Data and Information Committee Agenda
9 June 2021

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

09 June 2021 02:00 PM

Agenda Topic Page

Minutes of a meeting of the Data and Information Committee held in the Council Chamber on Wednesday 10 March 2021 at 2:00 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 Alexa Forbes welcomed Councillors, members of the public and staff to the meeting at 02:03 pm.

Staff present included Sarah Gardner (Chief Executive), 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 (Governance Support), Dianne Railton, Ellyse Gore, Jean-Luc Payan, Amir Levy, Marc Ettema, Sarah Harrison, Kyle Balderston and Garry Maloney.

1. APOLOGIES
There were no apologies.

2. PUBLIC FORUM
No public forum was held.

3. CONFIRMATION OF AGENDA
Cr Forbes asked to move consideration of the Queenstown and Dunedin Bus Patronage report to third in the order of business.

Moved: Cr Hope
Seconded: Cr Noone
CARRIED

4. CONFLICT OF INTEREST
No conflicts of interest were advised.

5. CONFIRMATION OF MINUTES
Resolution

That the minutes of the Data and Information Committee meeting held on 14 October 2020 be received and confirmed as a true and accurate record.

Moved: Cr Hobbs
Seconded: Cr Hope
CARRIED

6. ACTIONS
The Actions Register was reviewed with staff. Dr Jean-Luc Payan noted the outstanding action had been partially completed as the report is available on the ORC website and has been uploaded to the national Geotechnical Database. He said ORC staff are in discussions with DCC staff on the best way to use the report in the planning framework.

7. MATTERS FOR CONSIDERATION

7.1. Otago Climate Change Risk Assessment
This report was provided 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. Ellyse Gore, 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 Forbes moved its receipt.

Resolution

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 proactive presentation and dissemination of this information to the public and stakeholders.*

Moved: Cr Forbes
Seconded: Cr Wilson
CARRIED

7.2. Overview of Groundwater Quality State of Environment for Otago

This paper was provided to present the groundwater State of the Environment report as of December 2019. The paper highlighted key findings identified in the report regarding groundwater quality in Otago and identified a range of measures to consider for improving the Otago Regional Council's monitoring programme, public awareness, and the protection of groundwater quality. Amir Levy, Groundwater Scientist, and Gwyneth Elsum, GM Strategy, Policy and Science, were present to speak to the report and respond to questions.

After a thorough discussion of the report, Cr Noone moved its receipt.

Resolution

That the Committee:

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

Moved: Cr Noone
Seconded: Cr Hobbs
CARRIED

7.3. Queenstown and Dunedin 2020/21 Quarter 1 and 2 Patronage Report

This report was provided to update the Committee on the performance of its public transport and total mobility services for the first half of the 2020/21 financial year, including Super Gold usage. Julian Phillips, Implementation Lead - Transport, Garry Maloney, Manager Transport, and Gavin Palmer, GM Operations, were present to speak to the report and respond to questions.

After questions and discussion, Cr Hobbs moved receipt of the report.

Resolution

That the Committee:

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

Moved: Cr Hobbs
Seconded: Cr Malcolm
CARRIED

Cr Forbes requested a short adjournment at 3:20 p.m.

Cr Forbes called the meeting back to order at 3:25 p.m.

7.4. SoE Monitoring Bi-annual Update

This paper was provided to update the Committee about hydrological data capture and quality produced from the environmental monitoring network operated by the Otago Regional Council Environmental Monitoring team. Eike Breitbarth, Manager Environmental Monitoring and Gwyneth Elsum, GM Strategy, Policy and Science, were present to speak to the report and respond to questions. Following questions and discussion of the report, Cr Hope moved its receipt.

Resolution

That the Committee:

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

Moved: Cr Hope
Seconded: Cr Noone
CARRIED

7.5. Annual Air Quality Report 2020

This report was provided to review results of State of the Environment monitoring for air quality for the year 2020. Sarah Harrison, Air Quality Scientist and Gwyneth Elsum, GM Strategy, Policy and Science, were present to speak to the report and respond to questions. After a discussion of the report, Cr Malcolm moved:

Resolution

That the Council:

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

Moved: Cr Malcolm
Seconded: Cr Hope
CARRIED

7.6. Emissions Inventory and Low Emissions Technology Review

This report was provided to review the Emissions Inventory 2019 and the Low Emissions Technology Review 2020. Sarah Harrison, Air Quality Scientist and Gwyneth Elsum, GM Strategy, Policy and Science, were present to speak to the report and respond to questions. After a discussion of the report, Cr Laws moved:

Resolution

That the Committee:

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

Moved: Cr Laws
Seconded: Cr Calvert
CARRIED

7.7. Urban Monitoring Quarterly Update

This report was provided to review the initial Quarterly Monitoring Report produced by the Otago Regional Council, as required by the National Policy Statement on Urban Development 2020 (NPSUD) and covered the period up to and including the fourth quarter of 2020. Kyle Balderston, Team Leader Urban Growth and Development, and Gwyneth Elsum, GM Strategy, Policy and Science, were present to speak to the report and respond to questions. A discussion of the paper was held with several Councillors asking questions of Mr Balderston and Ms Elsum. Cr Forbes then moved:

Resolution

That the Committee:

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

Moved: Cr Forbes
Seconded: Cr Hope
CARRIED

8. CLOSURE

There was no further business and Co-Chair Forbes declared the meeting closed at 03:55 pm.

_________________________ _________________

Chairperson Date

OUTSTANDING ACTIONS OF RESOLUTIONS OF THE DATA AND IMPLEMENTATION COMMITTEE AT 9 JUNE 2021

Document	Item	Status	Action Required	Assignee/s	Action Taken	Due Date	Completed (Overdue)
Data and Information Committee 2020.10.14	OPS1020 Update on the Geology and Ground Conditions of South Dunedin and Harbourside	Completed	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	**31/03/2021** The report is now available on the ORC website and has been uploaded to the national Geotechnical Database. ORC staff are in discussions with DCC staff on the best way to use the report in the planning framework.	11/03/2021	31/03/2021

7.1. Otago Greenhouse Gas Profile 2018/19 financial year

Prepared for:	Data and Information Committee
Report No.	SPS2126
Activity:	Internal Projects: Corporate
Authors:	Dr Anne Duncan, Manager, Strategy and Dr Ann Yang, Senior Economist
Endorsed by:	Gwyneth Elsum, General Manager, Strategy, Policy and Science
Date:	9 June 2021

PURPOSE

[1] To present the first Otago Greenhouse Gas Emission Inventory FY2018/19 and report.

EXECUTIVE SUMMARY

[2] The Otago Greenhouse Gas (GHG) inventory for 2018/19 financial year provides an overview of the GHG emissions within Otago between July 2018 and June 2019. The emission data is shown by Otago's districts and sectors defined in the Global Protocol for Community-Scale Greenhouse Gas Emission Inventories (GPC).

[3] The inventory provides baseline data to understand Otago's emissions and monitor progress of any mitigation options. Further development of the data can also be used proactively to model outcomes and economic impacts of mitigation options. It can also be used to develop scenarios and provide a planning and engagement tool.

[4] The inventory was a close collaboration between ORC and Otago's District/City councils. The Councils provided their area specific data (e.g., information on landfill and wastewater treatment plants); have discussed the assumptions used to estimate the emissions; and have commented on the draft report.

[5] The findings included that the primary source of emissions in the Otago region is the agriculture sector. This is mainly from sheep and beef activities and is consistent across four of the five districts. Transportation was more significant in the emissions profiles of Dunedin and Queenstown-Lakes; and electricity makes up a significant proportion of stationary energy emissions across all districts.

[6] Key findings of the report and next steps will be discussed with District /City Councils as part of developing an ongoing partnership approach to climate change.

RECOMMENDATIONS

That the Committee:

1) ***Receives** this report.*
2) ***Notes** that the Otago Greenhouse Gas Inventory has been prepared in collaboration with Otago's Territorial Authorities as a compilation of emissions for each District/City.*

3) ***Notes*** *the Inventory Report and the baseline data that will be publicly available to build understanding and support further investigations and future regional planning in Otago.*
4) ***Notes*** *the further use of the inventory to inform development of mitigation options and scenarios for Otago.*
5) ***Notes*** *that the Otago Regional Council will seek to lead/initiate the Otago Greenhouse Gas Inventory every two years in cooperation with Otago's District/City councils.*

BACKGROUND

[7] Greenhouse gases (GHG) are a small number of gases that naturally exist in Earth's atmosphere which trap the heat from sunlight. They created the right conditions for life to grow on earth, but increasing levels are leading to over-heating in the atmosphere and climate change [Ministry for Environment][1]. Examples of GHG and sources of emissions include[2]:

- carbon dioxide (CO_2), mainly from fossil fuel use
- methane (CH_4), mainly from animals and organic waste
- nitrous oxide (N_2O), mainly from agriculture
- hydrofluorocarbons (HFCs), mainly from refrigerants
- sulphur hexafluoride (SF_6), mainly from the electricity industry
- perfluorocarbons (PFCs), mainly from aluminium production
- nitrogen trifluoride (NF_3), mainly from production of silicon wafers, liquid crystal displays and silicon-based solar cells

[8] The impacts of climate change will result in new risks, challenges and perhaps some opportunities for individuals, communities, businesses, and governments. In Otago, some of the changes include warmer temperatures (more hot days, fewer frosts), more wet conditions (winter and spring), significant decreases in snow, more windy days, an increase in storm intensity, local wind extremes, and more thunderstorms, and sea level rise (NIWA, 2021)[3]. A risk assessment[4] (Otago Climate Change Risk Assessment Report) for the impact of climate change in Otago has already been completed and presented to this Committee.

[9] To avoid the worst effects of climate change, significant and urgent global action is also required to reduce and remove GHG emissions to limit global warming to below 2^{o}C above pre-industrial levels. It is thus becoming increasingly important for governments and communities to understand their sources of GHG emissions.

[10] A GHG inventory or profile is a collection of emission data that is organised in a particular way for a certain time period and area.

[11] A GHG inventory for Otago is the first step in determining and quantifying emission sources on a path to reducing emissions in Otago and monitoring progress.

[1] https://environment.govt.nz/facts-and-science/climate-change/evidence-for-climate-change/
[2] https://www.toitu.co.nz/tools-and-resources/faqs-and-glossary#carboNZeroCEMARS
[3] https://www.orc.govt.nz/media/7591/niwa_climatechangereport_2019_final.pdf
[4] https://www.orc.govt.nz/managing-our-environment/climate-change/otago-climate-change-risk-assessment

DISCUSSION

[12] The Otago GHG inventory/profile for 2018/19 financial year provides an overview of the GHG emissions within Otago between July 2018 and June 2019, and the emission data is organised by Otago's districts and sectors defined in the Global Protocol for Community-Scale Greenhouse Gas Emission Inventories (GPC). The GPC was developed by the C40 Cities Climate Leadership Group, the World Resources Institute (WRI) and Local Governments for Sustainability (ICLEI)[5]. It is the world's most widely endorsed GHG accounting and reporting standard and is in wide use in New Zealand.

[13] The Otago GHG profile for 2018/19 was completed by consultants Ernst Young, working with ORC and each of the District and City Councils in Otago. While Dunedin City Council (DCC) and Queenstown Lakes District Council (QLDC) already had completed inventories, Waitaki, Clutha and Central Otago District Councils had not.

[14] The data collected for the inventory is summarised in Appendix 1. Data sources included Stats NZ, Kiwirail, Otago's main airports, Port Otago, electricity distributors, Ministry for Business, Innovation and Employment (MBIE), Ahika Consulting, LPG Association, Ministry for the Environment (MfE), ORC and Tonkin + Taylor. All five district councils provided data on waste, and QLDC provided data on the Earnslaw.

[15] The following emissions sources lacked reliable data and hence required more estimation: closed landfills, boilers that have energy output less than 100kw, Industrial Processes and Product Uses (IPPU), solid waste disposal, and wastewater treatment and discharge. The inventory process highlighted the need to think about how to have a better database for future analysis.

[16] The final inventory results were discussed with Stats NZ and compared to the regional inventory completed by Stats NZ using national data sets. It has been agreed that the discrepancies reflect methodological differences. Differences between the results of this inventory and the results of the previously completed inventories for QLDC and DCC were also discussed and are explainable in terms of methodology and data used.

[17] Key findings of the report included:

a. Total gross emissions (excluding Land Use, Land Use Change and Forestry (LULUCF)) for the Otago region in 2019 are estimated to be 5,821,025 tCO_2e. The LULUCF sector is a net emission sink at -2,640,398 tCO_2e which offsets approximately 47% of the region's gross emissions resulting in total net emissions for the Otago region of 3,180,627 tCO_2e.
b. The primary source of emissions in the Otago region is the agriculture sector, which is consistent across four of the five districts (Central Otago, Clutha, Dunedin City, Waitaki). A large proportion of these emissions is related to cattle and sheep farming.
c. Land use, land use change, and forestry (LULUCF) is a significant sink of emissions resulting in net negative emissions from this sector. Clutha District contributes the majority (59%) of this sequestration. However, all the districts had net positive emissions profiles as the sources of emissions outweighed the sinks.

[5] GHG Protocol, WRI, C40, ICLEI, Global Protocol for Community-Scale Greenhouse Gas Emission Inventories, available at: https://ghgprotocol.org/greenhouse-gas-protocol-accounting-reporting-standard-cities

d. Transportation was more significant in the emissions profiles of Dunedin and Queenstown-Lakes.
e. Electricity makes up a significant proportion of stationary energy emissions across all districts.

[18] The varied information sources required to collate a complete Otago GHG emissions inventory may present an ongoing challenge for ORC. ORC will need to develop efficient, effective, and robust long-term arrangements for collection of this information as part of the regional partnership approach.

[19] The GHG Inventory can immediately be used to develop a tool for proactive planning. Development of 'business-as-usual' emissions projections to 2050 and scenario modelling of mitigation options could be used to inform collaborative discussions and community engagement about mitigation and decarbonisation options, and priorities for action and engagement both at a regional and local level. Economic impacts of mitigation actions could also be estimated and used for planning, engagement and decision making.

[20] The GHG inventory and mitigation options and scenarios, together the with results of the OCCRA, provide data and information to support decision makers in developing a systematic understanding of the current challenges of climate change for Otago and a basis to work together to develop a regional partnership approach to address these challenges. ORC will be endeavouring to facilitate engagement in a regional partnership approach for both mitigation and adaptation, which will identify possible immediate actions, key risks and priorities and research and planning needs. Consideration of how to proceed will also need to consider how best to link to Dunedin City Council's Net Zero 2030 Partnership.

CONSIDERATIONS

Strategic Framework and Policy Considerations

[21] This inventory and report are broadly consistent with the commitment in ORC's Strategic Directions and the Long-Term Plan to provide an effective response to climate change. They will facilitate ORC:

a. taking a leadership role in developing an integrated regional partnership approach to climate change – one which includes mitigation as well as adaptation;
b. taking action to engage communities to increase understanding about climate change;
c. considering climate change in all ORC's decisions; and
d. monitoring Otago emissions and advocating for mitigation to meet the national zero emissions by 2050 target.

Financial Considerations

[22] Provision for ongoing collection of data to inform future updates of the inventory will need to be made in the next LTP. Discussions with District/City Councils about the most effective/efficient arrangements as part of partnership discussions should inform development of a business case.

Significance and Engagement Considerations

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

[24] The inventory and report are the result of significant cooperation between ORC and the five District/City councils as well as connecting with government agencies and industry stakeholders. The District/City Councils provided their area specific data (e.g., information on landfill and wastewater treatment plants), have discussed the assumptions used to estimate the emissions, and have commented on the draft report.

Legislative and Risk Considerations

[25] The inventory will enable ORC and Otago to better assess legislative and risk considerations. As part of forthcoming RMA reforms, a National Policy Statement will be developed to give mandatory direction on climate change – including both mitigation and adaptation. It is expected that it will provide direction on issues such as control of GHG emissions.

[26] Direction on mitigation is also likely to emerge through the national emission reduction budgets identified by the Climate Change Commission draft report. They are likely to be given effect to in the Regional Spatial Strategies under the new Strategic Planning Act.

Climate Change Considerations

[27] The inventory data provides essential benchmark data to enable monitoring of regional emissions and potentially, if ongoing, the effectiveness of mitigation actions. It will provide information which Council can use to consider climate change in its decision making.

Communications Considerations

[28] Climate change is an issue with wide impacts and therefore, of relevance and interest to the whole community. It is important that the data and information are made publicly available.

NEXT STEPS

[29] The inventory data set can be further developed into a series of mitigation options and scenarios for Otago and provide additional information for the region to consider. It is recommended that this be undertaken as a continuation of the current inventory project.

[30] The Report will be made available and promoted to stakeholders and the public. This will include:

a. A media release to advise the report has been presented to Council, with an outline of the purpose and next steps;
b. Uploading the report to the climate change section of the ORC website, with a description of the purpose and next steps;
c. The Strategy and Natural Hazards Teams are planning a roadshow within the next six months to speak with city/district councils and relevant industry groups. This will combine the Otago GHG Emissions Inventory 2018/19 and the Otago Climate Change Adaptation Risk Assessment (OCCRA) and raise awareness about climate change. The Communications Team will develop and assist with any materials needed for this;

d. Published through existing channels e.g. Facebook, On-Stream, Waterlines;
e. Public engagement events as opportunities arise (on both reports and climate change in general); and
f. Interactive and engaging education through Enviroschools, community events (on both reports and climate change in general).

It is recognised through the limitations highlighted within the inventory report that improvements can be made to both the data set and the methodology. It is recommended that ORC seeks to lead/initiate the Otago GHG inventory every two years in cooperation with Otago's District/City councils to enable monitoring of Otago's GHG emissions trends and any impacts of mitigation policies and actions.

Appendix – Data and sources used for the Otago GHG Inventory 2018/19

Source	Main Data	Data source	Emission factors
Agriculture			
Livestock	livestock numbers	Stats NZ Agricultural Production Census	Ministry for the Environment's 2020 Emission Factors Workbook
Fertiliser	fertiliser application numbers	Stats NZ Agricultural Production Census	..
Forestry	Forestry hectare	the LUCAS New Zealand Land Use Map (LUM)	..
Forestry harvest	Wood supply by district and age class	National Exotic Forest Description	..
Transportation			
On-and off-road	Quarterly fuel sales by district	Stats NZ Retail Trade Survey	..
	The proportion of petrol versus diesel use	Energy Efficiency and Conservation Authority's Energy End Use Database.	..
Railways	Fuel consumption by district	KiwiRail	..
Aviation	Flight schedule information	Dunedin Airport, Queenstown Airport and Wanaka Airport	..
	Fuel consumption calculated using fuel economy estimates (by aircraft type)	IAO	..
Waterborne navigation	Departing container vessels from Port Otago	Port Otago	..
	Earns law fuel consumption	QLDC	..
Stationary energy			
Electricity	Electricity delivered to users	Aurora Energy, Power Net and Network Waitaki	..
	Residential usage	Electricity Authority's Electricity Market Information website which provides total residential usage for the Otago region.	..
	Commercial, industrial and agriculture sector electricity consumption	National electricity consumption figures from MBIE.	..
Commercial and Industrial sector energy demand	Industrial sector energy demand from boilers with capacity greater than 100	Ahika Consulting	..
	Boilers with unknown capacity were excluded from this analysis and boilers with unknown fuel type were assumed to use coal		..
Agriculture sector energy demand	National energy balance data for the Agriculture sector	Ministry of Business, Innovation and Employment	..
Residential sector energy demand	LPG sales data for the South Island	LPG Association of New Zealand (LPANZ).	..
	Per capita daily coal and wood use	Home heating emission inventory and other sources evaluation (Wilton et al. 2015)	..
Waste			
Solid waste disposal - Active landfills	Where possible, actual data on historical waste to landfill was provided	District councils	..
	When unavailable, assumptions were made to fill the gaps.		..
	Only landfills closed after 2000 were considered.	ORC	..
Wastewater treatment and discharge	Emissions for all districts except for Queenstown-Lakes were calculated following IPCC guidelines.		..
	Wastewater emissions for Queenstown-Lakes were calculated	by Tonkin & Taylor in collaboration with Deta Consulting	..
Farm fills and rural waste	emissions from farm fills and rural waste	Stats NZ	..
Industrial processes and product uses (IPPU)			
Industrial processes and product uses	National industrial process and product use (IPPU) emissions	Ministry for the Environment's New Zealand's Greenhouse Gas Inventory 1990-2018	..
	Emissions from household use of industrial products and emissions from disposal of industrial products	Stats NZ	..

ATTACHMENTS

1. Otago Region GHG Profile - Report V 3 [**7.1.1** - 35 pages]

Otago Region Greenhouse Gas Profile

Prepared for Otago Regional Council

12 May 2021

Building a better working world

Table of contents

Disclaimer

Ernst & Young ("Consultant") was engaged on the instructions of the Otago Regional Council ("Client") to develop this Otago Region GHG Profile ("Project"), in accordance with the consulting services agreement dated 20 November 2020 ("the Engagement Agreement").

The results of the Consultant's work, including the assumptions and qualifications made in preparing the report, are set out in the Consultant's report dated 12 May 2021 ("Report"). You should read the Report in its entirety including the disclaimers and attachments. A reference to the Report includes any part of the Report. No further work has been undertaken by the Consultant since the date of the Report to update it.

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Acknowledgements

The development of a regionwide greenhouse gas emissions inventory is a complex process which requires input from a variety of stakeholders. Ernst & Young and the Otago Regional Council would like to thank contributors to this report; specifically, the Central Otago District Council, Clutha District Council, Dunedin City Council, Queenstown-Lakes District Council, Waitaki District Council, Statistics New Zealand – Tatauranga Aotearoa, Ministry for the Environment – Manatū Mō Te Taiao, PowerNet, Aurora Energy, Network Waitaki, KiwiRail, Ahika Consulting, Rockgas, Port Otago, Queenstown Airport and Dunedin Airport.

1. Executive Summary

Background and overview of work performed

The effects of climate change are already being observed in New Zealand. Average annual temperatures and sea levels are rising, glacier ice volumes are decreasing, and extreme weather events are more frequent. To avoid the worst effects of climate change, significant and urgent action is required to reduce and remove greenhouse gas (GHG) emissions in an effort to limit global warming to well below 2°C above pre-industrial levels. It is becoming increasingly important for governments, organisations, and communities to understand their sources of emissions so that efforts to reduce emissions are targeted and effective in order to mitigate the worst effects of climate change.

Governments and organisations all around the world use emission inventories to help determine and monitor significant sources of GHG emissions and to target mitigation efforts. It is the important first step on the path to reducing emissions and monitoring progress.

The Otago Regional Council's (ORC) long-term plan is to manage and mitigate climate change impacts. To support this, EY has developed an **Otago Region GHG Profile**. This inventory has been developed to enable ORC to better understand significant sources of GHG emissions across its five districts and the emissions profile of major industries for the latest applicable time period. The emissions inventory was developed for year ended 30 June 2019.[1] The results will help ORC and its districts to better understand and target climate change mitigation efforts.

The **Otago Region GHG Profile** was developed in line with the *Global Protocol for Community-Scale Greenhouse Gas Emission Inventories* (GPC) developed by the Greenhouse Gas Protocol for C40 Cities Climate Leadership Group, the World Resources Institute (WRI) and Local Governments for Sustainability (ICLEI)[2].

Key findings

Total gross emissions (excluding Land Use, Land Use Change and Forestry (LULUCF)) for the Otago region in 2019 are estimated to be **5,821,025 tCO_2e**. The LULUCF sector is a net emissions sink at -2,640,398 tCO_2e which offsets approximately 47% of the region's gross emissions resulting in total net emissions for the Otago region of **3,180,627 tCO_2e.**

The following key findings were noted by EY during development of the inventory:

What did EY find?	What does this mean for ORC?
The primary source of emissions in the Otago region is the agriculture sector, which is consistent across four of the five districts (Central Otago, Clutha, Dunedin City, Waitaki). A large proportion of these emissions is related to cattle and sheep farming.	There may be opportunities to target emission reduction activities with livestock farming however the carbon intensity of this activity should be considered due to the relative size of this sector.
Land use, land use change, and forestry (LULUCF) is a significant sink of emissions resulting in net negative emissions from this sector. Clutha district contributes the majority (59%) of this sequestration. However, all of the districts had net positive emissions profiles as the sources of emissions outweighed the sinks.	Although the LULUCF sector is a net emissions sink, forest harvest activities are a source of emissions. Forest conservation, regeneration and reforestation could be a significant contributor to balancing sources and sinks in the region.

[1] Whilst every effort was made to obtain activity data for the period 01 July 2018 – 30 June 2019 in some cases the latest available data was for a prior period. The latest available data was used.

[2] GHG Protocol, WRI, C40, ICLEI, Global Protocol for Community-Scale Greenhouse Gas Emission Inventories, available at: https://ghgprotocol.org/greenhouse-gas-protocol-accounting-reporting-standard-cities

What did EY find?	What does this mean for ORC?
Transportation was more significant in the emissions profiles of Dunedin and Queenstown-Lakes (the transportation sector is the most significant source of emissions in Queenstown-Lakes). The most significant contribution to emissions is related to on-road petrol and diesel consumption.	Considering how people move and the modes of transport they choose will be important in tackling emissions from this sector. A shift to electric vehicles replacing traditional internal combustion engine powered transport may reduce emissions from this sector.
Electricity makes up a significant proportion of stationary energy emissions across all districts. However, where coal, liquified petroleum gas (LPG) or light fuel oil (LFO) boilers are used this creates a significant source of emissions.	There may be opportunities for fuel switching (e.g. to biomass) and/or electrification to reduce emissions from stationary energy sources.
The varied information sources required to collate a complete emissions inventory for the region may present an on-going challenge for ORC as it seeks to monitor its emissions and the effectiveness of mitigation actions. ORC relied on a number of third parties to obtain the activity data used in the emissions inventory.	To maintain and update the regional emissions inventory it may be beneficial for ORC to formalise its climate data management to ensure efficient and effective processes are in place to obtain timely data to support an evidence-based climate action strategy.

