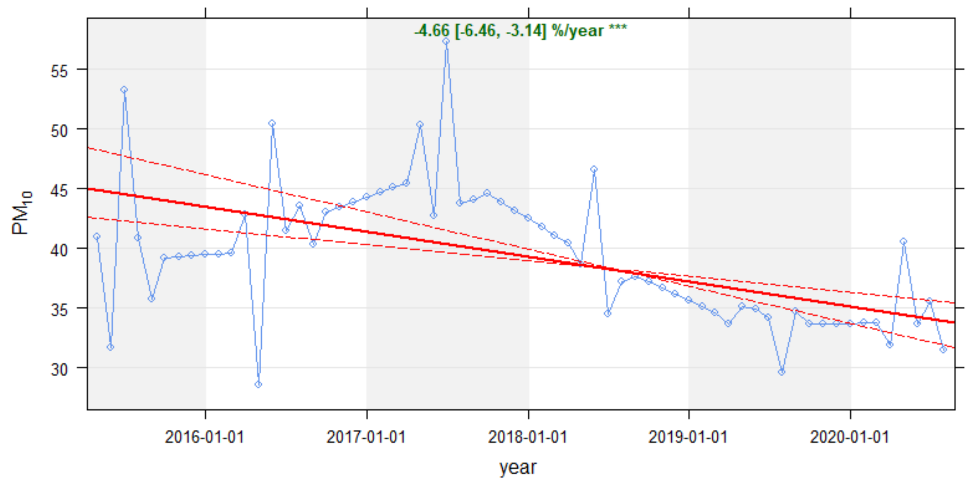


ARROWTOWN SPATIAL AND TEMPORAL TRENDS

[17] Arrowtown was the focus of a combined community engagement project undertaken by ORC, NIWA, Southern DHB and Cosy Homes Trust in 2019. The community response (feedback from Arrowtown Village Association, and the frequency of subsidy uptake in Arrowtown) to this work have shown that non-regulatory methods, such as education, help expand community understanding and enthusiasm for improving air quality (ORC 2020a).

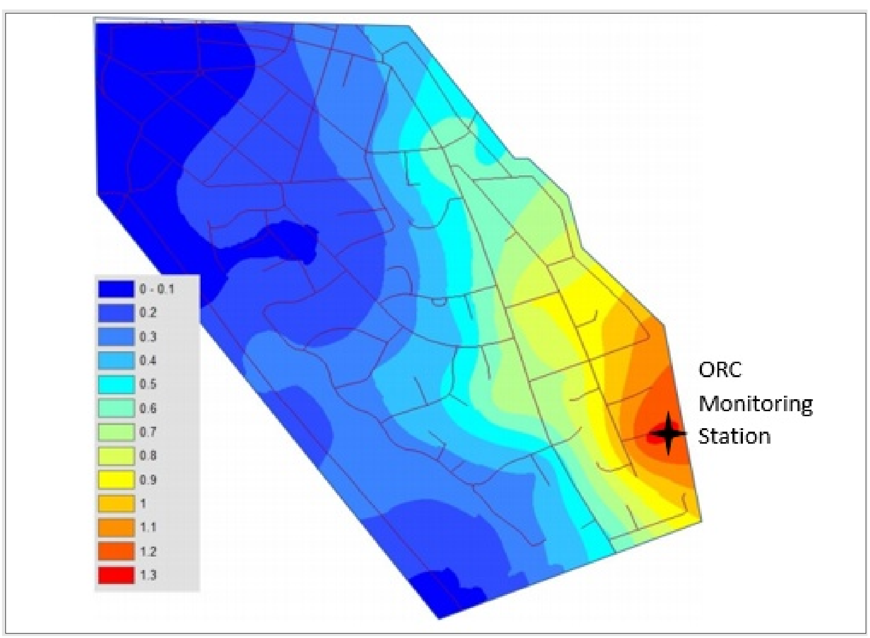
[18] Analysis of long-term trends have found that winter PM_{10} concentrations have decreased by 4% per year in Arrowtown between 2006 and 2014 (ORC, 2016), or 36% for the total period. In contrast winter-time emissions are estimated to have halved between 2006 and 2016, due to the replacement of older wood and coal burners to cleaner-burning or no-emission home heating (Wilton, 2016). This non-linear relationship between emissions and concentrations could be caused by a number of effects, however spatial variability, meteorological and topographical influences are some of the most likely. More recent analysis shows that the trend for winter concentrations is still decreasing by 4.7% per year (Figure 4), which equates to a 28% overall decrease between 2015 and 2020.

[19] Figure 4: Trend analysis for Arrowtown PM_{10} 2015 – 2020 (P<0.001). The blue line shows the de-seasonalised monthly averages, and the solid red line shows the trend, with dashed lines the 95% confidence of the slope.



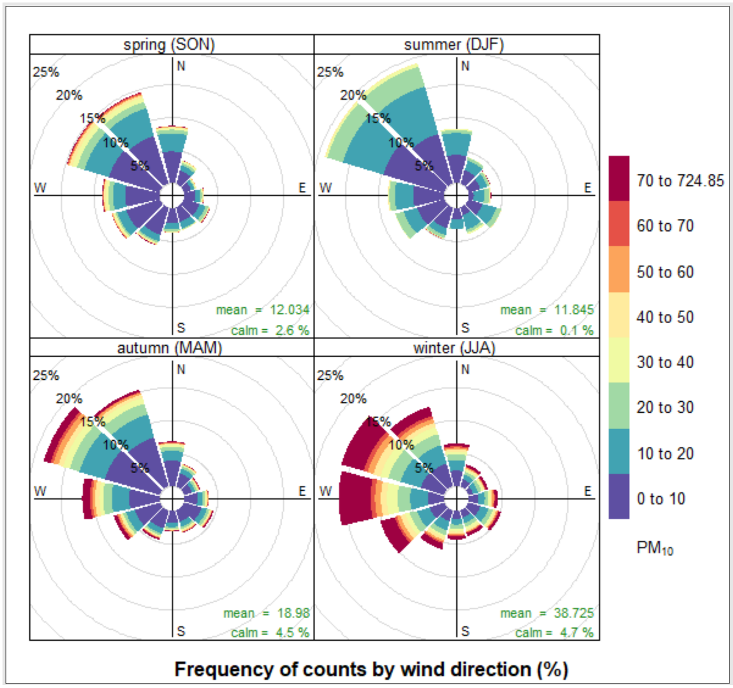
[20] Research conducted by NIWA in 2019, utilising a network of up to 47 low-cost sensors, concluded that $PM_{2.5}$ concentrations vary greatly across Arrowtown (Longley, 2020). NIWA indicate that these spatial differences are caused by the flow of smoke towards the eastern side of town, with the possibility of higher emissions from residences on the eastern side also contributing to the imbalance (Longley, 2020).

[21] Figure 5: Spatial variation in Arrowtown showing ratio of average $PM_{2.5}$ levels relative to the reference site, the ORC monitoring station. Source: Longley, 2020.



[22] Pollution roses for the ORC Arrowtown site indicate that the predominant wind directions are from the west to the northwest in all seasons. In winter the largest proportion of the highest PM_{10} concentrations come from the southwest to the north-west (Figure 6).

[23] Figure 6: Pollution roses by season for Arrowtown



[24] This work has helped increase awareness of air quality issues in Arrowtown and contributed to the continual replacement of inefficient wood burners. However, a large emissions reduction is required to improve air quality. The current target required for Arrowtown to meet the NESAQ for PM_{10} is 50 kg/day (ORC, 2017), and the latest emissions inventory estimated that the winter's daily average is 94 kg/day (Wilton, 2016). These targets will be reassessed with the onset of $PM_{2.5}$ monitoring and the new NESAQ limit.

[25] The 2016 emissions inventory also estimated that the number of burners non-compliant with Air Plan rules in Arrowtown to be around 260; the degree to which emissions would improve upon replacement of these burners depends on what they are replaced with, and user burn technique if replaced with ultra-low emission burners.

AIR PLAN REVIEW

[26] The Otago Regional Air Plan sets out the rules and policies for the different airsheds in Otago and is due to be updated in the near future. The proposed Long Term Plan will allow the investigation of the following, in order to obtain current air quality information for Otago's airsheds. The details of each issue are expanded upon below.

- Airshed categories

- Airshed boundaries
- Other pollutants

[27] The current NESAQ requires that all airsheds with the potential to exceed any of the standards must be monitored. Otago has 22 airsheds, and currently seven of these are monitored, with plans in place to expand to two new airsheds in Queenstown and Wanaka (Table 3). The 22 airsheds have been split into categories of Gazetted airshed (Gazette notice number 2005-go8236) and management areas named Air Zones, which are used in the Air Plan. This system of grouping airsheds together is unique to Otago, due to having more airsheds than other regions. Each group is represented by one permanently monitored site, except airshed 4, Queenstown, Wanaka, Hawea and Kingston. These sites were deemed unlikely to exceed the NESAQ at the time of gazetting. As there have been many changes to the urban areas in Otago since 2009, it would be beneficial to check that the airshed groups, and Air Zone groups are still relevant, and that the monitoring sites still represent the other airsheds in their groups. This would be undertaken using temporary monitoring of all airsheds that have neither recently or ever been monitored.

[28] Table 3: Current airsheds in Otago grouped by airshed and Air Zone number

Airshed Name	Airshed Number	Air Zone Number	Most recent year of monitoring
Alexandra	1	1	Current
Arrowtown*			Current
Clyde			Current
Cromwell			Current
Naseby		2	2007
Ranfurly			2008
Roxburgh			2007
Palmerston	2		2014
Mosgiel*			Current
South Dunedin			2009
Green Island			2002
Milton			Current
Balclutha	3		2018
North Dunedin			2007
Central Dunedin*			Current
Oamaru			2009
Port Chalmers			NA
Waikouaiti			NA
Hawea	4		NA
Kingston			NA
Queenstown			To be installed
Wanaka			To be installed
Middlemarch[†]	5	3	NA
Lawrence[†]			2012

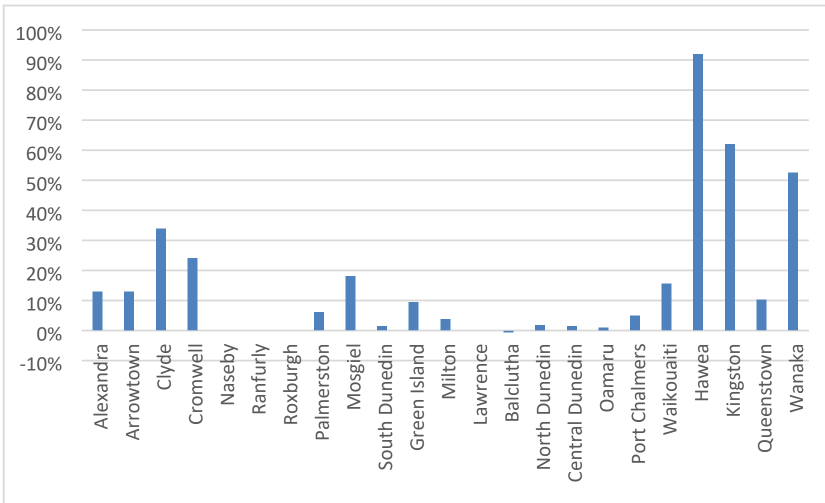
<Rest of Otago>			-
Total to be investigated in future			15

* Representative airshed site

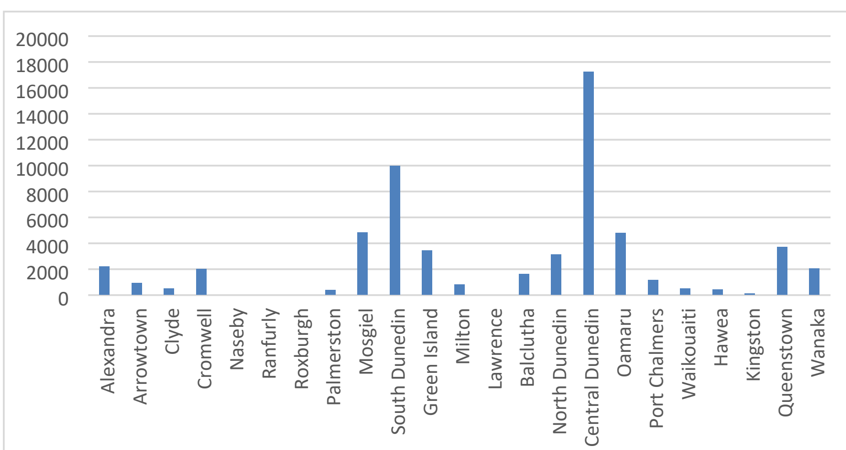
† Lawrence is due to become Airshed 2, Middlemarch is to be investigated.

[29] Some parts of Otago have been experiencing significant population growth and increased housing density. Figure 7 shows the percentage increase in households has changed significantly between 2006 and 2018. Hawea, Kingston and Wanaka have experienced the highest percentage of dwelling number increases within existing airshed boundaries (Figure 8).

[30] Figure 7: Number of household percentage change 2006-2018 within existing airshed boundaries



[31] Figure 8: Number of households in each airshed 2018



[32] Queenstown and Wanaka have experienced the most growth outside of their airshed boundaries with 46% and 69% respectively (Stats NZ, 2020). This is because they each have satellite suburbs growing outside of the central business districts, which didn't

exist when the airsheds were Gazetted. There are high winter concentrations of $PM_{2.5}$ in Albert Town, just outside of Wanaka (ORC 2020b). Any changes to airshed boundaries will be influenced by urban growth and district land use projections.

[33] There are five ambient air quality standards that regional councils are required to meet for the protection of human health, under the NESAQ. These are PM_{10}, nitrogen dioxide (NO_2), sulphur dioxide (SO_2), carbon monoxide (CO) and ozone (O_3). Prior to the current Air Plan release, CO, NO_2 and SO_2 were monitored in various places in Otago; and were found unlikely to exceed any NESAQ standards. It is recommended that this work is repeated to establish up-to-date concentrations, and has been proposed for the next LTP.

[34] There are two other pollutants of interest in Otago – black carbon and benzo[a]pyrene. Both are products of combustion and strongly associated with wood burning. Black carbon is considered a significant climate change pollutant, which contributes to global and localised warming (Davy and Trompetter, 2018). Benzo[a]pyrene is a carcinogen that is often present in high levels where PM_{10} concentrations are high (Environet, 2003). Short term studies, for detecting these pollutants, would be beneficial in Otago.

COVID-19 AIR QUALITY DATASETS

[35] The Covid-19 lockdown in early 2020 provided an opportunity to examine the effect of reduced vehicular and industrial activity on air quality. Analysis was conducted on the 2020 data compared to historical data (2016-2019) for the four continuous monitoring sites – Alexandra, Arrowtown, Dunedin and Mosgiel.

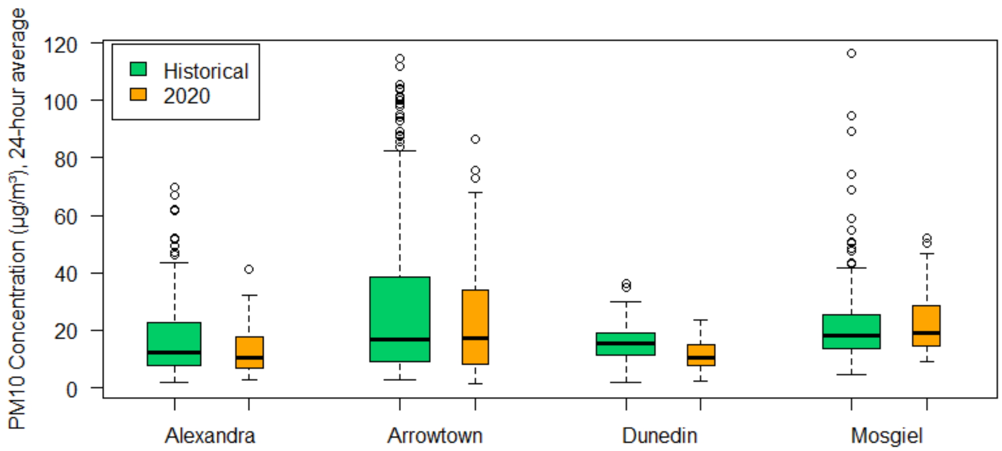
[36] Historical data used was “business as usual” data for a similar time of year, to allow for the seasonal impacts of meteorology on PM_{10} concentrations. Alert Level 4 corresponded with March and April, and Alert Levels 3 and 2 corresponded with April, May and June.

[37] When comparing the entire period of restrictions (27th March, start of Alert Level 4 to 7th June, end of Alert Level 2) with historical data both Alexandra and Dunedin show significantly lower PM_{10} concentrations (Table 4 and Figure 9).

[38] Table 4. Historical daily PM_{10} means compared to 2020 COVID-19 Alert Level data.

Site	Historical			2020			Difference		
	Mean	Std. dev	Data capture	Mean	Std. dev	Data capture	Concentration (µg/m³)	Concentration (%)	Significance to 95% confidence interval
Alexandra	16.2	11.7	77%	13.0	7.8	100%	-3.2	-20%	Significant
Arrowtown	26.8	24.2	95%	24.4	19.9	88%	-2.4	-9%	Not significant
Dunedin	14.6	6.0	89%	11.5	5.2	92%	-3.1	-21%	Significant
Mosgiel	21.5	11.9	82%	21.7	10.0	100%	0.3	1%	Not significant

[39] Figure 9. Historical daily PM_{10} compared to 2020 COVID-19 Alert Level data



[40] Further data analysis shows that Alexandra and Dunedin PM_{10} concentrations were lower during Alert Level 4 by 25% and 47% respectively, Alexandra PM_{10} was lower during Alert Levels 2 and 3 by 27%, and in contrast, Mosgiel PM_{10} was 27% higher during Alert Levels 2 and 3, than the same period for the previous years.

[41] International and New Zealand research has found that in most cases lockdowns have resulted in decreases of vehicle related emissions such as NO_2 and black carbon, with smaller reductions in particulate matter (Patel et al., 2019). The estimated contribution of vehicle emissions to PM_{10} was 42% in Alexandra in autumn (Wilton, 2017), so it is likely the reductions measured were due to the reduced amount of traffic and human activities. However, the traffic related emissions in Mosgiel (33% contribution to PM_{10} in autumn, Wilton, 2017) either didn't decrease or were compensated for by something else, with either natural or anthropogenic sources as possibilities.

[42] There were no significant changes in Arrowtown, however Level 4 restrictions took place prior to the beginning of wood-burning season. Arrowtown data suggests that there was not an increased amount of burning for home heating during any of the Alert Levels.

CONSIDERATIONS

[43] There are no considerations for the following:
- Policy
- Financial
- Significance and Engagement
- Legislative
- Risk

NEXT STEPS

[44] The next steps are:
- The monitoring network will continue upgrades and expansion during 2021.
- The proposed LTP includes programmes to inform the ORC Regional Air Plan review.

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APPENDIX

Exceedance Table 2020

Date	Site						
	Alexandra	Arrowtown	Clyde	Cromwell	Dunedin	Milton	Mosgiel
	PM_{10} µg/m³ (24-hour average)						
16-May			55	58			
17-May		52				52	
18-May						57	
19-May				58		57	
20-May		73		68		54	
21-May						69	
24-May						56	
29-May		54					
30-May		68				52	
31-May		76				59	
1-Jun		87				76	
2-Jun		55				95	
3-Jun						69	52
11-Jun						62	
13-Jun		76		69			
14-Jun		80		73		78	
15-Jun						77	
16-Jun	79		72			96	
19-Jun				61		61	
20-Jun		88		57			
21-Jun		69					
22-Jun		52					
23-Jun		57				51	70
24-Jun		87					67
27-Jun						63	
2-Jul				81			
3-Jul		57		71			
4-Jul	51			81			
5-Jul							61
10-Jul		82		77			
11-Jul		56		51			
13-Jul		55		55			
15-Jul		51					
16-Jul		56					
17-Jul		68				60	
18-Jul		93				54	
19-Jul		85				54	
20-Jul						64	71
27-Jul		59		82			
28-Jul		58		54		53	
1-Aug	55						
2-Aug	72						
3-Aug				55			
6-Aug	54						
16-Aug			54				
17-Aug			54				
18-Aug	57			52			
Total	**6**	**25**	**4**	**17**	**0**	**23**	**5**

ATTACHMENTS

Nil

7.5. Emissions Inventory and Low Emissions Technology Review

Prepared for:	Data and Information Committee
Report No.	SPS2110
Activity:	Governance Report
Author:	Sarah Harrison, Air Quality Scientist
Endorsed by:	Gwyneth Elsum, General Manager Strategy, Policy and Science
Date:	10 March 2021

PURPOSE

[1] As part of the 2019 and 2020 Annual Plans, Otago Regional Council contracted two pieces of work to investigate emissions:

a. Emissions Inventory 2019
b. Low Emissions Technology Review 2020

[2] Emissions inventories provide an estimate on the quantities and sources of pollutants in Otago's airsheds. They provide information regarding the main activities causing air pollution, and how these differ between airsheds, which allows ORC to consider how these activities can be improved to benefit air quality using regulatory and non-regulatory methods.

[3] The main pollutant of concern in Otago is particulate matter, of which the main source is home heating appliances in winter. Technology for home heating, particularly for solid-fuel burners is constantly evolving, driven by the need to reduce emissions. The review of this technology, including the identification of knowledge gaps is a starting point for potential future investigation of real-life emissions, and being able to factor the emission reductions into future emission inventories.

[4] This report summarises these two projects which are included as appendices.

RECOMMENDATION

That the Committee:

1) ***Receives*** *this report.*

EMISSIONS INVENTORY 2019

[5] An emissions inventory provides an estimate of the amount of emissions discharged into the air. This is useful to provide insight into the sources and quantities of pollutants emitted, and the populations of appliances from which emissions are released. In 2019 an emissions inventory was undertaken for the Otago towns of Clyde, Cromwell and Wanaka for anthropogenic emission sources such as domestic home heating, vehicles, outdoor burning and commercial/industrial activities. The method for collecting the data for home heating was an anonymous phone survey (sample error <5%).

[6] Domestic heating is the main source of particulate matter emissions in winter, comprising 97% of daily winter PM_{10} emissions in Wanaka (93% annually), 94% in Cromwell (88 annually) and 95% in Clyde (89% annually). Table 1 below shows the survey results for home heating methods.

[7] Table 1. Home heating methods 2019 (some households have more than one method)

Town	Number of households	Sample size	Electricity (%)	Solid-fuel Burners (%)	Gas (%)	Oil (%)
Clyde[1]	2679	370	72	59	12	8
Cromwell			72	59	12	8
Wanaka	3675	354	65	72	10	3

[1] Cromwell and Clyde were surveyed together to achieve a large enough sample size for Clyde

[8] Electricity is a more common heating method in Cromwell and Clyde than Wanaka. Conversely, solid-fuel burners (SFB) are present in 59% of Cromwell and Clyde households, and 72% of Wanaka households.

[9] The solid-fuel burners produce the following PM_{10} emissions per winter's day:

- 310 kg in Wanaka
- 150 kg in Cromwell
- 38 kg in Clyde

[10] Table 2 displays the different proportions of SFB types present in Wanaka, Cromwell and Clyde houses, with their respective contribution to the total SFB PM_{10} emissions.

[11] Table 2. Type of solid-fuel burners and PM_{10} emissions contributions

Town	**Number of SFB**		**Pre-2006 wood burner (%)***	**Post-2006 wood burner (%)**	**Multi-fuel (%)**	**Pellet burners (%)**	**Open fire (%)**
Clyde	327	Heating method	8	48	2	1	1
		PM_{10} emissions	25	70	5	0	2
Cromwell	1294	Heating method	8	58	2	1	1
		PM_{10} emissions	25	69	5	0	2
Wanaka	2658	Heating method	21	44	1.2	1	5
		PM_{10} emissions	47	44	2	0	7

*2006 is the year the NESAQ-imposed limits on wood burners (emission rate <1.5 g/kg) came into effect.

[12] This shows that pre-2006 wood burners are responsible for the second largest amount of emissions in Clyde and Cromwell, with 8% of burners contributing 25% of PM10 emissions. In both Clyde and Cromwell, the majority of emissions comes from the most common home heating method, that is the post-2006 wood burner. In Wanaka, there is a much higher proportion of pre-2006 burners, which accounts for 47% emissions. Table 3 shows other PM_{10} emission sources relative to home heating.

[13] Table 3. Relative annual contributions to PM_{10} emissions from all sources

Town	Home heating (%)	Vehicles (%)	Industry (%)	Outdoor Burning (%)
Clyde	89	2	0	9
Cromwell	88	2	1	9
Wanaka	93	3	1	3

[14] The majority of annual PM_{10} emissions in these three towns comes from home heating (88-93%), with the next most significant source in Clyde and Cromwell being outdoor burning (9%).

[15] The main findings of this report highlight the significance of home heating emissions in these three Otago towns. Home heating emissions differ depending on appliance type, and in the case of all three towns, older burners contribute a disproportionately large amount to the total particulate matter emissions.

LOW EMISSIONS TECHNOLOGY REVIEW 2020

[16] Emission inventories have identified domestic heating as the main source of particulate matter emissions in Otago airsheds. Solid-fuel burners (SFB) are one of the main methods used for heating in Otago, often used alongside electric methods such as heat pumps. Due to heating security in colder climates, lower costs, convenience and ambience, SFB remains a popular choice in the South Island, despite the higher emissions and associated negative health impacts.

[17] Consequently, one of the main intervention methods has been to focus on technology improvements for home heating appliances. During the 2000's, Environment Canterbury developed testing criteria and regulations for ultra-low emission burners (ULEB), which expanded the market for lower emission options. There are now many different types of ULEB that utilise different burning technologies.

[18] In 2020 ORC commissioned Environet Ltd to investigate current models, their viability for Otago towns, cost comparisons, and current knowledge gaps in the field of ultra-low emission technology. A summary of the findings is listed below.

a. ULEB wood burners available are now much more comparable to traditional burners in terms of installation cost (some models starting at $2700, excluding flue/installation). Running costs depend on efficiency of the ULEB (criteria for ULEB is they must have at least 65%), and the user burn technique.
b. Model variation includes down-draught, catalytic converters, heat storage and release, and a significant amount that use traditional technology and rely on user technique.
c. Authorised secondary technology exists for scrubbing emissions post combustion (Oekotube), at a current cost of $2800.
d. ULEB provide suitable heat output for Otago towns, some solutions are more cost effective than others, but the range of options is sufficient, and should continue to grow.

e. Uptake of ULEB in Otago has the potential to significantly improve air quality in urban areas.
f. Main knowledge gaps are the real-life emissions of different types of ULEB, upon which depends the scale of improvement Otago towns would see upon further uptake of ULEB technology.

CONSIDERATIONS

[19] There are no considerations for the following:
Policy
Financial
Significance and Engagement
Legislative
Risk

ATTACHMENTS

1. Otago Emissions Inventory 2019 [**7.5.1** - 64 pages]
2. Low Emissions Technology Review 2020 [**7.5.2** - 20 pages]

OCTOBER 2019

PREPARED FOR
Otago Regional Council

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ENVIRONET AIR QUALITY SPECIALISTS

Wanaka, Cromwell and Clyde Air Emission Inventory - 2019

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EXECUTIVE SUMMARY

The main air quality concern for urban towns in the Otago Region is concentrations of particles in the air less than 10 microns and less than 2.5 microns in diameter (PM_{10} and $PM_{2.5}$). An emission inventory was carried out in 2019 to estimate the amount of emissions of PM_{10} and $PM_{2.5}$ and other contaminants discharged to air in the towns of Wanaka, Cromwell and Clyde. These were the first emission inventory assessments to be carried out in these towns.

Sources included in the inventory were domestic heating, motor vehicles, industrial and commercial activities and outdoor burning. These are the main anthropogenic sources of air contaminants in urban areas of New Zealand. Natural source contributions (for example; sea salt and soil) are not included because the methodology to estimate emissions is less robust.

The inventory focuses on estimating emissions of suspended particles (PM_{10}) and the $PM_{2.5}$ subcomponent of PM_{10}, as well as carbon monoxide, nitrogen oxides, sulphur oxides, volatile organic compounds and carbon dioxide.

A domestic home heating survey was undertaken to determine the proportions of households using different heating methods and fuels. In Wanaka electricity and wood burning were found to be the most common methods of heating the main living area with 66 and 65% of households using these sources of heating. Open fires were used by 5% of households in Wanaka. In Cromwell and Clyde 72% of households used electricity and 56% used wood burners in their main living area. Many householders use more than one method to heat the main living area of their home.

Domestic heating was the main source of winter PM_{10} and $PM_{2.5}$ emissions in all three areas accounting for between 95% and 98% of the daily winter PM_{10} and $PM_{2.5}$ emissions. Other sources included outdoor burning (4% of daily winter PM_{10}) with motor vehicles and industry having relatively minor contributions. On an average winter's night, around 310, 150 and 38 kilograms of PM_{10} are discharged in Wanaka, Cromwell and Clyde respectively. The $PM_{2.5}$ emission estimates were 36, 22 and 5 tonnes per year in Wanaka, Cromwell and Clyde.

A comparison of daily PM_{10} emissions during the winter to a 2013 estimate suggests no real change in emissions in Wanaka and Cromwell and a slight decrease in emissions in Clyde.

1 INTRODUCTION

Emission inventories assess the amount of emissions from different sources and are used for air quality management purposes and to evaluate changes in emission sources with time. The sources that are included in emissions inventories in New Zealand are generally domestic home heating, transport, industrial and commercial activities, ports and shipping, aviation and outdoor burning.

In New Zealand the main air contaminant monitored in urban areas is PM_{10} as 24-hour average concentrations can exceed the National Environmental Standard (NES) in many locations in New Zealand. In 2015, a review of air quality by the Parliamentary Commissioner for the Environment highlighted issues with the current NES focus on PM_{10} suggesting investigation into the adoption of $PM_{2.5}$ as the key indicator with priority given to an annual average standard rather than a 24 hour average standard to capture the significant chronic impacts of particulate exposure. The refocus on $PM_{2.5}$ and annual average exposure is consistent with a recent WHO report (World Health Organization, 2013) which indicates that annual average $PM_{2.5}$ is the strongest indicator of health impacts.

The Otago Regional Council has gazetted three Air Zones for the management of air quality and in particular concentrations of PM_{10} in the Region. These are:

- Air Zone 1: Alexandra, Arrowtown, Clyde and Cromwell.
- Air Zone 2: Balclutha, Dunedin, Hawea, Kingston, Milton, Mosgiel, Naseby, Oamaru, Palmerston, Port Chalmers, Queenstown, Ranfurly, Roxburgh, Waikouaiti and Wanaka.
- Air Zone 3: The rest of Otago.

This report primarily focuses on emissions of particles (PM_{10} and $PM_{2.5}$) from domestic heating, motor vehicles, industrial and commercial activities and outdoor burning in Wanaka, Cromwell and Clyde. Other contaminants included in this emission inventory are carbon monoxide, nitrogen oxides, sulphur oxides, volatile organic compounds, carbon dioxide and benzo(a)pyrene.

Monitoring for PM_{10} has routinely been carried out in Cromwell and Clyde. In these areas, the 24-hour average concentrations of PM_{10} can exceed the 50 $\mu g/m^3$ (National Environmental Standard limit value) during the winter months. In Cromwell maximum daily PM_{10} concentrations higher than 100 $\mu g/m^3$ occur most years. In Clyde the highest 24-hour average PM_{10} concentrations are typically in the 60-70 $\mu g/m^3$ range.

Historical monitoring of PM_{10} in Wanaka suggested the town was compliant with the NES for PM_{10}. The Otago Regional Council will commence monitoring in Wanaka during 2020.

No previous air emission inventories have been carried out for Wanaka, Cromwell or Clyde.

2 INVENTORY DESIGN

This emission inventory focuses on PM_{10} and $PM_{2.5}$ emissions as the main contaminants of concern in urban New Zealand. It is unlikely that concentrations of other contaminants would exceed National Environmental Standards (NES).

2.1 Selection of sources

Estimates of emissions from the domestic heating, motor vehicles, industry and outdoor burning sector are included in the emissions inventory. The report also discusses particulate emissions from a number of other minor sources.

2.2 Selection of contaminants

The inventory included an assessment of emissions of suspended particles (PM_{10}), fine particles ($PM_{2.5}$) carbon monoxide (CO), sulphur oxides (SOx), nitrogen oxides (NOx), volatile organic compounds (VOC) and carbon dioxide (CO_2)

Emissions of PM_{10}, CO, SOx and NOx are included because of their potential for adverse health impacts and the existence of National Environmental Standards for each of them. $PM_{2.5}$ has been included in the inventory because this size fraction has significance in terms of the proposed annual average NES for $PM_{2.5}$. Carbon dioxide has been typically included in emission inventory investigations in New Zealand to allow for the assessment of regional greenhouse gas CO_2 emissions. However, these data are now generally collected nationally and for a broader range of greenhouse gases. Estimates of CO_2 have been retained in the inventory but readers should be directed to national statistics (e.g., www.climatechange.govt.nz.) should detailed data on this source be required. Volatile organic compounds (VOCs) are typically included in emission inventory investigations because of their potential contribution to the formation of photochemical pollution. In this report, VOC emissions have been estimated for sources already included in the inventory but data on emissions from VOC specific sources (e.g., spray painting, vegetation) has not been included. It is likely that the inventory does not capture a number of sources of VOCs.

2.3 Selection of areas

The inventory study areas for each town are the census area units for Wanaka, Cromwell and Clyde and are illustrated in Figures 2.1 to 2.3. These differ to the gazetted airsheds for Wanaka and Clyde. In Wanaka the inventory area includes Albert Town and extends further to the east relative to the airshed. In Clyde the airshed includes a small number of dwellings on the west side of the Clutha River which are not included in the Clyde inventory area. The Cromwell inventory area and airshed cover the same area.

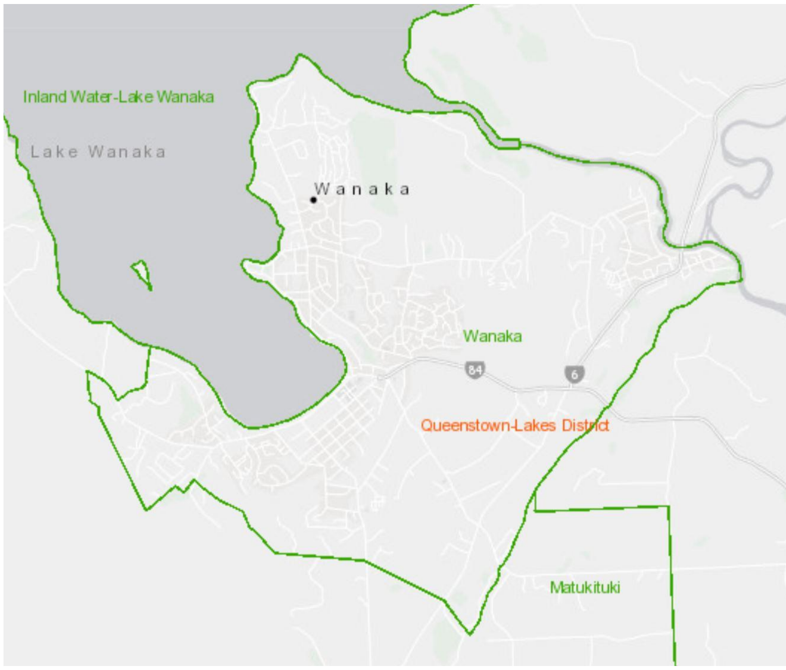

Figure 2.1: Wanaka inventory area (source StatsMaps, 2019).

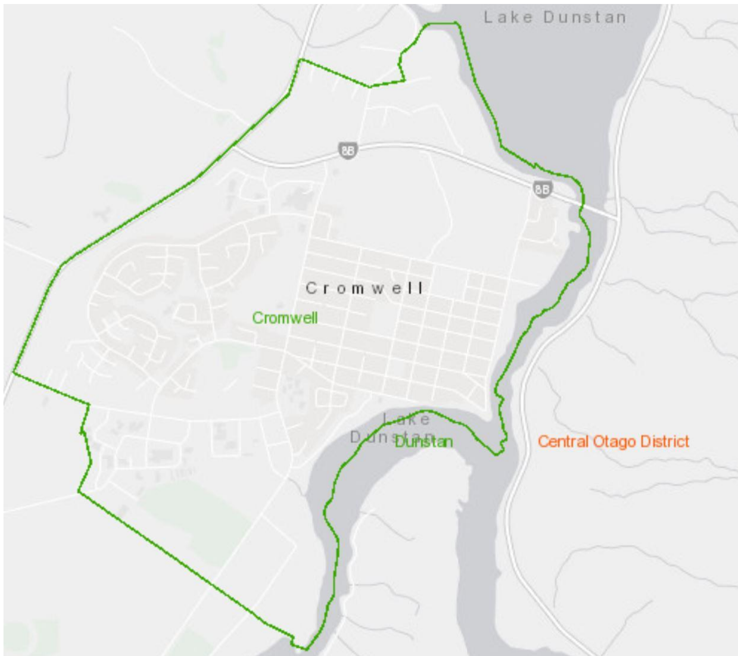

Figure 2.2: Cromwell inventory area (source StatsMaps, 2019).

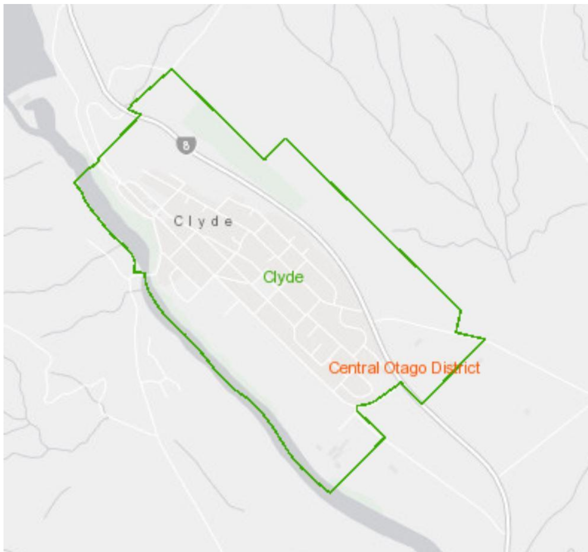

Figure 2.3: Clyde inventory area (source StatsMaps, 2019).

2.4 Temporal distribution

Data were collected based on daily data with some seasonal variations. Domestic heating data were collected based on average and worst-case wintertime scenarios and by month of the year. Motor vehicle data were collected for an average day as models do not contain seasonal variations in vehicle movements. Industrial data were collected by season as was outdoor burning data.

No differentiation was made for weekday and weekend sources.

3 DOMESTIC HEATING

3.1 Methodology

Information on domestic heating methods and fuel used by households in Wanaka, Cromwell and Clyde was collected using a household survey carried out by Versus during winter 2019 (Appendix A). A combined approach was used to gather information which included both a telephone survey and an online survey. Table 3.1 shows the number of households for 2019 based on 2018 census data for occupied private dwellings (Statistics NZ, 2019). The dwelling number is based on typically occupied dwellings which will differ from the total number of dwellings particularly in areas such as Wanaka where holiday homes are prevalent. Cromwell and Clyde were surveyed together because of sample size issues.

Table 3.1: Summary household, area and survey data.

	Dwellings in Airshed	Sample size	Area (ha)	Sample error
Wanaka	3675	354	2861	<5%
Cromwell/Clyde	2679	370	761 & 322	<5%

Home heating methods were classified as; electricity, open fires, wood burners, pellet fires, multi fuel burners, gas burners and oil burners. Emission factors were applied to these data to provide an estimate of emissions for each study area. The emission factors used to estimate emissions from domestic heating are shown in Table 3.2. The basis for these is detailed in Appendix B.

Table 3.2: Emission factors for domestic heating methods.

	PM_{10} g/kg	$PM_{2.5}$ g/kg	CO g/kg	NOx g/kg	SO_2 g/kg	VOC g/kg	CO_2 g/kg	BaP g/kg
Open fire - wood	7.5	7.5	55	1.2	0.2	30	1600	0.002
Open fire - coal	21	18	70	4	8	15	2600	2.70E-06
Pre 2006 burners	10	10	140	0.5	0.2	33	1600	0.003
Post 2006 burners	4.5	4.5	45	0.5	0.2	20	1600	0.003
Pellet burners	2	2	20	0.5	0.2	20	1600	0.003
Multi-fuel[1] - wood	10	10	140	0.5	0.2	20	1600	0.002
Multi-fuel[1] – coal	19	17	110	1.6	8	15	2600	2.70E-06
Oil	0.3	0.22	0.6	2.2	3.8	0.25	3200	
Gas	0.03	0.03	0.18	1.3	7.56E-09		2500	

[1] - includes potbelly, incinerator, coal range and any enclosed burner that is used to burn coal

The average weight for a log of wood is one of the assumptions required for this inventory to convert householder's estimates of fuel use in logs per evening to a mass measurement required for estimating emissions. This was converted into average daily fuel consumption based on an average log weight of 1.6 kg per piece of wood and integrating seasonal and weekly usage rates. The value of 1.6 kg/log was selected as the mid-point of the range found from different New Zealand evaluations (Wilton & Bluett, 2012, Wilton, Smith, Dey, & Webley, 2006, Metcalfe, Sridhar, & Wickham, 2013). The log weight recommended for this work (1.6 kg/ piece) is the midpoint and average of the range of values.

Emissions for each contaminant and for each time period and season were calculated based on the following equation:

Equation 3.1 CE (g/day) = EF (g/kg) * FB (kg/day)

Where:

CE = contaminant emission

EF = emission factor

FB = fuel burnt

The main assumptions underlying the emissions calculations are as follows:

- The average weight of a log of wood is 1.6 kilograms.

3.2 Home heating methods in Wanaka

The most popular forms of heating the main living area of homes in Wanaka are electricity and woodburners with around 65% of households using electricity and 66% using woodburners. Open fires and gas are used by 5% and 13% of households respectively. Table 3.3 also shows that households rely on more than one method of heating their main living area during the winter months.

Around 46 tonnes of wood was burnt per typical winter's night in Wanaka during 2019.

Figure 3.1 shows the proportion of households using different electrical heating types. This shows around 75% of households using electricity in their main living area use heat pumps.

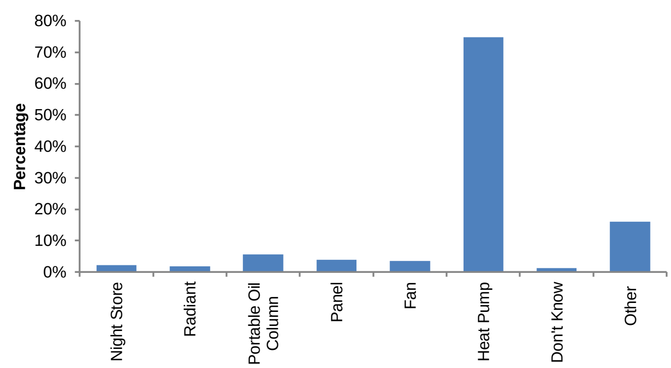

Figure 3.1: Electric heating options for Wanaka households (main living area).

Table 3.3: Home heating methods and fuels.

	Heating methods		Fuel Use	
	%	HH	t/day	%
Electricity	65%	2,398		
Total Gas	13%	467	0.4	1%
Flued gas	10%	383		
Unflued gas	2%	84		
Oil	3%	125	0.1	0%
Open fire	5%	187		
Open fire - wood	5%	187	2	5%
Open fire - coal	0%	10	0.1	0%
Total Wood burner	66%	2,408	44	92%
Pre 2006 wood burner	21%	785	14	30%
2006-2013 wood burner	27%	987	18	38%
Post-2013 wood burner	17%	637	12	24%
Multi-fuel burners	1.1%	42		
Multi-fuel burners-wood	0.6%	21	0.4	1%
Multi-fuel burners-coal	0.6%	21	0.1	0%
Pellet burners	1%	21	0.1	0%
Total wood	71%	2,616	46	98%
Total coal	1%	31	0.2	0.4%
Total		3,675	47	100%

3.3 Emissions from domestic heating.

In 2019 around 300 kilograms of PM_{10} was estimated to be discharged on a typical winter's day from domestic home heating in Wanaka. The annual $PM_{2.5}$ emission was estimated at 36 tonnes per year.

Figure 3.2 shows that the largest portion (47%) of the PM_{10} emissions are from pre-2006 wood burners. The NES design criteria for wood burners was mandatory for new installations on properties less than 2 hectares from September 2005. Wood burners installed during the years 2006 to 2013 contribute to 27% of domestic heating PM_{10} emissions and burners less than five years old contribute 17%. Burners in these two age categories represent the same technology (the same emission factors are used) and segregations just represent burners age distributions. Open fires contribute around 7% of daily winter PM_{10} emissions in Wanaka.

Tables 3.4 and 3.5 show the estimates of emissions for different heating methods under average and worst-case scenarios respectively. Days when households may not be using specific home heating methods are accounted for in the daily winter average emissions[1]. Under the worst-case scenario that all households are using a burner on any given night around 328 kilograms of PM_{10} is likely to be emitted.

The seasonal variation in contaminant emissions is shown in Table 3.6. Figure 3.3 indicates that the majority of the annual PM_{10} emissions from domestic home heating occur during May, June and July.

[1] Total fuel use per day is adjusted by the average number of days per week wood burners are used (e.g.,6/7) and the proportion of wood burners that are used during July (e.g.,95%).

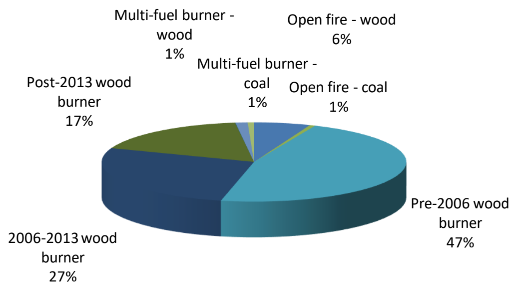

Figure 3.2: Relative contribution of different heating methods to average daily PM_{10} (winter average) from domestic heating in Wanaka.

Table 3.4: Wanaka winter daily domestic heating emissions by appliance type (winter average).

	Fuel Use		PM_{10}			CO			NO_x			SO_x			VOC			CO_2			$PM_{2.5}$		
	t/day	%	kg	g/ha	%	kg	g/ha	%	kg	g/ha	%	kg	g/ha	%	kg	g/ha	%	T	kg/ha	%	kg	g/ha	%
Open fire																							
Open fire - wood	2.4	5%	18	6	6%	131	46	4%	3	1	11%	0	0	4%	72	25	6%	4	1	5%	18	6	6%
Open fire - coal	0.1	0%	2	1	1%	6	2	0%	0	0	1%	1	0	6%	1	0	0%	0	0	0%	2	1	1%
Wood burner	43.7																						
Pre 2006 wood burner	14.2	30%	142	50	47%	1989	695	57%	7	2	27%	3	1	25%	469	164	41%	23	8	30%	142	50	47%
2006-2013 wood burner	17.9	38%	80	28	27%	804	281	23%	9	3	34%	4	1	32%	357	125	31%	29	10	38%	80	28	27%
Post 2013 wood burner	11.5	24%	52	18	17%	519	181	15%	6	2	22%	2	1	21%	230	81	20%	18	6	24%	52	18	17%
Pellet Burner	0.1	0%	0.1	0	0%	1	0	0%	0	0	0%	0	0	0%	1	0	0%	0	0	0%	0	0	0%
Multi fuel burner																							
Multi fuel– wood	0.4	1%	4	1	1%	54	19	2%	0	0	1%	0	0	1%	8	3	1%	1	0	1%	4	1	1%
Multi fuel – coal	0.1	0%	2	1	1%	12	4	0%	0	0	1%	1	0	8%	2	1	0%	0	0	0%	2	1	1%
Gas	0.4	1%	0.01	0	0%	0	0	0%	1	0	2%	0	0	0%	0	0	0%	1	0	1%	0	0	0%
Oil	0.1	0%	0.03	0	0%	0	0	0%	0	0	1%	0	0	3%	0	0	0%	0	0	0%	0	0	0%
Total Wood	46.4	98%	296.26	104	99%	3499	1223	99%	25	9	95%	9	3	83%	1137	398	100%	74	26	98%	296	104	99%
Total Coal	0.2	0%	3.80	1	1%	18	6	0%	1	0	2%	2	1	14%	3	1	0%	0	0	1%	3	1	1%
Total	47		300	105		3516	1229		26	9		11	4		1140	399		76	27		300	105	

Table 3.5: Wanaka winter daily domestic heating emissions by appliance type (worst case).

	Fuel Use		PM_{10}			CO			NO_x			SO_x			VOC			CO_2			$PM_{2.5}$		
	t/day	%	kg	g/ha	%	kg	g/ha	%	kg	g/ha	%	kg	g/ha	%	kg	g/ha	%	T	kg/ha	%	kg	g/ha	%
Open fire																							
Open fire - wood	3.5	7%	26	9	8%	191	67	5%	4	1	14%	1	0	6%	104	36	8%	6	2	7%	26	9	8%
Open fire - coal	0.1	0%	3	1	1%	9	3	0%	0	0	2%	1	0	8%	2	1	0%	0	0	0%	2	1	1%
Wood burner	46.2																						
Pre 2006 wood burner	15.1	30%	151	53	46%	2110	738	56%	8	3	26%	3	1	24%	497	174	40%	24	8	29%	151	53	46%
2006-2013 wood burner	18.9	37%	85	30	26%	853	298	22%	9	3	33%	4	1	30%	379	132	31%	30	11	37%	85	30	26%
Post 2013 wood burner	12.2	24%	55	19	17%	550	192	14%	6	2	21%	2	1	20%	244	85	20%	20	7	24%	55	19	17%
Pellet Burner	0.1	0%	0	0	0%	1	1	0%	0	0	0%	0	0	0%	1	1	0%	0	0	0%	0	0	0%
Multi fuel burner																							
Multi fuel– wood	0.5	1%	5	2	2%	72	25	2%	0	0	1%	0	0	1%	10	4	1%	1	0	1%	5	2	2%
Multi fuel – coal	0.1	0%	3	1	1%	15	5	0%	0	0	1%	1	0	9%	2	1	0%	0	0	0%	2	1	1%
Gas	0.4	1%	0	0	0%	0	0	0%	1	0	2%	0	0	0%	0	0	0%	1	0	1%	0	0	0%
Oil	0.1	0%	0	0	0%	0	0	0%	0	0	1%	0	0	3%	0	0	0%	0	0	0%	0	0	0%
Total Wood	50	98%	322	113	98%	3777	1320	99%	28	10	95%	10	4	80%	1237	432	100%	80	28	98%	322	113	99%
Total Coal	0	1%	5	2	2%	24	8	1%	1	0	2%	2	1	17%	4	1	0%	1	0	1%	5	2	1%
Total	51		328	115		3801	1329		29	10		13	4		1241	434		83	29		327	114	

Table 3.6: Monthly variations in contaminant emissions from domestic heating in Wanaka.

	PM_{10} kg/day	CO kg/day	NOx kg/day	SOx kg/day	VOC kg/day	CO_2 t/day	$PM_{2.5}$ kg/day
January	1	7	0	0	2	0	1
February	0	1	0	0	0	0	0
March	2	29	0	0	9	1	2
April	25	298	3	1	96	7	25
May	262	3064	23	9	997	66	261
June	297	3485	25	11	1132	74	297
July	300	3516	26	11	1140	76	300
August	210	2469	18	8	788	53	209
September	54	641	5	2	206	15	54
October	12	139	1	0	43	3	12
November	3	32	0	0	10	1	3
December	0	4	0	0	1	0	0
Total (kg/year)	35744	419798	3095	1281	135747	9075	35692

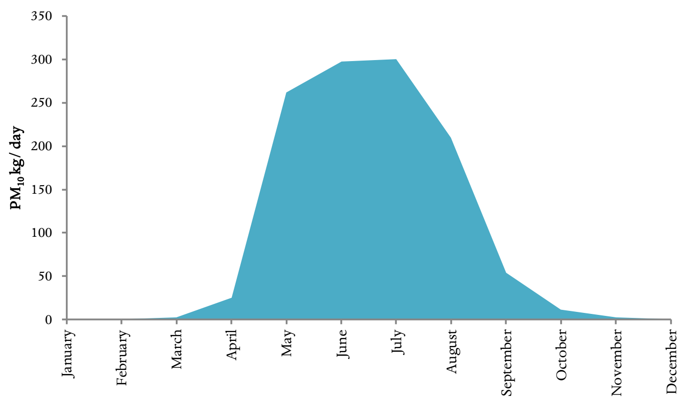

Figure 3.3: Monthly variations in PM_{10} emissions from domestic heating in Wanaka.

3.4 Home heating methods in Cromwell

The most popular form of heating the main living area of homes in Cromwell is electricity with around 72% of households using this method. Wood burners are the next most prevalent heating method with 56% of households using a wood burner in their main living area. Gas is used by 12% of households and 8% of households use oil. Table 3.7 also shows that households rely on more than one method of heating their main living area during the winter months.

Around 26 tonnes of wood was burnt per typical winter's night in Cromwell during 2019.

Figure 3.4 shows the proportion of households using different electrical heating types. This shows around 88% of households using electricity in their main living area use heat pumps.

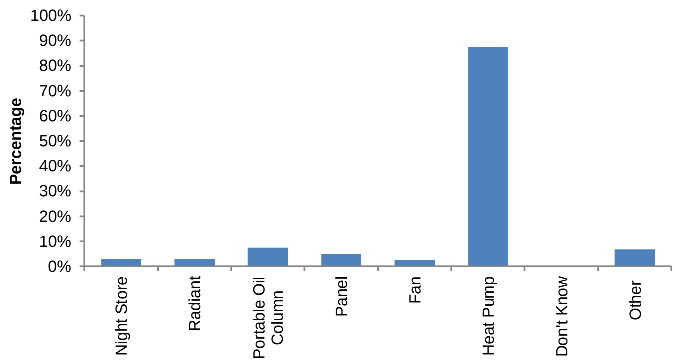

Figure 3.4: Electric heating options for Cromwell households (main living area).

Table 3.7: Home heating methods and fuels in Cromwell.

	Heating methods		Fuel Use	
	%	HH	t/day	%
Electricity	72%	1,549		
Total Gas	12%	254	0.2	1%
Flued gas	11%	225		
Unflued gas	1%	30		
Oil	8%	173	0.1	0%
Open fire	1%	17		
Open fire - wood	1%	17	0.3	1%
Open fire - coal	0%	0	0	0%
Total Wood burner	56%	1,202	25	95%
Pre 2006 wood burner	8%	167	3	13%
2006-2013 wood burner	23%	501	10	40%
Post-2013 wood burner	25%	534	11	42%
Multi-fuel burners	2%	46		
Multi-fuel burners-wood	1%	17	0.3	1%
Multi-fuel burners-coal	1%	29	0.2	1%
Pellet burners	1%	29	0.2	1%
Total wood	58%	1,237	26	98%
Total coal	1%	29	0	1%
Total		2,139	26	100%

3.5 Emissions from domestic heating in Cromwell

In 2019 around 141 kilograms of PM_{10} was estimated to be discharged on a typical winter's day from domestic home heating in Cromwell. The annual $PM_{2.5}$ emission was estimated at 18 tonnes per year.

Figure 3.5 shows that the largest portion (33%) of the PM_{10} emissions are from 2006-2013 wood burners. The NES design criteria for wood burners was mandatory for new installations on properties less than 2 hectares from September 2005. Wood burners installed prior to 2006 contribute to 25% of domestic heating PM_{10} emissions and burners less than five years old contribute 35%.

Tables 3.8 and 3.9 show the estimates of emissions for different heating methods under average and worst-case scenarios respectively. Days when households may not be using specific home heating methods are accounted for in the daily winter average emissions[2]. Under the worst-case scenario that all households are using a burner on any given night around 148 kilograms of PM_{10} is likely to be emitted.

The seasonal variation in contaminant emissions is shown in Table 3.10. Figure 3.6 indicates that the majority of the annual PM_{10} emissions from domestic home heating occur during May, June, July and August.

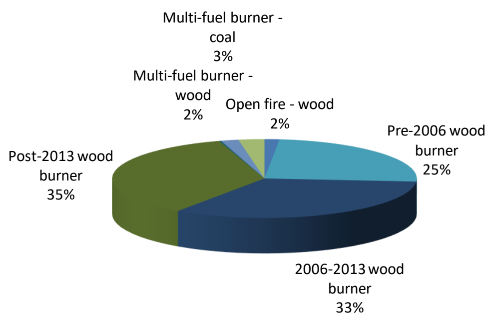

Figure 3.5: Relative contribution of different heating methods to average daily PM_{10} (winter average) from domestic heating in Cromwell.

[2] Total fuel use per day is adjusted by the average number of days per week wood burners are used (e.g.,6/7) and the proportion of wood burners that are used during July (e.g.,95%).

Table 3.8: Cromwell winter daily domestic heating emissions by appliance type (winter average).

	Fuel Use		PM_{10}			CO			NO_x			SO_x			VOC			CO_2			$PM_{2.5}$		
	t/day	%	kg	g/ha	%	kg	g/ha	%	kg	g/ha	%	kg	g/ha	%	kg	g/ha	%	T	kg/ha	%	kg	g/ha	%
Open fire																							
Open fire - wood	0.3	1%	2	3	2%	16	22	1%	0	0	3%	0	0	1%	9	12	2%	0	1	1%	2	3	2%
Open fire - coal	0.0	0%	0	0	0%	0	0	0%	0	0	0%	0	0	0%	0	0	0%	0	0	0%	0	0	0%
Wood burner	25.3																						
Pre 2006 wood burner	3.5	13%	35	46	25%	487	640	32%	2	2	12%	1	1	10%	115	151	20%	6	7	13%	35	46	25%
2006-2013 wood burner	10.5	40%	47	62	33%	471	619	31%	5	7	37%	2	3	29%	209	275	37%	17	22	39%	47	62	33%
Post 2013 wood burner	11.2	42%	50	66	36%	502	660	33%	6	7	40%	2	3	31%	223	293	39%	18	23	42%	50	66	36%
Pellet Burner	0.2	1%	0.4	0	0%	4	5	0%	0	0	1%	0	0	0%	4	5	1%	0	0	1%	0	0	0%
Multi fuel burner																							
Multi fuel– wood	0.3	1%	3	3	2%	37	48	2%	0	0	1%	0	0	1%	5	7	1%	0	1	1%	3	3	2%
Multi fuel – coal	0.2	1%	4	5	3%	22	30	1%	0	0	2%	2	2	22%	3	4	1%	1	1	1%	3	4	2%
Gas	0.2	1%	0.01	0	0%	0	0	0%	0	0	2%	0	0	0%	0	0	0%	1	1	1%	0	0	0%
Oil	0.1	0%	0.04	0	0%	0	0	0%	0	0	2%	0	1	7%	0	0	0%	0	1	1%	0	0	0%
Total Wood	25.9	98%	137.40	181	97%	1518	1995	99%	13	17	93%	5	7	71%	565	743	99%	41	54	96%	137	181	98%
Total Coal	0.2	1%	3.88	5	3%	22	30	1%	0	0	2%	2	2	22%	3	4	1%	1	1	1%	3	4	2%
Total	26		141	186		1540	2024		14	18		7	10		568	747		43	56		141	185	

Table 3.9: Cromwell winter daily domestic heating emissions by appliance type (worst case).

	Fuel Use		PM_{10}			CO			NO_x			SO_x			VOC			CO_2			$PM_{2.5}$		
	t/day	%	kg	g/ha	%	kg	g/ha	%	kg	g/ha	%	kg	g/ha	%	kg	g/ha	%	T	kg/ha	%	kg	g/ha	%
Open fire																							
Open fire - wood	0.3	1%	2	3	2%	18	24	1%	0	1	3%	0	0	1%	10	13	2%	1	1	1%	2	3	2%
Open fire - coal	0.0	0%	0	0	0%	0	0	0%	0	0	0%	0	0	0%	0	0	0%	0	0	0%	0	0	0%
Wood burner	26.3																						
Pre 2006 wood burner	3.6	13%	36	48	25%	510	670	32%	2	2	12%	1	1	10%	120	158	20%	6	8	13%	36	48	25%
2006-2013 wood burner	11.0	40%	49	65	33%	493	648	31%	5	7	37%	2	3	29%	219	288	37%	18	23	39%	49	65	33%
Post 2013 wood burner	11.7	42%	53	69	36%	525	690	33%	6	8	40%	2	3	31%	233	307	39%	19	25	42%	53	69	36%
Pellet Burner	0.2	1%	0	1	0%	4	5	0%	0	0	1%	0	0	1%	4	5	1%	0	0	1%	0	1	0%
Multi fuel burner																							
Multi fuel– wood	0.3	1%	3	4	2%	38	49	2%	0	0	1%	0	0	1%	5	7	1%	0	1	1%	3	4	2%
Multi fuel – coal	0.2	1%	4	5	3%	23	30	1%	0	0	2%	2	2	22%	3	4	1%	1	1	1%	3	5	2%
Gas	0.2	1%	0	0	0%	0	0	0%	0	0	2%	0	0	0%	0	0	0%	1	1	1%	0	0	0%
Oil	0.1	0%	0	0	0%	0	0	0%	0	0	2%	0	1	6%	0	0	0%	0	1	1%	0	0	0%
Total Wood	27	98%	144	189	97%	1587	2086	99%	14	18	94%	5	7	72%	592	778	99%	43	57	97%	144	189	98%
Total Coal	0	1%	4	5	3%	23	30	1%	0	0	2%	2	2	22%	3	4	1%	1	1	1%	3	5	2%
Total	28		148	194		1610	2116		15	19		8	10		595	782		45	59		147	194	

Table 3.10: Monthly variations in contaminant emissions from domestic heating in Cromwell.

	PM_{10} kg/day	CO kg/day	NOx kg/day	SOx kg/day	VOC kg/day	CO_2 t/day	$PM_{2.5}$ kg/day
January	0	0	0	0	0	0	0
February	0	0	0	0	0	0	0
March	1	12	0	0	5	0	1
April	13	138	2	0	52	4	13
May	111	1214	11	5	450	34	111
June	137	1493	13	7	551	41	137
July	141	1540	14	7	568	42	141
August	128	1395	12	6	513	38	127
September	43	473	4	2	178	14	43
October	16	181	2	1	68	5	16
November	2	23	0	0	9	1	2
December	0	2	0	0	1	0	0
Total (kg/year)	18159	198520	1775	846	73451	5503	18109

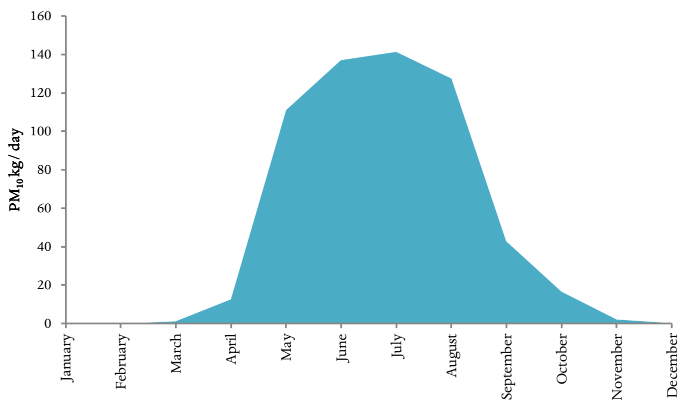

Figure 3.6: Monthly variations in PM_{10} emissions from domestic heating in Cromwell

3.6 Home heating methods in Clyde

The most common forms of heating the main living areas of homes in Clyde are electricity and woodburners with 72% and 56% of homes using these methods. Gas and oil are also used by a small proportion of households (12% and 8% respectively). Table 3.11 also shows that households rely on more than one method of heating their main living area during the winter months.

Around 6 tonnes of wood was burnt per typical winter's night in Clyde during 2019.

Figure 3.7 shows the proportion of households using different electrical heating types. This shows around 88% of households using electricity in their main living area use heat pumps.

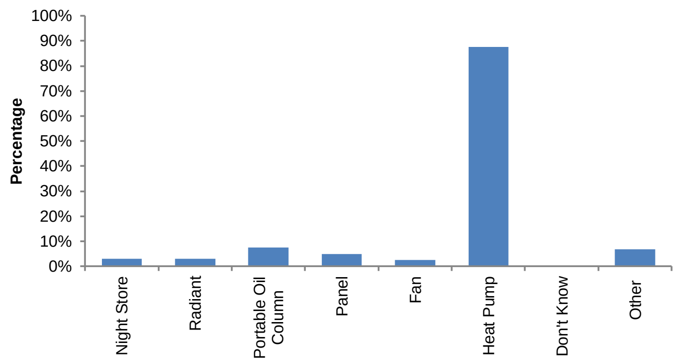

Figure 3.7: Electric heating options for Clyde households (main living area).