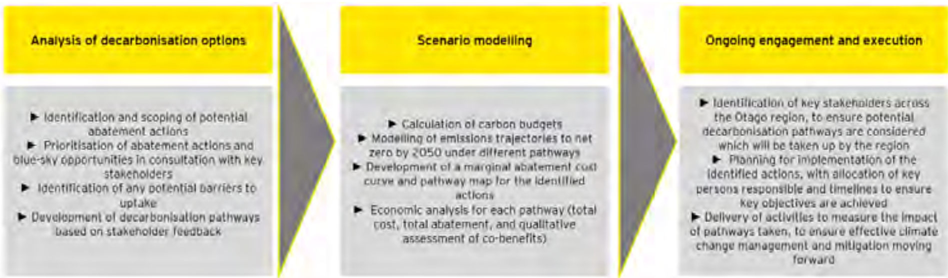
It should be noted that a number of assumptions were made during the development of ORC's GHG emissions inventory. These assumptions and associated limitations are outlined in the technical method presented in **Appendix A** of this report.

Proposed next steps

This regional dataset provides the ORC with an initial platform which can be used to initiate effective management and mitigation of climate change impacts.

<u>Recommendations</u>

1. Further analysis and modelling are required to turn the data into a tool for proactive planning. EY recommends both the development of 'business-as-usual' emissions projections to 2050 and the scenario modelling of mitigation options. This will assist in identification of effective mitigation and decarbonisation options and facilitate collective discussion of priorities for action and engagement, both at a regional and local level. Based on the development of options and scenario modelling, economic impacts of mitigation actions can also be estimated and used for planning, engagement and decision making. A quote for this section of work was included in the initial RFP.



2. The dataset will require maintenance and review to ensure its currency and accuracy. An approach to this will be required to be discussed and agreed by ORC and its districts.

3. In particular, efforts should be made to obtain better data for the following sources:

- Industrial processes and product uses
- Solid waste disposal
- Wastewater treatment and discharge.

This will improve the accuracy of the calculated emissions and projections (where applicable) ensuring decisions are made which reflect the actual impacts of climate change as a result of specific actions.

4. ORC and districts may wish to review their climate data management systems and processes in collaboration with third parties who also contribute, to ensure long term and timely access to the quality data on which this inventory relies. Good climate data management and established and reliable coordination arrangements with a range of stakeholders is needed to inform and improve climate policy design, implementation and decision-making.

2. Scope and Approach

EY developed a GHG emissions inventory for the Otago region, which comprises the following five districts:

- Central Otago
- Clutha
- Dunedin City
- Queenstown-Lakes
- Waitaki.

Whilst the *Otago Region GHG Profile* is broken down by district, it is noted that Dunedin City and Queenstown-Lakes have completed their own district level emissions inventories. Significant differences in results (due to method and assumption differences), are discussed in the relevant district chapters.

The GHG emissions inventory was developed across three key project phases, summarised below.

Figure 1 - Map of Otago Regional Council's boundaries (http://www.localcouncils.govt.nz/)

Phase	Key activities performed
Phase 1: Inception and planning	► A project inception meeting was facilitated. ► EY was introduced to key data owners across ORC's districts. ► A project plan was developed and used to track progress across the engagement.
Phase 2: Inventory development	► EY assessed the region's and individual districts' emissions boundaries and emissions sources in alignment with the GHG Protocol BASIC+ inventory reporting level. ► Key data sources and owners (landfill operators, large commercial and industrial sites, rail operators, government bodies and agencies etc.) were identified. ► Data was collected by performing desktop research and by contacting key stakeholders and data owners previously identified. ► EY assessed the data quality of each data source against GHG Protocol indicators and in line with the GHG Protocol's Global Protocol for Community-Scale Greenhouse Gas Emission Inventories and the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. ► EY developed estimation methods for data gaps. These estimation methods were validated with ORC and are outlined within the technical method in **Appendix A** of this report as relevant. ► EY identified appropriate emission factors and developed the inventory calculation method. ► EY calculated the emission inventory for the whole-of-Otago region, broken down by sector and by each of the five districts in the regional GHG inventory Excel file.
Phase 3: Reporting and transmittal	► EY developed the emission inventory in an Excel file and an accompanying report (this report). ► EY provided the draft report to ORC for comment. ► EY addressed ORC's comments and finalised the emission inventory and report accordingly.

The technical approach to inventory development, including assumptions made and associated limitations, is presented in **Appendix A** of this report.

3. Results

In 2019, the Otago economy generated $14 billion in gross domestic product (GDP) (4.5% of NZ's GDP). The top 5 industries by GDP were Construction (9.1% of total Otago GDP), Agriculture, Forestry and Fishing (6.6%), Rental, Hiring and Real Estate Services (6.3%), Accommodation and Food Services (6.2%), and Healthcare and Social Assistance (6.1%). The residential population in Otago was estimated at 239,700 people.

Total gross emissions (excluding Land Use, Land Use Change and Forestry (LULUCF)) for the Otago region in financial year ended 30 June 2019 are estimated to be 5,821,025 tCO_2e. The LULUCF sector is a net emissions sink at -2,640,398 tCO_2e which offsets approximately 47% of the region's gross emissions resulting total net emissions for the Otago region of 3,180,627 tCO_2e.

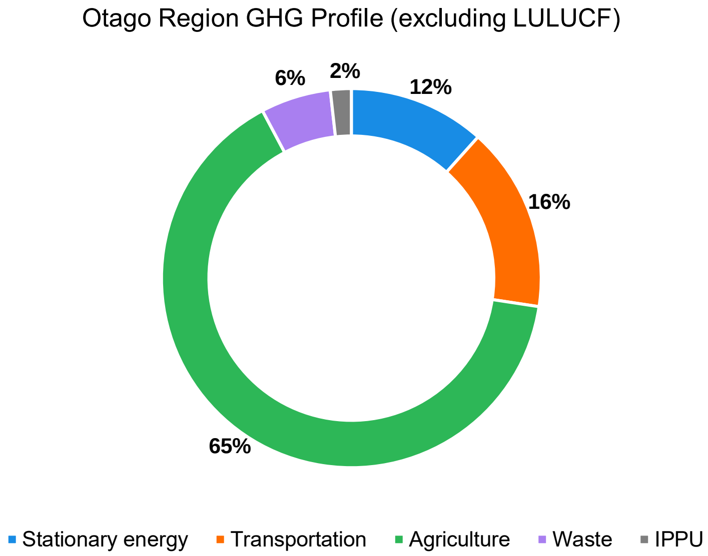


Figure 2 - Otago Region GHG Profile (excluding LULUCF)

	Emissions (tCO_2e)
Stationary energy	676,856
Transportation	918,438
Agriculture	3,774,184
Waste	348,036
Industrial Process and Product Use (IPPU)[3]	103,510
Gross emissions (exc. LULUCF)	**5,821,025**
LULUCF	-2,640,398
Net emissions (inc. LULUCF)	**3,180,627**

Table 1 – Otago Region GHG emissions by sector

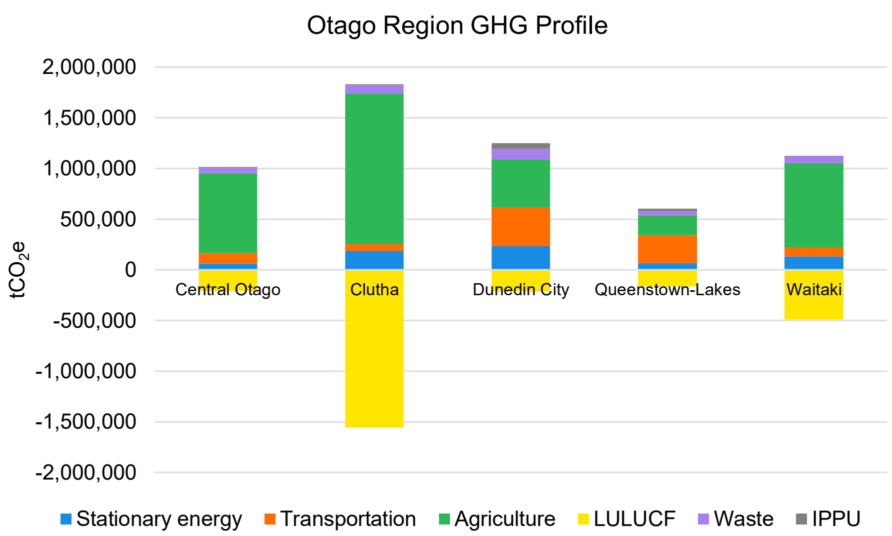
[3] IPPU covers the GHG emissions resulting from various industrial activities that produce emissions not directly the result of energy consumed during the process and the use of man-made greenhouse gases in products. Examples include the release of CO2 as a by-product of cement production and the use of fossil fuel (primarily natural gas) as a feedstock in ammonia production.

Key findings

What did EY find?	What does this mean for ORC?
The primary source of emissions in the Otago region is the agriculture sector, which is consistent across four of the five districts (Central Otago, Clutha, Dunedin City, Waitaki). A large proportion of these emissions is related to cattle and sheep farming.	There may be opportunities to target emission reduction activities with livestock farming however the carbon intensity of this activity should be considered due to the relative size of this sector.
Land use, land use change, and forestry (LULUCF) is a significant sink of emissions resulting in net negative emissions from this sector. Clutha district contributes the majority (59%) of this sequestration. However, all of the districts had net positive emissions profiles as the sources of emissions outweighed the sinks.	Although the LULUCF sector is a net emissions sink, forest harvest activities are a source of emissions. Forest conservation, regeneration and reforestation could be a significant contributor to balancing sources and sinks in the region.
Transportation was more significant in the emissions profiles of Dunedin and Queenstown-Lakes (the transportation sector is the most significant source of emissions in Queenstown-Lakes). The most significant contribution to emissions is related to on-road petrol and diesel consumption.	Considering how people move and the modes of transport they choose will be important in tackling emissions from this sector. A shift to electric vehicles replacing traditional internal combustion engine powered transport may reduce emissions from this sector.
Electricity makes up a significant proportion of stationary energy emissions across all districts. However, where coal, liquified petroleum gas (LPG) or light fuel oil (LFO) boilers are used this creates a significant source of emissions.	There may be opportunities for fuel switching (e.g. to biomass) and/or electrification to reduce emissions from stationary energy sources.
The varied information sources required to collate a complete emissions inventory for the region may present an on-going challenge for ORC as it seeks to monitor its emissions and the effectiveness of mitigation actions. ORC relied on a number of third parties to obtain the activity data used in the emissions inventory.	To maintain and update the regional emissions inventory it may be beneficial for ORC to formalise its climate data management to ensure efficient and effective processes are in place to obtain timely data to support an evidence-based climate action strategy.

District and National Comparisons

The below graph compares the five district GHG profiles that make up the total GHG profile for the Otago Region.



To enable meaningful comparison with the national inventory, international bunker fuels must be excluded. This exclusion affects the emissions of the Queenstown-Lakes and Dunedin City districts. However, to align with the *Global Protocol for Community-Scale Greenhouse Gas Emission Inventories*, the district breakdowns found in sections 3.1 to 3.5 of this report include emissions from international bunker fuels used in shipping and aviation.

Excluding international bunker fuels, total gross emissions for the Otago region are **5,708,198 tCO_2e** and net emissions are **3,067,800 tCO_2e**. The Otago region represents approximately 6.9% of New Zealand's 2019 gross emissions and 5.6% of New Zealand's net emissions. This compares with Otago accounting for approximately 5% of New Zealand's population and 4.5% of national GDP.

Emissions intensity, for example on the basis of population or GDP, has not been calculated. This decision was made to reflect the economic variability between districts, and that intensity-based metrics may be misleading. For instance, comparing primary production with services is not a fair comparison as economic activity in the services sector is relatively low emissions but often high GDP, and primary production is high emissions and lower GDP. Applying this to the districts, Dunedin is predominantly a service-based economy and has relatively low emissions and the highest GDP share in the region, whereas Clutha is focused on primary production and has the largest gross emissions and lowest GDP in the region.

3.1 Central Otago District

In 2019, the Central Otago economy generated $1.5 billion in GDP (11% of Otago's GDP). The economy is concentrated on the primary sector (Agriculture, Forestry and Fishing) and the Construction sectors, which both accounted for 14% of the district's total GDP share. The residential population in Central Otago was estimated at 23,100 people (10% of Otago's total population).

Key insights:

- Gross and net emissions for the Central Otago District are estimated at **1,013,444 tCO_2e** and **802,118 tCO_2e** respectively.
- The Agriculture sector accounts for most of the emissions in the district, reflecting the large number of sheep (over 1.3 million) in the district (contributing 58% to Agriculture emissions) followed by dairy and beef cattle which contribute 31% to Agriculture emissions.
- Transportation is the second largest source with on- and off-road transport contributing 106,925 tCO_2e.
- Stationary energy is the third largest source with electricity being the primary energy source.
- Central Otago has minimal waste emissions as solid waste is sent out-of-boundary for disposal to landfill.

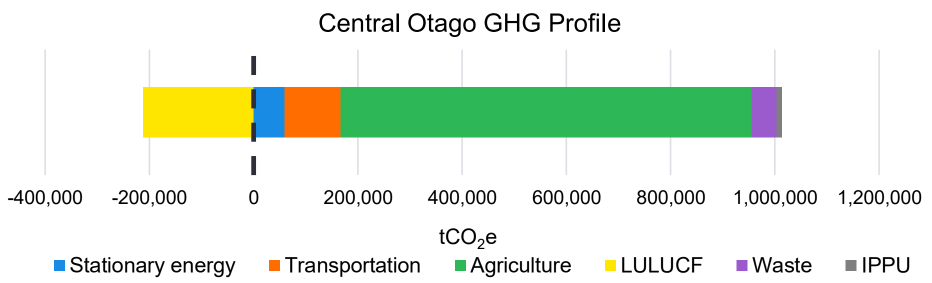


Table 2 Detailed GHG emissions breakdown for Central Otago by source

Source	Emissions (tCO_2e)	Contribution (%)
Agriculture		
Livestock	713,602	70.41%
Fertiliser	75,079	7.41%
Transportation		
On-road	78,978	7.98%
Off-road	27,948	2.82%
Railways	0	0.00%
Aviation	0	0.00%
Waterborne navigation	0	0.00%
Stationary energy		
Electricity	38,086	3.76%
Electricity T&D losses	3,266	0.32%

Coal	3,246	0.32%
Diesel	9,836	0.97%
Liquified petroleum gas	3,177	0.31%
Light fuel oil	34	0.00%
Wood	980	0.10%
Petrol	893	0.09%
Waste		
Solid waste disposal - Active landfills	0	0.00%
Solid waste disposal - Closed landfills	396	0.04%
Wastewater treatment and discharge	1,084	0.11%
Farm fills and rural waste	47,525	4.69%
Industrial processes and product uses		
Industrial processes and product uses	9,314	0.92%
Forestry		
Pre 1990 planted forest	-193,387	n/a
Post 1989 planted forest	-140,047	n/a
Regenerating natural forest	-888	n/a
Forest harvest	122,995	n/a

Table 2a Stationary energy emissions breakdown for Central Otago by subsector

Source	Subsector			
	Residential buildings	Commercial and institutional buildings and facilities	Manufacturing industries and construction	Agriculture, forestry, and fishing activities
Electricity	7,146	6,416	18,652	5,872
Electricity T&D losses	613	550	1,599	503
Coal	1,077	2,168	0	0
Diesel	40	184	0	9,612
Liquified petroleum gas	2,657	250	183	88
Light fuel oil	0	0	0	34
Wood	923	8	49	0
Petrol	0	0	0	893
Total	**12,456**	**9,576**	**20,483**	**17,002**

3.2 Clutha District

In 2019, the Clutha economy generated $1 billion in GDP (7% of Otago's GDP). Clutha's economy is heavily concentrated on the primary sector, which accounted for 33% of the district total GDP share. Manufacturing and Construction are the two other biggest sectors in Clutha, accounting for 10% and 6.4% of the district's GDP respectively. The residential population in Clutha was estimated at 18,150 people (8% of Otago's total population).

Key insights:

- Gross and net emissions for the Clutha District are estimated at **1,830,267 tCO_2e** and **270,491 tCO_2e** respectively.
- Clutha has the highest gross emissions out of all districts in the region but given its significant forest estate has the lowest net emissions in the region.
- Emissions come primarily from the Agriculture sector. Clutha has the highest number of sheep and dairy cattle in the region, each contributing 43% and 31% to Agriculture emissions respectively. Clutha also applies the largest amount of fertiliser, with fertiliser accounting for 15% of Agriculture emissions.
- Stationary energy is the next largest emitting sector, with large amounts of coal (59,882 tonnes) being used.

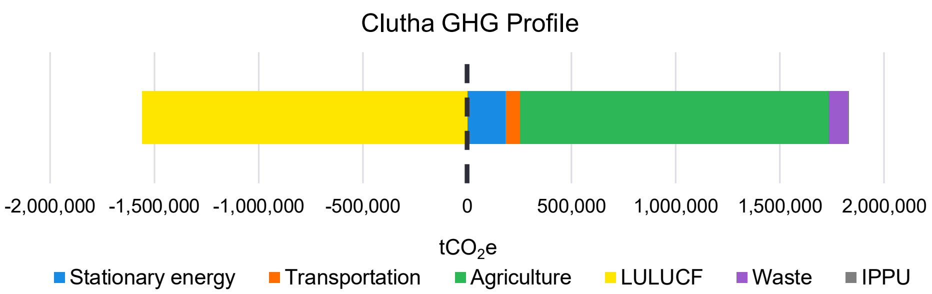


Table 3 Detailed GHG emissions breakdown for Clutha by source

Source	Emissions (tCO_2e)	Contribution (%)
Agriculture		
Livestock	1,262,817	69.00%
Fertiliser	219,086	11.97%
Transportation		
On-road	46,940	2.56%
Off-road	16,610	0.91%
Railways	3,975	0.22%
Aviation	0	0.00%
Waterborne navigation	0	0.00%
Stationary energy		
Electricity	19,551	1.07%

Electricity T&D losses	1,676	0.09%
Coal	120,371	6.58%
Diesel	16,587	0.91%
Liquified petroleum gas	24,216	1.32%
Light fuel oil	56	0.00%
Wood	1,988	0.11%
Petrol	1,469	0.08%
Waste		
Solid waste disposal - Active landfills	6,947	0.38%
Solid waste disposal - Closed landfills	0	0.00%
Wastewater treatment and discharge	3,386	0.18%
Farm fills and rural waste	78,221	4.27%
Industrial processes and product uses		
Industrial processes and product uses	6,369	0.35%
Forestry		
Pre 1990 planted forest	-2,024,590	n/a
Post 1989 planted forest	-1,125,359	n/a
Regenerating natural forest	-27,962	n/a
Forest harvest	1,618,135	n/a

Table 4a Stationary energy emissions breakdown for Clutha by subsector

Source	Subsector			
	Residential buildings	Commercial and institutional buildings and facilities	Manufacturing industries and construction	Agriculture, forestry, and fishing activities
Electricity	6,352	1,994	5,573	5,632
Electricity T&D losses	545	171	478	483
Coal	4,148	6,141	110,082	0
Diesel	33	733	0	15,821
Liquified petroleum gas	2,177	3,582	18,313	144
Light fuel oil	0	0	0	56
Wood	803	2	1,183	0
Petrol	0	0	0	1,469
Total	**14,057**	**12,623**	**135,629**	**23,606**

3.3 Dunedin City District

In 2019, the Dunedin economy generated $6.6 billion in GDP (47% of Otago's GDP). Compared to other districts in the region which have a strong concentration on one sector, Dunedin's economy is diversified, with similarly sized top industries; Health Care and Social Assistance sector (9.8% of Dunedin's total GDP), Education and Training (9.2%), Construction (8.5%), Professional, scientific and Technical Services (6.7%), and Retail Trade (5.9%). The residential population in Dunedin was estimated at 132,200 people (55% of Otago's total population).

Key insights:

- Gross and net emissions for the Dunedin City District are estimated at **1,250,047 tCO_2e** and **1,033,802 tCO_2e** respectively. Dunedin City contributes the most to emissions in the region on a net basis.
- Agriculture accounts for the largest share of gross emissions (38%).
- Transport emissions are a large emission source for the district (30%). Scope 3 emissions from domestic and international flights departing Dunedin Airport and container vessels departing Port Otago account for 29% of transport emissions. On- and off-road transport accounts for 70%.
- Stationary energy emissions account for 18% of the district's emissions. The primary energy sources are electricity (43% of emissions for the sector), coal (22%), LPG (16%) and diesel (15%).
- The waste sector generates a large amount of emissions relative to other districts. It should be noted that Dunedin City has implemented landfill gas collection and destruction at the Green Island Landfill which has reduced emissions in this sector.
- Dunedin City has the highest industrial process and product use emissions in the region (57,337 tCO_2e), accounting for 5% of gross emissions, coming primarily from hydrofluorocarbons used in refrigeration and air conditioning.

Dunedin City have completed their own district level emissions inventory. Key differences between their and this analysis are as follows:

- On- and off-road transport: This analysis estimates lower emissions from this source. This is expected to be a result of different methodologies and data sets utilised for the Dunedin City inventory.
- Waterborne navigation: This analysis estimates lower emissions from this source. An expected reason for this difference cannot be provided.
- Forest harvest: This analysis estimates higher emissions from this source. An expected reason for this difference cannot be provided.

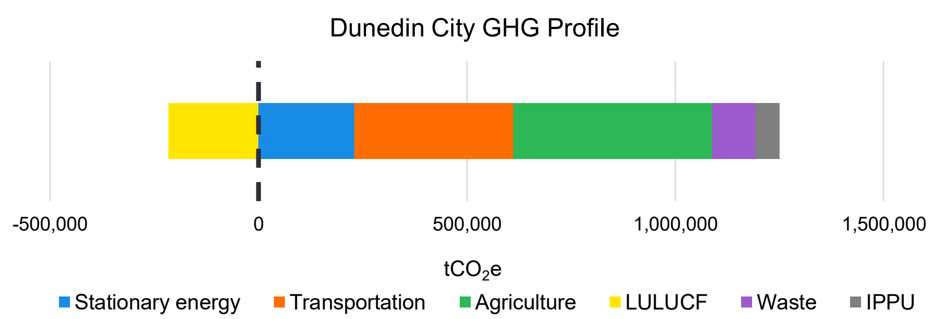


Table 5 Detailed GHG emissions breakdown for Dunedin City by source

Source	Emissions (tCO_2e)	Contribution (%)
Agriculture		
Livestock	426,568	34.12%
Fertiliser	51,106	4.09%
Transportation		
On-road	196,930	15.75%
Off-road	69,687	5.57%
Railways	3,269	0.26%
Aviation	35,118	2.81%
Waterborne navigation	75,375	6.03%
Stationary energy		
Electricity	87,415	6.99%
Electricity T&D losses	7,495	0.60%
Coal	50,289	4.02%
Diesel	34,335	2.75%
Liquified petroleum gas	35,968	2.88%
Light fuel oil	9,844	0.79%
Wood	4,602	0.37%
Petrol	714	0.06%
Waste		
Solid waste disposal - Active landfills	49,005	3.92%
Solid waste disposal - Closed landfills	3,116	0.25%
Wastewater treatment and discharge	13,852	1.11%
Farm fills and rural waste	38,020	3.04%
Industrial processes and product uses		
Industrial processes and product uses	57,337	4.59%
Forestry		
Pre 1990 planted forest	-534,087	n/a
Post 1989 planted forest	-155,708	n/a
Regenerating natural forest	-9,055	n/a
Forest harvest	482,606	n/a

Table 4a Stationary energy emissions breakdown for Dunedin City by subsector

Source	Subsector			
	Residential buildings	Commercial and institutional buildings and facilities	Manufacturing industries and construction	Agriculture, forestry, and fishing activities
Electricity	44,464	16,722	24,096	2,132
Electricity T&D losses	3,813	1,434	2,066	183
Coal	8,639	22,962	18,688	0
Diesel	235	18,224	8,186	7,690
Liquified petroleum gas	15,560	9,259	11,079	70
Light fuel oil	0	9,220	596	27
Wood	3,599	348	655	0
Petrol	0	0	0	714
Total	**76,310**	**78,168**	**65,368**	**10,816**

3.4 Queenstown-Lakes District

In 2019, the Queenstown-Lakes economy generated $3.3 billion in GDP (24% of Otago's GDP). Queenstown-Lakes' economy heavily relies on tourism-associated industries; its top three sectors in 2019 were accommodation and Food Services (17.6% of the districts' GDP), Construction (11%), and Rental, Hiring and Real Estate Services (10.2%). The residential population in Queenstown-Lakes was estimated at 44,800 people (19% of Otago's total population).

Key insights:

- Gross and net emissions for the Queenstown-Lakes District are estimated at **600,895 tCO_2e** and **438,591 tCO_2e** respectively.
- Transport is the highest emitting sector, accounting for 45% of gross emissions. On- and off-road transport accounts for 60%, and aviation accounts for 38% of sector emissions. The coal fired TSS Earnslaw, which operates on Lake Wakatipu, is estimated to generate 4,076 tCO_2e, or 1% of total transport emissions for the district.
- Stationary energy accounts for 11% of gross emissions and is dominated by electricity consumption (contributing 68% to sector emissions).
- Waste contributes a similar amount, 7% of gross emissions. This is largely due to solid waste disposal to landfills.
- Queenstown-Lakes has the second highest industrial process and product use emissions, accounting for 4% of gross emissions.

Queenstown-Lakes have completed their own district level emissions inventory. Key differences between their and this analysis are as follows:

- On- and off-road transport: This analysis estimates lower emissions from this source. This is expected to be a result of using fuel sales data and making no adjustment for resident population and visitor numbers.
- Aviation: This analysis estimates higher emissions from this source. This is expected to be due to the inclusion of international flights.
- Solid waste disposal - Active landfills: This analysis estimates lower emissions from this source. This is expected to be due to the utilisation of a First Order Decay method in this analysis and the resulting slow decomposition of degradable organic carbon over time.