Table 3.11: Home heating methods and fuels in Clyde.

	Heating methods		Fuel Use	
	%	HH	t/day	%
Electricity	72%	391		
Total Gas	12%	64	0.1	1%
Flued gas	11%	57		
Unflued gas	1%	7		
Oil	8%	44	0.03	0%
Open fire	1%	4		
Open fire - wood	1%	4	0.1	1%
Open fire - coal	0%	0	0	0%
Total Wood burner	56%	304	6	96%
Pre 2006 wood burner	8%	42	1	13%
2006-2013 wood burner	23%	127	3	40%
Post-2013 wood burner	25%	135	3	42%
Multi-fuel burners	2%	12		
Multi-fuel burners-wood	1%	4	0.1	1%
Multi-fuel burners-coal	1%	7	0.1	1%
Pellet burners	1%	7	0.01	0%
Total wood	58%	312	6	98%
Total coal	1%	7	0.1	1%
Total		540	7	100%

3.7 Emissions from domestic heating in Clyde

Around 36 kilograms of PM_{10} was estimated to be discharged on a typical winter's day from domestic home heating in Clyde. The annual $PM_{2.5}$ emission was estimated at 4.5 tonnes per year.

Figure 3.8 shows that the largest portion (33%) of the PM_{10} emissions are from 2006-2013 wood burners. The NES design criteria for wood burners was mandatory for new installations on properties less than 2 hectares from September 2005. Wood burners installed prior to 2006 contribute to 25% of domestic heating PM_{10} emissions and burners less than five years old contribute 36%.

Tables 3.12 and 3.13 show the estimates of emissions for different heating methods under average and worst-case scenarios respectively. Days when households may not be using specific home heating methods are accounted for in the daily winter average emissions[3]. Under the worst-case scenario that all households are using a burner on any given night around 37 kilograms of PM_{10} is likely to be emitted.

The seasonal variation in contaminant emissions is shown in Table 3.14. Figure 3.9 indicates that the majority of the annual PM_{10} emissions from domestic home heating occur during May, June, July and August.

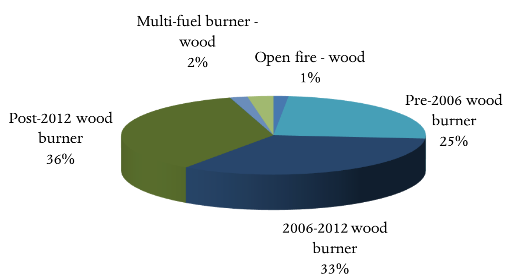

Figure 3.8: Relative contribution of different heating methods to average daily PM_{10} (winter average) from domestic heating in Clyde.

[3] Total fuel use per day is adjusted by the average number of days per week wood burners are used (e.g.,6/7) and the proportion of wood burners that are used during July (e.g.,95%).

Table 3.12: Clyde winter daily domestic heating emissions by appliance type (winter average).

	Fuel Use		PM_{10}			CO			NO_x			SO_x			VOC			CO_2			$PM_{2.5}$		
	t/day	%	kg	g/ha	%	kg	g/ha	%	kg	g/ha	%	kg	g/ha	%	kg	g/ha	%	T	kg/ha	%	kg	g/ha	%
Open fire																							
Open fire - wood	0.1	1%	1	2	2%	4	13	1%	0	0	3%	0	0	1%	2	7	2%	0	0	1%	1	2	2%
Open fire - coal	0.0	0%	0	0	0%	0	0	0%	0	0	0%	0	0	0%	0	0	0%	0	0	0%	0	0	0%
Wood burner	6.3																						
Pre 2006 wood burner	0.9	13%	9	27	25%	122	380	32%	0	1	12%	0	1	10%	29	90	20%	1	4	13%	9	27	25%
2006-2013 wood burner	2.6	40%	12	37	34%	119	370	31%	1	4	38%	1	2	29%	53	165	37%	4	13	39%	12	37	34%
Post 2013 wood burner	2.8	42%	13	39	36%	127	394	33%	1	4	40%	1	2	31%	56	175	40%	5	14	42%	13	39	36%
Pellet Burner	0.0	0%	0.0	0	0%	0	0	0%	0	0	0%	0	0	0%	0	0	0%	0	0	0%	0	0	0%
Multi fuel burner																							
Multi fuel– wood	0.1	1%	1	2	2%	9	29	2%	0	0	1%	0	0	1%	1	4	1%	0	0	1%	1	2	2%
Multi fuel – coal	0.1	1%	1	3	3%	6	18	1%	0	0	2%	0	1	23%	1	2	1%	0	0	1%	1	3	2%
Gas	0.1	1%	0.00	0	0%	0	0	0%	0	0	2%	0	0	0%	0	0	0%	0	0	1%	0	0	0%
Oil	0.0	0%	0.01	0	0%	0	0	0%	0	0	2%	0	0	7%	0	0	0%	0	0	1%	0	0	0%
Total Wood	6.5	98%	34.58	107	97%	382	1186	99%	3	10	93%	1	4	71%	142	441	99%	10	32	96%	35	107	98%
Total Coal	0.1	1%	0.98	3	3%	6	18	1%	0	0	2%	0	1	23%	1	2	1%	0	0	1%	1	3	2%
Total	7		36	110		388	1204		4	11		2	6		143	443		11	33		35	110	

Table 3.13: Clyde winter daily domestic heating emissions by appliance type (worst case).

	Fuel Use		PM_{10}			CO			NO_x			SO_x			VOC			CO_2			$PM_{2.5}$		
	t/day	%	kg	g/ha	%	kg	g/ha	%	kg	g/ha	%	kg	g/ha	%	kg	g/ha	%	T	kg/ha	%	kg	g/ha	%
Open fire																							
Open fire - wood	0.1	1%	1	2	2%	5	14	1%	0	0	3%	0	0	1%	2	8	2%	0	0	1%	1	2	2%
Open fire - coal	0.0	0%	0	0	0%	0	0	0%	0	0	0%	0	0	0%	0	0	0%	0	0	0%	0	0	0%
Wood burner	6.6																						
Pre 2006 wood burner	0.9	13%	9	28	25%	128	397	31%	0	1	12%	0	1	10%	30	94	20%	1	5	13%	9	28	25%
2006-2013 wood burner	2.8	40%	12	39	33%	125	387	31%	1	4	37%	1	2	29%	55	172	37%	4	14	39%	12	39	34%
Post 2013 wood burner	2.9	42%	13	41	36%	133	412	33%	1	5	40%	1	2	31%	59	183	39%	5	15	42%	13	41	36%
Pellet Burner	0.0	1%	0	0	0%	1	3	0%	0	0	1%	0	0	1%	1	3	1%	0	0	1%	0	0	0%
Multi fuel burner																							
Multi fuel– wood	0.1	1%	1	2	2%	9	29	2%	0	0	1%	0	0	1%	1	4	1%	0	0	1%	1	2	2%
Multi fuel – coal	0.1	1%	1	3	3%	6	18	1%	0	0	2%	0	1	22%	1	2	1%	0	0	1%	1	3	2%
Gas	0.1	1%	0	0	0%	0	0	0%	0	0	2%	0	0	0%	0	0	0%	0	0	1%	0	0	0%
Oil	0.0	0%	0	0	0%	0	0	0%	0	0	2%	0	0	6%	0	0	0%	0	0	1%	0	0	0%
Total Wood	7	98%	36	113	97%	400	1243	99%	3	11	94%	1	4	72%	149	464	99%	11	34	97%	36	113	98%
Total Coal	0	1%	1	3	3%	6	18	1%	0	0	2%	0	1	22%	1	2	1%	0	0	1%	1	3	2%
Total	7		37	116		406	1261		4	12		2	6		150	466		11	35		37	115	

Table 3.14: Monthly variations in contaminant emissions from domestic heating in Clyde.

	PM_{10} kg/day	CO kg/day	NOx kg/day	SOx kg/day	VOC kg/day	CO_2 t/day	$PM_{2.5}$ kg/day
January	0	0	0	0	0	0	0
February	0	0	0	0	0	0	0
March	0	3	0	0	1	0	0
April	3	35	0	0	13	1	3
May	28	306	3	1	114	9	28
June	35	376	3	2	139	10	34
July	36	388	3	2	143	11	36
August	32	352	3	2	129	10	32
September	11	119	1	0	45	3	11
October	4	46	0	0	17	1	4
November	1	6	0	0	2	0	1
December	0	1	0	0	0	0	0
Total (kg/year)	4581	50052	448	214	18534	1389	4568

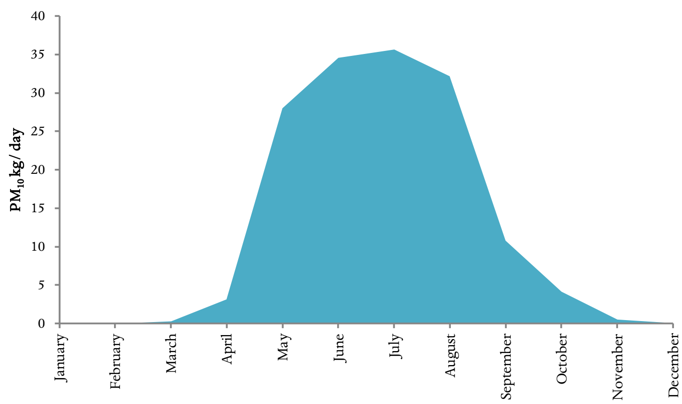

Figure 3.9: Monthly variations in PM_{10} emissions from domestic heating in Clyde

4 MOTOR VEHICLES

4.1 Methodology

Motor vehicle emissions to air include tailpipe emissions of a range of contaminants and particulate emissions occurring as a result of the wear of brakes and tyres. Assessing emissions from motor vehicles involves collecting data on vehicle kilometres travelled (VKT) and the application of emission factors to these data.

Emission factors for motor vehicles are determined using the Vehicle Emission Prediction Model (VEPM 6.0). Emission factors for PM_{10}, $PM_{2.5}$, CO, NOx, VOCs and CO_2 for this study have been based on VEPM 6.0. Default settings were used for all variables except for the temperature data, and the vehicle fleet profile which was based on Queenstown Lakes District (Wanaka) and Central Otago District (Cromwell and Clyde) vehicle registration data for the year ending July 2019 (Table 4.1). Temperature data were based on an average winter temperature of 3.6 degrees and an average speed the default setting of 50 km/hr was assumed. Resulting emission factors are shown in Table 4.2.

Emission factors for SOx were estimated for diesel vehicles based on the sulphur content of the fuel (0.01%) and the assumption of 100% conversion to SOx. Total VKT for diesel vehicles were estimated based on the proportion of diesels in the vehicle fleet.

In addition to estimates of tailpipe emissions and brake and tyre emissions using VEPM an estimate of the non-tailpipe emissions (including brake and tyre wear and re-suspended road dusts) was made using the emissions factors in the EMEP/EEA air pollutant emission inventory guidebook (Table 4.4).

The number of vehicle kilometres travelled (VKT) for the airshed was estimated using the New Zealand Transport Authority VKT data for 2017 for Queenstown Lakes and Central Otago areas multiplied by an estimate of the proportion of VKT for the District within each inventory area. The latter estimate was based on NZTA 2013 data (available by CAU). The estimated VKT for each urban area are shown in Table 4.3.

Table 4.1: Vehicle registrations for the year ending July 2019.

QLDC	Petrol	Diesel	Hybrid	Plug in Hybrid	Electric	LPG	Other	Total
Cars	26,482	5,288	245	39	94	2	3	32,153
LCV	1,554	4,902	1	0	2	0	1	6,460
Bus	109	514	0	0	0	1	0	624
HCV		2,438			5			2,443
Miscellaneous	601	464	2	0	16	9	2	1,094
Motorcycle	1,578							1,578
Total	30324	13606	248	39	117	12	6	44,352
Central Otago District	**Petrol**	**Diesel**	**Hybrid**	**Plug in Hybrid**	**Electric**	**LPG**	**Other**	**Total**
	14,645	2,659	73	20	30	5	2	17,434
Cars	1,103	4,052	0	0	2	1	0	5,158
LCV	29	174	0	0	0	0	0	203
Bus		1,947			5			1,952
HCV	308	851	0	1	9	5	3	1,177
Miscellaneous	1,071							1,071
Motorcycle	17156	9683	73	21	46	11	5	26,995
Total	14,645	2,659	73	20	30	5	2	17,434

Table 4.2: Emission factors for the Queenstown Lakes and Central Otago vehicle fleets (2019).

	CO	CO_2	VOC	NOx	PM_{10}	$PM_{2.5}$	PM brake & tyre	$PM_{2.5}$ brake & tyre
Area	g/VKT	g/VKT	g/VKT	g/VKT	g/VKT	g/VKT	g/VKT	g/VKT
Wanaka	2.38	230	0.21	0.70	0.030	0.030	0.021	0.019
Cromwell/Clyde	2.32	238	0.20	0.80	0.034	0.034	0.02	0.01

Table 4.3: Road dust TSP emissions (from EMEP/EEA guidebook, EEA, 2016).

	TSP g/KVT
Two wheeled vehicles	0.01
Passenger car	0.02
Light duty trucks	0.02
Heavy duty trucks	0.08
Weighted vehicle fleet factor	0.02
PM_{10} size fraction	0.5
$PM_{2.5}$ size fraction	0.27

Table 4.4: VKT estimates for 2019.

	VKT
Wanaka	51775
Cromwell	13306
Clyde	4390

Emissions were calculated by multiplying the appropriate average emission factor by the VKT:

Emissions (g) = Emission Rate (g/VKT) * VKT

4.2 Motor vehicle emissions

Tables 4.4 to 4.6 show the estimated contaminant emissions from motor vehicles for Wanaka, Cromwell and Clyde for 2019. The daily PM_{10} emissions range from 3.2 kilograms per day in Wanaka down to less than 0.5 kilograms per day for Clyde. In Wanaka around 50% of the PM_{10} from motor vehicles are estimated to occur as a result of tailpipe emissions with 35% brake and tyre wear and 15% resuspended road dust. Distributions are similar for Cromwell and Clyde (51% tailpipe).

Table 4.5: Summary of daily motor vehicle emissions in Wanaka

	PM_{10}		CO		NOx		SOx	
	kg	g/ha	kg	g/ha	kg	g/ha	kg	g/ha
Tailpipe	1.6	0.5	123	43	36	13	0.0	0.01
Brake and tyre	1.1	0.4						
Road dust	0.5	0.2						
Total	3.2	1.1	123	43.1	36	12.7	0	0.01
	VOC		CO_2		$PM_{2.5}$			
	kg	g/ha	t	kg/ha	kg	g/ha		
Tailpipe	11	4	12	4	1.0	0		
Brake and tyre					0.3	0		
Road dust					0.3	0		
Total	11	4	0	0	1.5	1		

Table 4.6: Summary of daily motor vehicle emissions in Cromwell

	PM_{10}		CO		NOx		SOx	
	kg	g/ha	kg	g/ha	kg	g/ha	kg	g/ha
Tailpipe	0.4	0.6	31	41	11	14	0.0	0.01
Brake and tyre	0.3	0.4						
Road dust	0.1	0.2						
Total	0.9	1.1	31	40.6	11	14.0	0	0.01
	VOC		CO_2		$PM_{2.5}$			
	kg	g/ha	t	kg/ha	kg	g/ha		
Tailpipe	3	4	3	4	0.3	0.4		
Brake and tyre	0	0	0	0	0.07	0.1		
Road dust	0	0	0	0	0.07	0.1		
Total	3	4	3	4	0.4	0.6		

Table 4.7: Summary of daily motor vehicle emissions in Clyde

	PM_{10}		CO		NOx		SOx	
	kg	g/ha	kg	g/ha	kg	g/ha	kg	g/ha
Tailpipe	0.1	0.5	10	32	4	11	0.0	0.01
Brake and tyre	0.1	0.3						
Road dust	0.0	0.1						
Total	0.3	0.9	10	31.7	4	10.9	0	0.01
	VOC		CO_2		$PM_{2.5}$			
	kg	g/ha	t	kg/ha	kg	g/ha		
Tailpipe	0.9	3	1	3	0.1	0.3		
Brake and tyre					0.02	0.1		
Road dust					0.02	0.1		
Total	0.9	2.8	0	0.0	0.1	0.4		

5 INDUSTRIAL AND COMMERCIAL

5.1 Methodology

Information on consented activities discharging to air in Wanaka, Cromwell and Clyde was provided by the Otago Regional Council. The selection of industries for inclusion in this inventory was based on potential for PM_{10} emissions. Industrial activities such as spray painting or drycleaning operations, which discharge primarily VOCs were not included in the assessment. A number of the consented discharges were for odour or other contaminants not included in the inventory.

In the Otago airsheds only boilers with heat outputs greater than 1 MW require resource consent. To capture smaller scale boilers schools, hospitals and recreation centres were also contacted. In Wanaka, Mount Aspiring College was the only school operating with a coal boiler, although it was noted that the boiler would be replaced with two wood chip boilers before winter 2020. In Cromwell, the high school boiler ran on coal during 2019 but wood chips would be the fuel source for 2020. The primary school used heat pumps as did Clyde primary school. Emissions from gas and diesel small scale boilers were not included in the inventory as the PM_{10} emissions from them are relatively minor.

Emissions were estimated based on equation 5.1 or equation 5.2 depending on the availability of site specific emissions data. Activity data from industry includes information such as the quantities of fuel used, or in the case of non-combustion activities, materials used or produced.

Equation 5.1 Emissions (kg/day) = Emission rate (kg/hr) x hrs per day (hrs)

Equation 5.2 Emissions (kg) = Emission factor (kg/tonne) x Fuel use (tonnes)

The emission factors used to estimate the quantity of emissions discharged are shown in Table 5.1. Fugitive dust emissions from industrial and commercial activities were not included in the inventory assessment because of difficulties in quantifying the emissions.

Table 5.1: Emission factors for industrial discharges.

	PM_{10}	CO	NOx	SOx	VOC	CO_2	$PM_{2.5}$
Underfeed stoker	2	5.5	4.8	19.0	0.1	2400	1.2
Wood boiler	1.6	6.8	0.8	0.04	0.1	1069	1.4
Open fire	7.5	55	1.2	0.2	30	1600	7.5
Concrete batching	0.003						
Cement loading	0.00017						0.00017
Aggregate loading	0.0017						0.0005
LPG boiler	0.1	1	1.8	0.0	0.1	1716	0.1

5.2 Industrial and commercial emissions

Tables 5.2 and 5.3 show the estimated emissions to air from industrial and commercial activities in Wanaka, Cromwell and Clyde for daily winter and annual emission estimates.

Table 5.2: Summary of emissions from industrial and commercial activities (daily winter) in Wanaka, Cromwell and Clyde.

		PM_{10}		CO		NOx		SOx	
	Hectares	kg	g/ha	kg	g/ha	kg	g/ha	kg	g/ha
Wanaka	2861	2.1	0.7	11.9	4.2	2.1	0.7	1.6	0.6
Cromwell	761	1.1	1.5	2.0	2.6	1.7	2.3	3.4	4.5
Clyde	322	0	0	0	0	0	0	0	0
		VOC		CO_2		$PM_{2.5}$			
	Hectares	kg	g/ha	t	kg/ha	kg	g/ha		
Wanaka	2861	5.2	1.8	1.3	0.5	1.8	0.6		
Cromwell	761	0.0	0.0	0.9	1.1	0.5	0.6		
Clyde	322	0	0	0	0	0	0		

Table 5.3: Summary of emissions from industrial and commercial activities (annual) in Wanaka, Cromwell and Clyde.

	PM_{10} tonnes	CO tonnes	NOx tonnes	SOx tonnes	VOC tonnes	CO_2 tonnes	$PM_{2.5}$ tonnes
Wanaka	0.4	2.2	0.5	0.3	1.0	221	0.3
Cromwell	0.17	0.20	0.24	0.34	0.00	86.40	0.06
Clyde	0	0	0	0	0	0	0

6 OUTDOOR BURNING

Outdoor burning of green wastes or household material can contribute to PM_{10} concentrations and also discharge other contaminants to air. In some urban areas of New Zealand outdoor burning is prohibited because of the adverse health and nuisance effects associated with these emissions. Outdoor burning includes any burning in a drum, incinerator or open air on residential properties in the study area.

The Otago Regional Plan permits outdoor burning of in Airzone 2 (Wanaka) all year around subject to conditions and in Airzone 1 (Clyde and Cromwell) during the non-winter months.

6.1 Methodology

Outdoor burning emissions for Wanaka, Cromwell and Clyde were estimated based on data collected during the 2019 domestic home heating survey.

Emissions were calculated based on the assumption of an average weight of material per burn of 159 kilograms per cubic metre of material[4] and using the emission factors in Table 6.1. The AP42 emission factor database includes estimates for a wide range of materials including different tree species, weeds, leaves, vines and other agricultural material. Emission factors for SOx are based on residential wood burning in the absence of emission factors for these contaminants within the AP42 database for outdoor burning. In comparison the European Environment Agency air pollution emission inventory guidebook (EEA, 2016) tier one assessment emission factors are based on tree slash for two species and tree pruning for two species only.

Table 6.1: Outdoor burning emission factors (AP42).

	PM_{10}	$PM_{2.5}$	CO	NOx	SOx	CO_2	BaP
	g/kg	g/kg	g/kg	g/kg	g/kg	g/kg	g/kg
Outdoor burning	8	8	42	2	0.5	1470	0.002

[4] Based on the average of low and medium densities for garden vegetation from (Victorian EPA, 2016)

6.2 Outdoor burning emissions

Table 6.2 shows that around 5, 7 and 2 kilograms of PM_{10} from outdoor burning could be expected per day during the winter months on average in Wanaka, Cromwell and Clyde respective.

It should be noted, that there are a number of uncertainties relating to the calculations. In particular it is assumed that burning is carried out evenly throughout each season, whereas in reality it is highly probable that a disproportionate amount of burning is carried out on days more suitable for burning. Thus, on some days no PM_{10} from outdoor burning may occur and on other days it might be many times the amount estimated in this assessment. In addition, the emission factors vary by a factor of three for different materials being burnt. Outdoor burning emissions include a higher degree of uncertainty relative to domestic heating, motor vehicles and industry owing to uncertainties in the distribution of burning and potential variabilities in material type and density.

Table 6.2: Outdoor burning emission estimates.

Wanaka	PM_{10} kg/ day	CO kg/ day	NOx kg/ day	SOx kg/ day	VOC kg/ day	CO_2 t/ day	$PM_{2.5}$ kg/day
Summer (Dec-Feb)	2	10	1	0	1	0	2
Autumn (Mar-May)	2	11	1	0	1	0	2
Winter (June-Aug)	5	24	2	0	2	1	5
Spring (Sept-Nov)	2	9	1	0	1	0	2
Cromwell	PM_{10} kg/ day	CO kg/ day	NOx kg/ day	SOx kg/ day	VOC kg/ day	CO_2 t/ day	$PM_{2.5}$ kg/day
Summer (Dec-Feb)	2	11	1	0	1	0	2
Autumn (Mar-May)	9	48	3	1	5	2	9
Winter (June-Aug)	7	35	3	0	3	1	7
Spring (Sept-Nov)	3	13	1	0	1	0	3
Clyde	PM_{10} kg/ day	CO kg/ day	NOx kg/ day	SOx kg/ day	VOC kg/ day	CO_2 t/ day	$PM_{2.5}$ kg/day
Summer (Dec-Feb)	0.5	3	0.2	0.0	0.3	0.1	0.5
Autumn (Mar-May)	2	12	1	0	1	0	2
Winter (June-Aug)	2	9	1	0	1	0	2
Spring (Sept-Nov)	1	3	0.2	0.0	0.3	0.1	1

7 OTHER SOURCES OF EMISSIONS

This inventory includes all likely major sources of PM_{10} that can be adequately estimated using inventory techniques. Other sources of emissions not included in the inventory that may contribute to measured PM_{10} concentrations at times during the year include dusts (a portion of which occur in the PM_{10} size fraction) and sea spray. These sources are not typically included because the methodology used to estimate the emissions is less robust.

Lawn mowers, leaf blowers and chainsaws can also contribute small amounts of particulate. These are not typically included in emission inventory studies owing to the relatively small contribution, particularly in areas where solid fuel burning is a common method of home heating. Historically a Pacific Air and Environment (1999) figure of around 0.07 grams of PM_{10} per household per day has been used. This was re-evaluated with more recent information in Wilton (2019). This indicated a range of 0.0012 to 0.05 g/household/day and results in an estimate of less than 0.3 kilograms of PM_{10} per day in each area from these sources.

8 TOTAL EMISSIONS

8.1 Wanaka

Around 310 kilograms of PM_{10} was discharged to air in Wanaka on an average winter's day for 2019. Domestic home heating is the main source of PM_{10} emissions in all areas contributing 97% of the daily wintertime emissions and 93% of the annual PM_{10} emissions. Outdoor burning, motor vehicles and industrial and commercial activities each contribute 1% of the daily PM_{10} and 1-3% of the annual emissions.

The relative contributions to daily winter and annual average $PM_{2.5}$ are similar as for PM_{10} with domestic heating contributing 97% and 95% respectively (Figure 8.2).

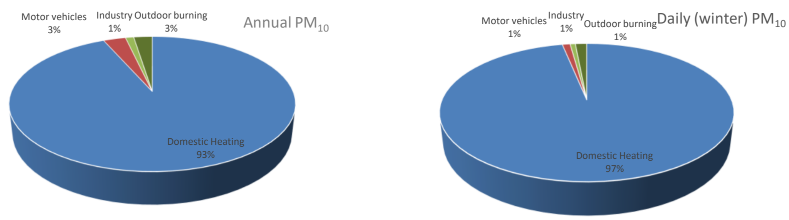

Figure 8.1: Relative contribution of sources to daily winter and annual PM_{10} emissions in Wanaka.

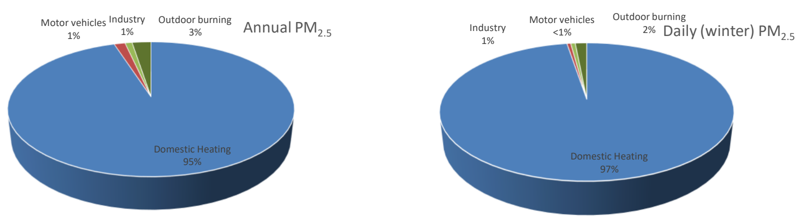

Figure 8.2: Relative contribution of sources to daily winter and annual $PM_{2.5}$ emissions in Wanaka.

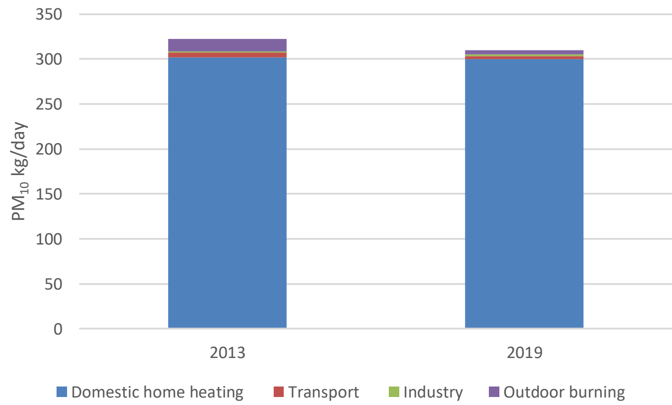

Figure 8.3: Daily winter PM_{10} emissions in Wanaka in 2013 and 2019.

Figure 8.3 compares daily PM_{10} emissions in Wanaka to the 2013 emission estimates from the national emission inventory carried out by the Ministry for the Environment, (2014). The latter was based on a region wide surveying of homes for heating methods (excluding Airzone 1 towns) and integration of census data for wood use to determine local emission rates. The 2013 method has high uncertainty and trend estimates are indicative only .

Domestic home heating is also the main source of CO, SOx, VOCs and CO_2. Motor vehicles are the main source of NOx in Wanaka (Figure 8.4).

Table 8.1 shows seasonal variations in PM_{10} emissions. Although domestic home heating is the dominant source of PM_{10} emissions during the winter months, during the summer motor vehicles is the main source of PM_{10} emissions. Daily wintertime emissions of PM_{10} and other contaminants (kg/day and g/day/ha) are shown in Table 8.2.

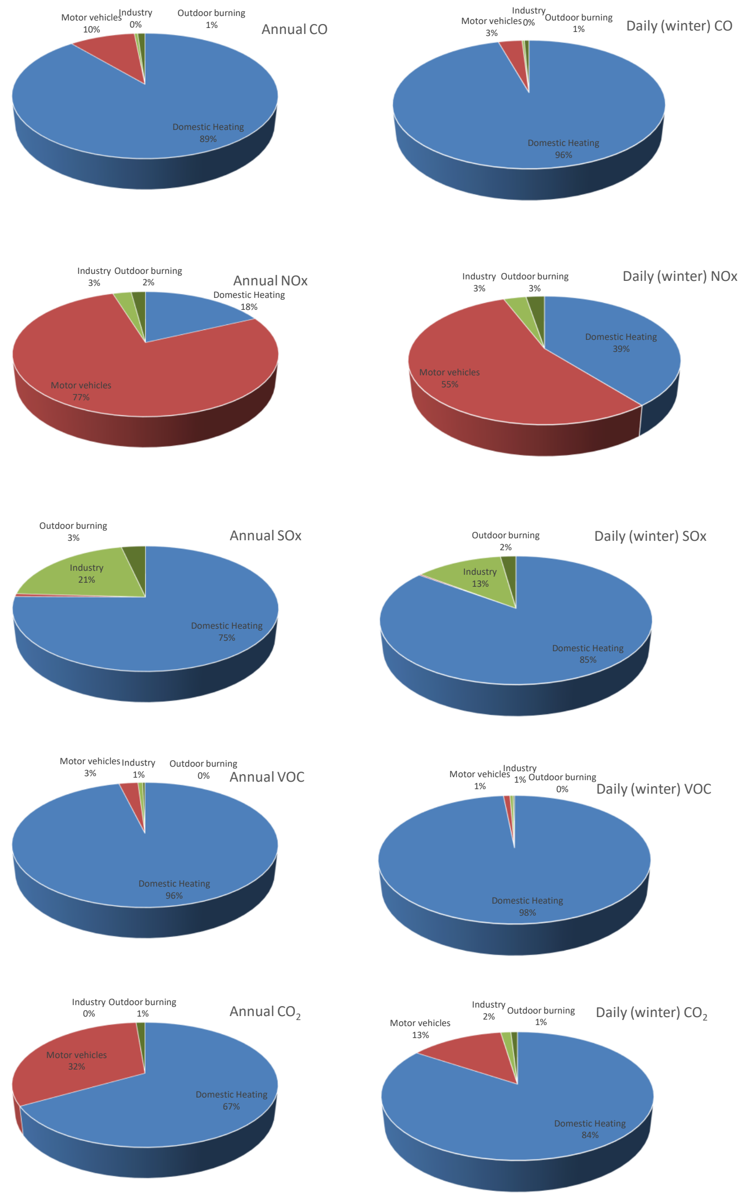

Figure 8.4: Relative contribution of sources to daily winter contaminant emissions in Wanaka

Table 8.1: Monthly variations in daily PM_{10} emissions in Wanaka.

	Domestic heating		Outdoor burning		Industry		Motor vehicles		Total
	kg/day	%	kg/day	%	kg/day	%	kg/day	%	kg/day
January	1	10%	2	33%	0	3%	3	53%	6
February	0	2%	2	36%	0	4%	3	59%	5
March	2	27%	2	24%	1	13%	3	36%	9
April	25	79%	2	7%	1	4%	3	10%	31
May	262	98%	2	1%	1	0%	3	1%	268
June	297	97%	5	2%	2	1%	3	1%	307
July	300	97%	5	1%	2	1%	3	1%	310
August	210	95%	5	2%	2	1%	3	1%	220
September	54	90%	2	3%	1	2%	3	5%	60
October	12	66%	2	10%	1	6%	3	18%	18
November	3	30%	2	20%	1	13%	3	36%	9
December	0	6%	2	35%	0	3%	3	56%	6
Total kg year	35744	93%	956	2%	424	1%	1152	3%	38275

Table 8.2: Daily contaminant emissions from all sources in Wanaka (winter average).

	PM_{10}		CO		NOx		SOx	
	kg	g/ha	kg	g/ha	kg	g/ha	kg	g/ha
Domestic home heating	300	105	3516	1229	26	9	11	4
Transport	3	1	123	43	36	13	0	0
Industry	2.1	0.7	11.9	4.2	2.1	0.7	1.6	0.6
Outdoor burning	5	2	24	9	2	1	0	0
Total	310	108	3676	1285	66	23	13	5
	VOC		CO_2		$PM_{2.5}$			
	kg	g/ha	tonnes	kg/ha	kg	g/ha		
Domestic home heating	1140	399	76	27	300	105		
Transport	11	4	12	4	2	1		
Industry	5.2	1.8	1.3	0.5	1.8	0.6		
Outdoor burning	2	1	1	0	5	2		
Total	1158	405	90	32	308	108		

8.2 Cromwell

Around 150 kilograms of PM_{10} was discharged to air in Cromwell on an average winter's day for 2019. Domestic home heating is the main source of PM_{10} emissions in all areas contributing 94% of the daily wintertime emissions and 88% of the annual PM_{10} emissions. Outdoor burning contributes 4% of the daily PM_{10} and 9% of the annual emissions (Figure 8.5).

The relative contributions to daily winter and annual average $PM_{2.5}$ are similar as for PM_{10} with domestic heating contributing 95% and 90% respectively (Figure 8.6).

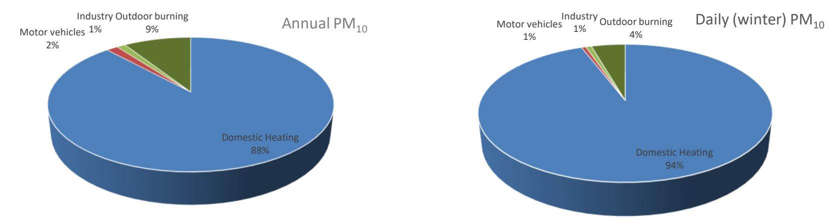

Figure 8.5: Relative contribution of sources to daily winter and annual PM_{10} emissions in Cromwell.

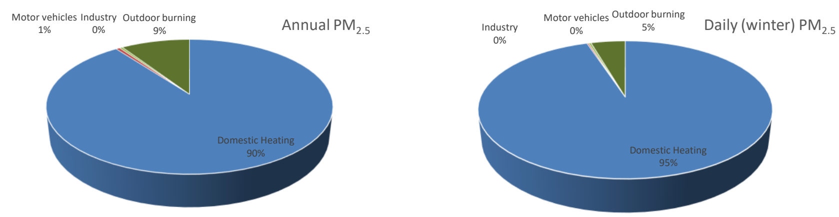

Figure 8.6: Relative contribution of sources to daily winter and annual $PM_{2.5}$ emissions in Cromwell.

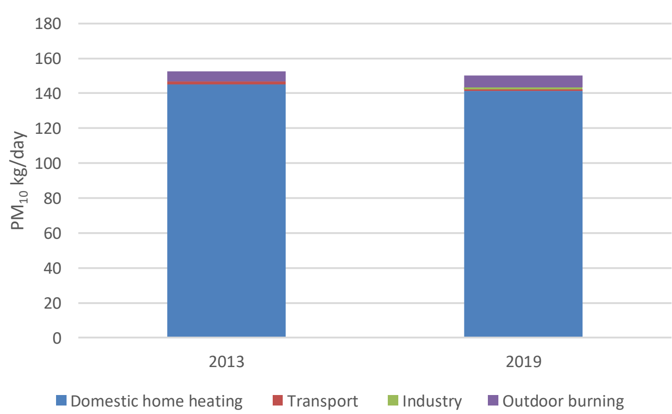

Figure 8.7: Daily winter PM_{10} emissions in Wanaka in 2013 and 2019.

Figure 8.7 compares daily PM_{10} emissions in Cromwell to the 2013 emission estimates from the national emission inventory carried out by the Ministry for the Environment, (2014). The latter was based on airzone wide surveying of homes for heating methods (Arrowtown, Alexandra, Cromwell, Clyde) and integration of census data for wood use to determine local emission rates. No trend in emissions is observed relative to 2013.

Domestic home heating is also the main source of daily winter CO, SOx, VOCs and CO_2. Motor vehicles are the main source of annual NOx in Cromwell (Figure 8.8).

Table 8.3 shows seasonal variations in PM_{10} emissions. Although domestic home heating is the dominant source of PM_{10} emissions during the winter months, during the summer outdoor burning is the main source of PM_{10} emissions. Daily wintertime emissions of PM_{10} and other contaminants (kg/day and g/day/ha) are shown in Table 8.4.

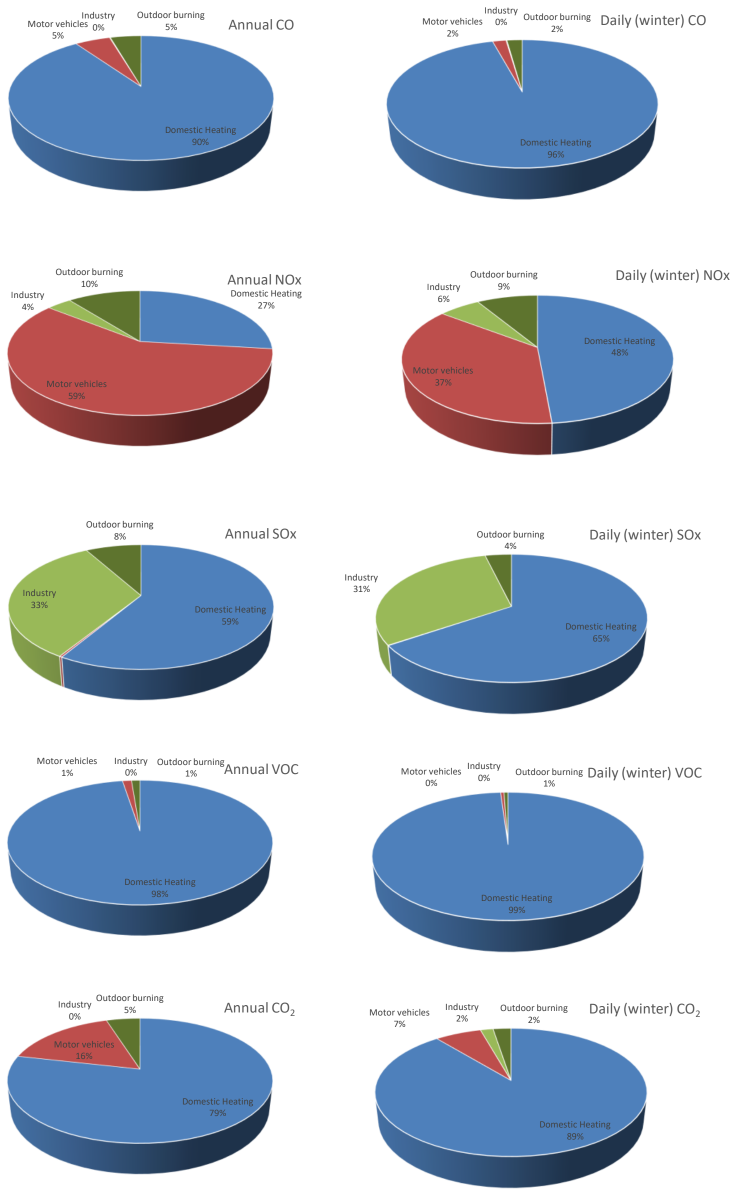

Figure 8.8: Relative contribution of sources to daily winter contaminant emissions in Cromwell

Table 8.3: Monthly variations in daily PM_{10} emissions in Cromwell.

	Domestic heating		Outdoor burning		Industry		Motor vehicles		Total
	kg/day	%	kg/day	%	kg/day	%	kg/day	%	kg/day
January	0	0%	2	62%	0	12%	1	27%	3
February	0	0%	2	61%	0	12%	1	26%	3
March	1	9%	9	78%	1	6%	1	7%	12
April	13	54%	9	39%	1	3%	1	4%	23
May	111	91%	9	8%	1	1%	1	1%	122
June	137	94%	7	5%	1	1%	1	1%	146
July	141	94%	7	4%	1	1%	1	1%	150
August	128	94%	7	5%	1	1%	1	1%	136
September	43	91%	3	5%	1	1%	1	2%	47
October	16	80%	3	12%	1	3%	1	4%	20
November	2	34%	3	41%	1	11%	1	14%	6
December	0	6%	2	58%	0	11%	1	25%	3
Total kg year	18159	88%	1868	9%	243	1%	318	2%	20588

Table 8.4: Daily contaminant emissions from all sources in Cromwell (winter average).

	PM_{10}		CO		NOx		SOx	
	kg	g/ha	kg	g/ha	kg	g/ha	kg	g/ha
Domestic home heating	141	186	1540	2024	14	18	7	10
Transport	1	1	31	41	11	14	0	0
Industry	1.1	1.5	2.0	2.6	1.7	2.3	3.4	4.5
Outdoor burning	7	9	35	46	3	3	0	1
Total	150	197	1608	2114	29	38	11	15
	VOC		CO_2		$PM_{2.5}$			
	kg	g/ha	tonnes	kg/ha	kg	g/ha		
Domestic home heating	568	747	43	56	141	185		
Transport	3	4	3	4	0	0		
Industry	0.0	0.0	0.9	1.1	0.5	0.6		
Outdoor burning	3	4	1	2	7	9		
Total	575	755	48	63	148	195		

8.3 Clyde

Around 38 kilograms of PM_{10} was discharged to air in Clyde on an average winter's day for 2019. Domestic home heating is the main source of PM_{10} emissions in all areas contributing 95% of the daily wintertime emissions and 89% of the annual PM_{10} emissions (Figure 8.9). Outdoor burning, motor vehicles and industrial and commercial activities each contribute 1% of the daily PM_{10} and 0-3% of the annual emissions.

The relative contributions to daily winter and annual average $PM_{2.5}$ are similar as for PM_{10} with domestic heating contributing 95% and 90% respectively (Figure 8.10).

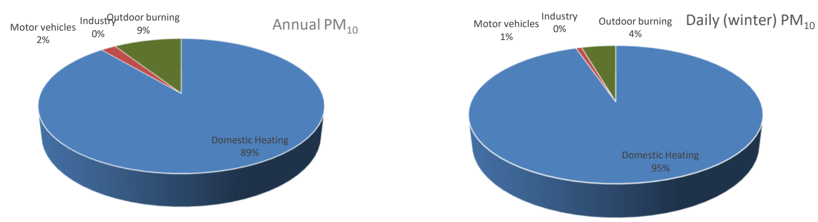

Figure 8.9: Relative contribution of sources to daily winter and annual PM_{10} emissions in Clyde.

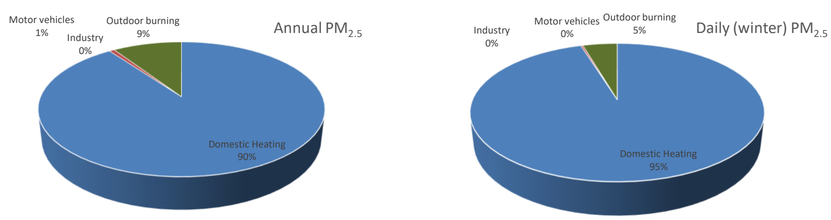

Figure 8.10: Relative contribution of sources to daily winter and annual $PM_{2.5}$ emissions in Clyde.

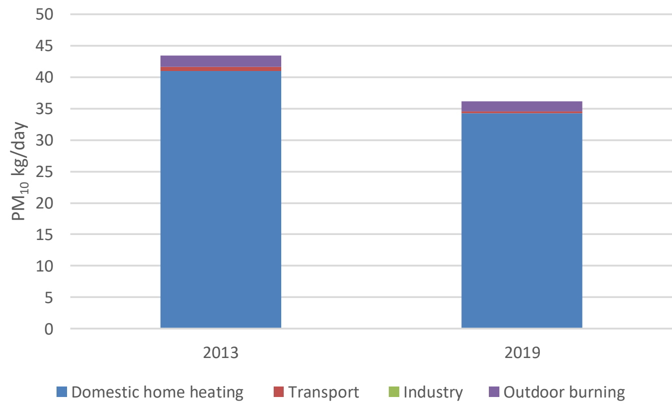

Figure 8.11: Daily winter PM_{10} emissions in Clyde in 2013 and 2019.

Figure 8.11 compares daily PM_{10} emissions in Wanaka to the 2013 emission estimates from the national emission inventory carried out by the Ministry for the Environment, (2014). The latter was based on an airzone wide surveying of homes for heating methods and integration of census data for wood use to determine local emission rates. A reduction in emission of around 13% relative to 2013 is estimated but contains a high degree of uncertainty because of the less robust emission estimate approach for 2013.

Domestic home heating is also the main source of daily winter CO, SOx, VOCs and CO_2. Motor vehicles are the main source of NOx in Clyde (Figure 8.12).

Table 8.5 shows seasonal variations in PM_{10} emissions. Although domestic home heating is the dominant source of PM_{10} emissions during the winter months, during the summer outdoor burning is the main source of PM_{10} emissions. Daily wintertime emissions of PM_{10} and other contaminants (kg/day and g/day/ha) are shown in Table 8.6.

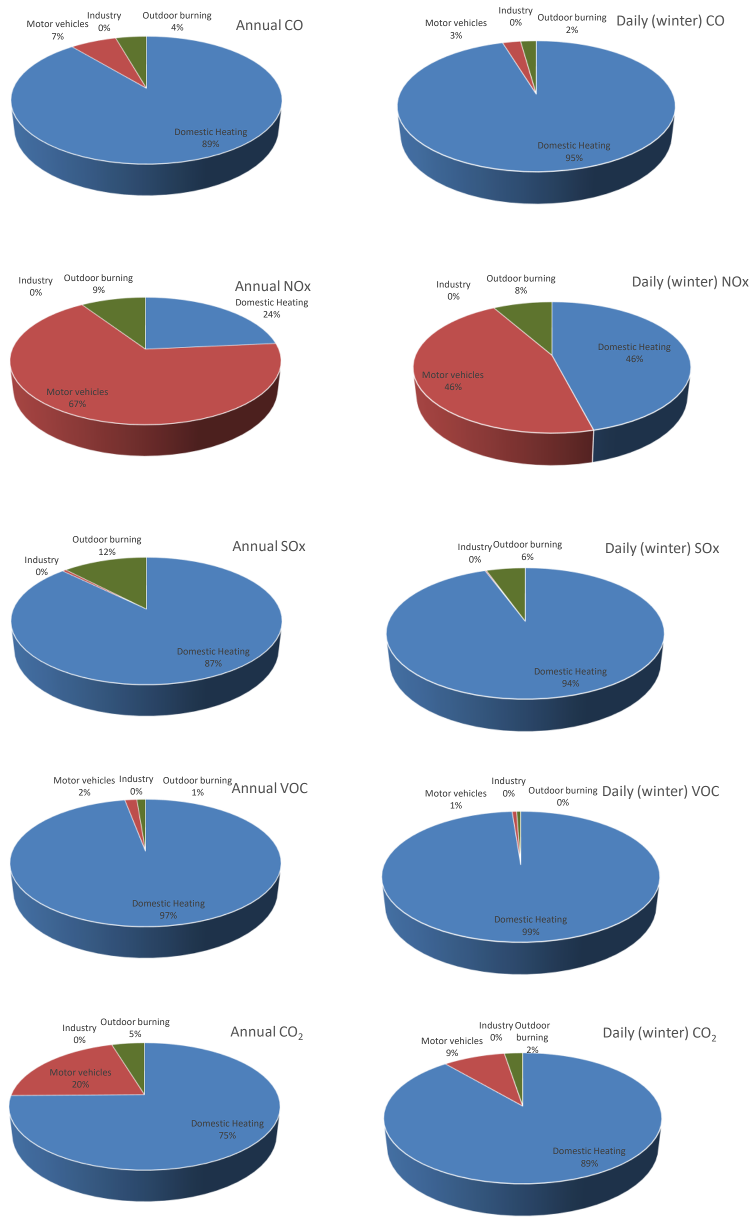

Figure 8.12: Relative contribution of sources to daily winter contaminant emissions in Clyde

Table 8.5: Monthly variations in daily PM_{10} emissions in Clyde.

	Domestic heating		Outdoor burning		Industry		Motor vehicles		Total
	kg/day	%	kg/day	%	kg/day	%	kg/day	%	kg/day
January	0	0%	1	64%	0	0%	0	36%	1
February	0	0%	1	64%	0	0%	0	36%	1
March	0	9%	2	81%	0	0%	0	10%	3
April	3	55%	2	40%	0	0%	0	5%	6
May	28	91%	2	8%	0	0%	0	1%	31
June	35	95%	2	5%	0	0%	0	1%	37
July	36	95%	2	4%	0	0%	0	1%	38
August	32	94%	2	5%	0	0%	0	1%	34
September	11	92%	1	5%	0	0%	0	2%	12
October	4	82%	1	12%	0	0%	0	6%	5
November	1	36%	1	44%	0	0%	0	20%	1
December	0	6%	1	60%	0	0%	0	34%	1
Total kg year	4581	89%	472	9%	0	0%	105	2%	5157

Table 8.6: Daily contaminant emissions from all sources in Clyde (winter average).

	PM_{10}		CO		NOx		SOx	
	kg	g/ha	kg	g/ha	kg	g/ha	kg	g/ha
Domestic home heating	36	110	388	1204	4	11	2	6
Transport	0	1	10	32	4	11	0	0
Industry	0	0	0	0	0	0	0	0
Outdoor burning	2	5	9	27	1	2	0	0
Total	38	117	407	1263	8	24	2	6
	VOC		CO_2		$PM_{2.5}$			
	kg	g/ha	tonnes	kg/ha	kg	g/ha		
Domestic home heating	143	443	11	33	35	110		
Transport	1	3	1	3	0	0		
Industry	0	0	0	0	0	0		
Outdoor burning	1	3	0	1	2	5		
Total	144	448	12	38	37	116		

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APPENDIX A: HOME HEATING QUESTIONNAIRE

Good morning / afternoon/evening - Is this a home or business number?(- terminate if business)

Hi, I'm _________from and I am calling from _____ on behalf of

Can you please confirm you live in Wanaka (or Clyde/ Cromwell).

May I please speak to an adult in your household who knows about your home heating systems? We are currently undertaking a survey in your area on methods of home heating. We wish to know what you use to heat your main living area during a typical year. The survey will take about 5-7 minutes depending on your answers. Is it a good time to talk to you now?

1. (a) Do you use any type of electrical heating in your MAIN living area during a typical year?

(b) What type of electrical heating do you use? Would it be...

- ☐ Night Store
- ☐ Radiant
- ☐ Portable Oil Column
- ☐ Panel
- ☐ Fan
- ☐ Heat Pump
- ☐ Don't Know/Refused
- ☐ Other (specify)

(c). Off the top of your head approximately how much would you spend, on average, per month during the winter, on electricity for space heating?

(d)Do you use any other heating system in your main living area in a typical year? *(If yes then question 2 otherwise Q9)*

2. (a) Do you use any type of gas heating in your MAIN living area during a typical year? *(If No then question 3)*

(b) Is it flued or unflued gas heating? If necessary: (A flued gas heating appliance will have an external vent or chimney)

(c) Which months of the year do you use your gas burner

☐ Jan	☐ Feb	☐ March	☐ April	☐ May	☐ June
☐ July	☐ Aug	☐ Sept	☐ Oct	☐ Nov	☐ Dec

(d) How many days per week would you use your gas burner during

☐ Jan	☐ Feb	☐ March	☐ April	☐ May	☐ June
☐ July	☐ Aug	☐ Sept	☐ Oct	☐ Nov	☐ Dec

(e) Do you use mains or bottled gas for home heating?

(f) Off the top of your head approximately how much would you spend, on average, per month during the winter, on gas for space heating?

3. (a) Do you use a log burner in your MAIN living area during a typical year? (This is a fully enclosed burner but does not include multi fuel burner i.e., those that burn coal) *(If No then question 5)*

(b) Which months of the year do you use your log burner

☐ Jan	☐ Feb	☐ March	☐ April	☐ May	☐ June
☐ July	☐ Aug	☐ Sept	☐ Oct	☐ Nov	☐ Dec

(c) How many days per week would you use your log burner during?

☐ Jan	☐ Feb	☐ March	☐ April	☐ May	☐ June
☐ July	☐ Aug	☐ Sept	☐ Oct	☐ Nov	☐ Dec

d) During the winter what times of the day do you use your wood burner (tick all that apply)

- ☐ 6am - 11am
- ☐ 11am - 4pm
- ☐ 5pm - 10pm
- ☐ 10pm - 6am

e) Approximately what time during the evening would you put your last load on the fire.

(f) How old is your log burner?

12 yrs+
5- 12 yrs old
Less than five years old
Don't know/refused

(g) In a typical year, how many pieces of wood do you use on an average winters day? Interviewers note : winter is defined as May to August inclusive.

(h) ask only If they used their log burner during non winter months How many pieces of wood do you use per day during the other months? Interviewers note : winter is defined as May to August inclusive.

(i) In a typical year, how much wood would you use per year on your log burner? (record wood use in cubic metres - note 1 cord equals 3.6 cubic meters of loosely piled blocks, one trailer equals about 1.65 cubic metres without cage, or 2.2 with cage)

(j) Do you buy wood for your log burner, or do you receive it free of charge?

(k) What proportion would be bought?

l) If you placed your hand on your burner first thing in the morning (e.g., 6am-7am) after having used it the night before would it be?

- ☐ Cold to touch (no feeling of leftover heat)
- ☐ Warm to touch (if you held your hand there for a bit it would warm them up)
- ☐ Hot to touch (too hot to hold a hand on for more than a few seconds)

4. (a) Do you use an enclosed burner which burns coal as well as wood – i.e., a multi fuel burner in your MAIN living area during a typical year? (This includes incinerators, pot belly stoves, McKay space heaters etc but does not include open fires.) *(If No then question 5)*

(b) Which months of the year do you use your multi fuel burner?

☐ Jan	☐ Feb	☐ March	☐ April	☐ May	☐ June
☐ July	☐ Aug	☐ Sept	☐ Oct	☐ Nov	☐ Dec

(c) How many days per week would you use your multi fuel burner during?

☐ Jan	☐ Feb	☐ March	☐ April	☐ May	☐ June
☐ July	☐ Aug	☐ Sept	☐ Oct	☐ Nov	☐ Dec

(d) How old is your multi fuel burner?

(e) In a typical year, how much wood do you use on your multi fuel burner per day during the winter? (ask them how many pieces of wood (logs) they use on an average winters day) Interviewer: Winter is defined as May to August inclusive

(f) ask only If they used their multi fuel burner during non winter months How much wood do you use per day during the other months?

(g) In a typical year, how much wood would you use per year on your multi fuel burner?_____ (record wood use in cubic metres - note 1 cord equals 3.6 cubic meters of loosely piled blocks one trailer equals about 1.65 cubic metres without cage, or 2.2 with

(h) Do you use coal on your multi fuel burner?

(i) How many buckets of coal do you use per day during the winter? (how many buckets of coal used on an average winters day) Interviewer: Winter is defined as May to August inclusive .

(j) Ask only If they used their multi fuel burner during non winter months How much coal do you use per day during the other months?

(k) Do you buy wood for your multi fuel burner, or do you receive it free of charge?

(l) What proportion would be bought?

(m) Off the top of your head approximately how much would you spend, on average, per month during the winter, on wood and coal for space heating?

5. (a) Do you use an open fire (includes a visor fireplace which is one enclosed on three sides but open to the front) in your MAIN living area during a typical year? *(If No then question 6)*

(b) Which months of the year do you use your open fire

☐ Jan	☐ Feb	☐ March	☐ April	☐ May	☐ June
☐ July	☐ Aug	☐ Sept	☐ Oct	☐ Nov	☐ Dec

(c) How many days per week would you use your open fire during?

☐ Jan	☐ Feb	☐ March	☐ April	☐ May	☐ June
☐ July	☐ Aug	☐ Sept	☐ Oct	☐ Nov	☐ Dec

(d) Do you use wood on your open fire?

(e) On a typical year, how much wood do you use per day during the winter? (ask them how many pieces of wood (logs) they use on an average winters day) Interviewer: Winter is defined as may to August inclusive

(f) Ask only If they used their open fire during non winter months How much wood do you use per day during the other months?

(g) In a typical year, how much wood would you use per year on your open fire? (record wood use in cubic metres - note 1 cord equals 3.6 cubic meters of loosely piled blocks one trailer equals about 1.65 cubic metres without cage, or 2.2 with cage)

(h) Do you use coal on your open fire?

(i) How many buckets of coal do you use per day during the winter? (how many buckets of coal used on an average winters day)____ Interviewer: Winter is defined as may to August inclusive

(j) Ask only If they used their open fire during non winter months How much coal do you use per day during the other months?

(k) Do you buy wood for your open fire, or do you receive it free of charge?

(l) What proportion would be bought?

(m) Off the top of your head approximately how much would you spend, on average, per month during the winter, on wood and coal for space heating?

6. (a) Do you use a pellet burner in your MAIN living area during a typical year? *(If No then question 7)*

(b) Which months of the year do you use your pellet burner

☐ Jan	☐ Feb	☐ March	☐ April	☐ May	☐ June
☐ July	☐ Aug	☐ Sept	☐ Oct	☐ Nov	☐ Dec

(c) How many days per week would you use your pellet burner during?

☐ Jan	☐ Feb	☐ March	☐ April	☐ May	☐ June
☐ July	☐ Aug	☐ Sept	☐ Oct	☐ Nov	☐ Dec

(d) How old is your pellet burner?

(f) In a typical year, how many kilograms of pellets do you use on an average winters day? Interviewers note : winter is defined as May to August inclusive.

(g) Ask only If they used their pellet burner during non winter months How many kgs of pellets do you use per day during the other months? Interviewers note : winter is defined as May to August inclusive.

(h) In a typical year, how many kilograms of pellets would you use per year on your pellet burner?

(i) Off the top of your head approximately how much would you spend, on average, per month during the winter, on pellets for space heating?

7. (a) Do you use any other heating system in your MAIN living area during a typical year? *(If No then question 8)*

(b) What type of heating system do you use (if they respond with diesel or oil burner go to question c otherwise go to Q8)

(c) Which months of the year do you use your oil burner

☐ Jan	☐ Feb	☐ March	☐ April	☐ May	☐ June
☐ July	☐ Aug	☐ Sept	☐ Oct	☐ Nov	☐ Dec

(d) How many days per week would you use your diesel/oil burner during?

☐ Jan	☐ Feb	☐ March	☐ April	☐ May	☐ June
☐ July	☐ Aug	☐ Sept	☐ Oct	☐ Nov	☐ Dec

(e) How much oil do you use per year ?

8. a) Do you use a wood fuelled cooking appliance during a typical year? (This is an appliance primarily used for cooking includes an oven and hot plate) Interviewers-pot belley stoves, chip heaters or wood burners are not wood fired cookers

b) Which months of the year do you use your wood fueled cooker?

☐ Jan	☐ Feb	☐ March	☐ April	☐ May	☐ June
☐ July	☐ Aug	☐ Sept	☐ Oct	☐ Nov	☐ Dec

☐ (c) How many days per week would you use your wood fueled cooker?

☐ Jan	☐ Feb	☐ March	☐ April	☐ May	☐ June
☐ July	☐ Aug	☐ Sept	☐ Oct	☐ Nov	☐ Dec

d) how old is your wood fired cooker

(e) In a typical year, how many pieces of wood do you use on an average winters day on your wood fired cooker? Interviewers note : winter is defined as May to August inclusive.

8. Does your home have insulation?

- ☐ Ceiling
- ☐ Under floor
- ☐ Wall
- ☐ Cylinder wrap
- ☐ Double glazing
- ☐ None
- ☐ Don't know
- ☐ Other

10. Do you burn rubbish or garden waste outside in the open or an incinerator or rubbish bin?

(If 3 skip to Demographics)

a) How many days would you burn waste or garden rubbish outdoors during winter? Interviewer note: Winter is defined as June, July and August.

b) How many days would you burn waste or garden rubbish outdoors during Spring? Interviewer note: Spring is defined as September to November.

c) How many days would you burn waste or garden rubbish outdoors during Summer? Interviewer note: Summer is defined as December to February.

d) How many days would you burn waste or garden rubbish outdoors during Autumn? Interviewer note: Autumn is defined as March to May.

(e) How many cubic metres of garden waste or other material would be burnt per fire on average.

DEMOGRAPHICS We would like to ask some questions about you now, just to make sure we have a cross-section of people for the survey. We keep this information strictly confidential.

- D1. Would you mind telling me in what decade/year you were born ?
- D2. Which of the following describes you and your household situation?
- Single person below 40 living alone
- Single person 40 or older living alone
- Young couple without children

Family with oldest child who is school age or younger

Family with an adult child still at home

- Couple without children at home
- Flatting together
- Boarder
- D3 With which ethnic group do you most closely relate?
- Interviewer: tick gender.
- D4 How many people live at your address?
- D5 Do you own your home or rent it?
- D6 Approximately how old is your home?

D7 How many bedrooms does your home have?

D8 How long have you lived in this house

1	1 – 2 years
2	3 – 5 years
3	6 -7 years
4	8 – 9 years

5	10 – 14 years
6	15 – 20 years
7	20+ years
98	Don't know/Refused

D9 How would you rate the level of warmth in your home during winter

1	Too cold
2	Adequate
3	Warm
98	Don't know/ refused

D10. If used wood for heating - Do you check the moisture content of your wood

1	Yes
2	No
97	Refused/not sure

D11. If yes to D11 – How do you evaluate the moisture content?

1	Visual inspection for cracks
2	Moisture meter
90	Other specify
98	Don't know/Refused

D12. Can you tell me the household annual income – if boarder refer to personal income

APPENDIX B: EMISSION FACTORS FOR DOMESTIC HEATING.

Emission factors were based on the review of New Zealand emission rates carried out by Wilton et al., (2015) for the Ministry for the Environments air quality indicators programme. This review evaluated emission factors used by different agencies in New Zealand and where relevant compared these to overseas emission factors and information. Preference was given to New Zealand based data where available including real life testing of pre 1994 and NES compliant wood burners (Wilton & Smith, 2006; Smith, et. al., 2008) and burners meeting the NES design criteria for wood burners (Bluett, Smith, Wilton, & Mallet, 2009; Smith, Bluett, Wilton, & Mallet, 2009).

The PM_{10} open fire emission factor was reduced in the review relative to previous factors. Some very limited New Zealand testing was done on open fires during the late 1990s. Two tests gave emissions of around 7.2 and 7.6 g/kg which at the time was a lot lower than the proposed AP42 emission factors (http://www.rumford.com/ap42firepl.pdf) for open fires and the factors used in New Zealand at the time (15 g/kg). An evaluation of emission factors for the 1999 Christchurch emission inventory revised the open fire emission factor down from 15 g/kg to 10 g/kg based on the testing of Stern, Jaasma, Shelton, & Satterfield, (1992) in conjunction with the results observed for New Zealand (as reported in Wilton, 2014). The proposed AP42 emission factors (11.1 g/kg dry) now suggest that the open fire emission factor may be lower still and closer to the result of the limited testing carried out in New Zealand. Consequently a factor of 7.5 g/kg for PM_{10} (wet weight) is proposed to be used for open fires in New Zealand based on the likelihood of the Stern et al., (1992) data being dry weight (indicating a lower emission factor), the data supporting a proposed revised AP 42 factor and the results of the New Zealand testing being around this value. It is proposed that other contaminant emissions for open fires be based on the proposed AP42 emission factors adjusted for wet weight.

The emission factor for wood use on a multi fuel burner was also reduced from 13 g/kg (used in down to the same value as the pre 2004 wood burner emission factor (10 g/kg). The basis for this was that there was no evidence to suggest that multi fuel burners burning wood will produce more emissions than an older wood burner burning wood.

Emission factors for coal use on a multi fuel burner are based on limited data, mostly local testing. Smithson, (2011) combines these data with some further local testing to give a lower emission factor for coal use on multi fuel burners. While these additional data have not been viewed, and it uncertain whether bituminous and subbituminous coals are considered, the value used by Smithson has been selected. The Smithson, (2011) values for coal burning on a multi fuel burner have also been used for PM_{10}, CO and NOx as it is our view that many of the more polluting older coal burner (such as the Juno) will have been replaced over time with more modern coal burners.