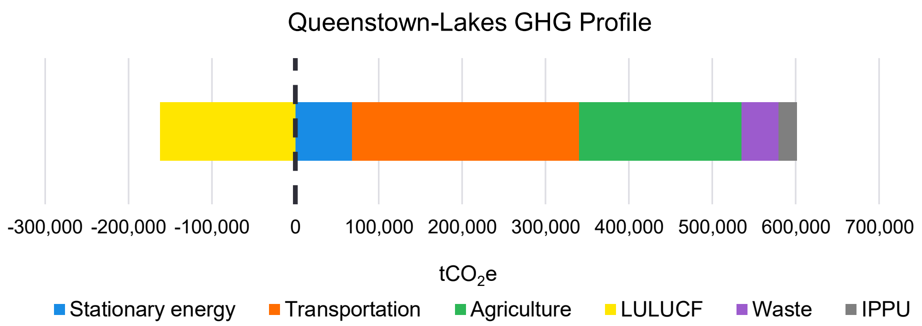


Table 6 Detailed GHG emissions breakdown for Queenstown-Lakes by source

Source	Emissions (tCO_2e)	Contribution (%)
Agriculture		
Livestock	175,034	29.13%
Fertiliser	19,827	3.30%

Transportation		
On-road	120,895	20.12%
Off-road	42,781	7.12%
Railways	0	0.00%
Aviation	104,190	17.34%
Waterborne navigation	4,076	0.68%
Stationary energy		
Electricity	42,729	7.11%
Electricity T&D losses	3,664	0.61%
Coal	2,621	0.44%
Diesel	3,273	0.54%
Liquified petroleum gas	14,696	2.45%
Light fuel oil	9	0.00%
Wood	1,193	0.20%
Petrol	229	0.04%
Waste		
Solid waste disposal - Active landfills	26,684	4.44%
Solid waste disposal - Closed landfills	120	0.02%
Wastewater treatment and discharge	5,005	0.83%
Farm fills and rural waste	12,191	2.03%
Industrial processes and product uses		
Industrial processes and product uses	21,678	3.61%
Forestry		
Pre 1990 planted forest	-86,070	n/a
Post 1989 planted forest	-67,112	n/a
Regenerating natural forest	-46,903	n/a
Forest harvest	37,781	n/a

Table 5a Stationary energy emissions breakdown for Queenstown-Lakes by subsector

Source	Subsector			
	Residential buildings	Commercial and institutional buildings and facilities	Manufacturing industries and construction	Agriculture, forestry, and fishing activities
Electricity	13,498	13,680	14,592	959
Electricity T&D losses	1,157	1,173	1,251	82
Coal	668	829	1,124	0
Diesel	73	661	73	2,466
Liquified petroleum gas	8,971	5,703	0	22
Light fuel oil	0	0	0	9
Wood	1,170	24	0	0
Petrol	0	0	0	229
Total	**25,536**	**22,070**	**17,041**	**3,767**

3.5 Waitaki District

In 2019, the Waitaki economy generated $1.7 billion in GDP (12% of Otago's GDP). Waitaki's economy is heavily concentrated on the Mining sector (28.3% of the district's GDP) and the primary sector (12.4%). The residential population in Waitaki was estimated at 23,200 people (10% of Otago's total population).

Key insights:

- Gross and net emissions for the Waitaki District are estimated at **1,126,372 tCO_2e** and **635,625 tCO_2e** respectively.
- Agriculture is a dominant source of emissions for Waitaki, contributing 74% of the district's gross emissions. Dairy cattle and sheep together produce 595,539 tCO_2e or 72% of total agriculture emissions.
- Waitaki's coal use accounts for 66% of the emissions from stationary energy. Most of the remaining emissions are attributable to electricity use and the associated transmission and distribution losses.
- Waste emissions are almost entirely attributable to farm fill and rural waste (79%) while solid waste in active landfills only produces 0.02% of waste emissions with much of Waitaki's waste sent out of district. 1% of total gross emissions in Waitaki come from closed landfills within the district boundary.
- Despite Waitaki having the third largest gross emissions, the size of its forest estate enables the district to also have the third lowest net emissions.

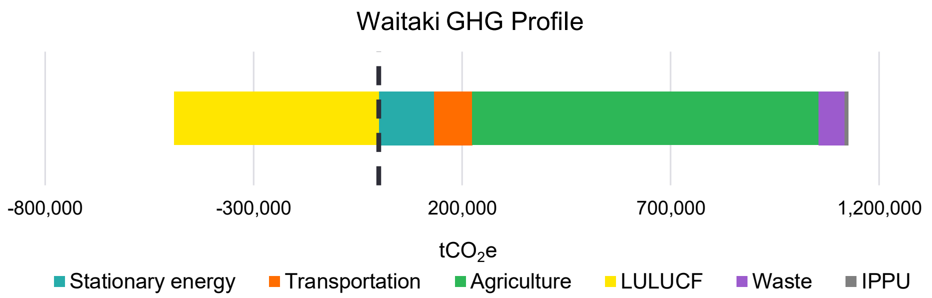


Table 7 Detailed GHG emissions breakdown for Waitaki by source

Source	Emissions (tCO_2e)	Contribution (%)
Agriculture		
Livestock	728,690	64.69%
Fertiliser	102,374	9.09%
Transportation		
On-road	65,933	5.85%
Off-road	23,331	2.07%
Railways	2,401	0.21%
Aviation	0	0.00%
Waterborne navigation	0	0.00%

Stationary energy		
Electricity	24,748	2.20%
Electricity T&D losses	2,122	0.19%
Coal	86,820	7.71%
Diesel	11,928	1.06%
Liquified petroleum gas	4,528	0.40%
Light fuel oil	35	0.00%
Wood	1,236	0.11%
Petrol	928	0.08%
Waste		
Solid waste disposal - Active landfills	177	0.02%
Wastewater treatment and discharge	11,766	1.04%
Farm fills and rural waste	1,156	0.10%
Industrial processes and product uses		
Industrial processes and product uses	8,812	0.78%
Forestry		
Pre 1990 planted forest	-317,319	n/a
Post 1989 planted forest	-542,679	n/a
Regenerating natural forest	-8,422	n/a
Forest harvest	377,673	n/a

Table 6a Stationary energy emissions breakdown for Waitaki by subsector

Source	Subsector			
	Residential buildings	Commercial and institutional buildings and facilities	Manufacturing industries and construction	Agriculture, forestry, and fishing activities
Electricity	7,940	1,736	12,929	2,144
Electricity T&D losses	681	149	1,109	184
Coal	1,040	1,486	84,293	0
Diesel	41	0	1,898	9,988
Liquified petroleum gas	2,749	461	1,227	91
Light fuel oil	0	0	0	35
Wood	1,047	5	184	0
Petrol	0	0	0	928
Total	**13,499**	**3,837**	**101,640**	**13,370**

3.6 Waste transfer

In accordance with the *Global Protocol for Community-Scale Greenhouse Gas Emission Inventories*, districts should account for scope 3 emissions from treatment of waste generated by the district but treated at a facility outside the district boundary.

Collecting this data is challenging. As such, it hasn't been quantified as part of the GHG emissions inventory. However, the following provides some commentary on waste transfer in the Otago region, and will hopefully provide a good starting point for further work in this area.

Central Otago

Central Otago has no active landfills. Therefore, all of its waste is exported and treated elsewhere. Waste is primarily sent to the Victoria Flats landfill in Queenstown-Lakes. Some waste is sent to the AB Lime landfill in Southland and a landfill in the Timaru District.

In FY19, Central Otago generated 7,865 tonnes of general solid waste, 2,669 tonnes of sludge and 70 tonnes of screenings. To put this into context, the Victoria Flats landfill received over 50,000 tonnes of waste in FY19.

Clutha

No data is kept by the Clutha District Council on waste generated in the district boundary and sent to other districts.

Waste is no longer accepted from out of district.

Dunedin

Some Dunedin waste is transported to Southland for treatment.

The Green Island landfill does not accept any out of district waste. No data is kept on whether other landfills in Dunedin are receiving waste from outside Dunedin's boundary.

Waitaki

Waitaki sends an estimated 11,000 tonnes of waste to the AB Lime landfill in Southland.

No waste is received from outside Waitaki's boundary.

Queenstown-Lakes

Queenstown-Lakes treats most of its own waste, other than sludge which is sent to the AB Lime landfill in Southland.

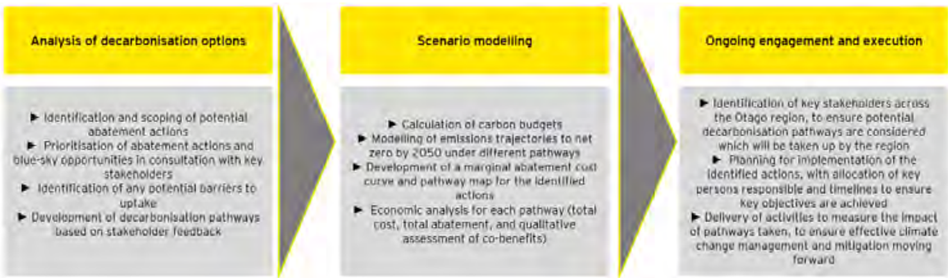
Queenstown-Lakes receives some waste from the neighbouring districts (e.g. Central Otago).

4. Proposed next steps

This regional dataset provides Otago with an initial platform which can be used to initiate effective management and mitigation of climate change impacts.

<u>Recommendations</u>

1. Further analysis and modelling are required to turn the data into a tool for proactive planning. EY recommends both the development of 'business-as-usual' emissions projections to 2050 and the scenario modelling of mitigation options. This will assist in identification of effective mitigation and decarbonisation options and facilitate collective discussion of priorities for action and engagement, both at a regional and local level. Based on the development of options and scenario modelling, economic impacts of mitigation actions can also be estimated and used for planning, engagement and decision making. A quote for this section of work was included in the initial RFP.



2. The dataset will require maintenance and review to ensure its currency and accuracy. An approach to this will be required to be discussed and agreed by ORC and its districts.

3. In particular, efforts should be made to obtain better data for the following sources:

   - Industrial processes and product uses
   - Solid waste disposal
   - Wastewater treatment and discharge.

   This will improve the accuracy of the calculated emissions and projections (where applicable) ensuring decisions are made which reflect the actual impacts of climate change as a result of specific actions.

4. ORC and districts may wish to review their climate data management systems and processes in collaboration with third parties who also contribute, to ensure long term and timely access to the quality data on which this inventory relies. Good climate data management and established and reliable coordination arrangements with a range of stakeholders is needed to inform and improve climate policy design, implementation and decision making.

5. Limitations

The services provided to ORC by EY were advisory in nature and thus did not constitute an audit, a review, or an engagement to perform agreed-upon procedures in accordance with the New Zealand Auditing Standards. Findings have been concluded based on examination of information provided to EY by ORC and key data owners across the region.

This assessment does not constitute certification to the GHG Protocol or any other standard. ORC shall be fully and solely responsible for applying independent judgment with respect to the services and work product provided by EY, to make decisions, if any, and to determine further courses of action with respect to any matters addressed in our report.

Ernst & Young is a registered trademark. Our report may be relied upon by ORC for the purpose of understanding the Otago region's greenhouse gas emissions profile only pursuant to the terms of our engagement letter dated 20 November 2020. We disclaim all responsibility to any other party for any loss or liability that the other party may suffer or incur arising from or relating to or in any way connected with the contents of our report, the provision of our report to the other party or the reliance upon our report by the other party.

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Appendix A Technical Method

The following pages list the key assumptions applied in this analysis.

Biogenic carbon dioxide emissions have been calculated but are excluded from the totals. Global warming potentials are sourced from the IPCC Fourth Assessment Report.

Agriculture, forestry and other land use	
Livestock	The latest available livestock numbers were obtained from the Stats NZ *Agricultural Production Census*. Livestock numbers were obtained by district for dairy cattle, beef cattle, sheep, pigs, deer, horses, goats, alpacas and llamas. Emission factors for enteric fermentation, manure management and agricultural soils were obtained from the Ministry for the Environment's *2020 Emission Factors Workbook*. Links: https://www.stats.govt.nz/information-releases/agricultural-production-statistics-june-2017-final https://www.mfe.govt.nz/publications/climate-change/measuring-emissions-summary-of-emission-factors-2020
Fertiliser	The latest available fertiliser application numbers were obtained from the Stats NZ *Agricultural Production Census*. Fertiliser use was obtained by district for urea (with and without inhibitor), diammonium phosphate, sulphate of ammonia, dolomite, lime and all other fertiliser. Emission factors for urea nitrogen fertiliser (with and without urease inhibitor coating), non-urea nitrogen fertiliser, dolomite and limestone were obtained from the Ministry for the Environment's *2020 Emission Factors Workbook*. Links: https://www.stats.govt.nz/information-releases/agricultural-production-statistics-june-2017-final https://www.mfe.govt.nz/publications/climate-change/measuring-emissions-summary-of-emission-factors-2020
Forestry	The latest version of the LUCAS New Zealand Land Use Map (LUM) was intersected with district boundaries using GIS software to obtain land use. Hectare information was obtained for Planted Forest - Pre 1990, Post 1989 Forest and Natural Forest. In the absence of better data, the Ministry for the Environment recommends applying the national split of Tall versus Regenerating Natural Forest. This split of 84% and 16% respectively was applied. Emission factors for pre 1990 and post 1989 planted forest were obtained from the Ministry for the Environment's *New Zealand's Greenhouse Gas Inventory 1990-2018*. Emission factors for regenerating natural forest and tall natural forest were obtained from the Ministry for the Environment's *2020 Emission Factors Workbook*. Links: https://data.mfe.govt.nz/layer/52375-lucas-nz-land-use-map-1990-2008-2012-2016-v008/

	https://datafinder.stats.govt.nz/layer/105153-territorial-authority-2021-generalised/ https://www.mfe.govt.nz/publications/climate-change/new-zealands-greenhouse-gas-inventory-1990-2018 https://www.mfe.govt.nz/publications/climate-change/measuring-emissions-summary-of-emission-factors-2020
Forest harvest	Wood supply by district and age class was obtained from the *National Exotic Forest Description*. 95% of trees in the age class of '26-30 years' were assumed to be harvested. The emission factor for planted forest harvest and deforestation was obtained from the Ministry for the Environment's *2020 Emission Factors Workbook*. Links: https://www.mpi.govt.nz/forestry/new-zealand-forests-forest-industry/forestry/new-zealands-forests-statistics/ https://www.mfe.govt.nz/publications/climate-change/measuring-emissions-summary-of-emission-factors-2020
Transportation	
On- and off-road	Quarterly fuel sales by district was provided by Stats NZ. The proportion of petrol versus diesel use was calculated by using the Energy Efficiency and Conservation Authority's *Energy End Use Database*. The proportions calculated from the EECA database were then price-weighted using energy prices from the Ministry of Business, Innovation and Employment. Fuel sales was then converted to fuel consumption. Fuel consumption was apportioned into on- versus off-road using the Energy Efficiency and Conservation Authority's *Energy End Use Database*. Emission factors for petrol and diesel were obtained from the Ministry for the Environment's *2020 Emission Factors Workbook*. Links: https://tools.eeca.govt.nz/energy-end-use-database/ https://www.mbie.govt.nz/building-and-energy/energy-and-natural-resources/energy-statistics-and-modelling/energy-statistics/energy-prices/ https://www.mfe.govt.nz/publications/climate-change/measuring-emissions-summary-of-emission-factors-2020
Railways	Fuel consumption by district was provided by KiwiRail. The emission factor for diesel was obtained from the Ministry for the Environment's *2020 Emission Factors Workbook*. Links: https://www.mfe.govt.nz/publications/climate-change/measuring-emissions-summary-of-emission-factors-2020
Aviation	This source is limited to departing flights from Dunedin Airport, Queenstown Airport and Wanaka Airport, as these are considered the most material activities within this source.

	Flight schedule information was obtained for all of the aforementioned airports, and distances were obtained for each of the routes flown. Fuel consumption was calculated using fuel economy estimates (by aircraft type), sourced from ICAO. The results are categorised into domestic and international aviation based on the destination. The emission factor for aviation fuel (kerosene) was obtained from the Ministry for the Environment's *2020 Emission Factors Workbook*. Links: https://www.flightradar24.com/data/airports/new-zealand https://www.distance.to/ https://www.icao.int/environmental-protection/Carbonoffset/Pages/default.aspx https://www.mfe.govt.nz/publications/climate-change/measuring-emissions-summary-of-emission-factors-2020
Waterborne navigation	This source is limited to departing container vessels from Port Otago, as this is considered the most material activity, and emissions from coal-fired waterborne navigation on Lake Wakatipu. The shipping schedule for a 49-day period was obtained from Port Otago. Container vessels were found to be departing to Napier, Lyttelton and Tanjung Pelepas in Malaysia. The distance to these ports was calculated and the average gross registered tonnage of the container vessels (provided by Port Otago) was used to determine tonne.kms. The results were then extrapolated to cover a full year. Freight to Napier and Lyttelton is considered domestic and freight to Tanjung Pelepas is international. Emission factors for domestic coastal freight - container freight and international sea travel - container ship – average were obtained from the Ministry for the Environment's *2020 Emission Factors Workbook*. Emissions from coal-fired waterborne navigation on Lake Wakatipu were calculated using publicly available information. Links: http://ports.com/sea-route/ https://www.mfe.govt.nz/publications/climate-change/measuring-emissions-summary-of-emission-factors-2020
Stationary energy	
Electricity	Electricity delivered by networks in the Otago region was provided by the network management providers; Aurora Energy, PowerNet and Network Waitaki. Aurora Energy data was broken down by district, except for the Cromwell grid exit point (GXP). Electricity delivered through this GXP was split evenly between Central Otago and Queenstown-Lakes. PowerNet data was not broken down by district and has been apportioned by EY, except for Dunedin City for which electricity data was provided separately. The Network Waitaki network extends outside of the Waitaki district boundary, to the Hakataramea Valley and the strip of land just north of the Waitaki river. These areas are primarily farmland with irrigation. When dry

	weather dominates, the irrigation load can be substantial, and load in these areas outside of the Waitaki district could stretch to about 5% of total consumption in some years, more typically it would be around 3.5% of total kWh load. This additional load is included in this analysis. Emission factors for electricity and transmission and distribution losses were obtained from the Ministry for the Environment's *2020 Emission Factors Workbook*. Electricity usage was then apportioned at the district level into residential, commercial, industrial and agriculture usage. Residential usage was obtained from the Electricity Authority's Electricity Market Information website which provides total residential usage for the Otago region. This was apportioned based on the population of each district and subtracted from the total electricity usage figures provided by the network providers. Commercial, industrial and agriculture sector electricity consumption used national electricity consumption figures from MBIE. The classification of an "agriculture", "commercial" or "industrial" electricity consumer utilised level 1 industry ANZSIC codes to ensure alignment with MBIE's classifications. Usage was apportioned across the districts based on the percentage that each sector in each district contributed to the total New Zealand GDP value for that sector. The apportioned amounts were then compared, at the district level, to the total electricity usage figures provided by network providers (minus residential usage). Any differences were apportioned across the agriculture, commercial and industrial sectors in each district based on the proportion of electricity use that each sector represented in that district. Differences were not applied to residential consumption due to a higher quality of data provided by the EMI website reports. Links: https://www.mfe.govt.nz/publications/climate-change/measuring-emissions-summary-of-emission-factors-2020 https://www.emi.ea.govt.nz/Retail/Reports/DUOM0B?DateFrom=20180701&DateTo=20190630&RegionType=REG_COUNCIL&Show=Tot&_si=v|3 https://www.mbie.govt.nz/building-and-energy/energy-and-natural-resources/energy-statistics-and-modelling/energy-statistics/electricity-statistics/ https://www.mbie.govt.nz/building-and-energy/energy-and-natural-resources/energy-statistics-and-modelling/energy-modelling/ https://ecoprofile.infometrics.co.nz/Waitaki%20District/Gdp/Structure https://ecoprofile.infometrics.co.nz/Clutha%20District/Gdp/Structure https://ecoprofile.infometrics.co.nz/Central%20Otago%20District/Gdp/Structure https://ecoprofile.infometrics.co.nz/queenstown-lakes%2bdistrict/Gdp/Structure https://ecoprofile.infometrics.co.nz/Dunedin%2bCity/Gdp/Structure
Commercial and Industrial sector energy demand	Energy demand (by district, sector and fuel type) from boilers with capacity greater than 100 kW was provided by Ahika Consulting. Information is based on Ahika's internal boiler database for the region which was cross-referenced with: ► ORC Air Discharge Permits via the ORC Open Data Platform ► 2017-2020 Permit information provided by ORC

	► CRL Energy Ltd Study 2007 ► Bioenergy Association NZ and EECA Heat Plant Study 2009 ► Aircomm Frankton Heating Study 2010 ► Central Otago Energy Database 2013 (Ahika) ► Heat-plant Database 2016 (MBIE and EECA) ► Otago Energy Database 2017 (Ahika) ► Dunedin School Boiler Database 2019 (Ahika) ► South Island Boiler Database 2021 (Transpower). Boilers with unknown capacity were excluded from this analysis and boilers with unknown fuel type were assumed to use coal. Boilers that use electricity have been excluded to avoid double counting with the above source. Further assumptions have been made around run time hours based on sector. Emission factors for coal, diesel, light fuel oil, liquefied petroleum gas and wood were obtained from the Ministry for the Environment's *2020 Emission Factors Workbook*. Rockgas Ltd provided LPG usage estimates for Queenstown-Lakes which superseded the estimates made from this and the below source for LPG. Links: https://www.mfe.govt.nz/publications/climate-change/measuring-emissions-summary-of-emission-factors-2020
Agriculture sector energy demand	National energy balance data for the Agriculture sector was apportioned to each of the districts using GDP data. The energy balance was sourced from the Ministry of Business, Innovation and Employment, and GDP data was sourced from Stats NZ. Calorific values for diesel, petrol, light fuel oil and liquefied petroleum gas were obtained from the Ministry for the Environment's *2020 Detailed Guide*. Emission factors for diesel, petrol, light fuel oil and liquefied petroleum gas were obtained from the Ministry for the Environment's *2020 Emission Factors Workbook*. Links: https://www.mbie.govt.nz/building-and-energy/energy-and-natural-resources/energy-statistics-and-modelling/energy-statistics/energy-balances/ https://www.stats.govt.nz/information-releases/regional-gross-domestic-product-year-ended-march-2020 https://environment.govt.nz/publications/measuring-emissions-detailed-guide-2020/ https://www.mfe.govt.nz/publications/climate-change/measuring-emissions-summary-of-emission-factors-2020
Residential sector energy demand	LPG sales data for the South Island was provided by the LPG Association of New Zealand (LPANZ). LPANZ estimated 50% of this would relate to residential use. The sales data was apportioned using district population estimates from the 2018 census data and applying the 50% assumption. Per capita daily coal and wood use was obtained from the *Home heating emission inventory and other sources evaluation (Wilton et al. 2015)*. Fuel usage figures used were Urban Otago and Rural South Island. Per capita values are provided as winter/non-winter and rural/urban. The rural versus urban district splits were obtained from Stats NZ's *Subnational population*

	estimates (urban rural). Urban areas in each district was determined using the Statistics NZ SSGA18 standard for geographical areas. Main types of household heating by district were obtained from Stats NZ and provided the number of wood and coal burners in each district. These burners were apportioned by the rural/urban split. Wood and coal consumption were calculated based on the number of urban/rural wood and coal burners using the per capita urban/rural consumption figures. National residential diesel consumption was obtained from the Ministry of Business, Innovation and Employment's *Energy balances*, and apportioned using district population estimates from the 2018 census. Emission factors for liquefied petroleum gas, coal, wood and diesel were obtained from the Ministry for the Environment's *2020 Emission Factors Workbook*. Links: https://www.mfe.govt.nz/sites/default/files/media/Air/national-air-emissions-inventory.pdf http://nzdotstat.stats.govt.nz/WBOS/Index.aspx?DataSetCode=TABLECODE7981 https://www.mbie.govt.nz/building-and-energy/energy-and-natural-resources/energy-statistics-and-modelling/energy-statistics/energy-balances/ https://www.mfe.govt.nz/publications/climate-change/measuring-emissions-summary-of-emission-factors-2020 https://www.emi.ea.govt.nz/Retail/Reports/DUOM0B?DateFrom=20180701&DateTo=20190630&RegionType=REG_COUNCIL&Show=Tot&_si=v|3 https://www.mbie.govt.nz/building-and-energy/energy-and-natural-resources/energy-statistics-and-modelling/energy-statistics/electricity-statistics/ https://www.mbie.govt.nz/building-and-energy/energy-and-natural-resources/energy-statistics-and-modelling/energy-modelling/ https://ecoprofile.infometrics.co.nz/Waitaki%20District/Gdp/Structure https://ecoprofile.infometrics.co.nz/Clutha%20District/Gdp/Structure https://ecoprofile.infometrics.co.nz/Central%20Otago%20District/Gdp/Structure https://ecoprofile.infometrics.co.nz/queenstown-lakes%2bdistrict/Gdp/Structure https://ecoprofile.infometrics.co.nz/Dunedin%2bCity/Gdp/Structure
Waste	
Solid waste disposal - Active landfills	Emissions from active landfills were estimated using a First Order Decay method. This method assumes that the degradable organic component in waste decays slowly over decades. Key modelling assumptions include:

Waste composition	Degradable organic carbon proportion	Fraction of carbon that disseminates	k value
Food	0.15	0.84	0.06
Paper and paper board	0.40	0.49	0.04
Garden and park	0.20	0.47	0.05
Wood and wood waste	0.43	0.23	0.02
Textiles	0.24	0.50	0.04
Sludge	0.05	0.50	0.06

	Nappies	0.24	0.50	0.04
	Rubber and Leather	0.39	0.50	0.04
	Concrete, metal, plastic and glass	0.00	NA	NA
	AWT Residue	0.08	0.50	0.04

Where possible, actual data on historical waste to landfill was provided by district councils. When unavailable, assumptions were made to fill the gaps. Waste composition over the life of the landfill is held constant using the latest available data.

Emissions reduction as a result of landfill gas collection and destruction at the Green Island Landfill in Dunedin has been modelled. Information to support this modelling was provided by the Dunedin District Council.

The same approach was adopted for closed landfills. Only landfills closed after 2000 were considered. The Waikouaiti Closed Landfill was excluded due to missing waste volume information, as was the closed landfill site at Fairfield because it's privately operated and the data is commercially sensitive. Given closed landfill waste volume is expressed in cubic metres, density assumptions were made to convert it to a mass basis. These assumptions were derived from the Draft 16 UK Waste Classification Scheme by DETR (now DEFRA).