No revision to the coal open fire particulate emission factor was proposed as two evaluations (Smithson, (2011) and Wilton 2002) resulted in the same emission factor using different studies. Emissions of sulphur oxides will vary depending on the sulphur content of the fuel, which will vary by location. A value of 8 g/kg is proposed for SOx based on an assumed average sulphur content of 0.5 g/kg and relationships described in AP42 for handfed coal fired boilers (15.5 x sulphur content).

Emission factors for $PM_{2.5}$ are based on 100% of the particulate from wood burning being in the $PM_{2.5}$ size fraction and 88% of the PM_{10} from domestic coal burning. The $PM_{2.5}$ component of PM_{10} is typically expressed as a proportion. The AP42 wood stove and open fire proportion is based on 1998 data and given as 93% of the PM_{10} being $PM_{2.5}$ (http://www.epa.gov/ttnchie1/efdocs/rwc_pm25.pdf). Smithson, (2011) uses a proportion of 97% which is more consistent with current scientific understanding that virtually all the particulate from wood burning in New Zealand is less than 2.5 microns in diameter (Perry Davy, pers comm, 2014). Literature review of the proportion of PM_{10} that was $PM_{2.5}$ returns minimal information for domestic scale wood use. The technical advisory group to the Ministry for the Environment (2014) air quality indicators project on emissions advised their preference for a value of 100% and we have opted for this value for subsequent work because information is indicative of a value nearing 100%. Further investigations into this may be warranted in the future given the focus towards $PM_{2.5}$. A value of 88% from Ehrlich & Kalkoff, (2007) was used for the proportion of PM_{10} in the $PM_{2.5}$ size fraction for small scale coal burning.

An emission factor of 0.5 g/kg was proposed for NOx from wood burners based on the AP42 data because the non-catalytic burner measurements were below the detection limit but the catalytic converter estimates (and conventional burner estimates) weren't. This value is half of the catalytic burner NOx estimate.

A ratio of 14 x PM_{10} values was used for CO emission estimates as per the AP42 emissions table for wood stoves. This is selected without reference to any New Zealand data owing to the latter not being in any publicly available form.

APPENDIX C – ANALYSIS OF ADDITIONAL INFORMATION

Table 1 shows that proportion of firewood burnt on wood burners that is bought versus self-collected for the four urban areas. Table 2 shows the amount of insulation in dwellings in Wanaka, Cromwell and Clyde. The prevalence of double glazing is high with 76% of dwellings in Wanaka and 65% in Cromwell and Clyde having double glazing. The majority of dwellings have ceiling and wall insulation.

Table 0.1:: Proportion of wood used on wood burners that is bought and self-collected

Firewood	Wanaka	Cromwell/ Clyde
Bought	79%	68%
Self-collected	21%	32%

Table 0.2:: Prevalence of household insulation by type

Household insulation	Wanaka		Cromwell		Clyde	
	Households	%	Households	%	Households	%
Ceiling	3198	96%	1882	96%	499	96%
Underfloor	1849	55%	833	42%	221	42%
Wall	2963	89%	1601	82%	424	82%
Cylinder wrap	1085	32%	530	27%	141	27%
Double glazing	2538	76%	1283	65%	340	65%
None	47	1%	5	0%	1	0%
Don't know	38	1%	48	2%	13	2%
Other	208	6%	186	9%	49	9%

Table 0.3:: Do you check the moisture content of your wood and if so how?

	Wanaka	Cromwell/ Clyde
Proportion that check wood	39%	40%
Visual inspection	18%	25%
Moisture meter	23%	9%
Other specify	60%	66%
Don't know/Refused	0%	0%

Around 40% of households that reported that they check the moisture content of the wood (Table 3). The most common response in the "other" category, was that they purchased the wood dry from the supplier or that they seasoned the wood themselves by keeping it for year or more before using. A number of households also measured the weight of the wood as a method of checking the moisture content.

Tables 4 to 6 summarise level of warmth, age of dwelling and length of time in a dwelling. Only 7% of households in Wanaka and 6% of households in Cromwell and Clyde reported their home warmth as being inadequate.

Table 0.4: How would you rate the level of warmth in your home during winter?

	Wanaka Households	Arrowtown Households	Milton Households
Too cold	123	53	14
Adequate	670	318	84
Warm	1038	573	152
Unsure/ refused	0	0	0

Table 0.5: How old is your dwelling?

	Wanaka %	Cromwell %	Clyde %
10 years or less	31%	25%	25%
11 - 20 years	31%	28%	28%
21 - 40 years	25%	25%	25%
41 + years	12%	20%	20%
Refused/not sure	1%	3%	3%

Table 0.6: How long have you lived in this dwelling

	Wanaka	Cromwell/ Clyde
1 - 2 years	21%	10%
3 - 5 years	16%	16%
6 -7 years	10%	8%
8 - 9 years	6%	3%
10 - 14 years	16%	22%
15- 20 years	16%	21%
20+ years	16%	20%
Don't know/Refused	<1%	1%

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Evaluation of technologies for reducing particulate emissions in Otago Airsheds

EXECUTIVE SUMMARY

The main air quality concern in urban towns in the Otago Region is concentrations of particles in the air (PM_{10} and $PM_{2.5}$). Concentrations exceed National Environmental Standards (PM_{10}) and proposed standards ($PM_{2.5}$) regularly during the winter months in many areas. Air emission inventories have identified domestic heating as the main source of anthropogenic PM_{10} emissions in towns where these studies have been carried out.

The use of technology targeting domestic scale wood burning has been a focus for management intervention over the last decade as traditional wood burner designs are likely ineffective in achieving further reductions beyond an emission limit of 1.5 g/kg. A number of technologies were identified in an early review (Wilton, 2012) including down draught burners, electrostatic precipitators, automated air flow burners and catalytic converters. However, was uncertain whether these would be effective, feasible or economically viable solutions.

Environment Canterbury introduced the ULEB criteria to provide a market for new technology in Canterbury and included regulations allowing only the installation of ULEB in some airsheds. At the time of introduction, it was unclear if any wood burners would be able to meet the specified emission limit.

The technologies now available for domestic scale solid fuel burning has advanced and many burners have been authorised as ULEB. Some are imported and others manufactured in New Zealand. Historical differentials with price are no longer significant with a number of new technology burners available at prices similar to traditional wood burners. The main limitations with burners currently on offer are heat output range, with lower cost models typically available only at higher heat outputs, and only a few models of insert appliances or wetbacks. A number of burners are marketed as being capable of an overnight burn and include technologies that support the potential for this.

A key limitation that requires addressing is the extent to which the new technology results in improvements in real life emissions. Some real-life emissions testing carried out on the early model down draught burners shows the burners to result in real life improvements in emissions. However, recent approved ULEB include burner designs with no significant technological features differentiating them from traditional burners. The extent to which these burners include sufficient technological advancements as to minimise the potential for significantly increased operational emissions, as seen with traditional burners, is unclear. Testing of the real-life emissions from other technologies such as the catalytic converters and automated airflows is also required.

A second information gap is the impact of ULEB for the different in Otago Airshed and how the technology could be best adopted to assist with airshed improvements. This gap could be addressed through projections modelling for airsheds that have air emission inventory data but requires knowledge of the real-life emissions from ULEB prior to assessments being carried out.

The adoption of ULEB technology in the Otago Region had the potential to significantly improve air quality in urban towns. Addressing the information gaps identified would assist the Otago Regional Council with effective air quality management and would contribute to the knowledge base around the impacts of technology.

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1 INTRODUCTION

Air quality is a concern in many urban towns in the Otago Region. In particular, concentrations of PM_{10} and $PM_{2.5}$ (particles in the air less than 10 microns and 2.5 microns in diameter respectively) exceed National Environmental Standards or proposed standards ($PM_{2.5}$) regularly during the winter months. Locations where exceedences have been measured include Alexandra, Arrowtown, Milton, Mosgiel, Clyde, Cromwell, Laurence, Oamaru and Balclutha.

Air emission inventories have identified domestic heating as the main source of anthropogenic PM_{10} emissions in Alexandra, Arrowtown, Milton, Mosgiel, Clyde and Cromwell. In Milton industrial emissions were also a significant contributor to PM_{10} contributing 16% of the daily winter concentrations on average.

The Otago Regional Council has gazetted three Air Zones for the management of air quality and in particular concentrations of PM_{10} in the Region. These are:

- Air Zone 1: Alexandra, Arrowtown, Clyde and Cromwell.
- Air Zone 2: Balclutha, Dunedin, Hawea, Kingston, Milton, Mosgiel, Naseby, Oamaru, Palmerston, Port Chalmers, Queenstown, Ranfurly, Roxburgh, Waikouaiti and Wanaka.
- Air Zone 3: The rest of Otago.

Measures have been adopted in the Otago Regional Air Plan to manage air quality within the Airsheds with Air Zone 1 implementing the most stringent measures because of the extent of air quality degradation historically. Despite these measures being adopted air quality in many urban areas remains in breach of the NES for PM_{10} and could also be in breach of the proposed NES for $PM_{2.5}$.

The Regional Council has developed an air quality strategy which aims to revisit the approach to air quality management to effectively address air quality issues and ensure that air is safe to breathe for everyone, and at any time in Otago. The strategy includes a range of measures including improving understanding of the connection between housing quality, air quality and human health and partner with central government and other regional councils to promote affordable clean heating technologies.

The purpose of this study is to identify information gaps which if addressed would provide opportunities in the clean heating technologies sphere for addressing air quality issues for the Otago Region. The focus of the technology review is on domestic heating as this is the main source of issues with particulate pollution in the Region. Emerging technologies in other areas are identified where these target particulate matter in a manner relevant to the Otago airsheds. It is noted that Council policy has resulted in improvements in industrial emissions through technology and fuel switching in many urban areas and the contribution of other sources to airshed emissions is not typically significant.

2 DOMESTIC SPACE HEATING TECHNOLOGY

2.1 Introduction

The adoption of low emission technology for wood burners as a result of the implementation of Air Plans or through the National Environment Standard specifications has resulted in improvements in emissions in many urban areas of New Zealand. Historically these relied on AS/NZS 4012 and 4013 which specify test methodology for emissions and efficiency from domestic scale solid fuel burners.

The National Environmental Design Standard for wood burners (1.5 g/kg particulate and 65% efficiency when tested to AS/NZS 4013/4012) was introduced with an aim to reduce particulate emissions from wood burners in urban areas of New Zealand through improved burner technology. The use of particulate emission limits and associated burner design characteristics has contributed to reductions in airshed PM_{10} in a number of locations in New Zealand. Ongoing real life improvements through use of older technology, and the 4013/4012 test method and criteria are unlikely, however, because of the impact of behavioural aspects of burner operation and potential variability in fuel quality.

To address this issue, Environment Canterbury introduced the Canterbury Test Method which aims to test burners under conditions closer to real life operation. In addition to the test method they specified that for a burner to be classified as an Ultra-Low Emission Burner it had to meet an emission limit of 0.5 g/kg of particulate. The objective of the method was to encourage technology that would be more effective in addressing real life emissions including the operational aspects resulting in higher emissions. Burners complying with this limit when tested to the Canterbury Method are referred to as ULEB.

The ULEB criteria was introduced following an evaluation of domestic scale wood burner technology and associated emissions (Wilton, 2012). The review identified a range of emerging domestic scale technologies with the potential for lower emissions. These included down draught burners, electrostatic precipitators, automated air flow burners, catalytic converters. At the time of that review, it was unclear if any of these technologies would meet the ULEB criteria or provide feasible domestic scale wood burning options for New Zealand.

2.2 How the standards relate to the Otago Airsheds

The emission limit set for Air Zone 1 is 0.7 g/kg of particulate for wood burners when tested to NZS 4013. This is lower than the NES design criteria for wood burners of 1.5 g/kg.

This setting of this emission limit has not been effective in reducing concentrations of PM_{10} in Air Zone 1 to meet the NES for PM_{10} (50 µg/m^3, 24-hour average)

In other Air Zones the NES design criteria for wood burners (1.5 g/kg emission limit and 65% efficiency) is the standard for new installations of wood burners.

2.3 Technology of ULEB – wood burners

2.3.1 Down Draught Burners

The first generation ULEB were authorised between 2014 and 2016 and included the Rias Bionic, Jayline Watherm, Xeoos and the TropicAir Duo. Prices ranged from around $7000 - $11,000 per unit excluding flue kits ($650-$800) and installation. These burners all utilised down draught technology with secondary combustion chambers. The Rias Bionic had the additional feature of automated switch to down draught mode.

Since these models were authorised additional down draught burners have been approved. These include the Masport Cromwell and Mystique, Jayline UL200, Tropicair Duo and Rua and the Harris Ferva Saturn. Two down draught burners are priced at around $4000 (excl flue and installation).

Down draught burners are suitable for installation in Otago Airsheds as they provide similar heating characteristics to existing burners but with lower emissions. The main drawback historically was cost but with a few models available at $4000 the price point differential is not as extreme but still in excess of $1000 more than the lower cost traditional burners.

2.3.2 Catalytic converters

A number of ULEB have been authorised based on catalytic converter technology. Several Blaze King models have been introduced to the New Zealand market and are priced from around $5000 to $5700 (excluding flue and installation). Blaze King has the addition of a thermostatically controlled air supply, based on the temperature of the room. This provides benefits to the user in terms of maintaining room comfort.

Masport New Zealand produces a range of ULEB which utilise catalytic converters to achieve low emissions. These range in price from around $2790 to $4500 (excluding flue and installation).

The catalytic burner technology options are both suitable for Otago Airsheds and available at reasonable prices for wood burners relatively.

It is unclear how the catalytic burner technology performs in real life, when operated by the householders.

2.3.3 Heat storage and release burners

Two heat storage and release burners, more commonly known as tile fires in Europe, have been authorised as ULEB. The T-Sky eco2 and T-Art eco 2 contain ceramic or natural stone which absorbs heat from the fire which is slowly released back into the room after combustion has ceased. The units burn around six kilograms of wood per burn cycle (around two hours), which produces heat for 6-9 hours. The heat output averages around 2.6-2.8 kW (19-20 kWh) including the heat release period, and around 10 kW during the burn cycle. The efficiency ranges from around 81-84%, meaning they are more cost effective to run than most wood burners in terms of cost per kWh.

The units weigh 300-400 kilograms compared with around 150 kilograms for a more conventional style burner. They are made in Switzerland and shipped to New Zealand following order, so there is a delay of around four months.

Historically heat storage fires (also known as tile fires) have been more suited to new builds where allowance in the house design caters for the additional space required for the heat storage mass. However, these units appear to spread the mass vertically and may therefore be more suited to retrofit scenarios. The units are feasible heating methods for Otago towns for households that can afford the capital cost of around $15,000 per unit. Cost is a likely limitation of uptake. They have the benefit of slow release of heat unattended, potentially overnight, which is a characteristic of value when temperatures are sub-zero, although the heat released post combustion (unoperated) is much lower than during the burn cycle. Thus, poorly insulated dwellings may not benefit sufficiently from the overnight heat release.

No real life testing of heat storage burners has been carried out in New Zealand.

2.3.4 Other authorised ULEB burners

A number of burners have been authorised as ULEB which appear to contain no substantive technology shifts, rather relying on optimisation of previous designs with variability in features such as air supplies to the combustion chamber.

These burners range in price from $2700 to $4300 and would be suitable for the Otago Airsheds.

A key concern with these burners is whether the design/ technology is adequate to minimise the impact of household operation, a key behavioural component influencing real life emissions and driving the introduction of the ULEB process.

2.3.5 Automated air control

The use of automated air supply to the firebox to optimise combustion conditions is the technology adopted in two Pyroclassic burners authorised as ULEB. These burners have heat outputs ranging from 10 to 16 kW and priced from $3200 to $3700 per unit excluding flue and installation costs. The technology is suitable to the Otago Region.

2.4 ULEB boilers

Two domestic scale wood boilers have also been authorised as ULEB providing a wood burning heat source for central heating systems. The two brands of boiler approved as ULEB are Fruling and ETA. A number of pellet-fuelled boilers have also been authorised as ULEB. Domestic scale boiler systems heat hot water for circulation throughout a house (via radiators) and are typically located outside of the main living areas (e.g., in a garage).

The authorised boilers come in a range of heat outputs for each brand (15kW – 60 kW) and have gasification systems and automated air flows to achieve low emissions. The benefits to users of boiler systems are load and leave, long burn times between refuelling, whole house heating and alternative space utilisation in living areas. The draw backs are cost of the whole system including boiler ($26,000 - $32,000), radiators and installation. Operational costs are also likely to be higher owing to the need to burn more fuel to provide heat to the whole house.

2.5 Pellet fires and boilers

Pellet fires meeting the NES and ULEB emissions standards have been available on the market in New Zealand for some time. The Environment Canterbury burner authorisation website (Environment Canterbury, 2016) identifies more than 40 pellet burners or boilers that meet the ULEB emission criteria.

The technology that results in lower emissions for pellet fires is both the fuel and the ability to automate the loading or supply of fuel to the combustion chamber.

Pellet fires are not a popular heating method in New Zealand with typically less than 4% of households using them. The cost of the pellets and reliance of pellet suppliers appears to be a key deterrent.

2.6 ULEB authorised secondary technology for domestic burners

Secondary technology refers to devices used to scrub emissions post combustion and in this instance is used to include secondary controls that may be applied to existing wood or coal burners to reduce particulate emissions.

The Oekotube is the only authorised ULEB secondary technology. It utilises electrostatic precipitation (ESP) to remove particles from the air flow through the chimney and is available for purchase in New Zealand. Tests done on the Oekotube in New Zealand suggest that it is an effective method for reducing particulate emissions from both wood and coal. Appendix C contains further technical details of the Oekotube including its estimated particle reduction efficiency based on New Zealand testing.

The cost is around $2800 + GST for an individual unit (plus installation if applicable) but discounts may be available for bulk purchases. Some maintenance is required.

The Oekotube can be applied to an existing NES compliant burner and be considered to have emissions equivalent of a ULEB under the Environment Canterbury authorisation process. Whilst this may suit certain applications it would seem likely that general uptake would be limited by the lack of price differential between the purchase of a new burner and the purchase of the Oekotube.

2.7 Summary - feasibility for Otago Airsheds

All the technologies authorised as ULEB would be feasible as home heating methods for the Otago Airsheds although cost may be a limiting factor in uptake for particular models. Overall, however, a good range is available in terms of heat output and cost and the availability of boiler systems provides for whole house solutions beneficial in cold climates. The range of appliances approved now includes a wetback and an inbuilt model. Whilst this is a step towards increasing versatility in the market at present homeowners wanting an inbuilt are limited in heat output (14 kW) and those wanting a wetback to 16 kW. It is likely that the list of ULEB authorised will continue to grow and with it the versatility and options for households should increase.

The practicalities of most technology are not significantly different to an older style burner, although additional measures such as switching on the catalytic converter may be required. A number of the ULEB are promoted on the basis of being able to achieve an overnight burn, which is a characteristic highly valued in many Otago towns because of sub-zero overnight temperatures.

A few ULEB (e.g., the Jayline Waltherm) require electricity to operate and this may be seen as an issue in areas where there are concerns around electricity supply and power cuts.

The two key uncertainties relating to the adoption of ULEB technology in the Otago Airsheds is the real-life emissions and the extent to which introducing them as emission limits for new installations with or without the regulatory phase out of non-complying burners might result in compliance with National Environment Standards in each Airshed.

The extent to which the various technologies will result in improvements in particulate emissions when operated by the householder in real life settings can be assessed through real life testing programmes which involve measuring emissions for a number of households operating these burners. Once the average emission levels for ULEB burners have been established, the impact of introducing the technology on PM_{10} and $PM_{2.5}$ concentrations for airsheds where air emission inventory data are available can be evaluated.

3 COMPARATIVE COSTS

3.1 Capital costs

The purchase of a domestic burner includes the purchase price of the burner, the flue kit and installation costs. Appendix A outlines the capital costs for ULEB on the market currently. Flue costs are typically around $800 - $1200. Installation costs will vary but could be around $1200.

In addition to burner costs, some of the heavier burner models such as heat storage and release and down draught burners may require floor strengthening to allow for their installation. These costs will vary depending on the strengthening required.

3.2 Operational costs

The operating costs for a wood burner depend on a number of variables including the operation, heat output, fuel type and quality and burner efficiency. The operation costs will in most instances be similar to a non-ULEB of a similar heat output. In a few instances the ULEB technology has associated efficiencies, for example the tile fires, which may reduce heating costs. Consumer New Zealand report a range for pinewood in a wood burner from 10 c/kWh to over 40 c/kWh nationally. In Otago the cost of wood typically is in the 11 – 18 c/kWh range depending on wood type.

Several pellet fires are authorised as ULEB. These typically have higher operational costs at around 20 - 30c/kWh in Otago.

Some ULEB may result in slightly higher maintenance costs because of the additional expertise and maintenance requirements.

Table 3.1 compares the cost of heating using different methods nationally.

Table 3-1: Operating costs for home heating fuels in New Zealand (Consumer, 2020 www.consumer.org.nz)

	National Median c/kWh	National Approximate range c/kWh
Wood	20	11-53
Flued gas (LPG)	30	27-34
Electricity – resistance	26	16-42
Electricity – heat pump	10	7-15

4 EMERGING AND OTHER TECHNOLOGIES

The range of combustion and secondary technologies available for reducing particulate emissions internationally does not appear to have evolved much in recent years. Previous evaluations of potential technology solutions for domestic scale devices have identified catalytic converters and electrostatic precipitator technologies (both now included with authorised ULEB). Wood gasification has been an emerging technology in the industrial sphere and has now been applied to domestic boilers as ULEB also. These technologies are now likely to be providing feasible options for emissions reductions for domestic scale devices.

Hydrogen and fuel cell technologies provide alternative non carbon-based options for heating but do not appear to be favoured for advancement in Europe. Existing fuel cells have built-in reformers that produce hydrogen from natural gas. Alternative fuels such as hydrogen produced from a low-carbon energy source could be used to power fuel cells in the future. Natural gas networks are not available in the Otago Region.

District heating schemes are not new or emerging technology but are an option used in overseas countries to achieve efficiencies. New technologies in the delivery of energy (minimising transmission energy loss) may assist with the feasibility of district energy schemes.

There are many emerging energy sources targeting electricity generation in the energy sector. These are outside of the scope of domestic scale heating as electricity is available in Otago and does not contribute to localised particulate issues.

5 KNOWLEDGE GAPS

Evaluation of knowledge gaps focuses on areas likely to provide benefits in terms of air quality rather than climate or energy related benefits.

In our view, the priority area for evaluation is the real life emissions from ULEB technologies other than down draught burners (assessed by Environment Canterbury and Bay of Plenty Regional Council). We recommend focusing on the catalytic converter technology, the automated airflow technology and the traditional burner design technologies that are now authorised as ULEB. Appendix B summarises the different burners authorised with these technologies.

An alternative information gap that is relevant to the Otago Airsheds is the impact of burner design and technology on emissions of hazardous air pollutants such as benzo(a)pyrene as this may be an emerging issue in wood smoke environments.

A further information gap is the extent to which improvements in Otago towns may occur as a result of the implementation of measures to transition households to ULEB. Measures could limit the installation of new burners to ULEB or limit the installation of new burners to ULEB and phase out older technology. Bridging this information gap robustly requires better information on the real life emissions from a range of ULEB burners. Thus the priority information gap in our view is the testing of real life emissions from ULEB.

APPENDIX A: HEAT OUTPUTS AND COSTS - ULEB

Fire	Reported kW rating	Indicative Price*	Technology
Bionic Fire Studio	4.6	$9,900	Down draught
RAIS Bionic Fire	8.5	$7,950	Down draught
T-ART	2.8	$14,944	Tile fire
T-SKY eco 2	2.8	$14,944	Tile fire
Masport Cromwell	13.3	$4,899	Down draught
Masport Mystique	16.2	$5,877	Down draught
Masport Rakaia	8.4	$4,499	Catalytic converter
Masport Rangitata Beveled (Inbuilt)	14	$2,699	Traditional burner
Masport Waimakariri ASH	Not reported	$3,284	Catalytic converter
Masport Waimakariri LEG	Not reported	$2,899	Catalytic converter
Masport Waimakariri PED	Not reported	$2,790	Catalytic converter
Firenzo Lady Kitchener Ultra (Drawer)	23		Traditional burner
Firenzo Lady Kitchener Ultra (Leg)	23	$4,337	Traditional burner
Firenzo Lady Kitchener Ultra (Pedestal)	23	$4,337	Traditional burner
Firenzo Lady Kitchener Ultra (Platform)	23	$4,337	Traditional burner (wetback option)
Blaze King Chinook CK20.NZ	9.7	$5,299	Catalytic converter and automatic thermostat - air controls
Blaze King Chinook CK30.NZ	9.2	$5,699	Catalytic converter and automatic thermostat - air controls
Blaze King Sirocco SC20L.NZ	9.7	$4,999	Catalytic converter and automatic thermostat - air controls
Blaze King Sirocco SC20P.NZ	9.7	$4,999	Catalytic converter and automatic thermostat - air controls
Blaze King Sirocco SC30L. NZ	9.2	$5,299	Catalytic converter and automatic thermostat - air controls
Blaze King Sirocco SC30P. NZ	9.2	$5,299	Catalytic converter and automatic thermostat - air controls
Metro Ultra Insert (Inbuilt)	15	$4,299	Traditional burner
Metro Ultra Tiny Rad	11		Traditional burner

Metro Ultra Xtreme Rad	20	$3,299	Traditional burner
Metro Wee Rad Ultra	15	$2,675	Traditional burner
Pyrclassic IV	15	$3,699	Automated air control
Pyroclassic Mini	10	$3,199	Automated air control
Jayline UL200	13	$3,999	Down draught
Jayline Walltherm Air	14.9	$5,998	Down draught
Xeoos Twinfire X8	8	$6,950	Down draught
Tropicair Duo	18	$5,490	Down draught
Tropicair Duo Wet	18	$5,950	Down draught
Tropicair Rua	9.9	$3,990	Down draught
Harris Ferva Saturn	18.9	$5,299	Down draught
Woodsman Serene	16	$3,399	Traditional burner
Woodsman Serene WB	16	$3,698	Traditional burner

* excludes installation, flue kit and extras. In some case prices is base case price and additional charges may be incurred depending on options selected.

APPENDIX B: TECHNICAL DETAIL - OEKOTUBE

The Oekotube uses electrostatic precipitation to reduce particulate concentrations in the chimney and has been designed for use with small scale burning devices up to 40 kW heat output. It removes particles using a high voltage electrode which releases electrons into the chimney space containing the particles. The particulates become polarised and move towards, and accumulate into coarser material on, the chimney wall.

Accumulated material is removed by a chimney sweep or if the mass of material on the chimney wall reaches a critical point prior to cleaning, particles can they detach from the inner flue pipe wall and exit the flue system or may drop back down the chimney. Particles leaving the chimney will most likely be of sufficient size to settle on the dwellings roof or deposit within a short distance of the chimney.

Electrostatic precipitators (ESP) are unlikely to remove the volatiles that are in gaseous forms when passing the ESP that will condense out to form particulates at lower temperatures. The effectiveness of the OekoTube in reducing PM_{10} from domestic heating is therefore likely depend on the proportion of volatiles in the air stream and the temperature of the flue at the point where the ESP is functioning.

A number of studies of the effectiveness of the Oekotube on wood or coal burners have been carried out in New Zealand in recent years (Spectrum Laboratories, 2015; Wilton, 2014). These include initial testing of effectiveness on wood burners done by Environment Canterbury (unpublished), testing of effectiveness on coal burners, Wilton, (2014) and more recently additional testing of effectiveness on wood burners (Spectrum Laboratories, 2015). Average burn cycle particle reduction efficiency of around 58% were indicated. The effectiveness was greatest when the fire was operated at a low burn setting and when emissions would otherwise have been greatest.

REFERENCES

Spectrum Laboratories. (2015). *Draft Report 0407 Oekotube Testing*. Spectrum Laboratories.

Wilton, E. (2012). *International review of best technology for low emission wood burners*. Environment Canterbury.

Wilton, E. (2014). *Evaluation of the effectiveness of the OekoTube ESP in the management of PM10 in Reefton*. West Coast Regional Council.

7.6. Urban Monitoring Quarterly Update

Prepared for:	Data and Information Committee
Report No.	SPS2109
Activity:	Governance Report
Author:	Kyle Balderston, Team Leader Urban Growth and Development
Endorsed by:	Gwyneth Elsum, General Manager Strategy, Policy and Science
Date:	2 March 2021

PURPOSE

[1] To note the first quarterly monitoring report, as required by Clause 3.9 of the National Policy Statement on Urban Development 2020.

EXECUTIVE SUMMARY

[2] This report presents the initial Quarterly Monitoring Report produced by ORC, as required by the National Policy Statement on Urban Development 2020 (NPSUD). The report covers the period up to and including the fourth quarter of 2020.

[3] The indicators covered in the report suggest that both housing demand and supply in Otago have increased steadily since 2002. From 2014, housing demand accelerated further, and while supply initially responded it has not kept up with demand. Prices are now rising fast, albeit not entirely due to supply issues. These price impacts were being felt earliest and hardest in Queenstown-Lakes District, but all parts of the region are being impacted.

[4] Future reports will update the key datasets presented in this report and explore new or relevant data as it comes to hand, including that under development or refined in partnership with the region's TA's.

RECOMMENDATION

That the Committee:

1) ***Receives*** *this report.*

DISCUSSION

[5] The report covers a range of key NPSUD price and market efficiency indicators, at a high level and mostly looks backwards over the last 10 to 20 years. The NPSUD required that the reports cover the following matters:

i. The demand for dwellings;
ii. The supply of dwellings;
iii. Prices of, and rents for dwellings;
iv. Housing affordability;
v. Housing capacity realisation in greenfields and brownfields areas; and
vi. Available data on business land.

[6] All the region's local authorities with Tier 2 (Dunedin City and Queenstown Lakes District) and Tier 3 (Central Otago and Waitaki District) Urban Environments are required to undertake this monitoring for the urban environments in their district or region. Clutha District (which does not contain any urban environments) has been included for completeness, and where Waitaki District data is included, this covers the whole district including that within Canterbury Region.

[7] Local authorities are jointly responsible for monitoring urban environments within their region or district. The regions TA's are continuing to develop their approach, as is ORC, and the reporting is expected to evolve as the collective and joint approach is refined over time. This report covers the whole region, and accordingly focusses on higher level trends and data to provide a regional overview and benchmarking.

[8] Dunedin City and Queenstown Lakes District already undertake quarterly reporting covering matters of interest to their district and decision makers and publish this on their websites, and so there is some overlap with the data in this report.

[9] ORC staff are also developing monitoring and analysis processes, and this report focusses on providing an overview of the key compulsory indicators that are available, as well as some explanation of what they mean and what the data available might indicate. Future reports will update this key baseline data and provide insights into new datasets or information when it comes available.

[10] MfE have published extensive guidance[1] on interpretation of the indicators, and it is complex and a new area for many council's staff, decision makers and central government. The key message from this guidance, is that it is the suite of indicators that tell a story, rather than any one indicator in isolation, and councils should (jointly) develop approaches that best assist them in their particular circumstances.

[11] These indicators suggest that population growth in Otago over the last 20 years has been positive (after a period of negative population growth in the late 1990s), averaging 2000 additional persons per year since 2000 until 2014, when net migration surged to push average population growth to between 5-6000 persons per annum. This growth mostly occurred in Queenstown and Dunedin, and more recently in Central Otago, though growth and change has occurred across most of the region in variable ways, reflecting the wide diversity of amenity factors, constraints and opportunities across the region.

[12] The data also suggests that the increase in housing demand from population growth resulted in an increase in housing supply, but also further strong rises in prices. While supply has remained relatively high, it has been slowing and prices have further accelerated.

[13] Housing supply has not increased in a way or at a rate that best met all households' preferences and it is likely that since 2014, and possibly before in some areas, housing price and availability issues have been increasing. These impacts are generally felt most acutely by lower income households who may even struggle to meet their basic housing

[1] https://www.mfe.govt.nz/publications/towns-and-cities/evidence-based-decision-making-under-national-policy-statement-urban

needs, and these rising prices also impact disproportionately on renters and first home buyers.