Links:

https://www.ghgprotocol.org/sites/default/files/ghgp/Global-Warming-Potential-Values%20%28Feb%2016%202016%29_1.pdf

https://www.sustainabilityexchange.ac.uk/conversion_factors_for_calculation_of_weight_to_vo

Wastewater treatment and discharge	Emissions for all districts except for Queenstown-Lakes were calculated following IPCC guidelines. The number of people covered by different wastewater treatment plants and types (e.g. septic, aerobic, anaerobic) was provided by the district councils. Assumptions were largely drawn from the IPCC. Some assumptions are New Zealand-specific and were obtained from the Ministry for the Environment's *New Zealand's Greenhouse Gas Inventory 1990-2018*, for example the annual per capita protein consumption and per capita biochemical oxygen demand. Wastewater emissions for Queenstown-Lakes were calculated by Tonkin & Taylor in collaboration with Deta Consulting. Tonkin & Taylor used a volume-based methodology along with site specific emission factors (developed by Bloomberg et al., 2018) to calculate emissions from each of the 5 wastewater treatment plants in the Queenstown-Lakes district. This approach results in a more detailed emissions output for each of the sites compared to the population-based IPCC approach used for the other districts. Link: https://www.ipcc-nggip.iges.or.jp/public/2019rf/vol5.html https://www.mfe.govt.nz/publications/climate-change/new-zealands-greenhouse-gas-inventory-1990-2018 https://www.ghgprotocol.org/sites/default/files/ghgp/Global-Warming-Potential-Values%20%28Feb%2016%202016%29_1.pdf
Farm fills and rural waste	Stats NZ have provided emissions from farm fills and rural waste. These are first estimated at the national level by using data from the Ministry for the Environment to allocate unmanaged waste disposal sites and rural waste (both parts of the waste sector) to industry. These are allocated across the

	four main agriculture industries: Horticulture and fruit growing; Sheep, beef cattle and grain farming; Dairy cattle farming; Poultry, deer and other livestock farming. The allocation to region is made using land use data by industry from the Agricultural Production Survey. Implicit in this approach is an assumption of equal emissions intensity per hectare by industry (farm type) across regions, but emissions intensity per hectare may vary across industries. Finally, this estimate was apportioned into districts on the basis of agricultural GDP.
Industrial processes and product uses	
Industrial processes and product uses	National industrial process and product use (IPPU) emissions were obtained from the Ministry for the Environment's *New Zealand's Greenhouse Gas Inventory 1990-2018*. District-level Gross Domestic Product (GDP) data was obtained from the Ministry of Business, Innovation and Employment. Each sector was assessed for relevance to IPPU emissions. For the sectors deemed relevant, each district's contribution to national GDP was calculated. National IPPU emissions were then apportioned using these contribution amounts. Additionally, included are emissions from household use of industrial products and emissions from disposal of industrial products. Stats NZ have provided this data from their greenhouse gas emissions by region (industry and household) series. The allocation of these emissions is first made at the national level by allocating GHG inventory data to households and industry based on the type of product, and then apportioned to region using population data for households and economic output for the waste industry. Household and international visitor emissions from industrial products associated with road transport (i.e. mobile air conditioning and lubricant use) are proportionate to the use of vehicles by these groups. Links: https://www.mfe.govt.nz/publications/climate-change/new-zealands-greenhouse-gas-inventory-1990-2018 https://www.mbie.govt.nz/business-and-employment/economic-development/regional-economic-development/modelled-territorial-authority-gross-domestic-product/modelled-territorial-authority-gdp-2020-release/

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7.2. Contact Recreation 2020-2021

Prepared for: Data and Information Committee

Report No. SPS2130

Activity: Governance Report

Author: Rachel Ozanne, Scientist – Water Quality

Endorsed by: Gwyneth Elsum, General Manager Strategy, Policy and Science

Date: 9 June 2021

PURPOSE

[1] This report provides a summary of contact recreation monitoring undertaken in Otago's rivers, lakes and coastal waters between 7 December 2020 and 31 March 2021. Monitoring is undertaken at 27 freshwater or coastal sites at weekly intervals over the summer months and focuses on human health risks relating to faecal contamination and/or potentially toxic cyanobacteria.

EXECUTIVE SUMMARY

[2] The programme follows the national microbiological water quality guidelines for marine and freshwater recreational areas, Ministry for the Environment and Ministry of Health, (2003)[1], the National Policy Statement for Freshwater Management 2020[2] (NPSFM, 2020) and the New Zealand Guidelines for Cyanobacteria in Recreational Fresh Waters: Interim Guidelines[3] (MfE/MoH, 2009).

[3] Weekly monitoring results and temporary health warnings about the risk from contact recreation at a site are reported on the LAWA website[4]. LAWA also report a 'long term grade' for each recreational site alongside the weekly sampling result.

[4] In the 2020-2021 season across both coastal and freshwater sites, 458 microbiological samples were taken, the 'unsuitable for swimming' category, due to faecal contamination risk, was met on 13 occasions and the 'caution advised' category was met on 10 occasions.

[5] For cyanobacteria, four river sites and four lake sites were monitored weekly, no river sites had a benthic (riverbed) algae bloom (>20% cover cyanobacteria), however two lake sites had a planktonic (floating) algae bloom that reached the 'amber' alert mode.

[6] Faecal source tracking (FST) because of high faecal contamination risk was undertaken on eight occasions. An avian source was determined for Lake Wanaka, a ruminant source for the Taieri at Waipiata and a combination of avian, ruminant and human sources for Lake Wakatipu at Queenstown Bay and Otokia Creek in Brighton (this site had FST analysis on four routine samples).

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[1] https://environment.govt.nz/assets/Publications/Files/microbiological-quality-jun03.pdf
[2] https://environment.govt.nz/assets/Publications/Files/national-policy-statement-for-freshwater-management-2020.pdf
[3] https://environment.govt.nz/assets/Publications/Files/nz-guidelines-cyanobacteria-recreational-fresh-waters.pdf
[4] https://www.lawa.org.nz

[7] This paper reports on the Otago Regional Council (ORC) recreational water quality programme and includes legislative requirements, microbiological water quality sampling results for the 2020/21 bathing season, river (benthic) and lake (planktonic) warnings for cyanobacteria over the 2020/2021 season, and recommendations for the 2021/22 bathing season.

RECOMMENDATION

That the Data and Information Committee*:*

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

LEGISLATIVE REQUIREMENTS

[8] Two main sources of legislation define the monitoring required to assess the water quality at contact recreation sites, the Resource Management Act (1991) and the Health Act (1956). The responsibility for overseeing these Acts is shared between regional councils, territorial local authorities (TAs) and the District Health Boards (DHBs).

[9] The National Policy Statement for Freshwater Management 2020 (NPSFM, 2020) provides national direction on how local and regional authorities should carry out their responsibilities under the Resource Management Act 1991 for managing freshwater. Human health for recreation is listed by the NPSFM 2020 as a compulsory value of freshwater at sites where people have contact with water through a range of activities including swimming.

[10] The NPSFM 2020 contains two attributes which can be measured to indicate the suitability of freshwater for recreation from a human health perspective. The first is E. coli as described in NPSFM 2020 (Appendix 2A, Table 11) and has several attribute states (ranging from A to E) for assessing human health for recreation. All monitored rivers and lakes are classified as A to E based on a combination of four measures of E. coli using year-round data. Compliance with this attribute has been reported in ORC's SOE Water Quality Report, 2021[5].

[11] The NPSFM 2020 also has a second separate framework specifically for assessing human health for recreation, at primary contact sites in lakes and rivers during the bathing season, this is described in NPSFM 2020 Appendix 2B, Table 22.

[12] Otago's recreational water quality monitoring programme follows guidance provided by the national microbiological water quality guidelines for marine and freshwater recreational areas (MfE/MoH 2003) and NPSFM 2020 and the New Zealand Guidelines for Cyanobacteria in Recreational Fresh Waters (MfE/MoH, 2009).

ROLES, RESPONSIBILITIES AND PROCEDURES

[13] Discussions were held between the organisations involved with Otago's recreational water quality monitoring and response programme before the 2020/2021 sampling season started. These organisations included the Southern District Health Board (SDHB), TAs, Environment Southland (ES) and ORC.

[5] https://www.orc.govt.nz/media/9781/state-and-trends-of-lake-and-river-water-quality-in-the-otago-region-2000-to-2020.pdf reported to ORC DAIC committee 14 April 2021

[14] The organisations involved discussed the framework provided by MfE/MoH 2003, NPSFM 2020 and developed protocols describing the roles and responsibilities of organisations, the contact details of key personnel, recreational monitoring site locations, usual monitoring routine, alert-response monitoring, contact recreation site gradings, public notifications, education and awareness, and temporary and permanent signage about health risks at sites.

[15] The procedure agreed by the organisations involved for the 2020/2021 season for Otago is shown in Figure 1. In Otago, Central Otago District Council, Dunedin City Council, Waitaki District Council and Clutha District Council, rely on ORC to provide follow up sampling if the 'action' level is reached, and to provide public information (through sign installation and media). The Queenstown Lakes District Council provides follow up monitoring and communication for sites monitored in their district.

2020/2021 sampling and response protocols

1) Signs were permanently installed at every ORC contact recreation monitoring site, the signs included the text 'check LAWA **before** you swim' and 'avoid swimming 48 hours after rainfall'
2) ORC did not sample lake sites if conditions were too dangerous for the sampler. For example, if the sampler was unable to get past the turbulent water of the wave zone safely.
3) ORC resampled sites when results were greater than 260 *E. coli*/100ml only when:
   a) The sites were practicable to get to (resources and remoteness). These included: Taieri at Outram, Otokia Creek at Brighton, Lake Waihola, Macandrew Bay, Manuherekia at Shaky Bridge.
   b) The site had a long-term grade of 'good' or 'excellent' (LAWA), weather conditions had been good and an unexpectedly high result had been returned.
   c) At sites with 'suitable for swimming' or 'caution' as a long-term grade, a duplicate sample for FST was taken on the next scheduled sampling date, if two consecutive samples exceed 540 *E. coli*/100ml.
4) Sites not to be resampled (i.e., ORC satisfied that the elevated result is temporary)
   a) if the original sample was taken when flows were above median flow
      - Outram (Taieri at Outram flow site[1])
      - Manuherekia (Manuherekia at Campground flow site)
   b) If >5mm rainfall had fallen in the in previous 24 hours
      - Otokia Creek (Rainguage at Dunedin at Musselburgh)
      - Macandrew Bay (Dunedin at Musselburgh)

Figure 1 2020/2021 sampling and response protocols

SAMPLING SITES

[16] Bacteria concentrations that are used as indicators for faecal contamination are monitored at 12 fresh water and 15 coastal sites throughout Otago, shown in Figure 2. Eight additional coastal sites between Sandfly Bay and St Clair Beach are sampled by the Dunedin City Council (DCC) and these results are added to ORC's summer recreational water quality monitoring reported on LAWA. The sampling by the DCC is a requirement in their consents for Dunedin City's wastewater discharges.

[17] In aquatic environments, under favourable conditions cyanobacterial cells can multiply and form planktonic (suspended in the water column) blooms or dense benthic (attached to the substrate) mats. Benthic cyanobacteria cover was regularly monitored at four contact recreation river sites and planktonic cyanobacteria at four lake sites (Waihola, Lake Hayes, Falls Dam and Tomahawk Lagoon).

[18] Sites which have known water quality issues or are high priority had duplicate samples taken during sampling in case they were needed for faecal source tracking (FST). FST uses DNA and Polymerase Chain Reaction (PCR) analyses to identify the animal source of the bacteria found in the samples (*E.coli*). Tests to identify bacteria from human, herbivore, dog, and wildfowl are available.

[19] FST tests were undertaken when routine sample results from Lake Hayes, Lake Wanaka at Roys Bay, Lake Wakatipu at Queenstown Bay, Lake Wakatipu at Frankton Bay, Otokia Creek at Brighton Beach, Manuherekia at Shaky Bridge or Taieri at Waipiata[6] showed elevated bacterial concentrations.

[6] FST analysis at Taieri at Waipiata was scheduled into monitoring halfway through the contact recreation season

Figure 2 Map of contact recreation sites monitored for microbiological water quality (E. coli and Enterococci) and cyanobacteria in Otago.

MICROBIOLOGICAL MONITORING

[20] The water samples taken at Otago's contact recreation sites are tested for one of two types of faecal bacteria; these bacteria are used as indicators for other harmful pathogens. The two types of faecal indicator bacteria are *Escherichia coli (E. coli)* in freshwaters and enterococci in marine waters. In estuaries enterococci were monitored.

[21] Weekly water quality sampling of recreational sites in the 2020-2021 season started on 7 December 2020 and ran through until the end of March 2021. Twenty-seven sites were monitored for indicator bacteria.

[22] The water quality results are compared against the National Microbiological Water Quality Guidelines for Marine and Freshwater Recreational Areas (MfE & MoH, 2003)[7] to assess the health risk for swimming. When the faecal indicator bacteria concentrations exceed the human health guidelines, results are immediately shared with the Southern District Health Board (SDHB) and local territorial authorities (TAs) and communicated to the public.

[23] The water quality results are reported on the Land Air Water Aotearoa (LAWA) website (www.lawa.org.nz), which is updated daily during summer with the latest risk assessment and the test data for swimming spots across New Zealand.

[24] The LAWA website shows weekly risk results (Table 1) and a long-term grade for each swimming site (Table 2). The three weekly 'risk' categories are: 'generally suitable for swimming' (green = low infection risk); 'caution advised' (amber = moderate infection risk); and 'not suitable for swimming' (red = high infection risk). The four long-term 'risk' grades are calculated using 95th percentile of *E. coli* and enterococci values obtained over the last five years of monitoring.

[25] The summer contact recreation programme is separate from the ORC's regular State of Environment monitoring programme and involves partnerships with the region's territorial authorities and Southern District Health Board (SDHB).

[7] Microbiological water quality results, and the way they are interpreted, are reported exclusively according to the MfE & MoH (2003) guidelines. This excludes any interpretation of results according to attribute states in the National Policy Statement for Freshwater Management 2014 (MfE, 2017)

Table 1 Water quality guideline values and indicator organisms used to assess marine and freshwater recreational areas (MfE and MoH, 2003).

Mode	Trigger level		Management response
	Beach: Enterococci / 100mL	**River/Lake: *E. coli*/100 mL**	
Surveillance	Equal to or less than 140 Enterococci / 100 mL	Equal to or less than 260 *E. coli* / 100 mL	Routine monitoring.
Alert	More than 140 Enterococci / 100 mL	More than 260 *E. coli* / 100 mL	Increase monitoring and investigate source.
Action	More than 280 Enterococci / 100 mL	More than 550 *E. coli* / 100 mL	Public warnings if required, increased monitoring and investigation of contaminant source

Table 2 The long-term grade determines whether a site is overall excellent, good, fair, or poor for swimming over the full recreational bathing season.

Long-term grade	Coastal beach sites	River and Lake sites
Excellent	95th percentile value of Enterococci / 100ml: 0 – 40 Description of risk: Risk of illness is less than 1% from contact with the water during the summer bathing period.	95th percentile value of *E. coli* /100ml: 0 – 130 Description of risk: Estimated risk of *Campylobacter* infection has a < 0.1% occurrence, 95% of the time.
Good	95th percentile value of Enterococci / 100ml: >40 – 200 Description of risk: Risk of illness is less than 5% from contact with the water during the summer bathing period.	95th percentile value of *E. coli* /100ml: >130 – 260 Description of risk: Estimated risk of *Campylobacter* infection has a 0.1 – 1.0% occurrence, 95% of the time.
Fair	95th percentile value of Enterococci / 100ml: >200-500 Description of risk: Risk of illness is between 5 and 10% from contact with the water during the summer bathing period.	95th percentile value of *E. coli* /100ml: >260 – 540 Description of risk: Estimated risk of *Campylobacter* infection has a 1 - 5% occurrence, 95% of the time.
Poor	95th percentile value of Enterococci / 100ml: > 500 Description of risk: Risk of illness is more than 10% from contact with the water during the summer bathing period.	95th percentile value of *E. coli* /100ml: > 540 Description of risk: Estimated risk of *Campylobacter* infection has >5% occurrence, at least 5% of the time

CYANOBACTERIA MONITORING

[26] An increasing number of cyanobacterial species are known to include toxin-producing strains. These natural toxins, known as *cyanotoxins*, are a threat to humans and animals when consumed in drinking water or by contact during recreational activities. The mechanisms of toxicity for cyanotoxins are very diverse, ranging from acute unspecified intoxication symptoms (e.g., rapid onset of nausea and diarrhoea), to gastroenteritis and other specific effects, such as hepatotoxicity (liver damage) and possibly carcinogenesis. In lakes, cyanobacterial species tend to float in the water (planktonic). In rivers, cyanobacterial species form dense mats on the riverbed (benthic), *Phormidium* is a common benthic cyanobacteria and occurs naturally in Otago.

[27] The New Zealand Guidelines for Cyanobacteria in Recreational Fresh Waters: Interim Guidelines[8] (MfE/MoH, 2009) contain suggested methods for monitoring and responding to benthic and planktonic cyanobacteria in streams, rivers, and lakes. The guidelines cover the health risks for swimming in recreational waters containing cyanobacteria, but not the risks for drinking water. The guidelines also do not address the health risks that cyanobacteria have for animals (e.g., dogs or livestock) that encounter or ingest water containing cyanobacteria.

[28] The ORC cyanobacteria monitoring and response methods for Otago follow the MfE & MoH (2009) guidelines (Table 2 and Table 3) and were developed in a collaboration between ORC, SDHB and TAs.

[29] The ORC undertakes weekly visual surveillance at four river contact recreation sites for potentially toxic benthic cyanobacteria growth over summer (Figure 1). Four sites had planktonic cyanobacteria monitored weekly; Lake Waihola, Lake Hayes, Falls Dam and Tomahawk Lagoon (Figure 1).

[30] Other sites were also tested for cyanobacteria when unexpected seasonal blooms occurred, or when ORC staff became aware of potential blooms either through notification from the public or through visual surveillance.

[8] http://www.mfe.govt.nz/sites/default/files/nz-guidelines-cyanobacteria-recreationalfresh-waters.pdf

Table 3 Alert-level framework for planktonic cyanobacteria (MfE, 2009)

Alert level	Actions (See section 2.4 for the recommended framework for roles and responsibilities relating to actions, and the text box at the beginning of Section 3 for advice on interpreting the guidance in this table.)
Surveillance (green mode) *Situation 1:* The cell concentration of total cyanobacteria does not exceed 500 cells/mL.[a] *Situation 2:* The biovolume equivalent for the combined total of all cyanobacteria does not exceed 0.5 mm^3/L.	• Undertake weekly or fortnightly visual inspection[b] and sampling of water bodies where cyanobacteria are known to proliferate between spring and autumn.
Alert (amber mode) *Situation 1:* Biovolume equivalent of 0.5 to < 1.8 mm^3/L of potentially toxic cyanobacteria (see Tables 1 and 2); **or** *Situation 2*[c]: 0.5 to < 10 mm^3/L total biovolume of all cyanobacterial material.	• Increase sampling frequency to at least weekly.[d] • Notify the public health unit. • Multiple sites should be inspected and sampled.
Action (red mode) *Situation 1:* ≥ 12 µg/L total microcystins; **or** biovolume equivalent of ≥ 1.8 mm^3/L of potentially toxic cyanobacteria (see Tables 1 and 2); **or** *Situation 2*[c]: ≥ 10 mm^3/L total biovolume of all cyanobacterial material; **or** *Situation 3*[e]: cyanobacterial scums consistently present.	• Continue monitoring as for alert (amber mode).[e] • If potentially toxic taxa are present (see Table 1), then consider testing samples for cyanotoxins.[f] • Notify the public of a potential risk to health.

Table 4 Alert-level framework for benthic cyanobacteria (MfE, 2009)

Alert level[a]	Actions (See section 2.4 for the recommended framework for roles and responsibilities relating to actions, and the text box at the beginning of Section 3 for advice on interpreting the guidance in this table.)
Surveillance (green mode) Up to 20% coverage[b] of potentially toxigenic cyanobacteria (see Table 1) attached to substrate.	• Undertake fortnightly surveys between spring and autumn at representative locations in the water body where known mat proliferations occur and where there is recreational use.
Alert (amber mode) 20–50% coverage of potentially toxigenic cyanobacteria (see Table 1) attached to substrate.	• Notify the public health unit. • Increase sampling to weekly. • Recommend erecting an information sign that provides the public with information on the appearance of mats and the potential risks. • Consider increasing the number of survey sites to enable risks to recreational users to be more accurately assessed. • If toxigenic cyanobacteria (see Table 2) dominate the samples, testing for cyanotoxins is advised. If cyanotoxins are detected in mats or water samples, consult the testing laboratory to determine if levels are hazardous.
Action (red mode) *Situation 1:* Greater than 50% coverage of potentially toxigenic cyanobacteria (see Table 1) attached to substrate; **or** *Situation 2:* up to 50% where potentially toxigenic cyanobacteria are visibly detaching from the substrate, accumulating as scums along the river's edge or becoming exposed on the river's edge as the river level drops.	• Immediately notify the public health unit. • If potentially toxic taxa are present (see Table 2) then consider testing samples for cyanotoxins.. • Notify the public of the potential risk to health.

MONITORING RESULTS

[31] Table 5 shows results LAWA displays for ORC's recreational monitoring sites. Results are displayed as the percentage of the time test results comply with each different category for the weekly results (2020-2021) and the long-term grade (2015-2020).

[32] Most of Otago's freshwater sites have a 'poor' or 'fair' long term grade (LAWA), only Lake Hawea has an 'excellent' long term grade. Three sites; Lake Dunstan at Alpha Street, Lake Dunstan at Clyde and Lake Wanaka at Roy's Bay have not been monitored for long enough to have a long-term grade and so this is blank.

[33] Three sites during the 2020-2021 season (Table 6) had an 'unsuitable for swimming' status on at least one occasion; Taieri at Outram, Taieri at Waipiata and Waikouaiti at Bucklands. Another three sites had a 'caution advised' status: Lake Wakatipu at Queenstown Bay, Lake Wanaka at Roys Bay, and the Manuherekia at Shaky Bridge.

[34] Most of Otago's coastal sites have a 'fair' or 'good' long term grade (LAWA); only Kaka Point has an 'excellent' long term grade, and Otokia Creek and Kakanui Estuary have a 'poor' grade.

[35] Three coastal sites had an 'unsuitable for swimming' weekly status on at least one occasion during the 2020-2021 season; Kakanui Estuary, Otokia Creek and St Kilda Beach. Four sites had a 'caution advised' weekly status: Hampden Beach, Pounawea (Catlins), Tomahawk Beach East and Waikouaiti Estuary.

[36] Additional water quality samples were taken in the ocean at Brighton Beach to understand if the high bacterial levels in Otokia Creek affected nearby shore swimming at the beach. The samples were taken opposite Brighton Beach surf club and in the ocean at Otokia Creek mouth. All samples taken at the Brighton Ocean locations had bacteria concentrations safe for swimming (Table 6).

[37] From 458 samples, the 'unsuitable for swimming' category was met on 13 occasions and the 'caution advised' category was met on 10 occasions during the 2020-2021 season across both coastal and freshwater sites.

[38] Faecal source tracking (FST) to identify the source of contamination was undertaken on samples from four sites, Lake Wanaka at Roys Bay, Otokia Creek at Brighton, Taieri at Waipiata and Lake Wakatipu at Queenstown Bay due to high bacteria results found in weekly samples.

[39] Each DNA marker (i.e., avian, ruminant) is a separate test with its own scale of results. Therefore, the level of DNA marker between species within the same sample cannot be compared. Levels of the same marker in different samples can be compared.

[40] The results from FST are shown in Table 7. The Lake Wanaka bacterial contamination had an avian source, the Taieri at Waipiata had a ruminant source, and Lake Wakatipu at Queenstown Bay had a combination of avian, ruminant, and human sources. Otokia Creek had FST completed on five separate occasions. An avian source was determined on every occasion, a human source on three occasions and a ruminant source on two occasions.

Table 5 Results from freshwater contact recreation sampling December 2020 to March 2021. 'Suitable for swimming' shows water quality is good and risk to health is low (E. coli <260 cfu/100ml or Enterococcii <140 cfu/100ml), 'caution advised' indicates the health risk has increased (E. coli 260-550 cfu/100ml or Enterococci* 140-280 *cfu/100ml) and 'unsuitable for swimming' indicates an unacceptable health risk (E. coli >550cfu/100ml or* Enterococci *>280 cfu/100ml)

	Weekly results (Enterococci) 2020-2021			Five year (Enterococci) 2015-2020			Long Term Grade
Coastal Sites	Suitable for swimming (%)	Caution Advised (%)	Unsuitable for Swimming (%)	Suitable for swimming (%)	Caution Advised (%)	Unsuitable for Swimming (%)	
Hampden Beach	93	7		95	4	1	Good
Kaka Point	100			99		1	Excellent
Kakanui Estuary	73	20	7	79	11	9	Poor
Lawyers Head	100			96	1	3	Good
Macandrew Bay	100			88	6	6	Fair
Otokia Creek Brighton	63	11	26	76	7	17	Poor
Middle Beach	100			96	1	2	Good
Pounawea (Catlins)	93	7		95	2	2	Fair
Sandfly Bay	100			98		2	Good
Smaills Beach	100			97	2	2	Good
St Clair Beach	100			98	2		Good
St Kilda Beach	95		5	99		1	Good
Tomahawk Beach (East)	95	5		95	1	4	Fair
Tomahawk Beach (West)	100			95	1	4	Fair
Waikouaiti Estuary	94	6		96	2	2	Good
	Weekly results (E.coli) 2020-2021			Five year (E.coli) 2015-2020			Long Term Grade
Freshwater sites	Suitable for swimming (%)	Caution Advised (%)	Unsuitable for Swimming (%)	Suitable for swimming (%)	Caution Advised (%)	Unsuitable for Swimming (%)	
Lake Dunstan at Alpha St	100			98		2	n/a
Lake Dunstan at Clyde	100			100			n/a
Lake Hawea	100			100			Excellent
Lake Hayes	100			88	7	6	Poor
Lake Waihola	100			95	2	3	Fair
Lake Wakatipu at Queenstown Bay	93	7		84	8	8	Fair
Lake Wakatipu Frankton Bay	100			94	3	3	Fair
Lake Wanaka at Roys Bay	94	6		97	2	2	n/a
Manuherekia River	81	19		79	15	6	Poor
Taieri River at Outram	79	16	5	84	44	5	Poor
Taieri River at Waipiata	83		17	77	14	9	Poor
Waikouait River at Bucklands	88	6	6	91	5	4	Fair

Table 6 Weekly results from contact recreation monitoring 2020-2021. Cells are highlighted in orange when results indicate bacterial concentrations at the 'caution advised' level, cells are highlighted in red when results indicate bacterial concentrations at the 'unsuitable for swimming' level and resamples show cells highlighted in green when bacterial concentrations are at the 'suitable for swimming' level. Site names in red are additional to those shown on LAWA. Please refer to Figure 1 for details on when sites are resampled.

ORC/DCC	Site	7/12	14/12	Resample 16/12	21/12	29/12	Flood 5/01	11/01	Resample 14/01	18/01	Resample 20/01	25/01	Resample 28/01	1/02	9/02	15/02	22/02	Resample 24/02	1/03	Resample 3/03	8/03	16/03	23/03
	Waikouaiti at Bucklands	17	31		21	98		261	120	980		48		28	33	29	24		21		11	49	4
Marine	Otokia Creek at Brighton	10	10		52	63		156	28	1076	100	988	440	<10	216	96	1274	10	697	10	120	10	41
	Pacific Ocean at Brighton Beach Surf Club	ns	ns		ns	ns		20		31		10		<10	<10	<10	<10		<10		<10	<10	<10
	Pacific Ocean at Brighton Creek Mouth	ns	ns		ns	ns		10		131		<10		<10	<10	<10	<10		<10		<10	<10	<10
	Macandrew Bay	<10	<10		<10	10		<10		109		<10		10	<10	<10	<10		10		<10	10	<10
	Waikouaiti Estuary	<10	10		<10	10		223	62	63		<10		<10	31	<10	<10		41		<10	<10	<10
DCC	Lawyers Head Beach	16	<4		4	4		16		4		<4		<4	32	24	4		8		4	4	<4
DCC	Middle Beach	<4	<4		4	<4		8		4		4		<4	16	<4	<4		<4		<4	<4	<4
DCC	Sandfly Bay	48	<4		<4	<4		<4		4		<4		<4	4	<4	<4		<4		<4	<4	<4
DCC	Smaills Beach	84	12		<4	<4		<4		40	12	8		<4	<4	32	<4		<4		<4	40	<4
DCC	St Clair Beach	<4	<4		<4	<4		<4		<4		<4		<4	<4	<4	4		<4		<4	<4	<4
DCC	St Kilda Beach	8	36		<4	<4		8		<4		24		<4	<4	8	<4		4		<4	<4	<4
DCC	Tomahawk Beach (East)	<4	<4		<4	4		<4		180	4	<4		<4	<4	<4	<4		4		<4	<4	<4
DCC	Tomahawk Beach (West)	8	<4		<4	20		20		<4		<4		<4	8	16	24		<4		<4	<4	<4
Clutha District																							
	Lake Waihola at Jetty	1	56		13	20		68		260		77		51	54	48	32		13		55	82	27
	Kaka Point	<10	<10		20	<10		<10		<10		<10		<10	<10	<10	<10		<10		<10	<10	<10
	Catlins at Pounawea	<10	<10		<10	<10		<10		74		<10		<10	<10	15	<10		<10		<10	<10	262
Central Otago District Council																							
	Taieri River at Waipiata	66	72		156	153		816		1733		727		172	185	144	99		179		117	17	228
	Lake Dunstan at Alpha Street	66	<1		2	3		<1		6		13		1	6	6	10		3		5	2	3
	Lake Dunstan at Clyde Rowing Club	<1	1		3	2		12		7		16		<1.00	1	2	1		<1		<1	1	<1
	Manuherikia River at Shaky Bridge	236	461	48	179	45		488		345		61		54	206	89	86		44		192	108	57
Queenstown Lakes District																							
	Lake Hayes (Shallows)	9	10		12	2		4		10		7		23	<1	1	10		5		1	4	35
	Lake Wanaka at Roys Bay	1	15		<1	7		13		921	20	16		3	16	<1	<1		2		<1	13	1
	Lake Hawea at Holiday Park	<1	<1		3	<1		5		10		2		<1	5	6	<1		<1		<1	13	<1
	Lake Wakatipu at Queenstown Bay	23	<1		7	19		26		45		20		6	7	45	7		291		41	45	1
	Lake Wakatipu at Frankton Bay	<1	<1		15	<1		23		43		16		14	3	2	<1		21		ns	1	1

Table 7 Results from faecal source tracking undertaken between December 2020 to March 2021.

Sample Type	Site	Date	Escherichia coli (Colilert-18) MPN/100 mL coli	Avian GFD copies/100mL	Avian Gull4 copies/100mL	Canine DG72 copies/100mL	Human HF183/BacR287 copies/100mL	Human HumM2 copies/100mL	Ruminant BacR copies/100mL
Routine	Lake Wanaka at Roys Bay Shore	18/01/2021	922	490	<180	<180	<180	<180	<180
Routine	Otokia Creek at Brighton	19/01/2021	1076	40000	7300	<1800	43000	<1800	2200
Routine	Otokia Creek at Brighton	26/01/2021	988	1300	11000	<180	730	330	600
Routine	Taieri at Waipiata	26/01/2021	727	<1800	<1800	<1800	<1800	<1800	4600
Routine	Otokia Creek at Brighton	23/02/2021	1274	<180	8000	<180	<180	<180	<180
Investigation	Otokia Creek by Bridge*	27/02/2021	910	530	12000	<180	510	<180	<180
Routine	Lake Wakatipu at Queenstown Bay	1/03/2021	291	3000	420	<180	1500	<180	320
Routine	Otokia Creek at Brighton	2/03/2021	697	3700	13000	<1800	<1800	<1800	<1800

* additional samples were taken upstream of Brighton road bridge, but none returned bacteria results high enough for FST analysis

[41] Results from planktonic cyanobacteria tests in lakes during the 2020-2021 summer are summarised below and use the MfE 2009 reporting framework (Table 3).

- Lake Hayes and Falls Dam did not have a cyanobacteria bloom.
- At Lake Waihola, *Anabaena lemmermani* was present at low biovolumes (surveillance mode) in early December. On 22 February, the 'alert' (amber mode) was reached with a biovolume of 0.68 mm^3/L. The SDHB and DCC were notified, and weekly sampling continued. After 22 February, the bloom subsided and no further 'alert' levels occurred at Lake Waihola for the remainder of the season.
- In Tomahawk Lagoon, *Anabaena lemmermani* was found in samples taken on 09/02/21 triggering the 'alert' (amber mode) with a biovolume of 5.01 mm^3/L. The SDHB and DCC were notified, and weekly sampling continued. The next two samples on 15/02/21 and 22/2/21 remained at 'alert' level. On 1/3/21 sampling showed no cyanobacteria was present and the bloom was over.
- At Butchers Dam a bloom was confirmed by a test after a pollution hotline notification on 17/2/21. *Anabaena lemmermanii* was present in samples taken and the 'alert' (amber mode) was reached with a biovolume of 1.96 mm3/L. The SDHB and CODC (Central Otago District Council) were informed, and signs were put up.
- The bloom had subsided by 22/2/21 with a biovolume of 0.03 mm3/L.

[42] Results from benthic cyanobacteria testing in rivers and streams during the 2020-2021 summer are summarised below and use the MfE 2009 reporting framework (Table 4).

- None of the four regularly tested freshwater contact recreation sites had a benthic algae bloom.
- The Waitaki River near SH1 is not regularly monitored, but a bloom was confirmed with a test following a pollution hotline notification to Environment Canterbury (ECan) on 24/12/20. The bloom on the South side of the Waitaki, was at 'surveillance' level with 14% cover of cyanobacteria. ECan put up signs and the SDHB and WDC (Waitaki District Council) were informed.
- The Silverstream at Riccarton Road is not regularly monitored, but a bloom was confirmed following an observation from the ORC Environmental Monitoring Team on 10/12/20. The bloom was at 'action' level with 90% *Phormidium* cover. The SDHB and DCC were informed, and signs were erected at key access points onto the Silverstream, these remained in place over summer.

DISCUSSION

[43] A significant amount of pre-season preparation was undertaken by the ORC, ES, SDHB and TAs to ensure there was consistency across the region for contact recreation monitoring, reporting and compliance with the NPSFM 2020.

[44] There were two main changes in this season compared to 2019-2020:

- Signs were installed at each monitoring site before the season started directing the public to the LAWA website for swimming safety information. This was consistent with additional communication to the public throughout the season which also promoted LAWA as the 'one source of truth.'
- Re-sampling after an elevated bacteria result and before the next weekly regular sample was only done where 'practicable.' For ORC, the sites considered practicable for re-sampling are listed in Figure 1.

[45] The LAWA website states that 'quality at many rivers and beach swimming spots is affected in wet weather because of urban or rural runoff'[9]. Otago experienced widespread flooding in the first week of January, and a decision was made not to take contact recreation monitoring samples on Monday 5 January. The flooding continued to affect water quality in the following week and samples taken on the 11 January had many high bacteria results. In that week, bacteria results reached 'action' level in the Taieri at Outram and the Taieri at Waipiata and the 'alert' level at Waikouaiti at Bucklands, Otokia at Brighton, and Manuherekia River.

[46] FST tests during the season indicated that avian bacterial DNA was present in all samples except the Taieri at Waipiata. At Otokia Creek avian bacterial DNA were detected in all five samples, human bacterial DNA was indicated in three samples and ruminant bacterial DNA in two samples. The sample taken on 19/1/2021 at Otokia Creek had the most contamination from avian and human bacteria. The investigation team at ORC worked with DCC to investigate the source of the human faecal contamination. Despite dye testing of infrastructure and targeted water sampling, no source was able to be identified.

[47] The FST tests show that birds are a significant source of bacteria in the samples tested. It is likely that the shores of lakes are the original source of *E. coli* contamination (from gulls/ducks), wind driven waves onto the lake shore can churn up the sand/sediment and carry the avian sourced *E. coli* back out into the water. ORC environmental monitoring officers noted large numbers of ducks at most lake sites, for example at the Lake Wakatipu Queenstown Bay site there were between 20-80 ducks in the sampling zone on every occasion.

[48] At the sites monitored for planktonic cyanobacteria (lakes), Tomahawk Lagoon had an 'alert' level for most of February and Lake Waihola had one 'alert' level on 22/2/2021. Cyanobacteria blooms cannot be predicted, but they are more likely after long stable spells of weather in nutrient rich waterbodies.

CONSIDERATIONS

Strategic Framework and Policy Considerations

[49] A review of the ORC contact recreation procedures to ensure compliance with the NPSFM 2020 will be undertaken and presented at the September 2021 DAIC committee.

Financial Considerations

[50] No significant increase in the 2021/2022 season, other than increasing use of FST analysis.

Significance and Engagement Considerations

[51] Engagement around mahinga kai sites will be discussed at the September 2021 DAIC committee.

Legislative and Risk Considerations

[52] Compliance with the NPSFM 2020 for the 2021/2022 season.

Climate Change Considerations

[53] In the future sites and period of monitoring may need review and amendment.

[9] https://www.lawa.org.nz/learn/factsheets/coastal-and-freshwater-recreation-monitoring/

Communications Considerations

[54] Consultation with TAs, SDHB, ES and ORC before the next season begins will start from September 2021. The communications plan is updated annually to reflect any changes in approach. The ORC Communications Team works with LAWA and other regional councils to ensure message alignment at a national level.

[55] Permanent signs updated as necessary. Otokia Creek will have a permanent information board installed prior to December 2021. The board will provide information about the catchment and why bacterial contamination is likely to be present.

[56] Primary communication channel is through LAWA.

NEXT STEPS

[57] A review of the ORC contact recreation procedures will be undertaken and presented at the September 2021 DAIC committee.

[58] Programme recommences in December 2021.

ATTACHMENTS

Nil

7.3. Lake Buoy Programme

Prepared for:	Data and Information Committee
Report No.	SPS2131
Activity:	Environmental: Water
Author:	Hugo Borges, Scientist - Lakes
Endorsed by:	Gwyneth Elsum, General Manager Strategy, Policy and Science
Date:	09 June 2021

PURPOSE

[1] To inform and update the Council on the purchase of monitoring buoys for Lake Wakatipu and Lake Wanaka and to provide an overview of the performance of the Lake Hayes buoy in its first two operational years.

EXECUTIVE SUMMARY

[2] The lake buoys improve the Otago Regional Council (ORC) lakes monitoring programme and measure parameters required in the National Policy Statement for Freshwater Management 2020 (NPS-FM) in near real-time.

[3] The 2018 Annual Plan allocated $280,000 in the State of Environment monitoring capex budget for three lake buoys (Hayes, Wanaka, and Wakatipu). One buoy was installed in Lake Hayes in July 2019, and the two remaining buoys are scheduled for installation in 2021.

[4] A resource consent application to install the monitoring buoys and moorings on Lake Wanaka and Lake Wakatipu was lodged with Queenstown Lakes District Council (QLDC) in April 2021.

[5] The Lake Hayes buoy data is presented in this paper, and the benefits and challenges of the first two years of operation are discussed.

RECOMMENDATION

That the Committee:

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

BACKGROUND

[6] Comprehensive monitoring is vital for tracking changes in water quality. Important lake processes can be affected by land-use changes, point source pollution and both short-term and long-term climatic conditions. Often, these changes may not be adequately described by traditional, infrequent sampling. High-frequency monitoring buoys give a better understanding of the processes affecting lake health, including temperature stratification patterns, oxygen depletion from bottom waters, algal species succession, sediment re-suspension and water clarity. This data helps us evaluate the effectiveness

of any restoration measures we may undertake in lakes and catchments and enable us to detect any sign of degradation in our lakes.

[7] Lake buoys are a very useful tool to monitor and better understand lake dynamics. The high-frequency data provided are an essential guide and used to model water movements (hydrodynamics) which control nutrient transport and nutrient cycling. Having the buoys in our lakes will give a whole new perspective of how lake Wanaka, Hayes, and Wakatipu behave and what pressures they may be under. For example, improved information will provide accurate characterisation of key ecological processes, such as bottom water oxygen consumption, phytoplankton (algae) growth and vertical distribution, water column temperature dynamics, and changes in clarity over time.

[8] Information on stratification and mixing will assist ORC to understand the changes in trophic state that we see through our regular monthly water quality sampling. It is essential to note that a buoy monitoring station cannot replace ORC's regular monitoring programme and would not justify a reduced frequency of regular discrete sampling. This is because nutrients cannot currently be measured by the automatic sensors (except nitrate-N for which sensors do exist but offer lower accuracy than laboratory analysis), nor can phytoplankton community composition be measured by buoys. Secchi depth (water clarity) also cannot be measured by automatic sensors.

[9] The buoys will greatly improve our lakes monitoring programme and measure the parameters required in the National Policy Statement for Freshwater Management 2020 (NPS-FM) in near real-time. Monitoring buoys also provide a highly visible and ongoing demonstration of the effort ORC spends on water quality monitoring programmes and can elicit a strong interest from the public.

[10] The negotiation for getting the two lake buoys for Wanaka and Wakatipu with Limnotrack, started at the end of 2019, but Limnotrack only started developing the buoys for lakes Wanaka and Wakatipu towards the end of 2020 (COVID-19 caused some delays). These deeper lakes, such as Lake Wanaka (311 m) and Wakatipu (380 m), required trials of the technology because up until now the system has only been used in shallow lakes.

DISCUSSION

Programme outline

[11] Two new lake monitoring buoys will be deployed in 2021. The Lake Wakatipu site (Figure 1) was chosen near the State of the Environment (SOE) open water site, but in a more sheltered location to avoid any possible issues caused by strong winds. The Lake Wanaka site will be at the same place as our current SOE open water site (Figure 2), similar to the already operational Lake Hayes buoy. The buoys are currently being designed (a schematic diagram can be seen in Figure 3) and are planned to be installed by September 2021, depending on resource consent and finalisation of buoy assembly.

[12] The lake monitoring buoys will complete 4 to 8 profiles a day. A profile is the collection of measurements taken across the depth of the lake. Profile timing and the depth resolution can be programmed by ORC. The profiles will measure water temperature, chlorophyll and phycocyanin (Lake Hayes only) fluorescence, dissolved oxygen, turbidity, pH/ORP, conductivity, and meteorological variables.

[13] The Lake Wakatipu and Lake Wanaka buoys will be profiling the lakes at depths of up to 130m for the full set of parameters. A fixed-depth sensor will be installed 1m above the lakebed of both lakes to measure dissolved oxygen and temperature.

[14] The data will be telemetered by Spark 3G cellular, and the buoys are compatible with the HydroTel database, for display and management of data via standard workflows. The data will be available on the Hyquest database. After the data is processed and analysed, it will be archived in our Aquarius database and made available to the public.

[15] The data will be continuously analysed to inform our lake management, and an annual report will be produced and available on the ORC website. ORC is currently working with the University of Otago to develop a set of water quality metrics to apply to the buoy's data, which will also meet NPS-FM attribute requirements. This will enable ORC to compare Otago's Lake buoy data to assess lake dynamics. This is required because there are no guidelines for use applicable to buoy data currently.

[16] Data collected directly from the buoy will be available on a digital platform in near real-time (every 30 min updates) for community access, after a one-year trial period.

Lake Hayes buoy performance

[17] Limnotrack has supplied one profiling buoy to ORC, for Lake Hayes. The buoy was deployed in early July 2019 and has proven reliable with relatively low demands for maintenance in the first year. However, in the second year the winch system has been presenting some issues and is due to be replaced by July 2021. All sensors connected to the profiler have been working as expected.

[18] Data from the buoy is essential for better understanding of key processes in Lake Hayes, including the development of summer phytoplankton blooms (e.g. toxic algae) which are the focus of public attention and have implications for human and animal health.

[19] The data produced in the buoy's first two years of operation highlighted issues Lake Hayes is currently facing, such as long periods of time when the different layers of the lake do not mix (stratification) and when some layers contain very little or no dissolved oxygen. When this happens in association with high nutrient inputs (e.g., N and P) it favours more frequent algal blooms; these then promote a cycle of less oxygen available in the water column and internal release of nutrients from the lakebed causing deterioration of the lake ecosystem overall.

[20] Constant stratification in Lake Hayes can be seen throughout the summers (Figure 4). In February 2020 the difference in temperature between surface and bottom waters was over 10° C and was similar in 2021. Long stratification periods, when there are also high levels of nitrogen and/or phosphorus, can lead to an increase in algal blooms, fish die-offs and increased methane emissions.

[21] The levels of dissolved oxygen were very low in the deep-water layers (hypolimnion) over both analysed summers (Figure 5). Anoxic (0 percent saturation of dissolved oxygen) levels were observed from November 2019 through to June 2020 and repeated over the 2020/2021 summer and autumn season. At times these anoxic levels were from 10m depth all the way to the bottom of the lake. Anoxic conditions promote ecological processes that degrade water quality through the release of problem-causing

compounds from anoxic sediments including phosphates, ammonia, sulfides, methyl-mercury, iron and manganese, and also affect biological conditions limiting the habitat availability to animals and plants in the lake.

[22] Chlorophyll a (phytoplankton; Figure 6) levels increased towards summer in both years. High concentration of phytoplankton was recorded during lake stratification periods. High levels of phytoplankton are an indication of poor ecosystem health.

[23] The climate data was reliable and consistent throughout the nearly two years of buoy operation and will provide a valuable source of information for future Lake Hayes models and climate change predictions.

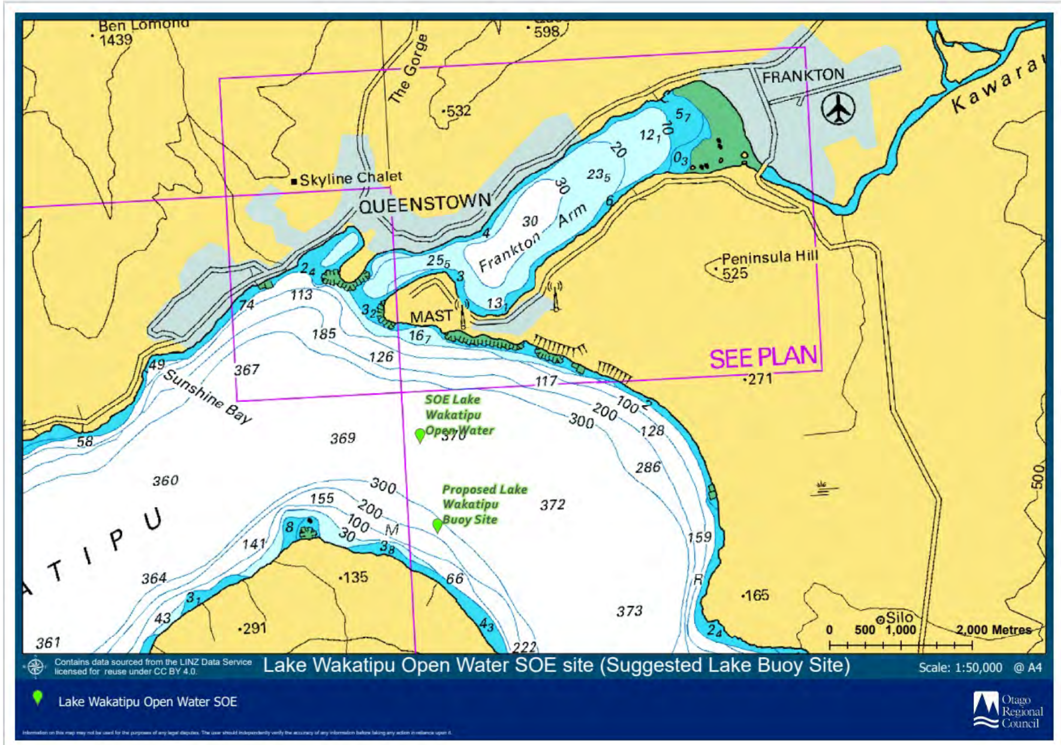


Figure 1 – Lake Wakatipu SOE open water site and the proposed site of the Limnotrack buoy (green text).

Figure 2 – Lake Wanaka SOE open water site (yellow dot) which will also be the location of the Limnotrack buoy.

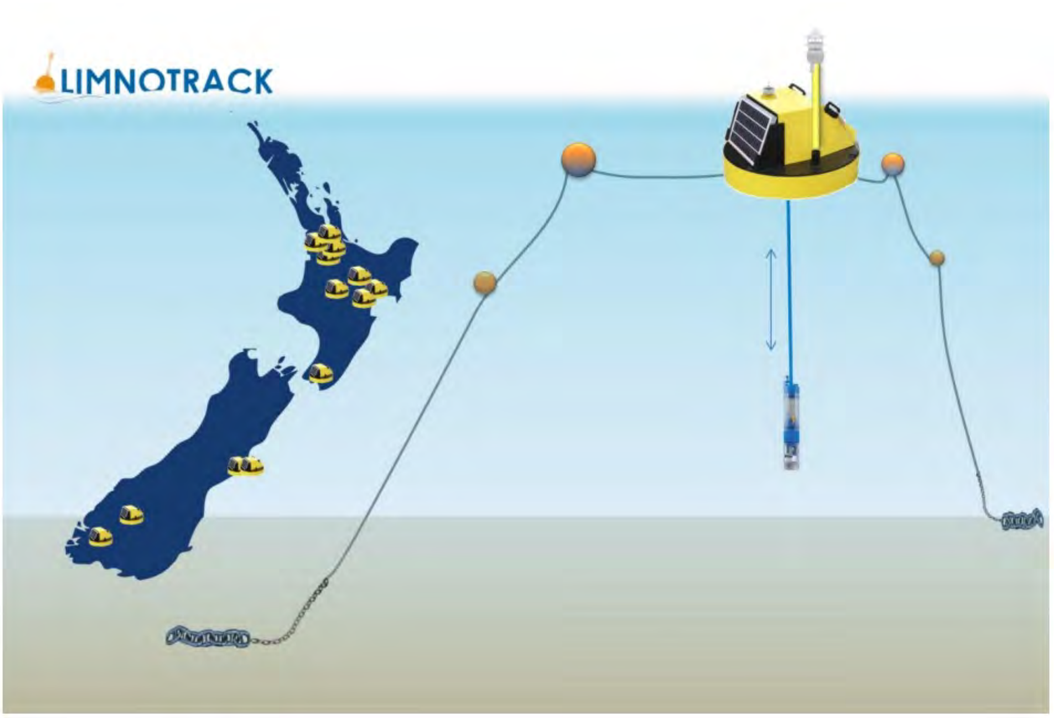


Figure 3 – Schematic diagram of Limnotrack's water column profiling monitoring buoy, and the distribution of Limnotrack's lake monitoring buoy network in New Zealand.