[14] Facilitating an ongoing supply of dwellings, particularly more affordable dwellings, will be required to address existing shortfalls, and deal with continued net migration, which has (likely temporarily) slowed. Growth is expected to accelerate back to past levels once COVID-19 restrictions ease, albeit uncertainty about the timing, rate, volume and nature of those who may be attracted to Otago and why into the future post-COVID-19 remains elevated, over the usual levels of uncertainty inherent in any forecast.

[15] Continuing to progress on a range of short- and long-term planning, zoning, and infrastructure capacity improvements to facilitate a wide range of development types, locations and types remains important, to both address existing issues, provide more choice for consumers, competition amongst developers and landowners, and to 'get ahead of the curve'.

CONSIDERATIONS

Policy Considerations

[16] This report is required under the NPSUD 2020 and provides a general overview of some key datasets to support evidence-based decision making around housing and development.

[17] Looking ahead, significant recent local events, forthcoming major data releases and ongoing Covid uncertainty make future predictions more difficult than usual.

[18] The findings suggest ongoing effort across the planning and development systems and sectors to provide more housing and development options in a range of locations, and choice of types and prices is required, and planning should be responsive to new proposals as well as continue to align land use and infrastructure into the medium and long terms to unlock and facilitate strategic and well planned developments.

Financial Considerations

[19] There are no financial considerations.

Significance and Engagement

[20] This report does not trigger the Significance and Engagement Policy.

Legislative Considerations

[21] This report is required under the NPSUD 2020, a regulation of the Resource Management Act 1991.

Risk Considerations

[22] There are no relevant risk considerations.

NEXT STEPS

[23] Next Quarterly Update will be in June 2021, and will also include some exploration of 2018 Census Data, and new Statistics NZ 2018 Census rebased projections which are expected in late March 2021.

ATTACHMENTS

1. 2020Q4 Urban Development Quarterly Monitoring Report [**7.6.1** - 26 pages]

Otago Regional Council

Quarterly Monitoring Report, Q4 2020

National Policy Statement on Urban Development Capacity

Contents

Figures:

Data Sources, Coverage and Time

[1] For the purposes of the first quarterly regional reporting, most data is provided at the district level for all districts in the region. The report includes Clutha District, which is not subject to the NPSUD[1]; and all of Waitaki District, of which part is in Canterbury Region[2]. Regional figures will vary between the 'sum of TAs' (ie including all of Waitaki) and 'regional' figures (including only part of Waitaki) but this has very limited impact on overall housing related patterns at the regional level. Data reported is to the end of December 2020 where available.

[2] Some Tier 2 urban environments data is provided (Queenstown and Dunedin) where available and relevant, noting that for both DCC and QLDC the 'urban environments' encompass a significant majority of current and future population and building activity within the respective district.

[3] Provision of a regional overview, complementing more specific and targeted local monitoring undertaken by TAs is considered appropriate given ORC's limited role in the day to day urban planning and consenting processes (acknowledging our limited functions in these spaces, relative to the TAs), and our regional 'big picture' perspective and regional function. This regional information will also provide local authorities, developers and other stakeholders with a regional benchmark, enabling more targeted actions to be taken where required.

[4] The information required to be collated is all collected over different time intervals, with some monthly and some significantly less frequently. There are also differences in spatial scales. Other complications include data not being publicly available, requiring purchase or requires specific monitoring processes and data arrangements that are still under development by the relevant local authorities (including ORC), or central government.

[5] Given the above limitations and context, the regional quarterly monitoring reports will focus on providing a longer term, regional baseline at the district level and overview for the limited number of key public and compulsory datasets, and highlight the availability of new or particularly relevant data where and when it becomes available.

[6] The next quarterly monitoring report will, for example, seek to explore some of the recently released fine grain 2018 census data that provides a rich source of social information and counts of population, household and dwelling change over the last 2 census, and will provide a good picture of 'current' state, and some spatial patterns useful to inform a wide range of other processes and discussions and further work.

[7] Statistics New Zealand is also expected to release subnational population projections, rebased on the 2018 Census in late March 2021. This will likely generate significant discussion about future assumptions and may result in significant reworking of a wide range of existing projections series, including those utilised by the regions TAs and ORC.

[8] More detailed (higher spatial resolution and some commentary) information for the regions Tier 2 urban environments is available for Dunedin and Queenstown via the respective territorial authority quarterly monitoring reports.

[1] Clutha District does not contain any 'Urban Environments', however when making planning decisions that affect any urban environment the NPSUD will apply (Clause 1.3(2)) - this provision allows for the consideration of cross boundary impacts given the labour and housing markets that define 'urban environments' don't respect arbitrary council jurisdictional boundaries.

[2] While slightly more than half of the District by area falls in the Canterbury Region, approximately 90% of the Districts population and the Districts Tier 3 Urban Area (Oamaru) fall within the Otago Region. Statistics cover the whole of the Waitaki District unless otherwise noted.

a. Dunedin City provides a 'live' data site that is updated when data comes to hand: https://www.dunedin.govt.nz/council/district-plan/monitoring-and-research/monitoring-and-research-housing-market-and-population-trends
b. Queenstown-Lakes District produces quarterly reports[3]: https://www.qldc.govt.nz/your-council/council-documents/national-policy-statement-urban-development-2020-nps-ud#quarterly-reports

[9] Ministry for the Environment (MfE) and Ministry for Housing and Urban Development (HUD) also jointly publish the urban development dashboard, which contains some key inputs (market indicators and price efficiency indicators) required to be monitored, and also analysed and considered during the development of FDS and HBAs, available here: https://huddashboards.shinyapps.io/urban-development/

[3] At the time of writing, the latest published report for QLDC is from December 2019

Dwelling Demand

[10] Dwelling demand is taken to be the demand from the past, current and expected future population accounting for their likely preferences and trade-offs over time. Underlying demand considers the need of the population and visitors being housed in accordance with their assumed preferences, on basis of one additional household 'demanding' one additional dwelling, at the aggregate level. Revealed or effective demand is understood as how people actually live, and is often much 'lower' than underlying demand. This occurs for a wide range of reasons, mainly measurable as price/cost/budget differences, where households are not always housed in accordance with their preferences, and at worst sometimes not even in accordance with their basic needs. The difference between underlying and effective demand determines the size and nature of any assumed demand (or supply shortfall).

Past Demand:

[11] Population growth in the region has been spatially variable with strong demand in the Queenstown-Lakes area Central Otago and Dunedin City, and lesser growth in Waitaki and Clutha. This growth has been primarily driven by net internal and international migration, with 89.8% of the region's growth from net migration in 2020, compared with 75.6% for NZ as a whole. Natural increase in the region is in contrast low, but steady and rising slowly, reflecting the age and ethnicity of most current and future residents.

[12] The Graph below shows sources of past population growth in the region since 1997, highlighting the slow but steady role of natural increase and the high variability of net migration, notably increasing significantly since 2014 after a 12 year period of relatively slow and steady growth from 2002, following a period of negative population growth from 1997-2001:

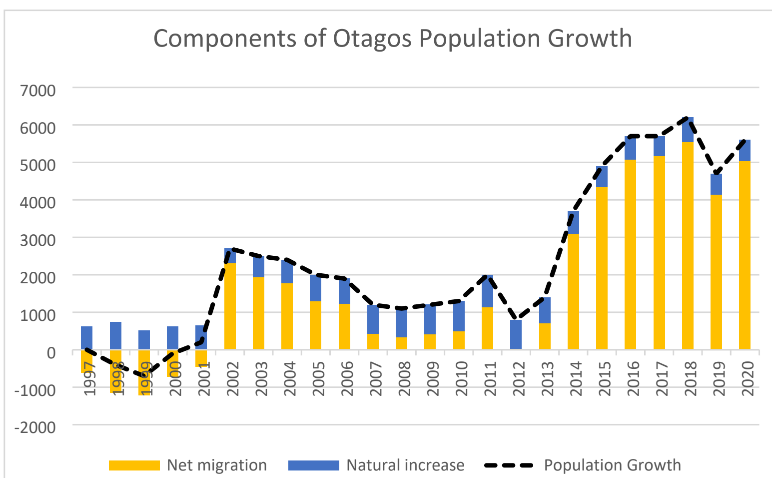

Figure 1: Components of Otago Regions population growth, Source: Statistics NZ

[13] Net migration driven demand is driven by the perceived relative advantages the region has over other areas migrants could choose to live including their current location. Amenity, employment opportunities and (relative) affordability are key drivers of net migration to the Otago region

and the variability of growth across the region reflects the variability in these factors (and many others) across the region.

[14] Queenstown Lakes District has taken approximately 50% of the region's net migration in any given year since 2002, reflecting a high level of attractiveness to those migrants - people have literally been voting with their feet, consistently. As a relatively young population in the regional context, also QLDC also generates ~50% of the regions natural increase, despite having only 10% of the region's total population in 2002. These high rates of growth in both population change components has meant Queenstown Lakes has grown rapidly to be home to 20% of the regions[4] estimated population in 2020.

[15] Dunedin is the region's largest urban area by an order of magnitude, and in addition to the natural gravity and agglomerative effects of large urban areas, has a very high attractiveness for tertiary education driven migrants, (students, researchers, educators and their families), but this tends to be cyclical and results in high levels of churn or turnover of a relatively slow growing total student population[5], rather than leading to significant sustained population growth over the longer term, albeit the alumni community is also a strong source of future migrants in later life stages as these students forge strong connections with the city and wider region while studying.

[16] Over and above growth, population and preference *change* in the region reflects expected changes over time as a result of cohort aging and demographic change from migration and natural increase. For example even with a static population, overall housing demand will change over time as people and households move though different life stages, typically requiring more dwellings as household sizes reduce, with an increasing preference for lower maintenance and easy accessibility both internally and to surrounding amenities with age. Enabling a wide range of dwelling choices can facilitate people to remain within their neighbourhood and also reduces the friction of moving to a preferred neighbourhood, throughout various life stages.

Current Demand:

[17] StatisticsNZ provides the official subnational population estimates, and a range of private companies provide various refinements. The subnation projections are updated annually, but components are available more regularly. Companies use the components to develop more frequent subnational estimates. The diagram below[6] illustrates how the population growth change components for New Zealand as at December 2020 and the change from the year previous. Of note both deaths and births are down slightly, with deaths reducing more than births resulting in a small increase in natural increase. Both inward and outward migration are also down significantly, with an associated decrease in net migration from the year previous:

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4 Regional figures include all of Waitaki District.

5 Student numbers in 2020 and 2021 are down significantly on previous years, and all tertiary providers have plans or forecasts to increase enrolments, though this may not necessarily result in resident population growth in Dunedin given the increasing role of distance learning.

6 Source: https://www.stats.govt.nz/information-releases/national-population-estimates-at-31-december-2020-infoshare-tables

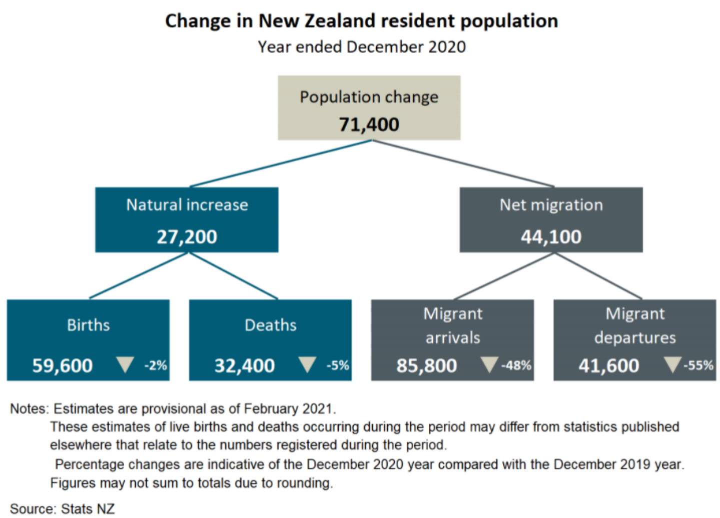

Figure 2: Components of change in NZ resident population, Year End 30 December 2020, Source: Statistics NZ

[18] Long term migration data for NZ highlights the impact of closed borders on net international migration, a key source of population growth in New Zealand. Monthly net migration dropped from a rising trend of near 15,000 persons to almost zero overnight. Otago's population growth is dominated by the impact of net migration, which includes international movements as well as internal migration which has been less restricted particularly in lower Covid-19 alert levels.

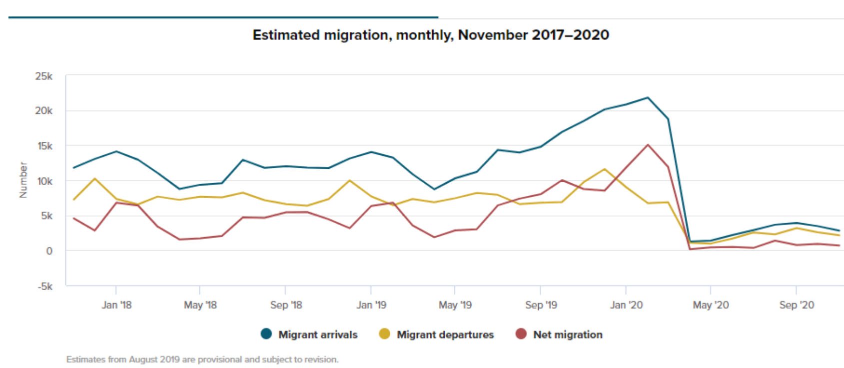

Figure 3: Monthly Net Migration, Nov 2017- Nov 2020, Source StatsNZ

Current Population:

[19] Subnational Population Estimates are currently available from Statistics NZ at TA level, for June 30th years from 1996 to 2020. The Graph below shows this data[7] for the regions districts, of

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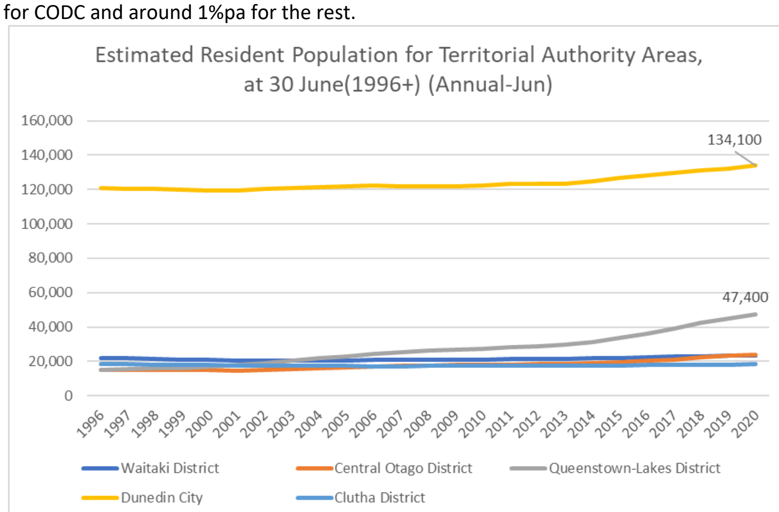
[7] Source: http://infoshare.stats.govt.nz/ViewTable.aspx?pxID=8048ed8d-9087-4b85-b173-b69ed8c1d3a4

particular note being the rate of change between 2019 and 2020 was 5.8% for QLDC, and 3.5% for CODC and around 1%pa for the rest.



Estimated Resident Population for Territorial Authority Areas, at 30 June(1996+) (Annual-Jun)					
TA Area:	**Waitaki District**	**Central Otago Distri**	**Queenstown-Lakes**	**Dunedin City**	**Clutha District**
Change from 2019 population	300	800	2600	1800	150
2020 Population Estimate	23500	23900	47400	134100	18300
% change 2019-2020	1.3%	3.5%	5.8%	1.4%	0.8%

[20] Dunedin's seemingly small 1.4% change represents some 1800 persons given the large base population, compared to the additional 800 added to CODCs much smaller base population resulting in a 3.5% change. The rate of change provides some indication of the relative impact of growth on an area and the likely visibility and urgency of its impacts on a host area. Overall quantum of change does remain an important metric as this represents the total need for dwellings and associated population supporting infrastructure.

[21] Population is 'converted' to dwelling demand by assumptions about household formation and size to provide an estimate of potential housing demand, the exact figure dependant on assumptions about the nature, and composition of expected demographic changes over time.

a. For example, lots of natural increase would not infer an immediate increased housing quantum demand as babies don't live alone, but it might infer a change in demand from that segment towards housing with more bedrooms near schools.
b. For migration driven demand, who they are and why they come matters and not just for the number and type of dwellings that would likely be needed:
    i. high proportions of young couples with children may tend household sizes upwards and imply a preference for standalone housing, and increased need for schooling and maternity services.
    ii. More empty-nesters or retiree's would imply a smaller household size, but more houses, in more accessible locations and increased demand for age appropriate services and facilities.

[22] More detailed exploration of some of the demographic detail of the population will be included in the next quarterly update using 2018 census data.

[23] In general, observed data suggest that underlying population driven household demand is greater than observed dwelling and household growth alone suggests, after allowing for demographic and preference changes within the existing population, plus the need to address existing shortfalls. NPSUD regulation also requires an additional allowance for the 'competitive margin' that also has the effect of building in some buffer (in capacity for building) in the case of unexpected growth spikes. Slower than expected growth simply allows the additional provided capacity provided to be taken up in later years.

Future Demand:

[24] StatisticsNZ are expected to release their 2018 Census rebased population forecasts in late March. This will provide a major opportunity for rebasing a wide range of existing national, regional and more customised projections including those regularly commissioned by all of the regions TAs from specialist demographic consultants, and utilised by ORC.

[25] ORC has collated the most current TA commissioned and utilised population forecasts to utilise as a key non-financial forecast in the LTP, also enabling consistency with current TA strategic planning assumptions.

[26] These figures are shown in the graphs below which highlight the strong percentage change expected in Queenstown-Lakes, Central Otago and Waitaki in particular, and the overall numerical growth expected in Queenstown, Central Otago and Dunedin.

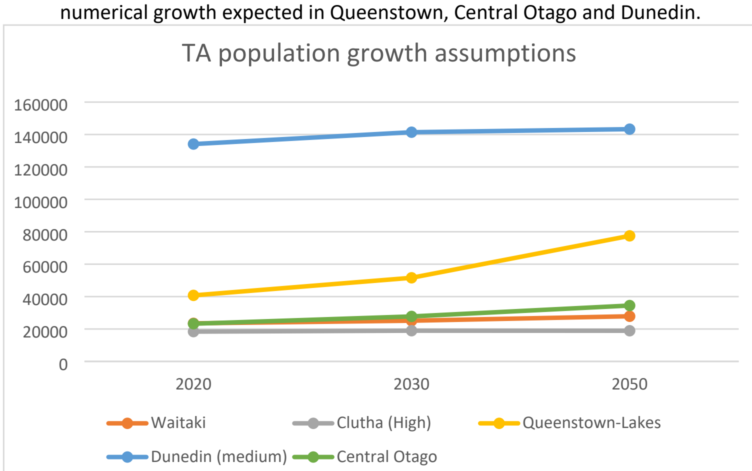


Figure 4: Current TA population growth assumptions as used for ORC LTP. Source: respective TAs/ORC

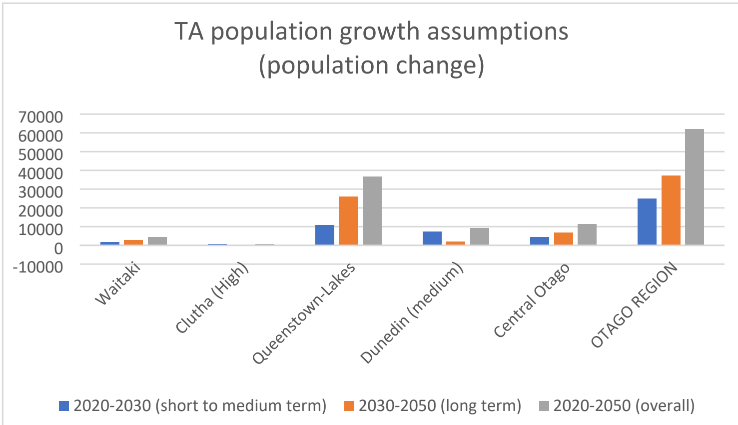


Figure 5: Current TA population growth assumptions as used for ORC LTP, overall assumed population change. Source: respective TAs/ORC

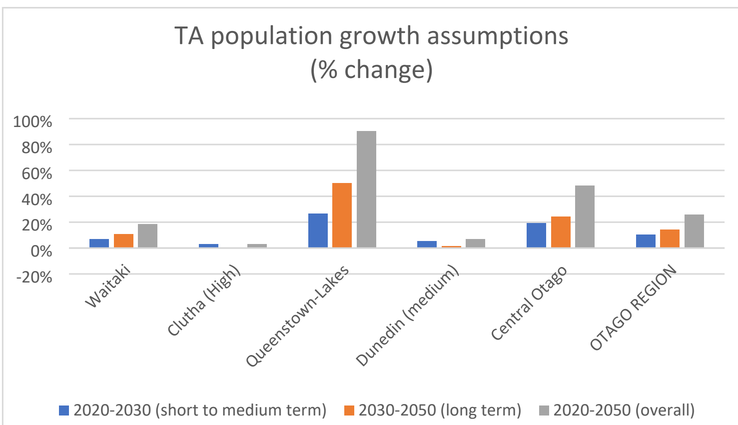


Figure 6: Current TA population growth assumptions as used for ORC LTP, percentage change in population. Source: respective TAs/ORC

[27] These assumptions are subject to regular review and future reviews will be strongly informed by upcoming national projections release from Statistics NZ expected in late March.

[28] Dunedin City Councils urban growth monitoring page includes annual population growth estimates alongside their future projection series[8]. Of note is the variation between projected and actual growth since 2016 and present, which continues the high variability of actual growth in Dunedin the recent past.

[8] Source: https://www.dunedin.govt.nz/council/district-plan/monitoring-and-research/monitoring-and-research-housing-market-and-population-trends

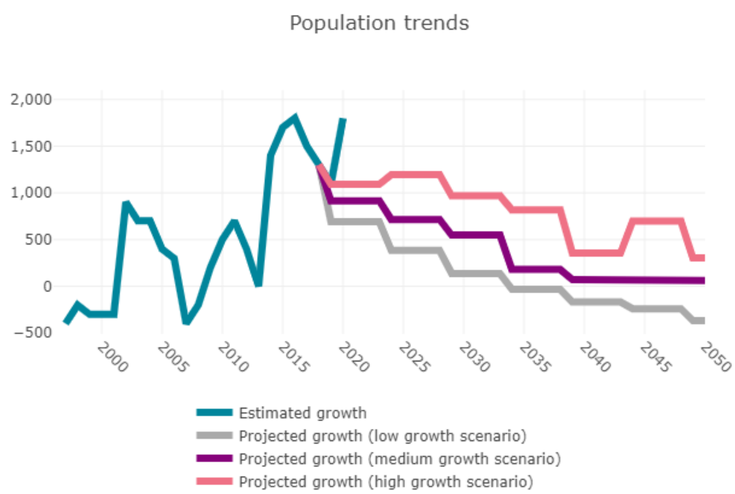


Figure 7: Dunedin City Council population trends, estimated and projected growth, Source: DCC

[29] A challenge for any forecasting is to make reasonable estimates given such high uncertainty. Covid-19 and the associated global uncertainty means making assumptions about who and why people might move house, city or country, or have kids, move house, change job or retire, even more difficult let alone forecasting the economy that would drive all of this. This if nothing else indicates the value of having a capacity buffer (or 'competitive margin', in the language of the NPSUD) and being ahead of the game in terms of planning and infrastructure, as the costs of over-provision are almost always less (but do fall narrowly almost entirely on providers of infrastructure and relate mostly to (temporarily) underutilised infrastructure) than the costs of under-provision which are more widely distributed and cumulatively larger in terms of social, economic and environmental pressures.

Dwelling Supply

[30] Dwelling supply is typically measured by Building Consents, as all new residential buildings require a Building Consent under the Building Act 2004. A building consent provides a leading indicator of a very strong intention to develop given the time and costs involved in preparing the documentation needed, over and above council fees. A high proportion of building consents granted are commenced.

[31] A high proportion of commenced building projects are also 'completed'. Recent Data from Auckland show 90% of dwelling unit CCC are issued within two years of the building consent being granted[9] and this provides a useful rule of thumb for considering the translation of building consent data as an indicator of future supply.

[32] Data for new dwellings consented on an annual basis for each TA in the region is shown below. Note significant rise in annual volumes in QLDC from 2013 and CODC from 2016.

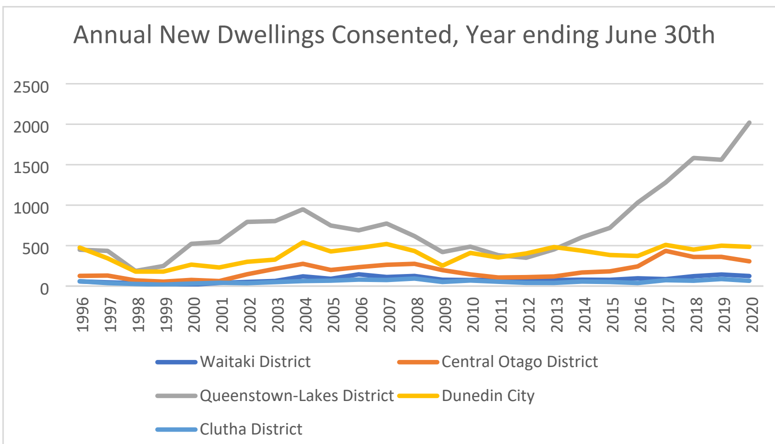


Figure 8: Annual new dwellings consented, by TA, Source: Statistics NZ

[33] Monthly totals for the Region are also shown below alongside a 12 month rolling average:

[9] https://knowledgeauckland.org.nz/media/1827/auckland-monthly-housing-update-06june-2020.pdf

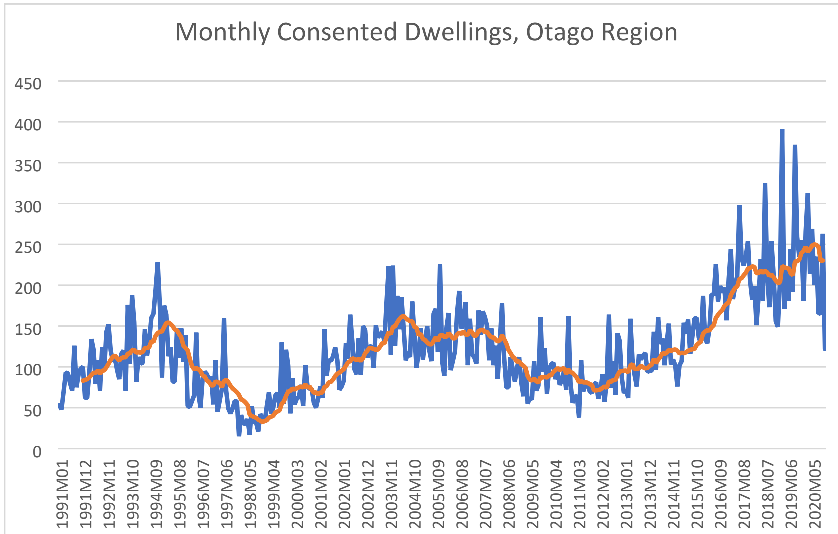


Figure 9: Monthly new dwellings consented with 12 month rolling average, Otago Region, Source: Statistics NZ

[34] Data on a month by month basis for the last 3 years are shown below, essentially highlighting the last section of the graph above in more detail. Data in this series is to October 2020.

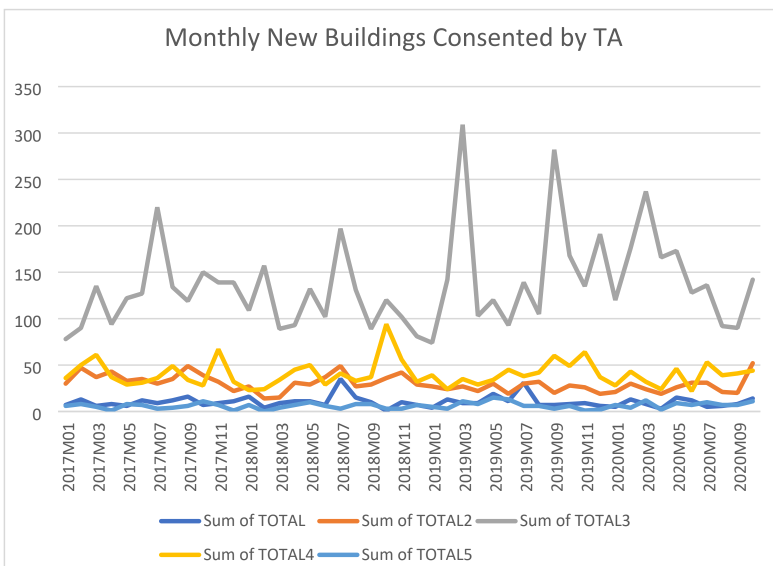


Figure 10: Monthly new dwellings consented by TA

[35] Data showing the dwellings consented by type for the region as a whole is shown in the graph below. Queenstown, Dunedin and Central Otago districts represent around 90% of the building

activity in the region, with Queenstown-Lakes peaking at around 60% in some months. Houses (standalone dwellings) make up between 40% to 80% of new dwellings consented in the region. It is notable that the dwelling quantity and dwelling typology curves are closely aligned but inverted - this suggests that peaks in additional supply are strongly dominated by attached dwellings.

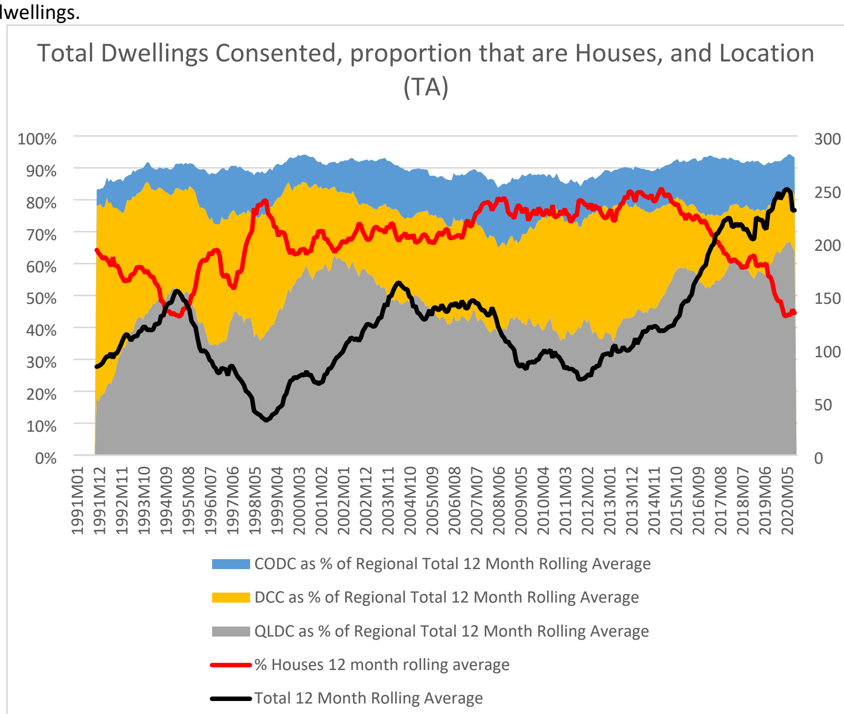


Figure 11: Regional new dwelling distribution by TA, and type

[36] Outside of Queenstown Lakes and Dunedin City, standalone dwellings make up the bulk of consented dwelling units. Breaking down the monthly data by type highlights the role of attached dwellings in providing for strong increases in supply:

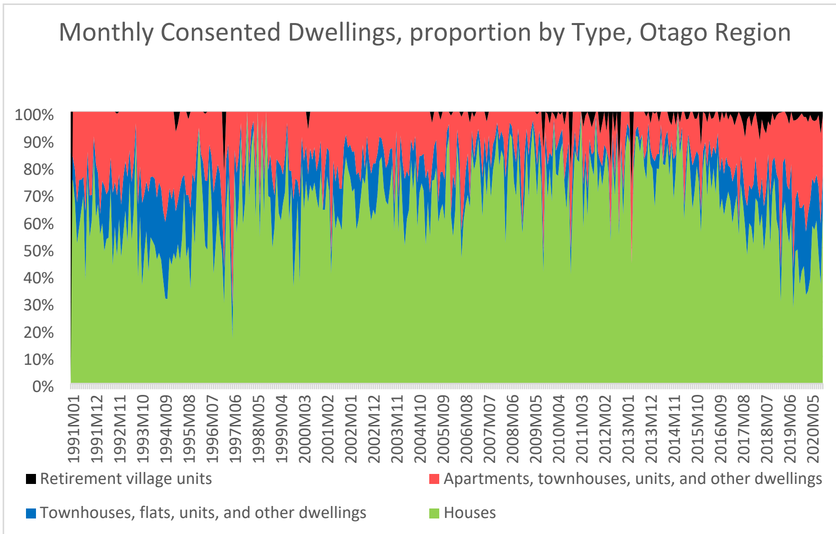


Figure 12: Monthly new dwellings consented by typology, proportion of total, Otago Region. Source: Statistics NZ

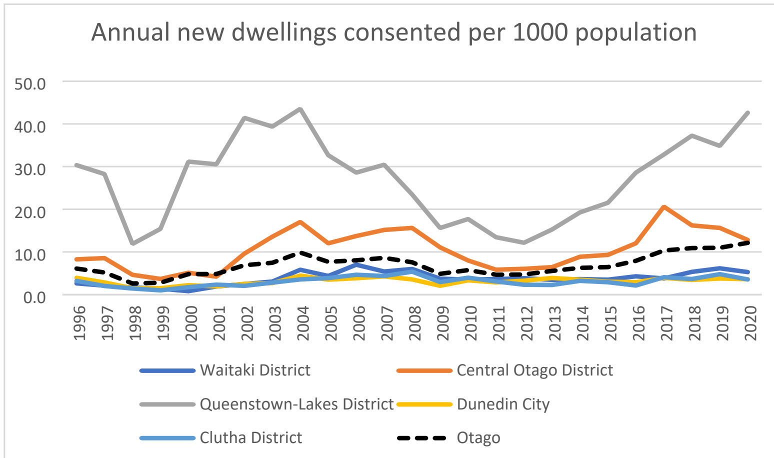
[37] Additions and Alterations have anecdotally been increasing as homeowners and investors seek to improve their properties to provide for better internal and external spaces for working from home and potential lockdown. Further exploration of this data will reveal if this has come to pass. This will be an important consideration going forwards, as this work has an impact on future redevelopment potential and sales rates by increasing both the utility and improvement value of the existing housing stock, thereby reducing both the willingness to sell, and viability of subsequent redevelopment if sold.