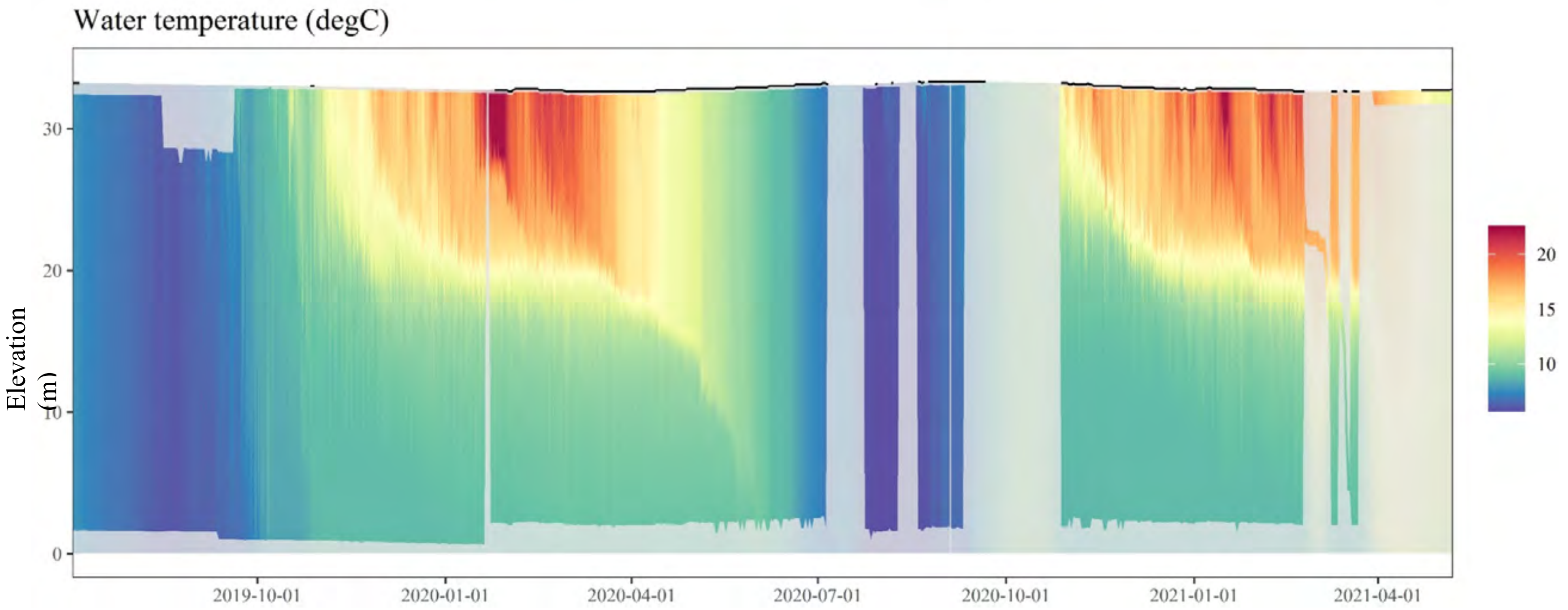


Figure 4 – Water temperature (◦C) vertical profiles from Lake Hayes high-frequency monitoring buoy, July 2019 to May 2021. *Gray areas = buoy was not operational. 30m is the surface of the lake and 0 m is the lakebed.

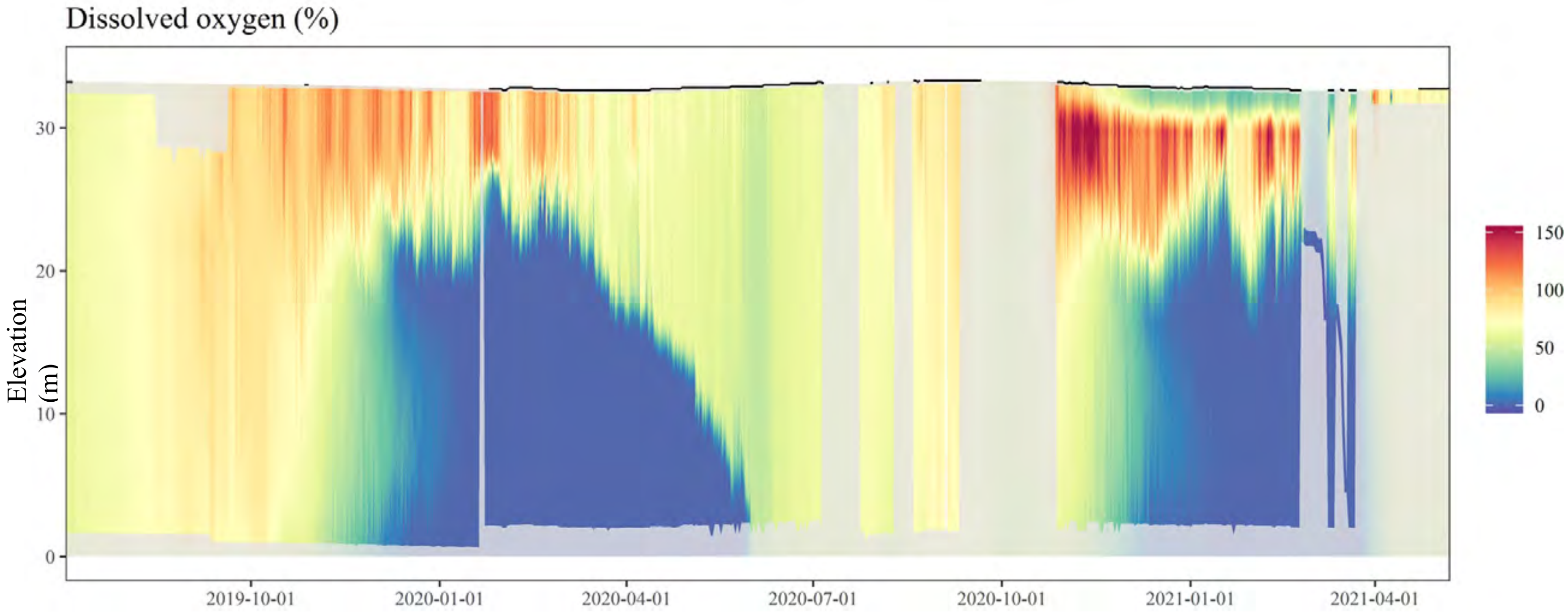


Figure 5 – Dissolved oxygen (%) vertical profiles from Lake Hayes high-frequency monitoring buoy, July 2019 to May 2021. *Gray areas = buoy was not operational. 30m is the surface of the lake and 0 m is the lakebed.

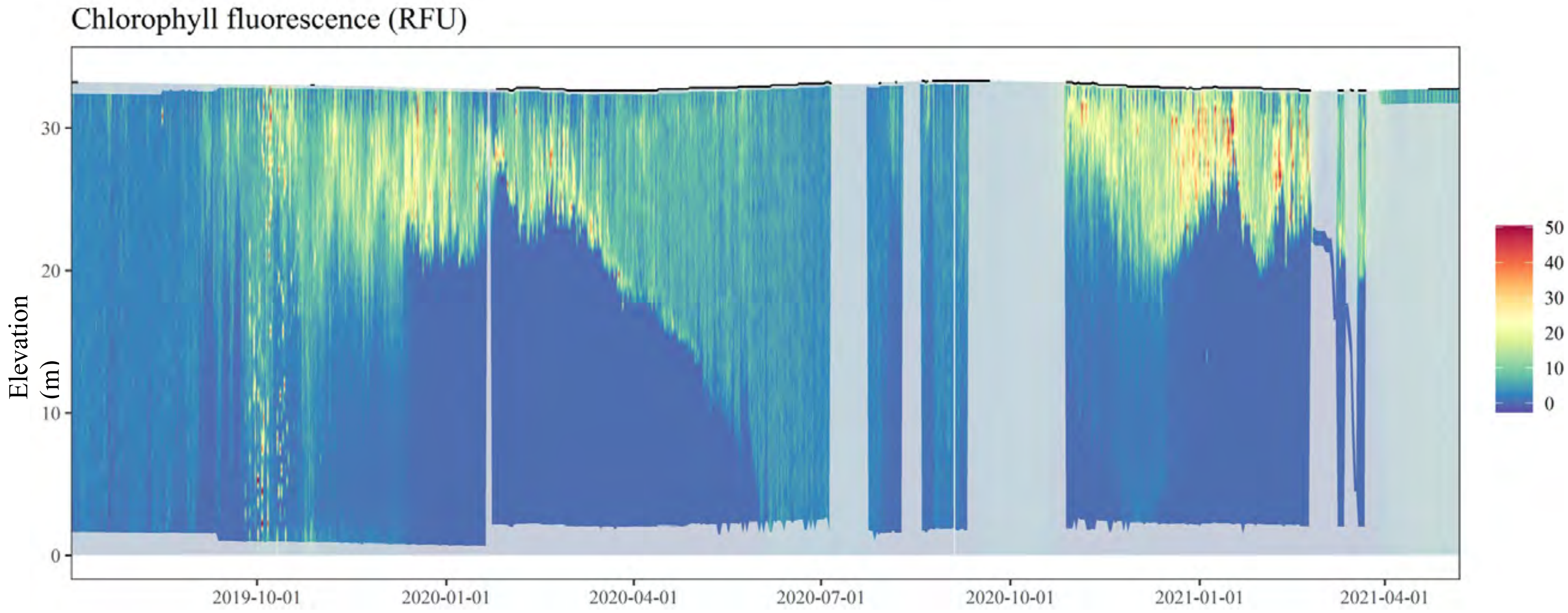


Figure 6 – Chlorophyll fluorescence (RFU) vertical profiles from Lake Hayes high-frequency monitoring buoy, July 2019 to May 2021. *Gray intervals = buoy was not operational. 30m is the surface of the lake and 0 m is the lakebed.

CONSIDERATIONS

Strategic Framework and Policy Considerations

[24] Lake buoy installation fits with ORC's Strategic Directions to monitor and investigate water quality and ecosystem health.

Financial Considerations

[25] The 2018 Annual Plan allocated $280,000 in the State of Environment monitoring capex budget for three Lake Buoys (Hayes, Wanaka, and Wakatipu).

[26] The sum of $300,000 has been proposed as part of the current 2021-31 Long Term Plan process, $150,000 for the 2021/22 Financial Year and $150,000 for the 2022/23 Financial Year for the purchase of four lake buoys (two in each proposed financial year).

Significance and Engagement Considerations

[27] When each lake buoy is installed, we will invite local media along to speak with our scientist about the importance of the data we are collecting and how it will be used. This will be accompanied by media release of the same nature.

[28] Relevant territorial authorities and Iwi have been consulted as part of consenting process (Affected Person’s Approval).

Legislative and Risk Considerations

[29] The buoys will be performing on a single site in lakes Wanaka and Wakatipu, and due to the extension and morphology complexity of those lakes the data produced may not be a true representation of the whole lake. Purchase of additional buoys are planned in the draft LTP 2021-2031, which may mitigate this issue.

Climate Change Considerations

[30] Lake buoys will provide an important source of data and information for future predictive climate change models and will support research in this area.

Communications Considerations

[31] Lake buoy data will be available in near-real time at Limnotrack’s website, and Otago’s Lake buoys data will be accessible through a dedicated webpage on ORC’s website for our community to view after a trial period.

NEXT STEPS

[32] Subject to confirmation of LTP funding, four more lake buoys are planned to be installed in the Otago high country lakes, two per year in the next two years. Another three buoys, with a fixed string of sensors technology, will be acquired for three lowland shallow lakes (Tuakitoto, Waihola, and Tomahawk) allowing continuous monitoring of required NPS-FM 2020 parameters.

[33] An annual report on the data produced by all lake buoys will be provided in 2022.

ATTACHMENTS

Nil

7.4. Coastal Monitoring Programme

Prepared for:	Data and Information Committee
Report No.	SPS2132
Activity:	Environmental: Rivers & Waterway Management
Author:	Sam Thomas, Coastal Scientist
Endorsed by:	Gwyneth Elsum, General Manager Strategy, Policy and Science
Date:	9 June 2021

PURPOSE

[1] To outline the stages of gathering data/information to inform the *Regional Plan: Coast* review and the pathway to the creation of a coastal monitoring programme.

EXECUTIVE SUMMARY

[2] Otago's coastline is a wild and diverse environment running 480km from the Waitaki River mouth in the north down to Wallace Beach in the south in the Catlins. Otago's coast is a hotspot of biodiversity containing iconic species such as yellow-eyed penguins and sperm whales through to important habitats such as Macrocystis kelp forests in the shallow subtidal zone out to deep sea canyons that all occur within 12 nautical miles of the coast.

[3] Due to the importance of Otago's marine environment and ORC's regulatory obligations, knowledge of marine significant ecological habitats and ground-truthing of key habitat is required to inform both the *Regional Plan: Coast* review and to provide information on key areas to monitor. A representative monitoring network is required to determine the current state of key ecosystems, changes in state and to identify management options required to maintain or improve ecosystem/habitat health in Otago's marine environment. The SOE Coastal monitoring programme will complement the estuary monitoring programme and will cover the marine area but will exclude estuary monitoring, however, information from the estuary SOE programme will be used in the coastal monitoring programme.

[4] Spatial mapping and knowledge gap analysis will be undertaken to provide information for the *Regional Plan: Coast* review and potential areas that require monitoring and/or protection. Data from the spatial mapping and coastal plan review will provide the framework and direction for the SOE coastal monitoring programme. A monitoring network specifically for kelp forests will be established using new and current technologies to map extent and change along Otago's coastline.

RECOMMENDATION

That the Committee:

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

2) ***Notes*** *that Otago's SOE Coastal Monitoring programme is currently under development and will follow a four-staged process over 6 years. A paper will be presented to the*

Strategy and Planning Committee in 2022 outlining monitoring options for an SOE (State of the Environment) network and seeking Council approval for programme implementation.

BACKGROUND

[5] Otago's coastline is home to a wide range of diverse and unique ecosystems. These ecosystems are biodiversity hotspots with deep sea canyons, bryozoan reefs, Rhodolith beds, gravel/boulder fields and kelp forests providing habitat for Pāua, crayfish, blue cod, sperm whales, albatross, yellow-eyed penguins and sea lions. This diversity of habitats and the nutrient rich currents such as the Southland and sub-Antarctic currents create conditions that make Otago's marine life richly biodiverse with many iconic species, of which only some are mentioned in this paper. These unique ecosystems and habitats also provide many ecosystem services and functions from commercial and recreational fishing, cultural significance, nutrient and oxygen cycling, primary productivity, and carbon storage.

[6] Many different stressors such as climate change (warming seas), ocean acidification, increased sedimentation, pollution, and fishing pressure occur in the coastal space and can affect the ecosystems and species and the functions and services they provide. These stressors can be individual (e.g., sediment) or multiple (e.g., sediment and warming seas) with differing impacts depending on the ecosystem/habitat and the species. Losing habitat or species can have a cascading destructive effect due to the complex interactions that occur in marine ecosystems, reducing ecosystem functions and services that the marine environment provides.

[7] Due to the importance of these ecosystems and habitats, both knowledge of Otago's marine environment and monitoring is required. Marine spatial mapping is required to provide information about the significant marine ecosystems that occur in Otago's waters and the key habitats and ecosystems such as kelp forests and bryozoan reefs. Monitoring is required to determine current state and any change in state within an ecosystem/environment so that appropriate management actions can be undertaken if the state is degrading or degraded. Monitoring methods can include satellite monitoring, remote-operated submarines, drop cameras, and multibeam using echolocation and diving.

[8] Otago Regional Council currently does not monitor the coastal marine area beyond estuaries. Otago Regional Council has regulatory obligations under the Resource Management Act 1991 (RMA) and the New Zealand Coastal Policy Statement, in particular Policy 11, to *protect indigenous biological diversity in the coastal environment.* Regional councils must provide for the preservation of natural character (which includes an ecological element) (RMA, Section 6a) and protection of indigenous vegetation and fauna (RMA, Section 6c). Otago's jurisdiction (Regional Policy Statement and Regional Plan: Coast) runs from mean high water springs (MHWS) out to 12 nautical miles. Therefore, mapping of the marine habitats and monitoring of key ecosystems/habitats is important to create an effective coastal plan that enables informed and robust decision making to manage the coastal environment.

DISCUSSION

[9] The review of Otago's *Regional Plan: Coast* is overdue. To meet ORC's regulatory responsibilities and to provide information and data to undertake the review of the *Regional Plan: Coast*, spatial mapping needs to occur, and a marine monitoring network needs to be established. Comprehensive spatial mapping identifies habitats and ecosystems, enables identification of knowledge gaps, and provides information to inform a coastal plan and the areas to focus on for marine monitoring.

[10] Many other regional councils (Environment Southland and Waikato for example) have already undertaken marine significant ecological area mapping which provides information on the significant ecological areas and habitats in the marine environment. This spatial mapping provides key information to inform the review and creation of a coastal plan about where protection and monitoring needs to occur. These councils have used the mapping and data in updating their coastal plans.

[11] The marine spatial mapping will highlight the knowledge gaps where further research or mapping is required to understand Otago's marine environment and provide information on the marine diversity hotspots. The highest priority biodiversity hotspots will be further refined by undertaking zonation modelling on the spatial data. Zonation modelling refines the spatial data to identify areas that are important for retaining habitat quality and connectivity for multiple species, habitats, or ecosystems. This information will then enable a representative SOE coastal monitoring network to be established to meet ORC's statutory obligations.

[12] The coastal environment is a vast and expensive place to monitor and manage, therefore, where possible, collaboration is beneficial to share data, avoid doubling up of monitoring and to get the best result for the marine environment. Currently on the Otago Coast there is a Taiapure reserve running from Blueskin Bay to Karitane which has been monitored by the Marine Science Department on behalf of Ngāi Tahu. The Southeast Marine Protection Forum protected areas network is currently under review by the Minister of Conservation (decision overdue) which will determine how many marine protected areas are established along Otago's coastline and will be managed by the Department of Conservation (DoC). Collaboration between iwi and key stakeholders such as DoC will allow for leveraging of other people's monitoring to "fill in gaps" along the coast in key ecological areas. Monitoring programmes could be established between agencies to share information and get the best result for the coastal environment.

[13] Otago's coastline has extensive *Macrocystis* kelp forests and bull kelp beds that support high levels of biodiversity, provide habitat for key species such as Pāua and crayfish as well as being critical to ecosystem functioning through oxygen production and carbon storage. These kelp beds are important both recreationally and culturally. Kelp forests are under threat from multiple stressors such as warming seas and sedimentation from land run off. Building on work undertaken by NIWA monitoring sediment effects on kelp forests, in relation to consent conditions for dredging extensions of port channels, a kelp forest monitoring programme will be developed and implemented. This programme will provide ORC with information on kelp forest extent and potential drivers of any change in kelp forest extent. This monitoring will allow ORC to start meeting regulatory obligations under the New Zealand Coastal Policy Statement.

[14] Due to the complexity of the marine environment and the cost associated with coastal monitoring, the coastal programme will be implemented as a staged process over six years as information is gathered (to work in with the Policy Team's timeframes for Coastal Plan notification). Initial marine significant ecological mapping will provide the information to create an effective *Regional Plan: Coast* that allows ORC to manage the coastal marine environment effectively. A kelp forest monitoring programme will be rolled out over the next three years providing information on this key ecosystem that is known to be under pressure from multiple stressors, such as warming seas and sedimentation from land. A comprehensive SOE coastal monitoring programme will be created based on spatial mapping, baseline surveys and founded on ORC's statutory obligations. This will be reviewed and updated after the *Regional Plan: Coast* is notified.

Proposed Coastal Monitoring Programme for Otago

[15] Otago's coastal monitoring programme will be set up in a staged process over six years (years are stated below with some stages occurring in parallel) to provide information to inform the *Regional Plan: Coast* review (proposed to be notified in 2025/26) and build a fit for purpose SOE coastal monitoring network to manage Otago's coastal marine environment. There are two main workstreams to the proposed coastal monitoring programme: a kelp monitoring programme and an overall SOE coastal monitoring programme.

[16] It should be noted that the Policy Team will commence the *Regional Plan: Coast* review in 2024/25, and it will be notified in 2025/26 and made operative in 2028. The SOE coastal monitoring programme will undergo a second review following notification and will be updated to monitor the effectiveness of the coastal plan.

[17] <u>Stage one (2021/2022)</u>: Undertake marine significant ecological mapping and run zonation modelling on the outputs of this spatial mapping. Zonation will be used to further refine hotspots of biodiversity for both policy development and monitoring purposes.

[18] <u>Stage two (2021/22)</u>: The development of a cost-effective kelp monitoring programme for Otago's east and south coast (all of Otago's coast). This will involve an inventory of current data (both NIWA and ORC data (freshwater and estuary) from several monitoring sites, assessing the suitability of kelp forest monitoring to understand broader changes to marine ecosystems, and the potential to link land impacts to potential changes in kelp forest extent. The programme will aim to build on work already undertaken by NIWA on kelp forest monitoring along the east coast for Port Otago during the channel widening consent phase (2015-2019). The aim is to build on current work and assess the potential integration of satellite monitoring, drones, river monitoring data, estuary data, diving and remoted-operated submarine monitoring. The end result will be to advise on a cost-effective, long-term monitoring programme that can be used to track changes to key ecosystem engineers (i.e., giant kelp), and accurately determine the drivers of change (e.g., land-use changes, global and local climate change).

[19] <u>Stage three (2021-2023):</u> Implement the kelp forest programme over 3 years. After this period the kelp forest monitoring will be included into the wider SOE coastal monitoring programme.

[20] Stage four (2021-2026): The marine significant ecological mapping will highlight key areas to monitor and identify knowledge gaps along Otago's coast. Further mapping and/or data gathering will be undertaken to refine information required for the *Regional Plan: Coast* review. Baseline data will be gathered for key habitats/ecosystems that are identified from the initial mapping process utilising cost-effective technologies such as drop cameras, remote-operated submarines, and divers if appropriate. A SOE coastal monitoring programme to meet ORC's statutory obligations will be created (FY 2023/24) once baseline data has been gathered, analysed and interpreted.

CONSIDERATIONS

Strategic Framework and Policy Considerations

[21] The marine significant ecological areas mapping, kelp monitoring and any baseline surveys undertaken will provide the information to undertake the review of ORC's *Regional Plan: Coast*. The Policy Team proposes to start the review in 2024/25 and notify the plan in 2025/26.

[22] The SOE coastal monitoring programme will be created over the next three years (2021 to 2024) to enable ORC to meet its statutory obligations and enable ORC to monitor the effectiveness of its *Regional Plan: Coast* upon notification in 2025/26.

Financial Considerations

[23] This work has been budgeted in the draft Long-Term Plan 2021-2031 and is conditional on its approval.

Significance and Engagement Considerations

[24] There will be engagement with key stakeholders that hold marine spatial data on Otago's ecosystems and species during two workshops as part of the marine significant ecological area mapping (undertaken in 2021/22).

[25] Engagement will be ongoing between iwi and stakeholders that operate in the coastal space and on a project-by-project basis.

[26] Collaboration between key agencies with the aim to develop an MOU/partnership arrangement between these agencies such as Fisheries NZ, DoC and the Marine Science Department at the University whom ORC may rely on for data.

Legislative and Risk Considerations

[27] ORC doesn't currently meet its legislative obligations under the RMA or the New Zealand Coastal Policy Statement as it has no coastal monitoring programme.

Climate Change Considerations

[28] Kelp forests are large sinks for carbon and marine soft sediments are the biggest sink of carbon in the world. Monitoring of kelp forests and information gathering on Otago's marine environment allows for management decisions to be made that help reduce stress on these key ecosystems and to increase carbon storage capacity. Monitoring provides the information on the state and potential causes of decline in kelp forest or destruction of soft sediment structure which allows for informed management decisions to be made to reduce these impacts and improve carbon storage.

Communications Considerations

[29] Communication between iwi and key stakeholders will occur on a project-by-project basis.

[30] A communications plan will be developed ahead of the start of the review of the *Regional Plan: Coast* in 2024/25.

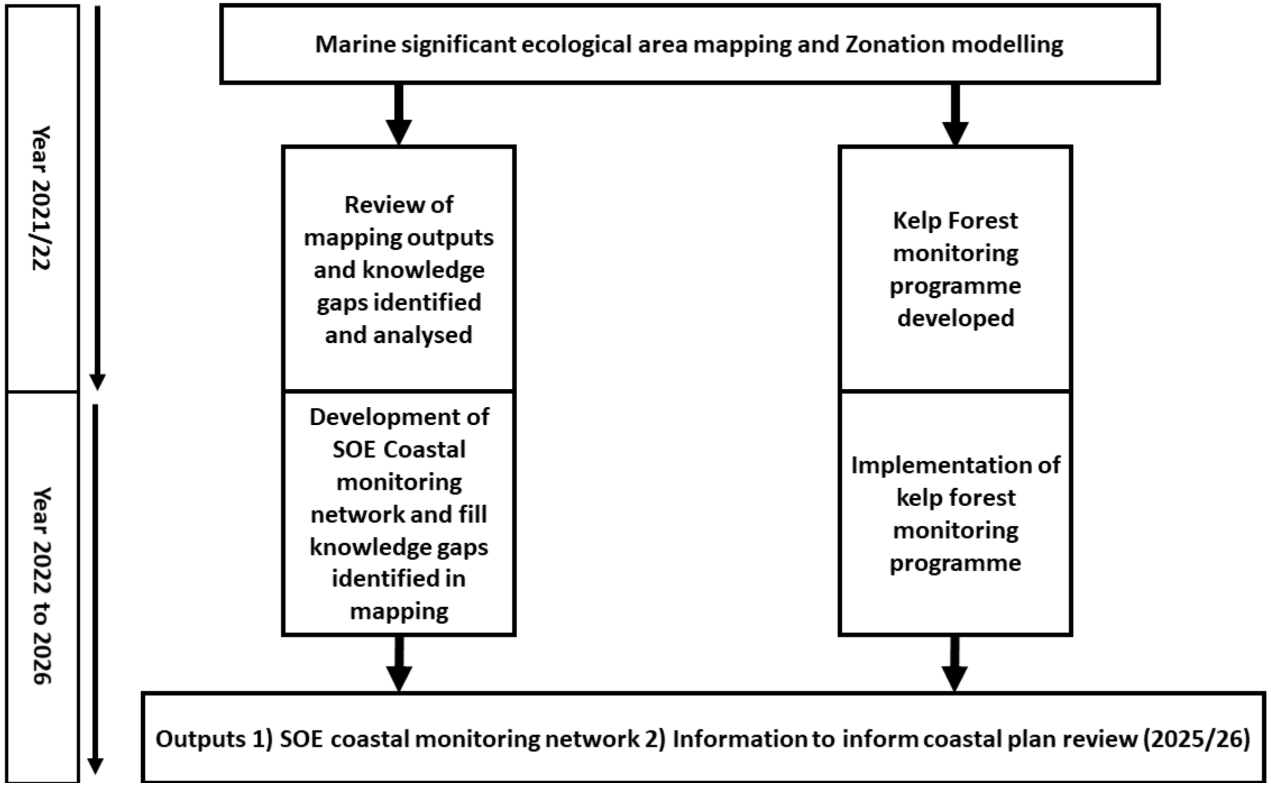
NEXT STEPS

[31] A paper will be taken to the Strategy and Planning Committee in 2022, outlining ongoing SOE coastal monitoring programme options for Council to consider, prior to implementation.

ATTACHMENTS

1. Pathway to a coastal monitoring programme [**7.4.1** - 1 page]

Pathway to an SOE coastal monitoring programme



7.5. Quarterly Urban Monitoring Report

Prepared for:	Data and Information Committee
Report No.	SPS2134
Activity:	Governance Report
Author:	Phillip Waters, Senior Analyst, and Kyle Balderston, Team Leader – Urban Growth and Development
Endorsed by:	Gwyneth Elsum, General Manager Strategy, Policy and Science
Date:	9 June 2021

PURPOSE

[1] To note the quarterly monitoring report, up to and including, March 2021, as required by Clause 3.9 of the National Policy Statement on Urban Development 2020.

EXECUTIVE SUMMARY

[2] This report presents the second Quarterly Monitoring Report (Appendix 1) 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 first quarter of 2021.

[3] This report builds upon the initial Quarterly Monitoring Report received by the Data and Information Committee on 2 March 2021. It includes some new datasets and newly published data that expands the compulsory indicator timeseries data published in the initial report. New datasets include updated sub-national population growth projections based on the 2018 Census and REINZ sales data spanning the last five years.

[4] To avoid repetition, this quarterly update does not provide an equivalent depth of explanation or analysis to that provided in the initial quarterly monitoring report where timeseries data has been expanded by a few months, unless significant trend variations are noted. Fuller analysis will be provided when a full year of data is available (i.e. the 5^{th} quarterly monitoring report will cover a full year's data).

[5] The indicators covered in the report suggest that housing demand has continued to increase since the previous report, as it has done since 2002. House prices continue to rise quickly across Otago in a context of relative stability in the number of house sales in each of Otago's housing markets. This situation highlights continuing underlying supply issues, though wider economic conditions (low interest rates and post-Covid recovery being better than expected) have combined to increase demand for housing above and beyond the level that may otherwise have been the case under more 'normal' economic conditions. As housing supply is relatively inelastic, it is unsurprising that rapid increases in demand would cause short-term value hikes. House values in both Central Otago and Queenstown Lakes appear to have rebounded from the immediate value falls in the initial period of pandemic management measures of the second quarter of 2020, including the disappearance of international tourism and its impact upon local economies.

RECOMMENDATION

That the Data and Information Committee*:*

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

DISCUSSION

Housing Indicators Update

[6] 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 requires that the reports cover the following indicators:

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.

[7] Due to the limited new data that expands upon timeseries data presented in the initial report, the trends identified, and the interpretation provided of those trends, remain valid and up to date. In summary, the data shows that growth in housing demand has steadily outpaced new housing supply and that housing costs have been steadily rising since the mid-1990s. The pace of house price inflation has accelerated notably over the last year and median prices have grown substantially. Median house prices in Otago have increased on average by 22 percent from March 2020 to March 2021. In real terms the median value of a home in Otago has grown $118,000 over this period (albeit there are significant variations across Otago's districts).

[8] 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 needs, and these rising prices also impact disproportionately on renters and first home buyers. New supply has remained relatively stable, although slowing over the past year.

[9] 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. 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 in a variety of locations remains important, to provide more choice for consumers, greater competition amongst developers and landowners, and to 'get ahead of the curve'.

[10] Statistics NZ have recently released sub-national population growth projections based on the 2018 Census. These replace the last official release from 2016, which was 2013 Census based. The new projection series is generally higher than the 2016 release, which means there is likely to be greater need for new homes and infrastructure than previously anticipated. ORC's LTP 2021-2031 population growth assumptions are more similar to the new Statistics NZ projection than the former release, as it had already accounted for the population adjustment identified in the 2018 Census. However, the new release serves as confirmation that the LTP is based on sound assumptions.

CONSIDERATIONS

Strategic Framework and Policy Considerations

[11] 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.

[12] The report also supports ORC's Strategic Directions. In particular, it provides a sound evidence base of contextual information that supports ORC's role in contributing towards sustainable urban development. The information and analysis provided in Quarterly Monitoring Reports helps identify regional urban issues and challenges and enables ORC to work to address and overcome these. This includes working independently and collaboratively with TAs to ensure integration of urban planning, infrastructure planning and environmental management.

Financial Considerations

[13] There are no financial considerations.

Significance and Engagement Considerations

[14] This does not trigger the Significance and Engagement Policy.

Legislative and Risk Considerations

[15] This report is required under the NPSUD 2020, a regulation of the Resource Management Act 1991. There are no risk considerations.

Climate Change Considerations

[16] There are no direct climate change considerations relevant to this report. However, projected population growth and housing demand has the potential to impact Otago's greenhouse gas emissions and development needs to be assessed in light of climate hazards such as flooding.

Communications Considerations

[17] There are no communications considerations.

NEXT STEPS

[18] The next quarterly update will be in September 2021 and will also include some exploration of 2018 Census Data and building consent data relating to home improvements and non-residential development.

[19] The NPSUD requires quarterly reporting and at least annual publishing. Once a full year of reporting has occurred, staff will suggest a timetable for future quarterly monitoring reports that aligns with Committee schedules and still ensures that Council is able to make informed decisions.

ATTACHMENTS

1. 2021Q1 Urban Development QMR V2 [DLZT] [**7.5.1** - 28 pages]

Quarterly Monitoring Report, Q1 2021

National Policy Statement on Urban Development

Contents

Figures

Data Sources, Coverage and Time

[1] Most data are provided at the district level for all districts in the region. The report includes Clutha District, which is not subject to the monitoring requirements of the NPSUD; and all of Waitaki District, of which part is in Canterbury Region. As such, regional figures may vary between the 'sum of TAs' (i.e. 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 April 2021, where available.

[2] 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 ORC's limited functions in these spaces, relative to the TAs), and ORC's 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.

[3] 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.

[4] 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.

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:
https://www.qldc.govt.nz/your-council/council-documents/national-policystatement-urban-development-2020-nps-ud#quarterly-reports

[5] 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/

Dwelling Demand

[6] 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.

[7] 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, which has been net positive every year since 2002, 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.

[8] The first Monitoring Report showed components of growth (i.e. natural increase and migration) annually from 1997 to 2020. This Report presents Statistics New Zealand medium projection for the components of growth from 2023 to 2048 (Figure 1). This shows Otago's population is projected to continue to grow, but the pace of growth is expected to slow continuously over this 25-year period. This is likely to be caused by a gradual reduction in net migration and a gradual reduction in natural increase which is projected to be negative from 2038 (i.e. there will be more deaths than births). However, despite the negative rate of natural increase from 2038, net positive migration is projected to offset this effect and overall population growth numbers at the regional scale are expected to be positive.

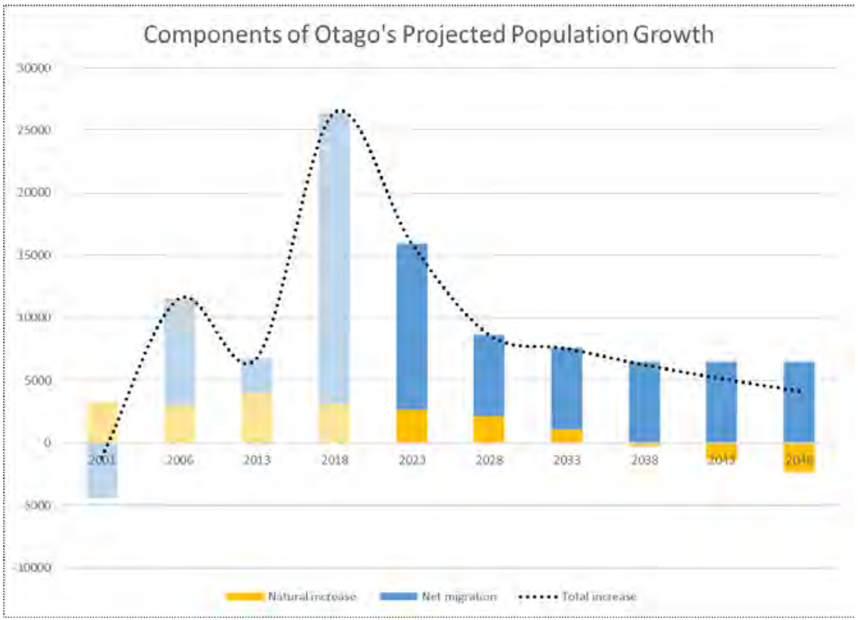


Figure 1: Components of Otago Region's Projected Population Growth: Statistics NZ

[9] Figures 1a to 1e provide the components of projected population growth in each of Otago's Territorial Authorities using the medium series. These show stark differences in the relative contribution of migration and natural increase to growth in each TA, as well as considerable variation in the scale and rate of growth across the region.

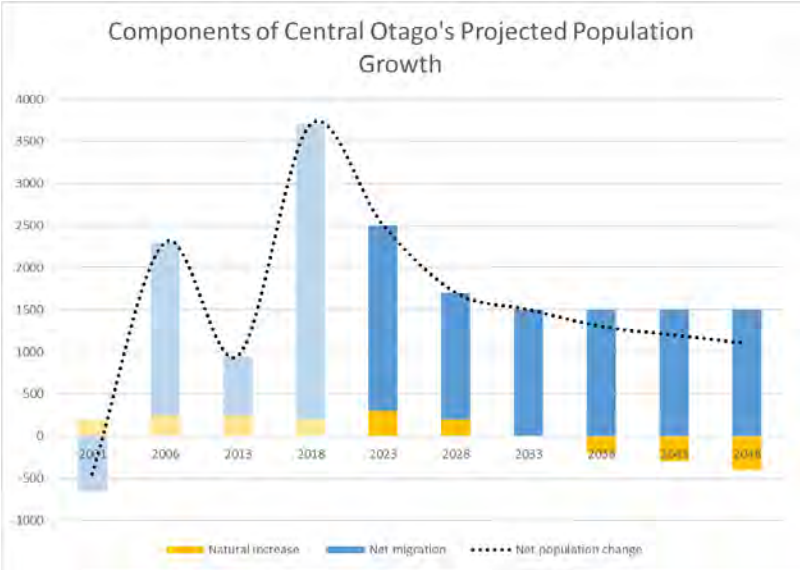


Figure 1a: Components of Central Otago's Projected Population Growth: Statistics NZ

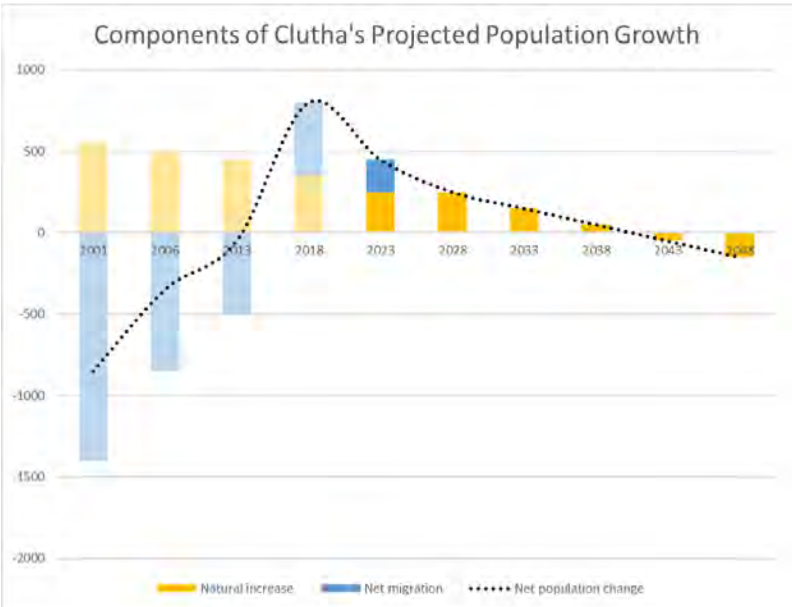


Figure 1b: Components of Clutha's Projected Population Growth: Statistics NZ

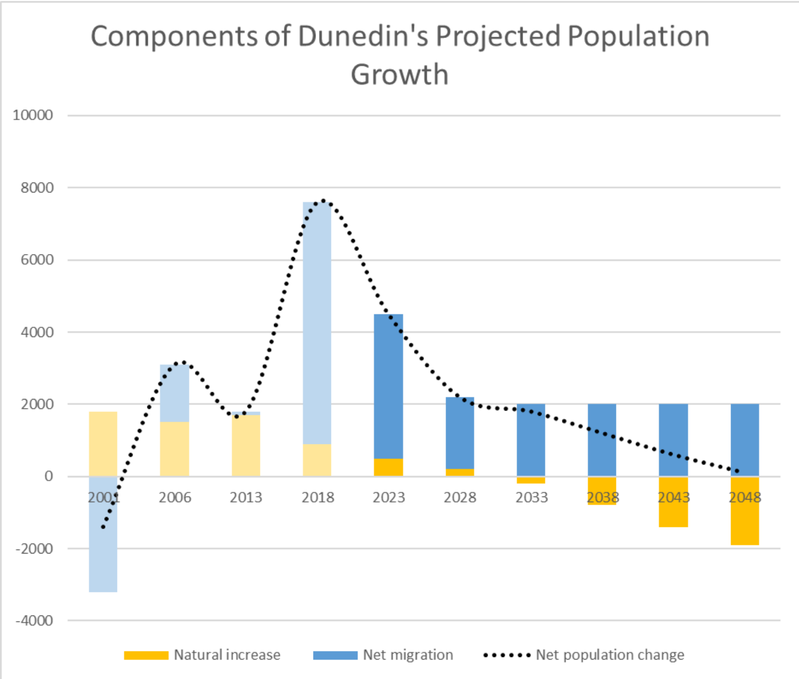


Figure 1c: Components of Dunedin's Projected Population Growth: Statistics NZ

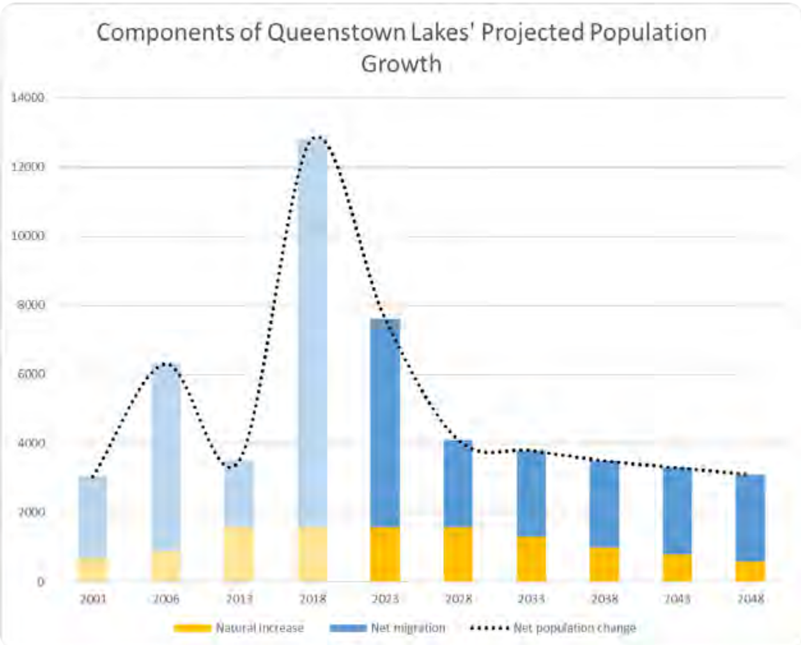


Figure 1d: Components of Queenstown Lakes' Projected Population Growth: Statistics NZ

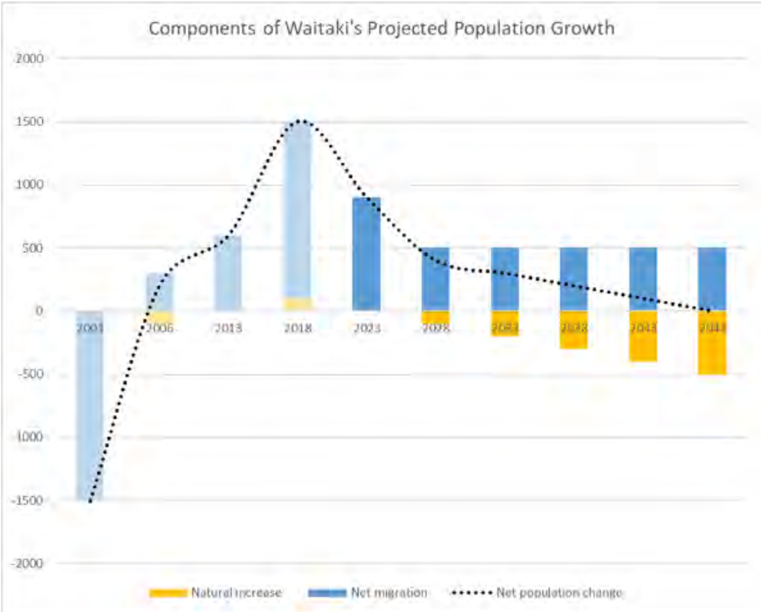


Figure 1e: Components of Waitaki's Projected Population Growth: Statistics NZ

[10] 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. Even discounting any changes in natural increase or net migration, 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 or within a preferred neighbourhood, throughout various life stages and also allows existing houses better suited for families or larger households either to be purchased by new owners, or redeveloped to meet other needs. The sale of property is strongly associated with subsequent property changes, such as redevelopment or improvement. Higher levels of property changes after sale indicates that existing housing stock is relatively unsuited to current housing needs.

[11] The following figures (figures 2 to 2e) show the past, current, and projected population of the Otago region and the region's Territorial Authorities by age bands. In all areas this shows the age group that is projected to grow most significantly is the population of over 65s. Central Otago and Queenstown Lakes are both projected to experience significant grow in all ages except under 15s between 2021 and 2014. All graphs show the medium projection assumptions. The Low and High series have lower or higher net migration and natural increase assumptions. Across Otago an aging population is projected to occur, albeit to different degrees across the region.

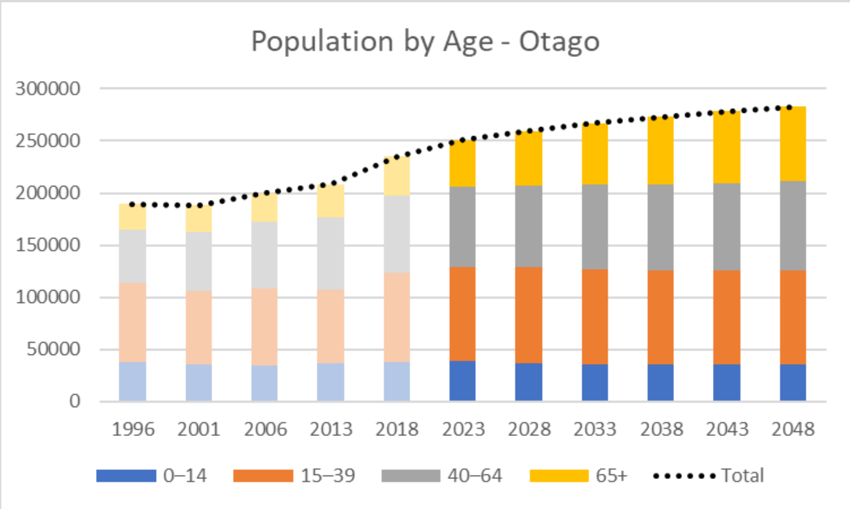


Figure 2: Otago's Total Projected Population by age structure: Statistics NZ

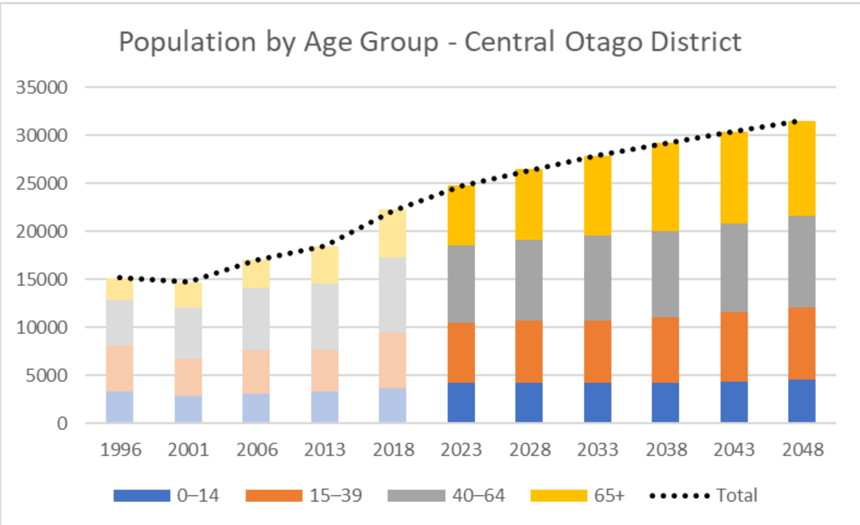


Figure 2a: Central Otago's Total Projected Population by age structure: Statistics NZ

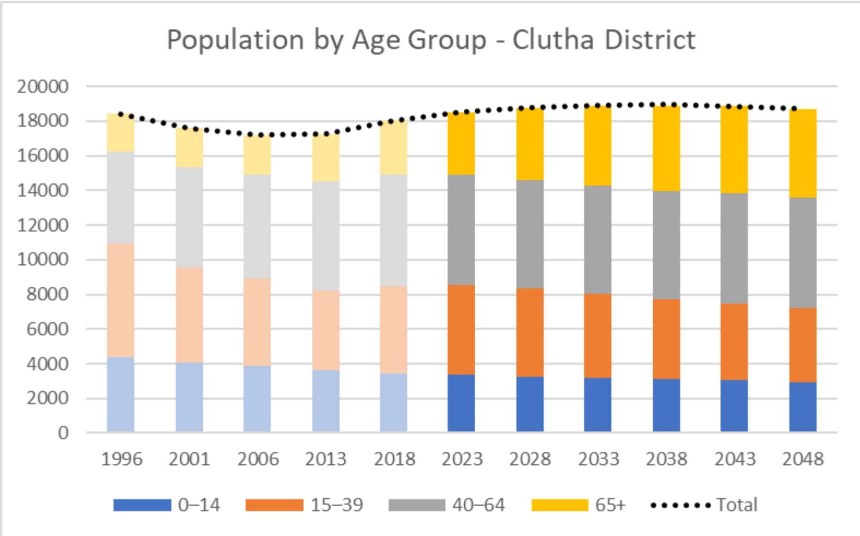


Figure 2b: Clutha's Total Projected Population by age structure: Statistics NZ

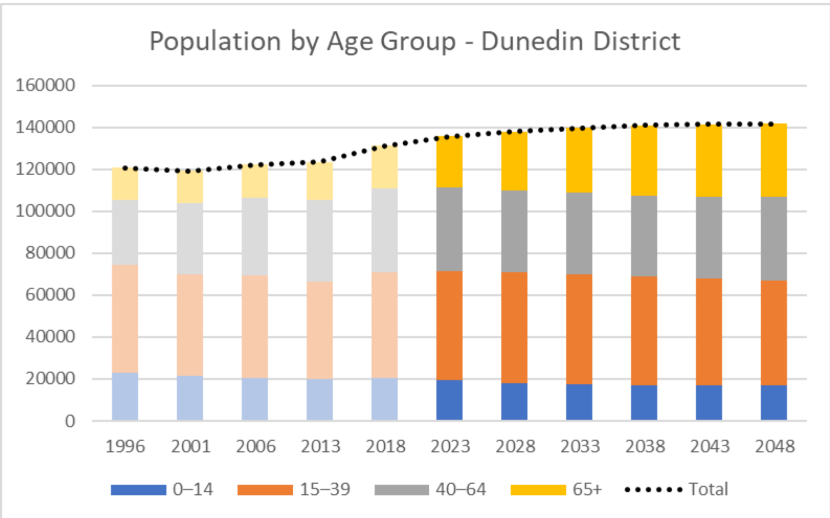


Figure 2c: Dunedin's Total Projected Population by age structure: Statistics NZ

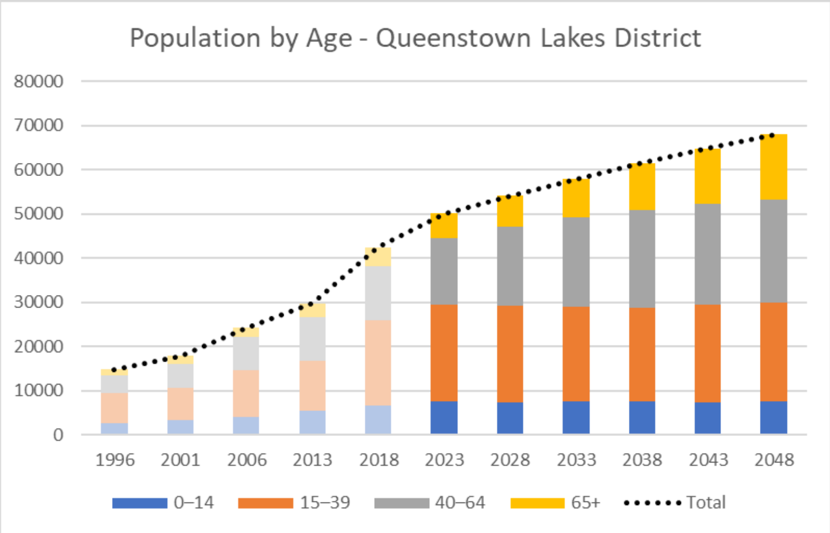


Figure 2d: Queenstown Lakes' Total Projected Population by age structure: Statistics NZ

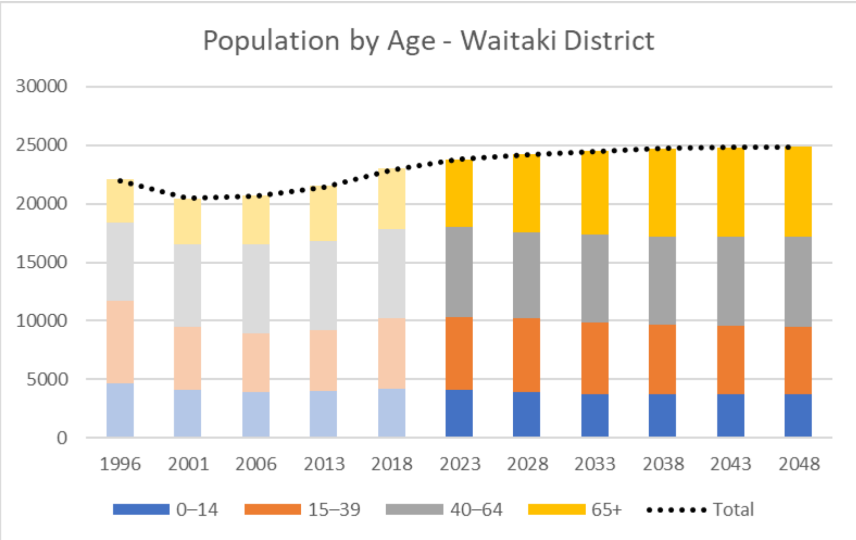


Figure 2e: Central Otago's Total Projected Population by age structure: Statistics NZ

Current Demand

[12] The first Report published a diagram illustrating 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 were down slightly, with deaths reducing more than births resulting in a small increase in the natural increase numbers. Both inward and outward migration were also down significantly to a net total of 44,100 for the year, with an associated decrease in net international migration from the year previous.