[38] Consent data for non-residential activity is also available but is measurable as value of works and floor area by a wide range of consented end use types and industries. Future reports will provide more detail on this dataset.

How responsive is housing supply to demand?

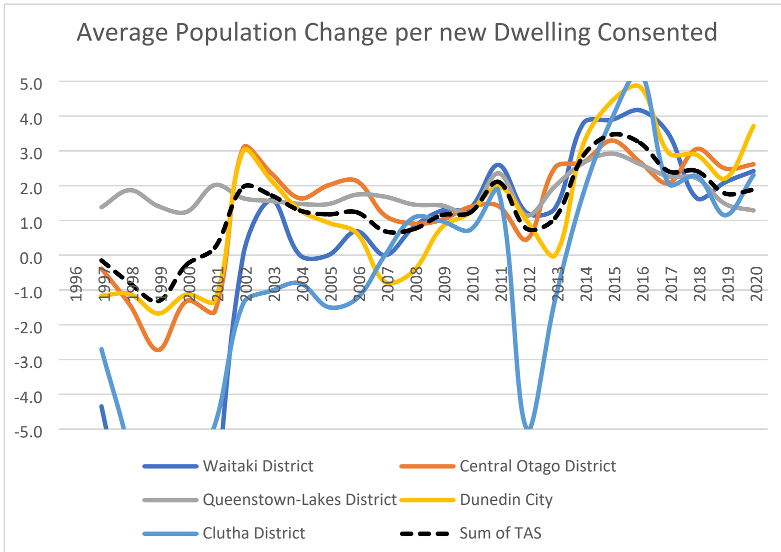
[39] Relationships between demand and supply responsiveness can be considered in many ways, the most simplistic by comparing overall population growth and dwellings consented.

[40] The graph below compares new dwelling consented with total population in a June year at the TA level. A higher number is 'better' reflecting greater supply responsiveness to total population level demand, including churn and preference change. QLDC and CODC areas consistently provide a greater level of new housing for their population. This may also partially reflect high levels of holiday house building in these areas, high levels of net migration requiring new housing (some 50% of the regions net migration goes to QLDC but this area has 20% of the regions current population) and in the other three TA areas high levels of existing underutilised development, including older and heritage buildings and therefore potential for reuse.



[41] Comparison of the number of additional new people per consented dwelling provides a slightly different perspective as it compares new population growth only to new dwellings consented. In general, a lower number is 'better', reflecting a higher responsiveness to 'new' population demand, as well as facilitating more churn and preference change. Negative values are artefacts of small *resident* population declines in that TA in that year. New dwellings consented are recorded as positive integers (it is not a net figure, so some dwellings are replacements)

[42] Of note is the relative closeness of all TAs figures at a level that suggests relatively high (and slowly improving) levels of supply responsiveness, with a long trend of around 2.0 new persons per new dwelling consented average ratio with a strong 'peak' to over 4 in 2016 for Dunedin, Waitaki and Clutha, reflecting population growth but low levels of consented dwellings, and then slight improvements since then to 2018, with a notable uptick in all TAs from 2019.


Average Population Change per new Dwelling Consented
5.0
4.0
3.0
2.0
1.0
0.0
-1.0
-2.0
-3.0
-4.0
-5.0
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
Waitaki District
Central Otago District
Queenstown-Lakes District
Dunedin City
Clutha District
Sum of TAS

Dwelling Prices and Rents

[43] Dwelling prices and rents reflect the point of intersection between demand and supply for housing. Price series reflect the average (or indexed) purchase price (or estimated overall value based on actual sales) of properties in a given time period, and rent is the average (or indexed) payment made by tenants to live in houses owned by others.

[44] Because house prices and rents reflect different market segments, participants and motivations, the variance between the two in the same market can often be more informative than considering either one alone. For example, where house prices are rising but rents are stable (or falling) could indicate a speculative asset boom fuelled by, say, low interest rates rather than a shortage of housing needed for household occupation. Where both are rising, particularly at increasing rates, this is more likely to indicate underlying housing shortages relative to demand.

[45] Data for the region at the TA level is shown in the graphs below:

PRICES

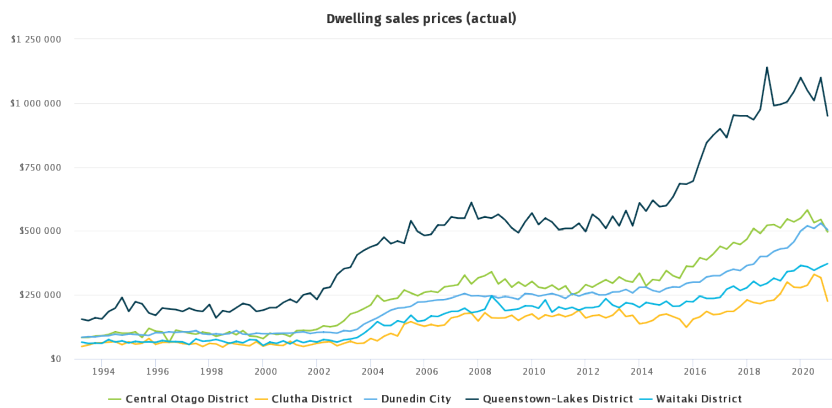


Figure 13: Dwelling Sale Prices (actual) by TA: Source: Urban Development Dashboard, HUD

[46] This graph aggregates all residential sales as recorded by TAs via their rating systems (DVR), so can be affected by compositional changes within a given month and can lag sales due to conveyancing delays. For example, month to month variation in the DVR sourced average can be a result of more high-end properties being sold in one month than another month. Figures are actual and so are not adjusted for inflation[10]. Changes in the rate of change are therefore of most interest.

[47] Of note is the consistently high value of sold QLDC properties relative to the rest of the region, a gap that has been increasing particularly since 2016. Significant increases across all districts are notable around the 2004 period followed by a long period of flat prices, and then protracted increases since 2016. Small dips at the end of the period reflect the impacts of Covid which have since been largely reversed (based on REINZ data) which indicates a 15% increase for year on year increase for Median House prices as at January 2021.

[10] Of some debate would be the appropriate measure of inflation (of which there are several) to apply to house prices.

Other Possible sources of Price Data:

[48] REINZ also provides sales data, with the benefit of being more 'timely' than DVR, as it reflects unconditional sales, reported by agents as soon as the contract is signed (rather than post-settlement conveyancing for DVR data), and they also manage and publish a Housing Price Index, that controls for compositional impacts meaning these different series can vary slightly even if they tend to track the same direction. The SPAR affordability measure is also derived using REINZ data by the RBNZ.

[49] Corelogic also develops a range of housing data sets leveraging off their ownership of QV (who undertake most council valuation services) and global data analysis. Buyer profiles, and regular revaluation algorithms providing more or less live valuation of the entire property cadastre based on rezoning to nearby and comparative sales is possible at a cost.

[50] Access to REINZ and Corelogic data is by subscription, and future reports may include this.

VOLUMES

[51] Sales volumes provide an indication of churn in the market. Figures below indicate total sales which are dominated by Dunedin as a largest pool of houses. Significant decreases from long term steady trends at the end of the period reflect the impact of Covid (including lockdown and transfer restrictions) in mid to late 2020.

[52] Total sales figures should in theory increase as population increases and the pool of housing is added to, but the figures appear relatively steady, with the exception of QLDC which has increased since 2014. One effect that can moderate this general assumption is that greenfields development areas with significant amount of house and land packages can reduce 'house sales' figures as only the initial section (i.e. vacant section or land) sale is recorded (and therefore not recorded as a dwelling sale), and the house is subsequently built and occupied, so only the second sale (or the sales of turnkey spec builds) show up.

[53] Further complicating analysis is that Queenstown also has high levels of net migration and is also a key holiday destination meaning that a significant proportion of the dwelling sales may not be between residents.

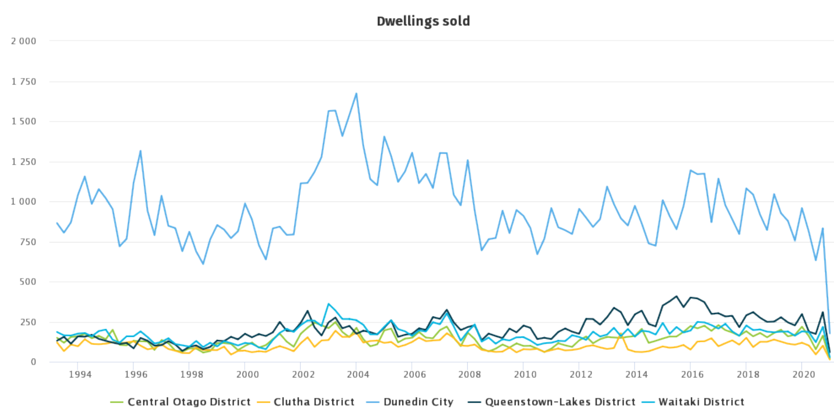


Figure 14: Monthly dwellings sold by TA: Source Urban Development Dashboard, HUD/Corelogic

[54] The figures below compare the total sales to the total pool of properties. This shows that across almost all districts, sales have tracked between 1 and 2% since about 2009. The percentage of stock sales data does not extend as far as total sales so does not yet show the Covid related dip expected from the drop in total sales, though sales proportions have been slowing since about 2016.

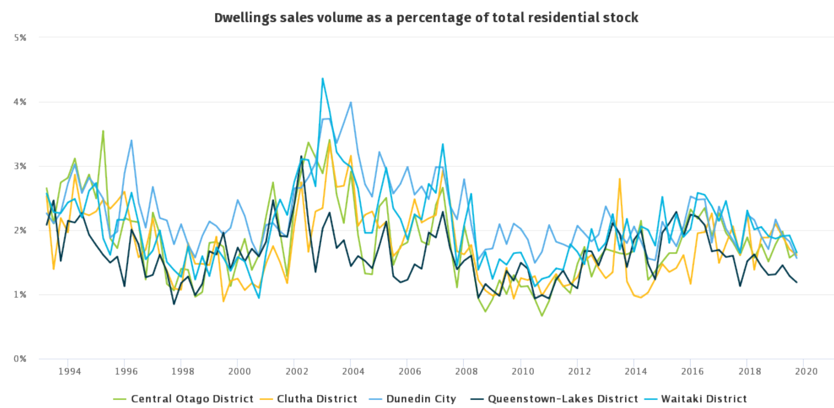


Figure 15 Monthly dwellings sold as a proportion of total dwelling stock, by TA: Source Urban Development Dashboard, HUD/Corelogic

RENTS

[55] Rental data is based on bond lodgements from new tenancies recorded with Tenancy Services which are calculated as multiples of weekly rents.

[56] Of note is the similarities between this data and sales data, where QLDC is consistently higher than the rest of the region, and the general periods of growth and relative stasis align. However the difference in QLDC rents to the rest of the region is not as extreme as house price difference, perhaps reflecting the controlling impacts of income limiting ability for rents to increase completely in line with house prices, particularly in QLDC which has a high level of seasonal and lower paid casual workers. Significant growth in rents are however observable across all TAs since 2014, with QLDC rising fastest, and CODC rents now tracking closely with Dunedin City and often lightly higher. Drops in average new rents are also observable across all TAs, in late 2020 reflecting impact of Covid which disproportionately impacted the QLDC area given its reliance on Tourism and Construction, returning average new rents to 2017 values.

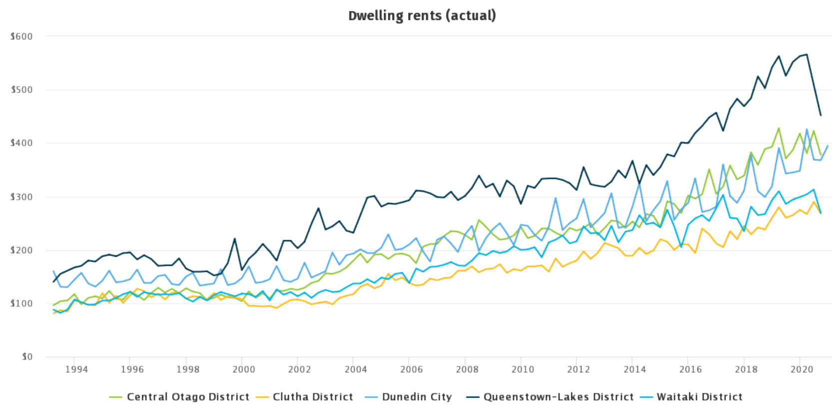


Figure 16: Monthly dwelling rents, by TA: Source Urban Development Dashboard, HUD/MBIE

[57] DCC publishes rental data providing a mean as well as an upper and lower quartile on a monthly basis. Of note in this series is the extreme seasonal peakiness of rents, reflecting student housing tenancies which have traditionally worked on an Annual fixed term basis (1 Jan to 31 December), a practice which also applies more widely across the Dunedin rental market, resulting in limited rental movements/relocations outside of these periods and possible discounting relative to 'peak' rents. Recent changes to the Residential Tenancies Act now make these fixed term arrangements illegal (all tenancies are now periodic), so it will be interesting to see if this peakiness is notably reduced as a result, but given the strong seasonal fluctuations in the student population this may not be as apparent as it might be in other TAs.

[58] Rapid raise across all three series since 2016 and accelerating from 2018 are potentially indicative of growing housing pressures, where students (and others) are increasingly competing for homes.

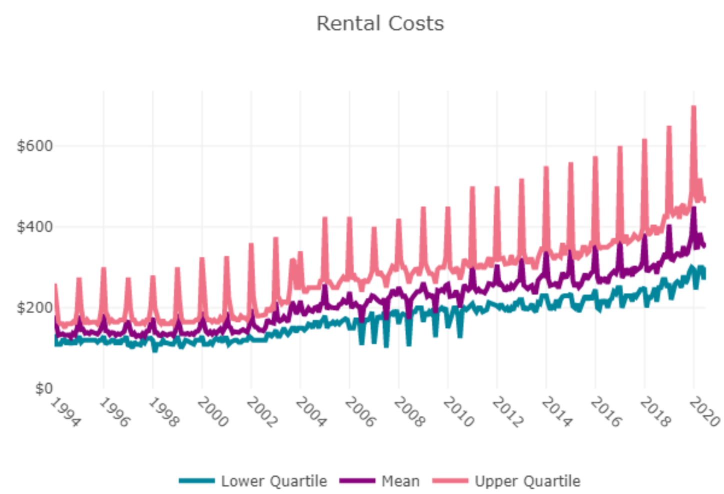


Figure 17: Dunedin monthly rental costs, quartiles: Source: DCC/MBIE

PRICE COST RATIO

[59] The Price cost ratio provides a ratio of the estimated costs to construct a standalone dwelling, including a reasonable profit (being a value of 1.0) compared to the sales price (being relative to the 1.0). The 'target' value is 1.5 which implicitly assumes that the land component of a standalone house 'should' be half the construction cost (or, alternatively, no more than 33% of the sale price).

[60] In effect this measure can be considered the degree to which land or construction costs influence (standalone) house prices. The measures implies that the more efficient a market is, the lower the ratio should be as land will make up a smaller proportion of standalone dwellings by way of high volumes of (land) supply. However, this must also be balanced against the fact that sales include second hand houses that may be development sites and the potential to supply land may be constrained geographically in some areas. Measure focussing on standalone houses also misses the potential signals that standalone housing may be an inefficient use of higher value land. Of interest is that Queenstown (where many dwelling sales will be development sites, facilitates higher density redevelopment and is highly geographically constrained) has such variability in the price cost ratio and in particular that the price cost ratio has been declining since 2018. However, the elevated level of QLDC relative to all other TAs is also interesting as is the clustering of all the other TAs in a fairly consistent low banding, albeit all on an increasing trend from around 2015/2016.

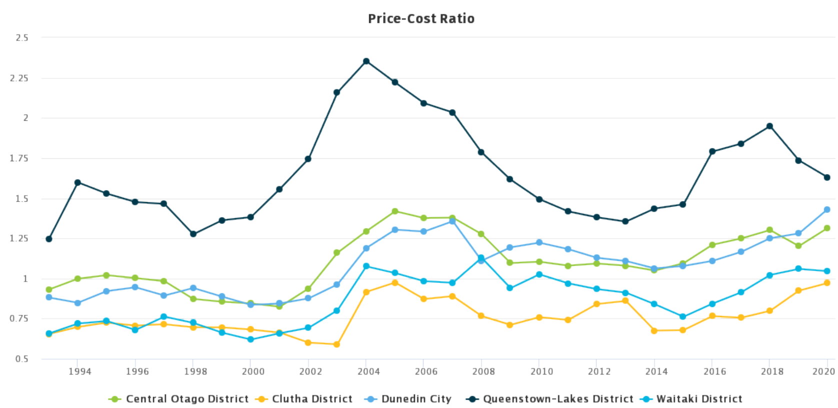


Figure 18: Annual Price:Cost Ratio, by TA, Source: Urban Development Dashboard

Housing Affordability

[61] Housing affordability measures are essentially ratios between a households ability to pay and the price they pay for housing. There are a wide range of potential housing affordability measures from the simplistic gross annual income to sales price ratio measures that are useful for over time and across space comparisons, to more complex analyses better reflecting the reality of how people pay for housing and the money they have available to spend on it.

What 'affordable' actually means is also subject to debate – for example a multiple median price to income ratio of 3 or a spending of no more than 30% of gross income on housing are often quoted as common affordability measures, and are most useful for comparison between different areas or over longer time periods, and lower is almost always better. Affordability is important for everyone, but is a more relevant measure for lower income households, as higher income households tend to have both more options (ability to move and or negotiate) and usually a greater quantity of money left over after the same proportion or quantity of housing costs are accounted for.

[62] The data below are taken from the Housing Affordability Measure (HAM) Rent and HAM Buy measures from the MHUD Urban Development Dashboard, which reflects the points made above. Unfortunately the measure has not been updated by MHUD for some time, and data is only available to Q4 2018 (i.e. pre-Covid). Future reports will include any updated data.

[63] The measure is based on the estimated proportion of households in the district who would need to spend more than 30% of their income on housing, as weekly rent (HAM Rent) or as first home buyers on a mortgage (Ham Buy). A lower figure is 'better' indicating a lower proportion of households need to spend more than 30% of their income on housing.

[64] The HAM percent rent shows relatively steady affordability over the measured period (ending Q4 2018), with a greater proportion of renters paying more than 30% of their income on median rents in Queenstown-Lakes and Dunedin City than the other TAs, with Central Otago not far behind. The gap between TAs has also been narrowing over time with improving affordability in the more expensive TAs and growing unaffordability in the traditionally less expensive TAs with all TAs between 40% and 20% in Q42018, from 50% to 15% in 2003.

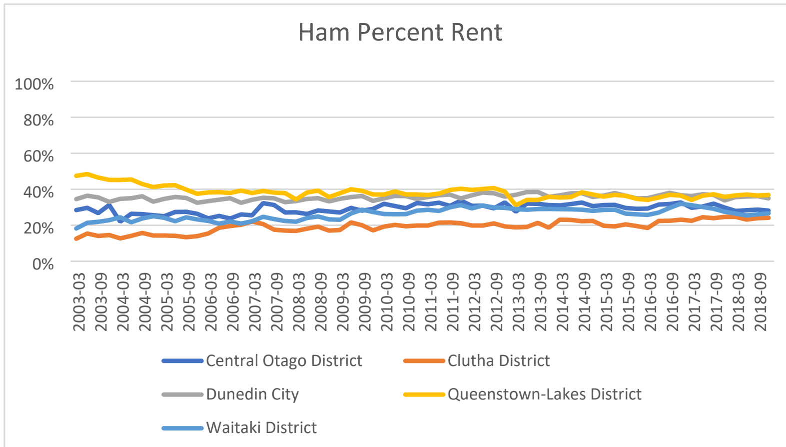


Figure 19: HAM Percent Rent, Source: Urban Development Dashboard

[65] The HAM percent Buy measure shows a similar pattern and TA ranking, but with all values significantly higher, with Queenstown-Lakes having a consistent near or over 80% of its population needing to spend more than 30% of their income on a median house if purchasing. Rises from highly affordable values in the rest of the region in 2003 to more or less present day values by 2006 are notable.

[66] Comparison of the two series also confirms that renting is almost always more affordable (as measured as a proportion of household income required) than buying in all of the regions TAs.

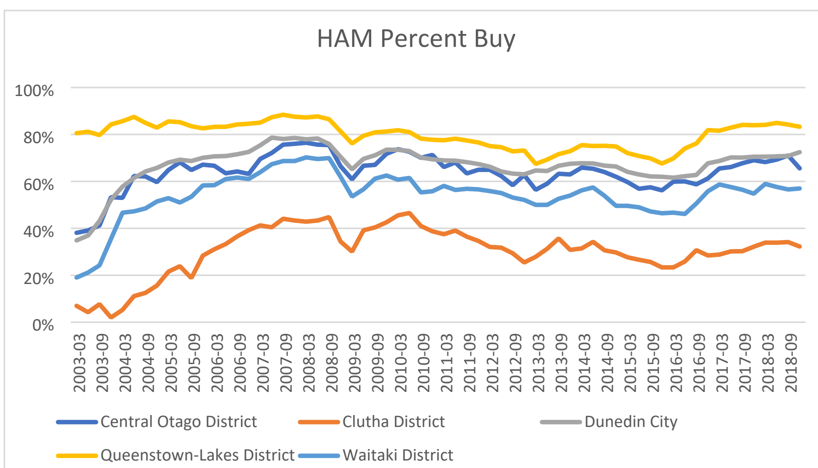


Figure 20: HAM Percent Rent, Source: Urban Development Dashboard

Housing Capacity Realisation

[67] No reportable data available at the time of writing.

[68] Reporting on capacity realisation requires
   a. a fine grain understanding of plan enabled capacity,
   b. an objectively determinable definition of ‘brownfields’ and ‘greenfield’, that changes over time (as once built out, greenfield areas are brownfields) and
   c. the ability to match development outcomes information (for example building consents) to this assessed capacity data in a way that it can be usefully compared and reported on.

[69] This is a capability that is still being developed in the region, and likely to only start occurring post completion of Housing and Business Assessments, as this will provide the required baseline of fine grain capacity information.

Business Land Data

[70] None available at this time. Future quarterly reporting will explore non-residential building consent data.

[71] The Housing and Business Assessments required to be undertaken in Dunedin and QLDC will initially focus on housing in order to meet the June 2021 deadline. Further work to progress fuller Housing *and* Business Assessments will progress to deliver information in time to inform the Future Development Strategies required to be in place by June 2024, which will establish baseline conditions and monitoring programmes going forwards.

[72] Industrial Zone differentials have been developed by MfE using valuation data for Queenstown and Dunedin, for 2014 and 2016 respectively[11], but are well out of date, subject to some debate regarding their technical appropriateness, and quite difficult to interpret in any case. The NPSUD has also changed the requirements around interpretation of industrial price differentials, recognising the importance of industrial uses to the functioning of urban and rural areas, and the difficulty of providing for land extensive industrial uses, These factors can in some cases justify or require protecting them from ‘higher and better’ uses that are willing to pay more.

[11] https://huddashboards.shinyapps.io/urban-development/#

7.7. Queenstown and Dunedin 2020/21 Quarter 1 and 2 Patronage Report

Prepared for:	Data and Information Committee
Report No.	PPT2102
Activity:	Transport: Public Passenger Transport
Author:	Julian Phillips, Implementation Lead Transport
Endorsed by:	Gavin Palmer, General Manager Operations
Date:	2 March 2021

PURPOSE

[1] The purpose of this report is to update Council on the performance of its public transport and total mobility services for the first half of the 2020/21 financial year, together with Super Gold patronage.

[2] Monthly statistics comparing the previous two financial years are also provided. It also addresses customer complaints and the provision of real time passenger information in Dunedin and Queenstown. Finally, it provides information on the Total Mobility scheme.

EXECUTIVE SUMMARY

[3] COVID-19 has had a significant effect on our public transport activity.

[4] In Dunedin, July 2020 patronage was up 32% and 18% in August 2020 compared to the previous year. This was due primarily to fare-free travel. September 2020 patronage fell by 9% comparted to September 2019, representing the re-introduction of revenue collection and the launch of the Bee Card. October, November and December 2020 patronage was +0.2%, -1.5% and +4% respectively, compared to a year ago and this represents an upward trend overall.

[5] Queenstown has been significantly affected by COVID-19. Whilst July and August 2020 patronage fell by 26% and 24% respectively compared to the previous year, this was during the free-travel period. September patronage fell by 41% compared to September 2019, with Bee Card launching on 15 September and revenue collection resuming. Thereafter, patronage has significantly declined versus the previous year, as expected. October, November, and December patronage fell by 38%, 44% and 46% respectively, compared to a year ago.

[6] From September 2020 to January 2021, Queenstown Routes 1 (Sunshine Bay to Airport & Remarkables Shops) and 2 (Arrowtown to Shotover River & Arthurs Point) have seen patronage fall by 57% and 50% respectively compared to the previous financial year. However, the more commuter/residential oriented Routes 3 (Kelvin Heights to Frankton Flats) and 4/5 (Jacks Point/Hanley's Farm and Lake Hayes Estate services) have seen increases of 17% and 7% respectively.

[7] 601 complaints were received in the period November 2020 to February 2021. Of those, just over three-quarters of them related to the Dunedin bus service. About one-

third of total complaints related to bus drivers. All complaints have been followed up by staff.

[8] The Council has been trialling an interim real time passenger information system in Queenstown since mid-2019.

[9] For Queenstown customers, the current system allows them to view the location of buses across any route on their device (big screens at Frankton Hub, computer, mobile, etc). That is, through the Orbus Queenstown website, which is not currently optimised for mobile devices (therefore not mobile-friendly).

[10] The proposal for Dunedin is to implement the same system as Queenstown by early-April.

RECOMMENDATION

That the Committee:

*1) **Receives** this report.*

BACKGROUND

[11] The Council (ORC) contracts public transport services in Dunedin and Queenstown to two transport operators; Ritchies and Go Bus. Network coverage is shown in the following two figures:

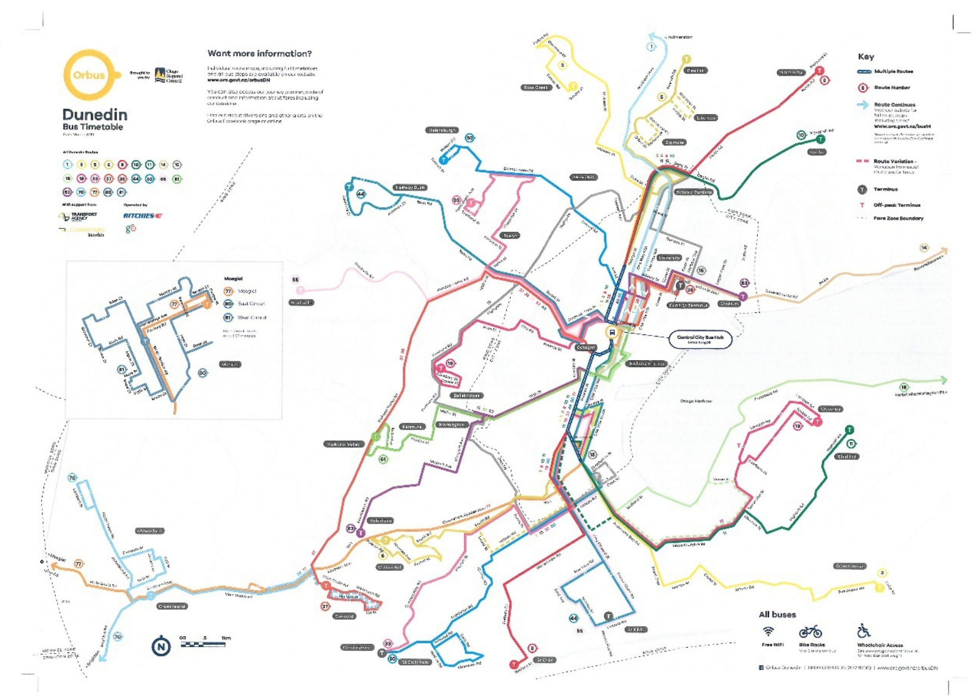


Figure 1: Dunedin Bus Network

[12] As can be seen in Figure 1, the Dunedin network comprises 23 routes that extend to Palmerston in the north and Mosgiel in the west. For the 2019/20 financial year, the Dunedin network carried 2.2 million passengers (2.5 m the year before).

[13] The Queenstown network comprises five routes that extend to Arrowtown in the east to Jack's Point in the south (see Figure 2). For the 2019/20 financial year, the Queenstown network carried 1.2 million passengers (1.5 m the year before).

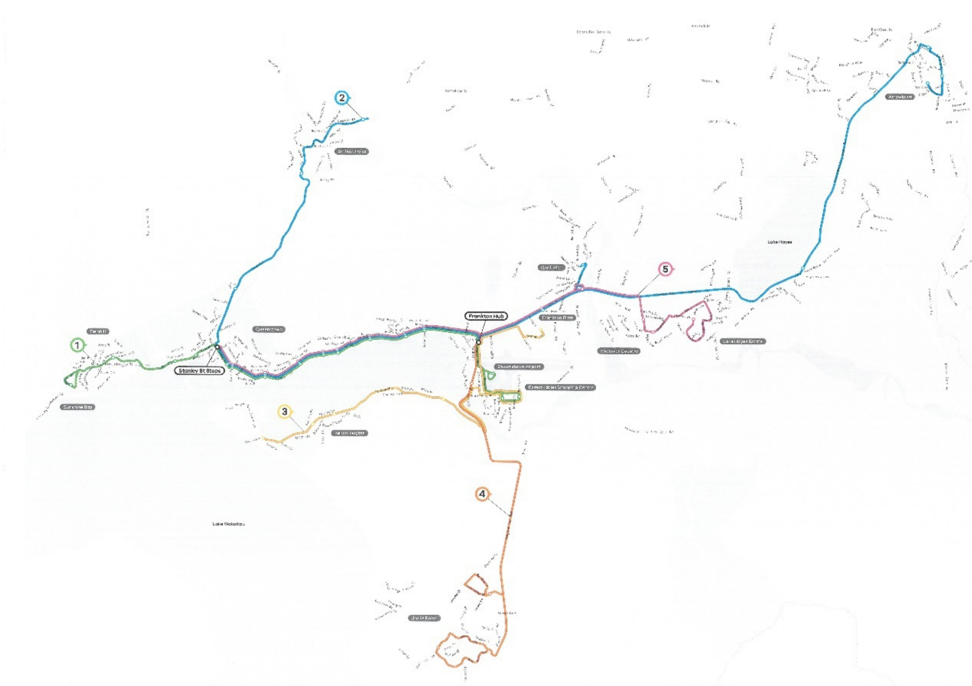


Figure 2: Queenstown Bus Network

[14] COVID-19 has had a significant effect on public transport activity. The following factors should be taken into consideration when reviewing comparisons of the first half of the 2020/21 financial year to the previous financial year:

a. services operated on either reduced capacity, reduced frequency timetables, or both through Alert levels 3 and 4, catering primarily for transport of essential staff, or essential trips for all other passengers;

b. reduced capacity services typically operated at approximately 40% capacity due to social distancing guidelines;

c. from the commencement of lockdown (26 March 2020) to the introduction of the Bee Card in September 2020 (1st September for Dunedin, 15th September Queenstown), fare-free travel has been in place, i.e. there was no revenue collection;

d. a $2 flat fare trial has been in operation in Dunedin since the 1 September 2020.

[15] The timeline for the above is below in Figure 3:

21 March 2020 – Covid Alert Level 2

⇩

23 March 2020 – Covid Alert Level 3

⇩

26 March 2020 – Covid Alert Level 4 – lockdown

⇩

28 April 2020 – Covid Alert Level 3

⇩

14 May 2020 – Covid Alert Level 2

⇩

9 June 2020 – Covid Alert Level 1

⇩

12 August 2020 – Covid Alert Level 2 (3 in Auckland)

⇩

1 September 2020 – Bee card goes live in Dunedin and $2 interim fares begin

⇩

15 September 2020 – Bee card goes live in Queenstown

⇩

22 September 2020 – Covid Alert Level 1

Figure 3: Covid-19 and ticketing introduction timeline

[16] In early February 2021, the Otago region had just over 40,000 registered Bee cards, which at the time was the most of any of the member Councils in the ticketing consortium.

[17] The following report summarises patronage trends across both networks, comparing Quarters 1 and 2 of Financial Year 2019/20 to FY 2020/21, together with Super Gold patronage. Monthly statistics comparing the previous two financial years are also provided. It also addresses customer complaints and the provision of real time passenger information in Dunedin. Finally, it provides information on the Total Mobility scheme.

TOTAL PUBLIC TRANSPORT BOARDINGS, DUNEDIN AND QUEENSTOWN

Monthly Total Patronage

[18] Both the Dunedin and Queenstown networks show a marked drop in patronage from August to September 2021 (see Figures 4 and 5), which coincides with the transition from fare-free travel to revenue collection. In Dunedin, September marked the beginning of the $2 flat fare trial whilst Queenstown returned to its previous $2 flat fare, albeit with a reduced cash fare for direct-to-airport trips.

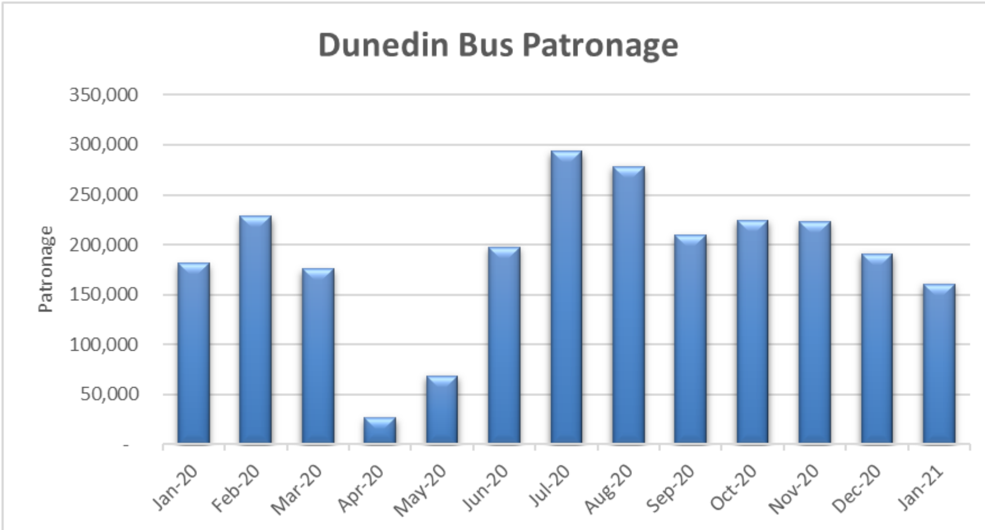


Figure 4: Dunedin Monthly Bus Patronage

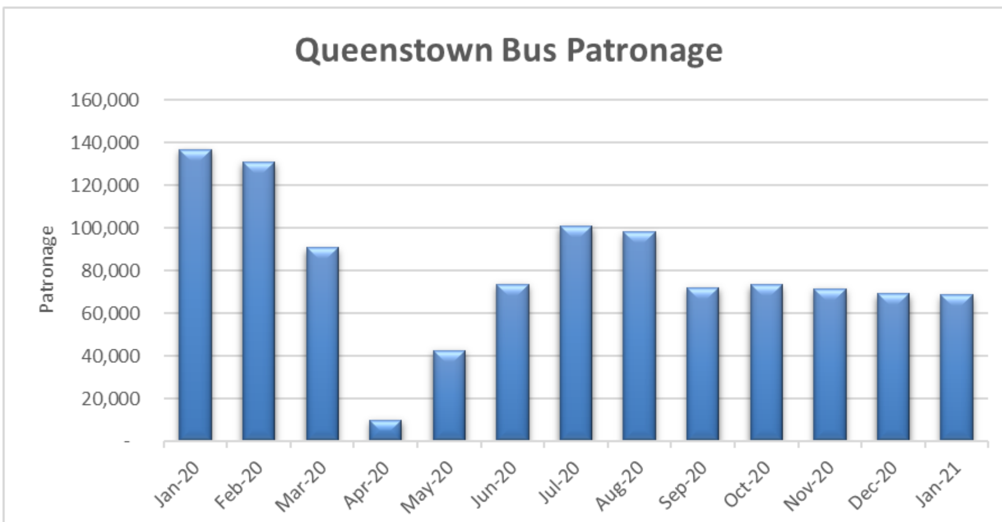


Figure 5: Queenstown Monthly Bus Patronage

Monthly Total Patronage Comparison Against Previous Financial Years

[19] In Dunedin (Figure 6), July 2020 patronage was up 32% and 18% in August compared to the previous year. This was due primarily to fare-free travel. September patronage fell by 9%, representing the re-introduction of revenue collection and the launch of the Bee Card.

[20] October, November and December 2020 were at 0.2%, -1.5% and 4% respectively, representing an upward trend overall. Note that from late November onwards, new vehicle fleet was being introduced in Dunedin, requiring ticketing hardware installations, testing and inspections. During this period, it is likely that patronage was

under reported. Nevertheless, it is significant that the Dunedin patronage trend is tracking higher than the pre-COVID reporting period.

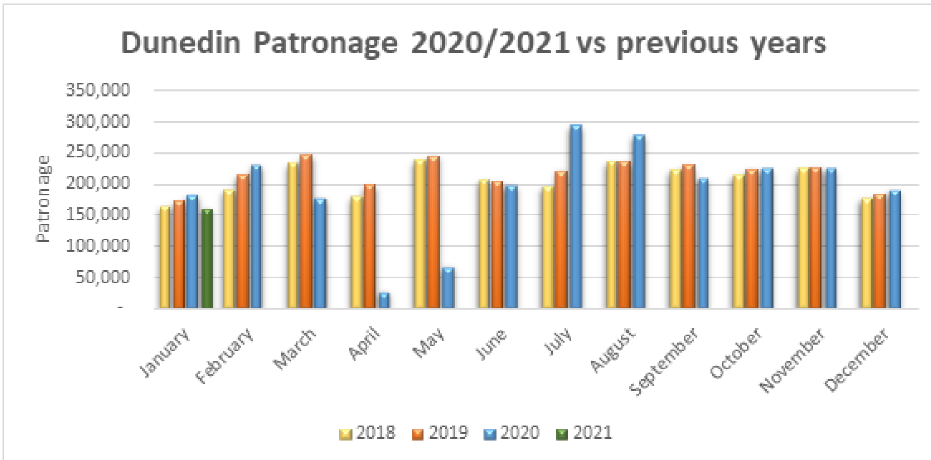


Figure 6: Dunedin Monthly Bus Patronage Comparison with Previous Years

[21] Queenstown has been significantly affected by COVID-19 (Figure 7). Whilst July and August 2020 patronage fell by 26% and 24% respectively compared to the previous year, this was during the free-travel period.

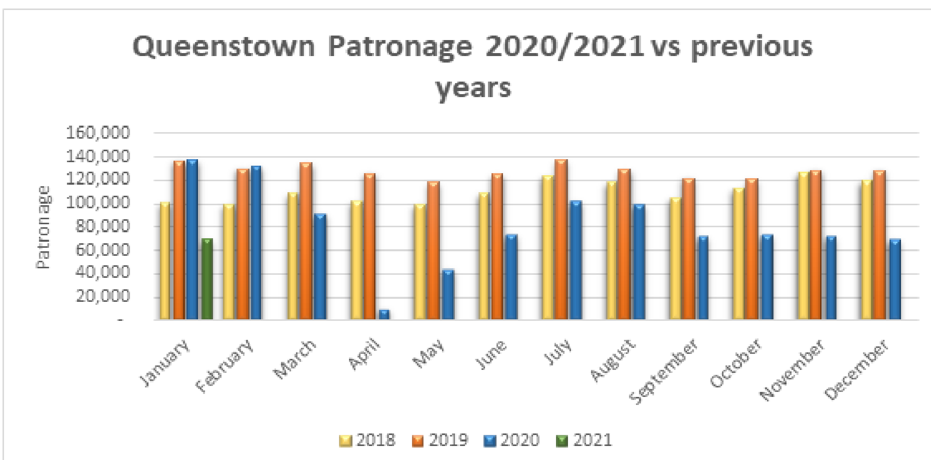


Figure 7: Queenstown Monthly Bus Patronage Comparison with Previous Years

[22] Analysis of Queenstown data split by route supports the theory that whilst commuter routes remain well patronised at similar or even greater levels than the previous Financial Year, tourist-oriented routes have seen significant falls.

[23] Using the new Bee Card reporting data, we can see that from September 2020 launch to January 2021, Routes 1 (Sunshine Bay to Airport & Remarkables Shops) and 2 (Arrowtown to Shotover River & Arthurs Point) have seen patronage fall by 57% and 50% respectively compared to the previous financial year. However, the more commuter/residential oriented Routes 3 (Kelvin Heights to Frankton Flats) and 4/5 (Jacks Point/Hanley's Farm and Lake Hayes Estate services) have actually seen

increases of 17% and 7% respectively – noting that these routes have been revised by ORC over the past year to better service commuters (see Figure 8).

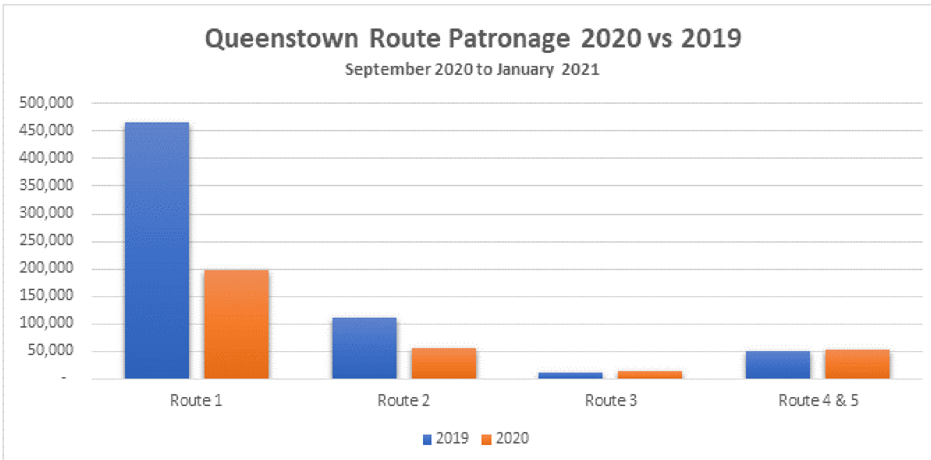


Figure 8: Queenstown Patronage by Route Comparison with Previous Year

[24] Overall, September patronage fell by 41%, with Bee Card launching on 15th September and revenue collection resuming. Thereafter, patronage has significantly declined versus the previous year, as expected. October, November, and December fell by 38%, 44% and 46% respectively.

Monthly Total Patronage 12 Month Rolling Total

[25] In terms of a 12-month rolling total1, the Dunedin network displays a flat/marginally upward trend (Figure 9), whilst Queenstown shows a decreasing trend (Figure 10). Note that the statistics below are significantly affected by the impacts on capacity caused by COVID.

[1] [20] The 12-month rolling sum is the total amount from the past 12 months. As the 12-month period "rolls" forward each month, the amount from the latest month is added and the one-year-old amount is subtracted. The result is a 12-month sum that has rolled forward to the new month. So, in essence, it shows how patronage is trending.

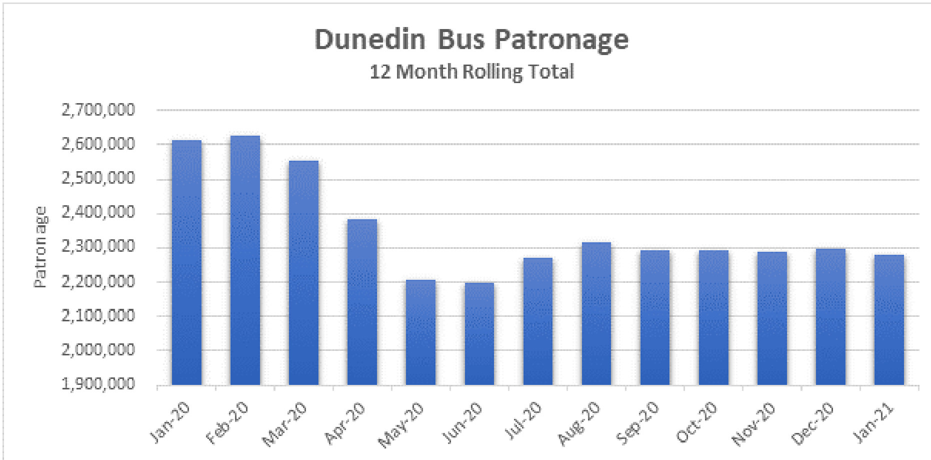


Figure 9: Dunedin Patronage – 12 Month Rolling Total

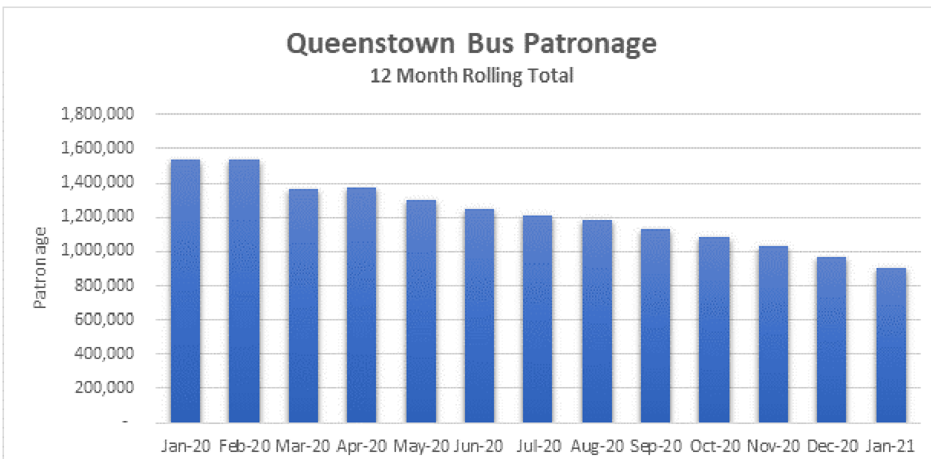


Figure 10: Queenstown Patronage – 12 Month Rolling Total

SuperGold Card Patronage

[26] SuperGold Card holders have been able to travel for free at peak times since the launch of the Bee Card (September 2020). There has been an immediate impact on travel patterns. SuperGold peak boardings have increased over the past three months by 122%, with a total of 27,927 SuperGold Card users boarding during peak times during November, December and January compared to a year ago.

[27] Year-on-year, for the Dunedin network, SuperGold patronage is relatively flat, with slight growth in December 2020 (Figure 11). Whilst COVID significantly impacted SuperGold patronage, the introduction of the Bee Card and $2 fare trial allowed for free SuperGold travel at all times, rather than off-peak only. This is likely to have contributed to the marginal post-COVID growth trend and diversion of some travel from off-peak to peak.

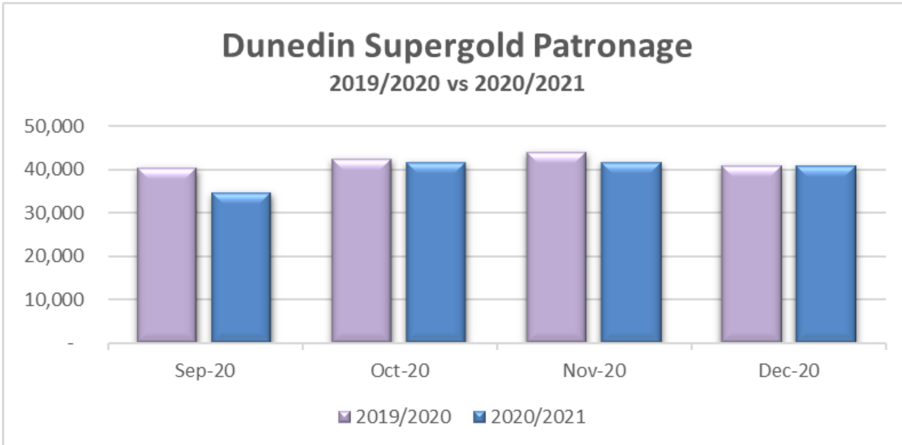


Figure 11: Dunedin SuperGold Card Patronage

[28] In Queenstown, SuperGold Card patronage has not recovered to the same levels, but December statistics point towards similar year-on-year patronage recovery (Figure 12). Note that Queenstown SuperGold holders are less likely to have been impacted by impacts to the hospitality sector; however, SuperGold patronage in Queenstown is around 40 times smaller than Dunedin, reflecting the differing demographics in the two regions.

Figure 12: Queenstown SuperGold Card Patronage

CUSTOMER FEEDBACK AND COMPLAINTS

[29] Table 1 below captures feedback and complaints data, segregated by enquiry type, for November and December 2020 and January and February 2021.

Detail	Nov 2020	Dec 2020	Jan 2021	Feb 2021
Total Escalated enquiries	128	75	150	248
Queenstown	35	17	35	47
Dunedin	93	58	115	201
General Enquiries	12	11	35	51
Form of Request	13	1	13	12
Praise for Driver/Service	2	0	4	8
Lost Property	1	0	23	42
Complaints total	100	63	75	135
Complaints breakdown:				
Complaints related to the Bus Hub	2	1	1	2
Complaint about cost	1	1	0	5
Complaints about drivers	39	28	39	43
Complaint about lost property	1	0	27	42
Complaint about passenger behaviour	1	0	0	5
Complaints about routes and times	17	8	29	24
Complaints about ticketing	4	0	5	4
Complaints about on-street infrastructure	10	2	6	14
Complaints about timeliness	23	20	14	62
Complaints about timetables/schedules	11	2	7	5
Complaint about on-bus wi-fi	1	0	1	0
Complaints related to other unclassified issues	18	13	34	18
Complaints about cleanliness/condition of bus	-	-	-	6
Complaints about transfers	-	-	-	4
Complaints about Information/comms	-	-	-	10
Complaints related to app/website	-	-	-	4

Table 1: Complaints

[30] Escalated complaints are addressed in a number of ways, for example:

- infrastructure and maintenance matters often require a collaborative response between ORC and road controlling authorities (DCC, QLDC, NZTA);
- driver and/or passenger behaviour complaints can be verified by on-board monitoring systems and CCTV;
- timeliness and timetable complaints are usually approached collaboratively by ORC staff and the Transport Operator; and
- complaints that are more serious in nature, or issues where there are large numbers of complaints, are always addressed appropriately and via the suitable authority. For example, recent concerns related to bus driver observance of correct traffic light/intersection manoeuvres resulted in a positive meeting between the NZ Police District Road Policing Manager, Council staff and both

transport operators. A follow-up meeting involving the Dunedin City Council will collaboratively address safety concerns at key city intersections across Dunedin.

[31] Where our customers have provided their details at the time they made their complaint, in general, Council staff will close those matters out by either calling or e-mailing the customer to advise of the outcome. In other occasions the matter will be resolved directly between the contractor and customer (for example, on matters relating to insurance claims).

REAL TIME PASSENGER INFORMATION

[32] The Council has been trialling an interim real time passenger information system in Queenstown since mid-2019. The system is provided by TrackAbus and at the moment, reliant on on-bus Wi-fi (see appended imagery).

[33] For Queenstown customers, the current system allows them to view the location of buses across any route on their device (big screens at Frankton Hub, computer, mobile, etc). That is, through the Orbus Queenstown website, which is not currently optimised for mobile devices (therefore not mobile-friendly).

[34] The proposal for Dunedin is to implement the same system as Queenstown by early-April.

[35] Concurrently, we are working with the Transit application developers to use its application for mobile devices for both the Queenstown and Dunedin networks. We do not yet have a completion date for this step, but it will likely be post go-live of the system in Dunedin.

[36] The TrackAbus system will provide a back-end for reporting reliability and punctuality. We need to configure this to report against our Annual Plan/Long Term Plan measures and how we automate evaluation of that data.

TOTAL MOBILITY

[37] The ORC also manages the Total Mobility scheme within the region (and has for the last 30 years). Total Mobility is a taxi or van/shuttle-based service available to people that have an impairment that prevents them from using public transport. Council currently provides this service in Dunedin (including Mosgiel), Oamaru, Queenstown and Wanaka.

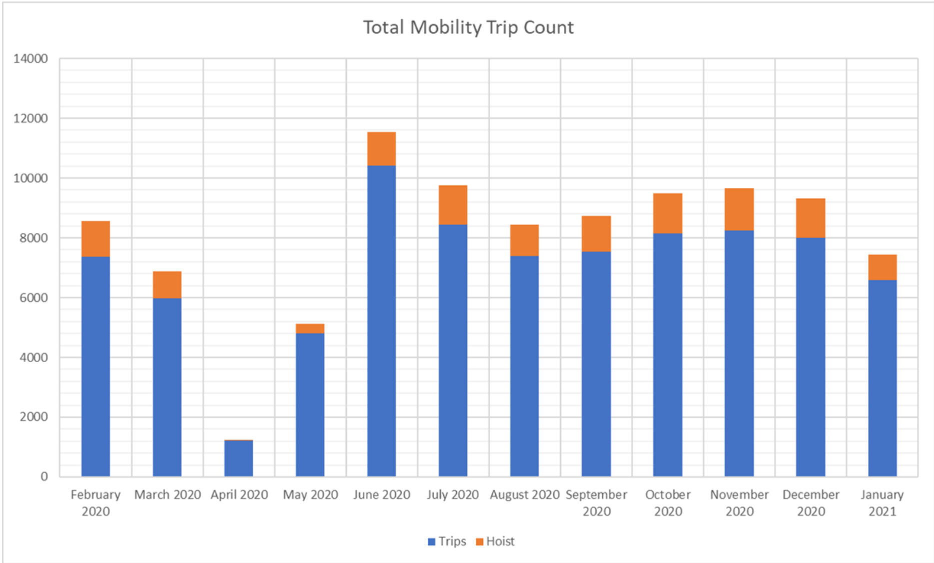


Figure 13: Total Mobility Trips

[38] In terms of the numbers above in Figure 13, 'Trips' includes 'Hoist' trips. 'Hoist' refers to those customers that require use of a hoist-equipped vehicle to travel for which suppliers receive a separate reimbursement.

[39] For the 12 months shown above, the mean monthly number of 'Trips' was just over 8,000 per month and of those, on average, 1,000 required hoist transport.

[40] About 85% of trips take place in Dunedin and Mosgiel, followed by 11% in Oamaru. The balance are travellers in Wanaka and Queenstown.

[41] In regard to hoist vehicles, since July 2020, Council has assisted in the installation of three hoists in vehicles – two in Dunedin and one in Oamaru.

NEXT STEPS

[42] The next steps are to:

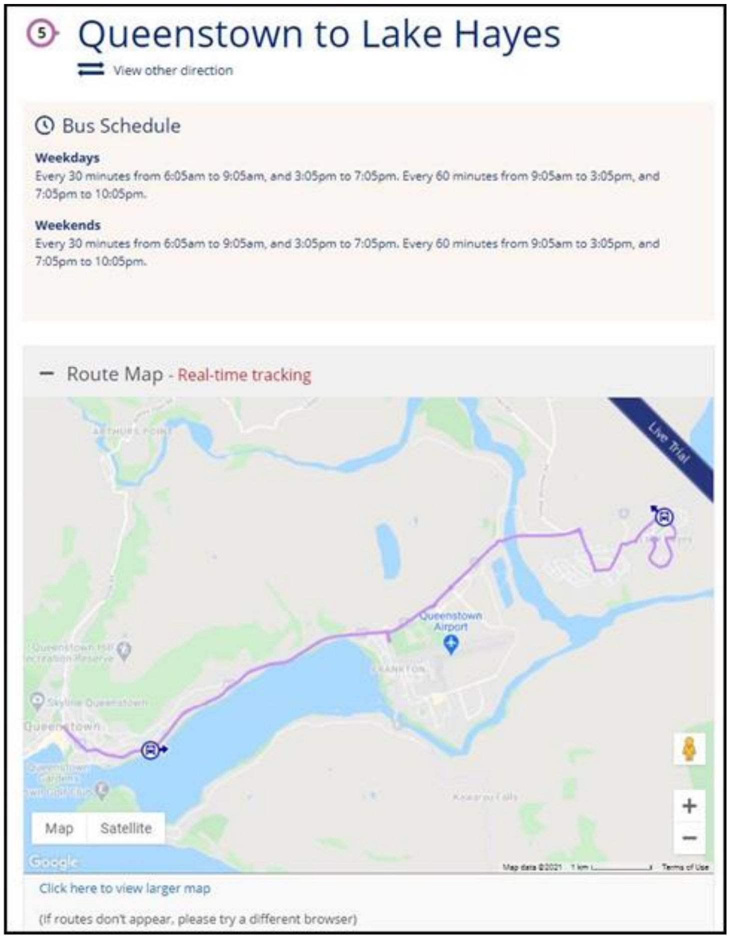
- continue to work with bus contractors to address customer feedback and work to identify trends in that feedback with the ultimate objective to grow/recover patronage;
- continue to collaborate with local and central government partners on public transport matters;
- undertake a passenger satisfaction survey of our Dunedin and Queenstown bus services;
- provide an update on the performance to the two public transport networks at the June 2021 Data and Information Committee meeting; and

- refine current Long Term Plan performance indicators for the next Long Term Plan to better measure patronage growth, reliability and punctuality and customer satisfaction (both for customers using bus services and Total Mobility).

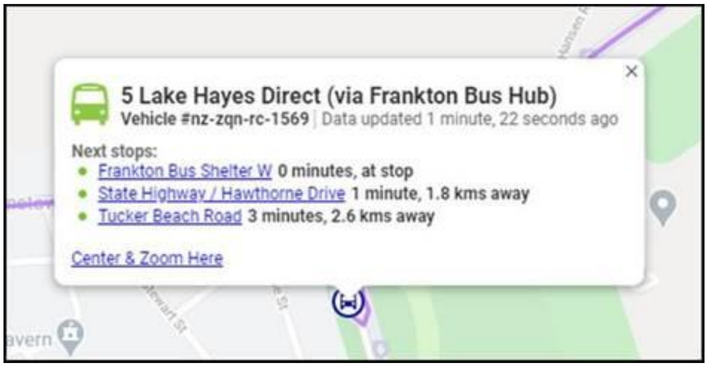
ATTACHMENTS

1. Real Time Passenger Information System Imagery [**7.7.1** - 5 pages]

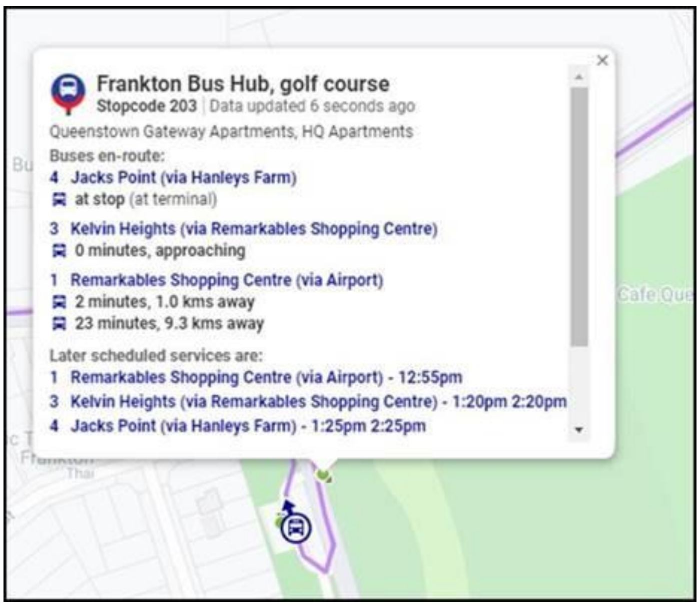
1. Live tracking map on the Orbus Queenstown website



2. Bus info from the Queenstown live map:

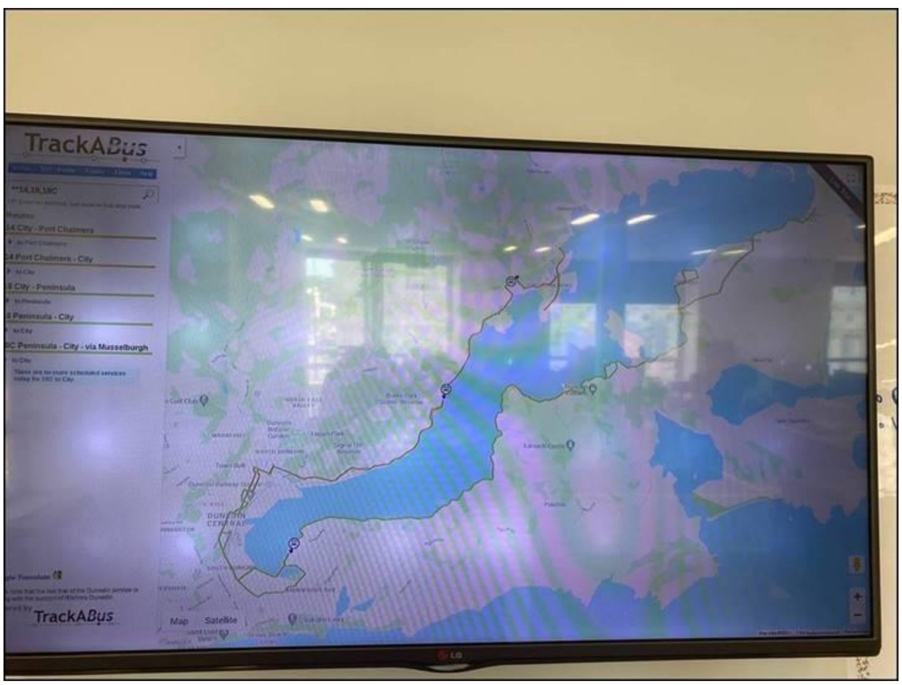


3. Bus stop info from the Queenstown live map.



4. Screens at the Frankton Hub

5. Screen in the Dunedin PT office, showing the Dunedin network live map.



6. Solar-powered e-stop at MacAndrew bay

7. The Transit App