[13] Statistics NZ has not published more up-to-data showing natural increase. However, provisional international migration estimates to year end February 2021 have been published (Figure 3) and this shows very significant falls in net migration from the previous year. This is largely a result of the restricted border entry due to Covid for all migrants, but particularly impacting on non-NZ citizens or residents as the Managed Isolation facilities had been prioritised for returning citizens or permanent residents. There has been a net positive migration of returning NZ citizens of 18,900 (largely fuelled by a 77% drop in NZ Citizen departures) and a net negative migration of non-NZ citizens of -1,400 (largely fuelled by an 84% reduction in non-NZ citizen arrivals).

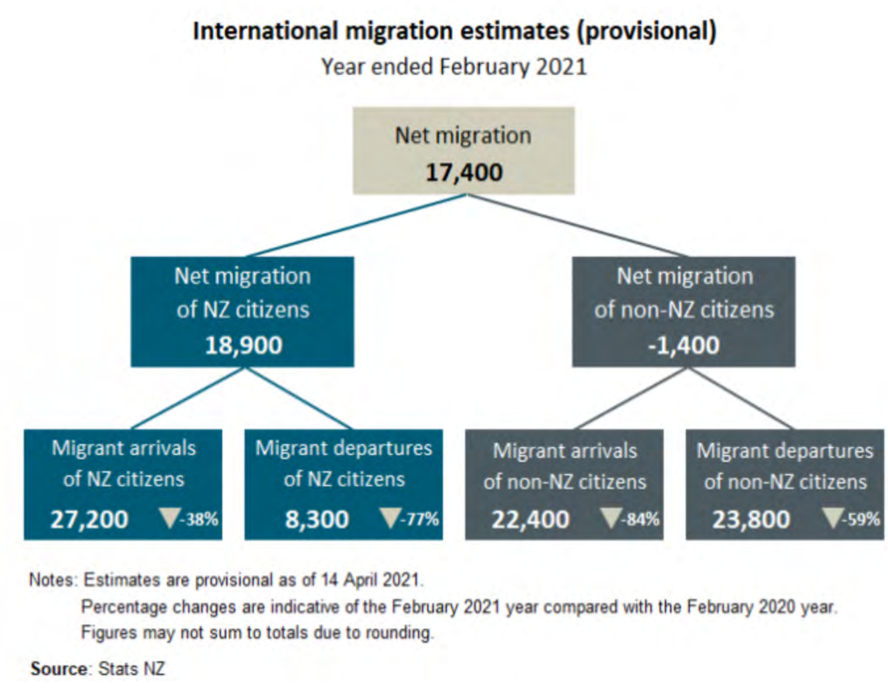


Figure 3: Provisional international migration estimates – year end February 2021: Statistics NZ

[14] 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, as illustrated in Figure 4. 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. Internal migration, including of international migrants once they enter the country, is much harder to track.

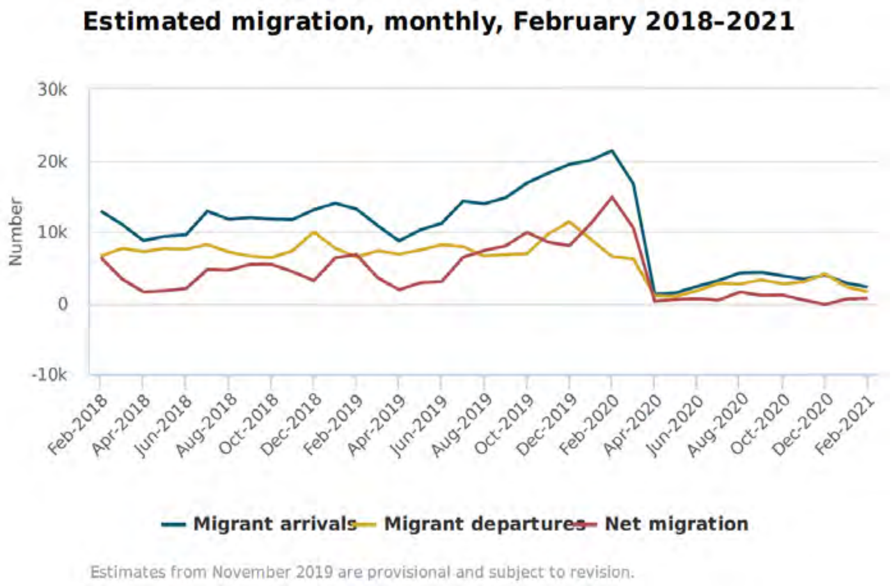


Figure 4: Monthly net migration, Feb 2018 to Feb 2021: Statistics NZ

Current Population and Future Demand:

[15] The first Quarterly Report provided TA-level population estimates for the period 1996 to 2020. Statistics NZ recently published updated population estimates that have been re-based from the 2018 Census. The update adjusted the 2020 population estimate from 247,200 to 243,270 (determined from average annual interval between 2018 Census return and 2023 mid projection). This shows the earlier population projections had slightly overestimated the Otago's population in 2020 (by less than 2%).

[16] Otago's current Long Term Plan assumption, based on amalgamating TA level assumptions is for Otago's population to reach 302,000 by 2050, (being ~298,000 by 2048). Statistics NZ's re-based medium population projection in contrast is for a region-wide population of 282,600 by 2048. This is 15,000 fewer people (or ~5% lower) than the Long Term Plan assumption. Figure 5 shows the Long Term Plan projection against, the re-based SNZ 2021 population projections and the previous 2016 projection series as well.

[17] In effect the LTP assumption (amalgamating TA assumptions) is in line with or slightly below the 2016 SNZ High series, and in line with or slightly above the 2021 SNZ Medium series. SNZ advise that users consider the medium to be 'most likley' and test any assumptions using the low and high for sensitivity, given they represent a reasonable probability range given inherent uncertainty about the future. It is also important to note the projections are based on assumptions - including that present government

policy settings on immigration and current locational preferences of migrants are maintained into the future.

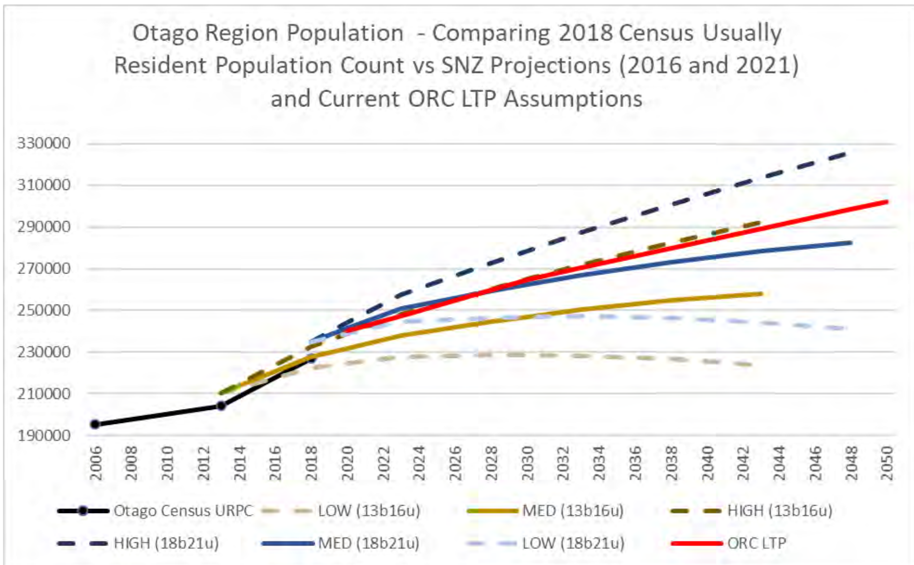


Figure 5: Otago Region Population Projection Comparing 2018 Census Usually Resident Population Count vs SNZ Projections (2016 and 2021) and Current ORC LTP Assumptions: Statistics NZ

[18] The 2018 re-based population projections have been provided at the TA level. This demonstrates the different sizes of Otago TA's populations as well as the anticipated scale of growth in each district. Figure 6 shows projected population for the whole of the Otago region with the relative contribution of each district. This shows Queenstown Lakes, Central Otago and Dunedin are projected to experience the most significant population growth to 2048, both in absolute terms and as a percentage of their original population. Waitaki and Clutha are projected to have relatively stable populations in terms of net population growth. However, both districts are projected to experience a net population growth and demographic change within their population, including an aging population is likely to result in continued growth in housing demand over this period. Figure 7 shows the cumulative projected population change at five year intervals from 2018 to 2048.

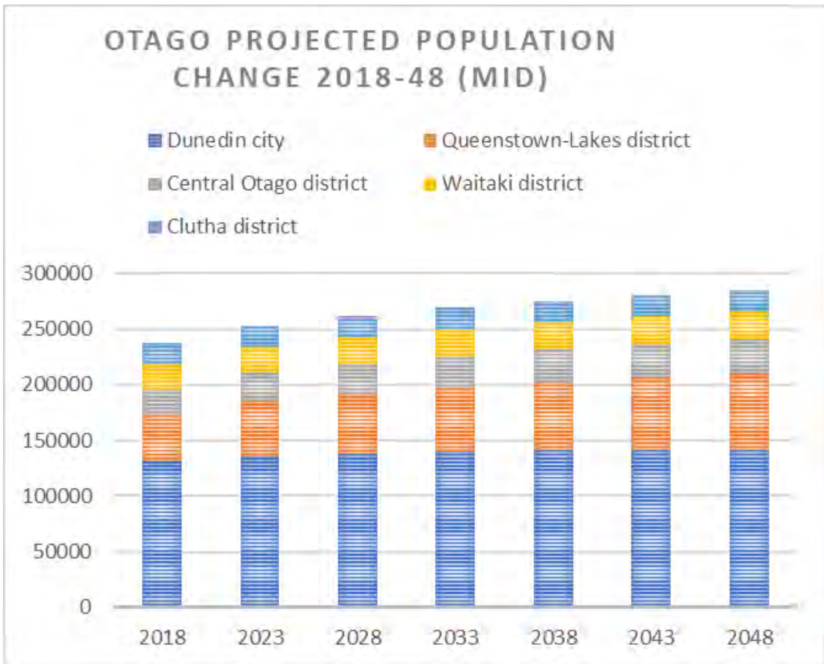


Figure 6: Projected Population Change and Growth in Otago 2018 to 2048: Statistics NZ

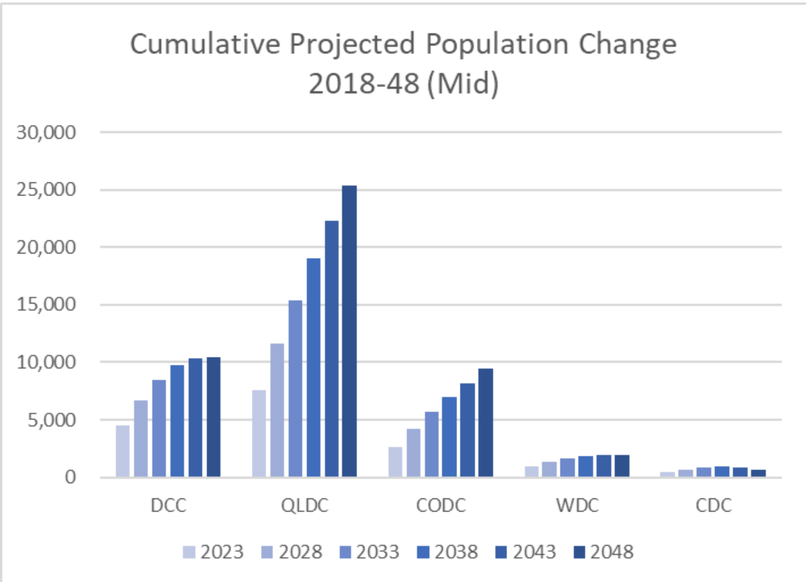


Figure 7: Cumulative Projected Population Change in Otago TAs 2018 to 2048: Statistics NZ

[19] A challenge for any forecasting is to make reasonable estimates given such high uncertainty, which increases over time. Covid-19 and the associated global uncertainty means making assumptions about who and why people might move house, city or country, or have children, 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.

[20] Accordingly, having a projection on the optimistic side is considered reasonable given the volatility, and the relative cost difference and impact between under-estimation and over-estimation.

Dwelling Supply:

[21] 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 ultimately commenced. We are not currently monitoring completions rates (this would involve Certificate of Code Compliance tracking), but once commenced an even higher proportion of commenced projects are ultimately completed, using Auckland data as a guide, generally within 18 months of the issue of the building consent, albeit with significant project specific variation.

[22] Data for new dwellings consented on an annual basis (financial years) for each TA in the region is shown below. Note significant rise in annual volumes in QLDC from 2013 and, to a lesser extent, CODC from 2016. Total annual consents remained relatively consistent across Otago in the 2020 financial year, with the exception of Queenstown Lakes District, which experienced a 27% reduction from the previous year.

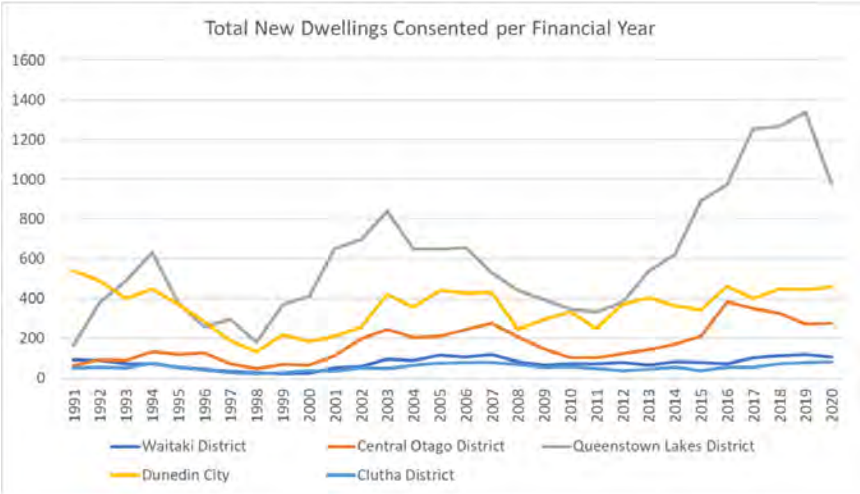


Figure 8: Annual new dwellings consented, by TA: Statistics NZ

[23] Monthly totals for the Region are also shown below alongside a 12-month rolling average, which shows that despite recent slowdowns the rate of consenting remains at historic highs:

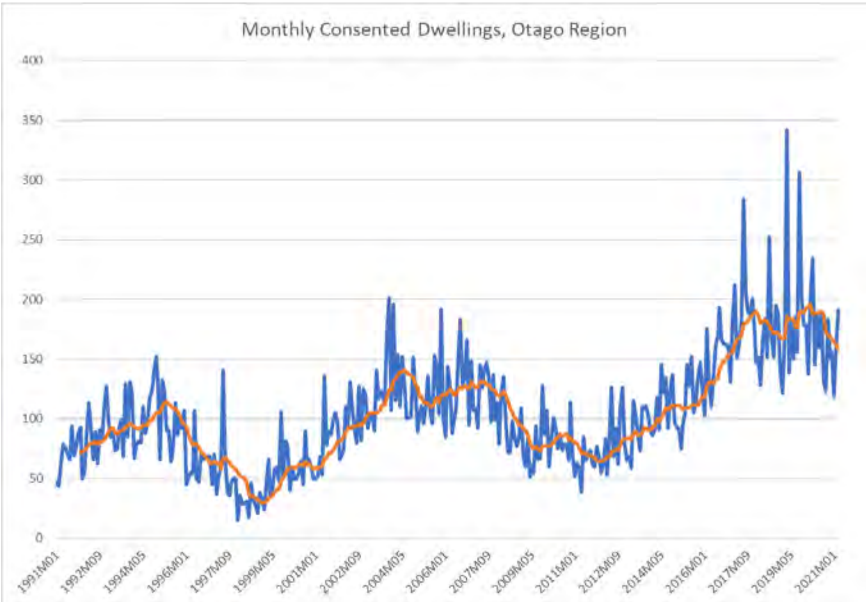


Figure 9: Monthly new dwellings consented with 12 month rolling average, Otago Region: Statistics NZ

Data showing the dwellings consented by type and location for the region as a whole is shown in the graph below (Figure 10). 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.

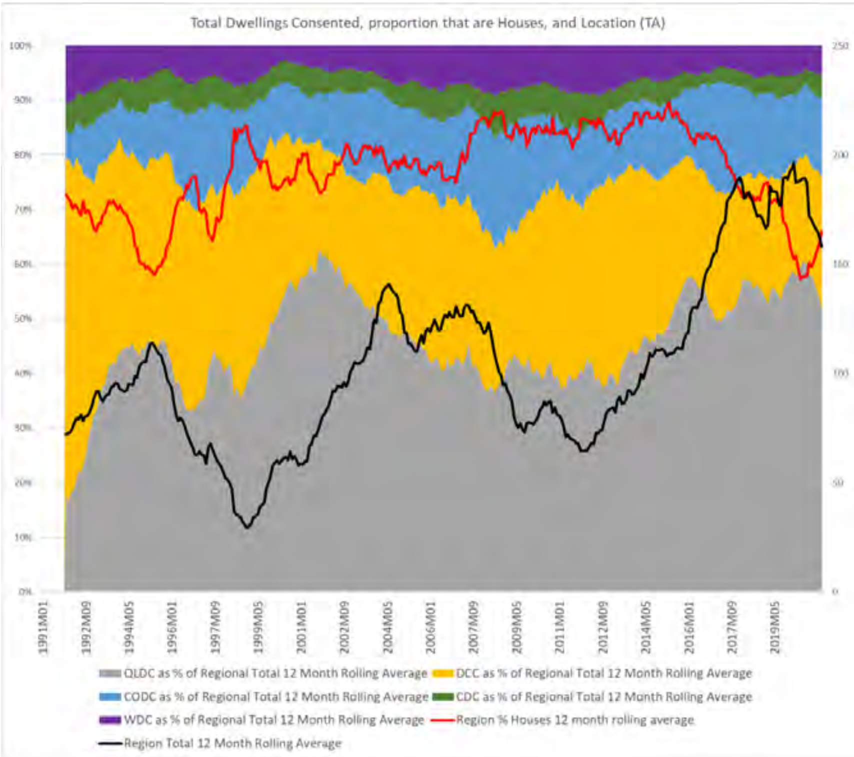


Figure 10: Regional new dwelling distribution by TA, and type: Statistics NZ

[24] Houses (standalone dwellings) make up between 40% to 80% of new dwellings consented in the region (Figure 11). 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. 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:

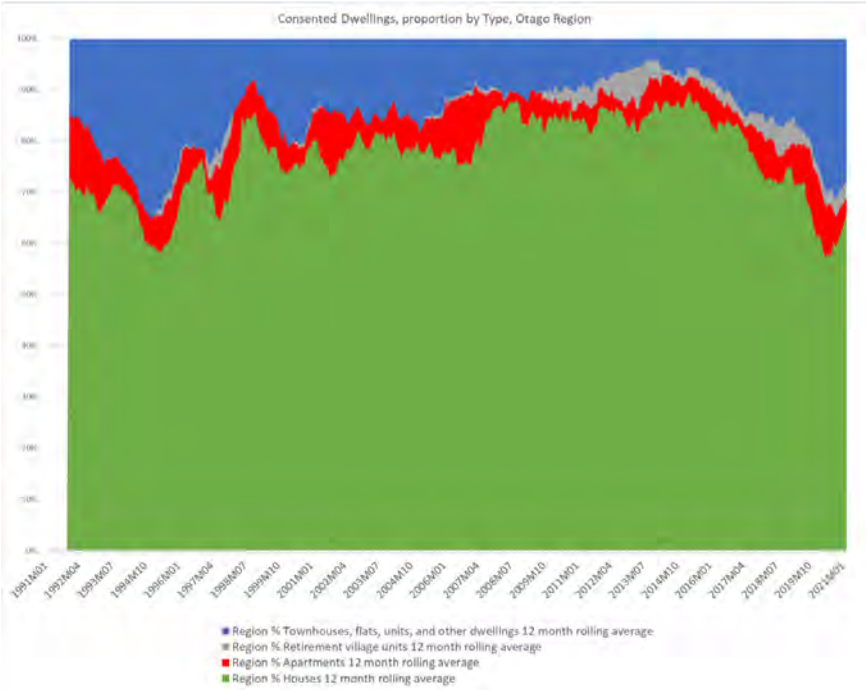


Figure 11: Monthly new dwellings consented by typology, proportion of total, Otago Region: Statistics NZ

<u>How responsive is housing supply to demand?</u>

[25] Relationships between demand and supply responsiveness can be considered in many ways, the most simplistic by comparing overall population growth and dwellings consented. The first Quarterly report provided an analysis of annual new dwellings consented per 1,000 population and average population change per new dwelling consented from 1996 to 2020. This report does not update these data sets as we are awaiting mid 2021 population estimates to compare with consents.

Dwelling Prices and Rents

[26] 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.

[27] 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 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.

[28] Figure 12 shows the year-on-year percentage growth rate for both sales and rents (12-month rolling averages). It is notable that growth rates in sales values is more volatile and severe than growth in rents. In the early 2000s, year-on-year house value inflation rose dramatically and then fell in a similar dramatic fashion. Over this period, variation in rental growth was comparatively understated. Recent data suggests sales values and rental growth rates are, once again, diverging (with stronger growth in sales values than rents).

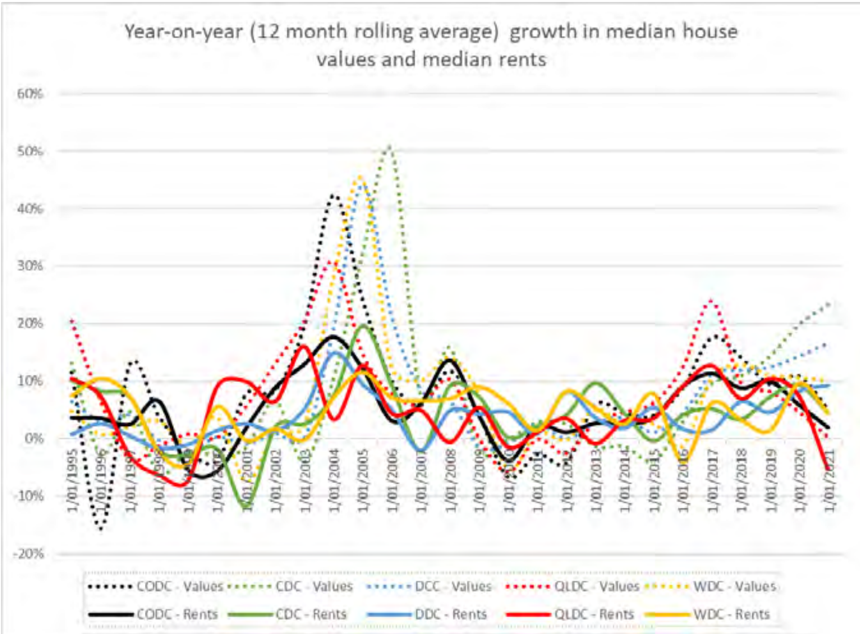


Figure 12: Year-on-year (12-month rolling average) growth in median values and median rents, TA level: Statistics NZ

[29] Over the longer-term, despite significant year-on-year volatility, sales values have achieved far stronger cumulative growth than rents. Between 1995 and 2021, the average price of a home in Waitaki District increased by 453% (the lowest in Otago). Over the same period, the average price of a home in Central Otago District increased by 544% (the highest in Otago). Comparatively, rents have grown by just 173% in Dunedin District (the lowest in Otago) and 280% in Central Otago District (the highest in Otago) over the same period - as shown in Figure 13.

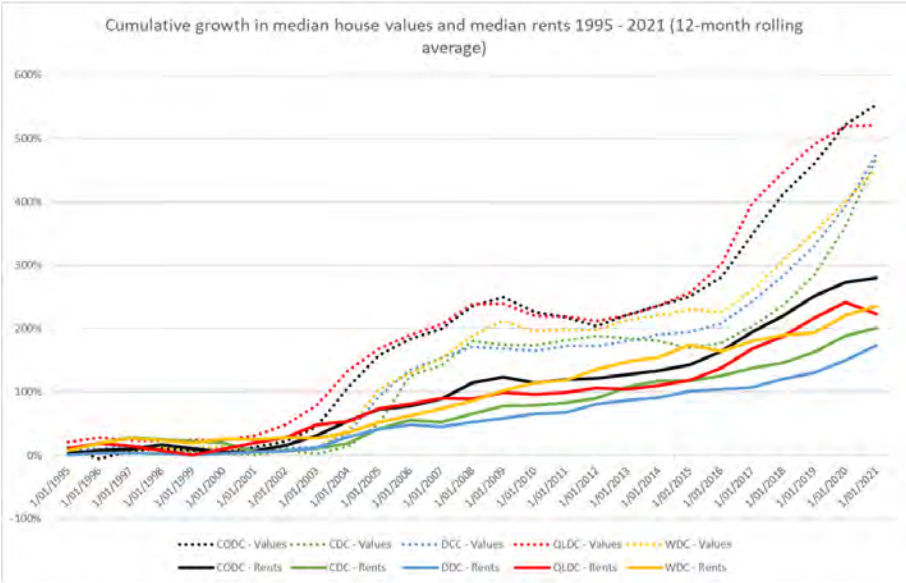


Figure 13: Cumulative growth in median house values and median rents 1995 - 2021 (12-month rolling average): Statistics NZ

[30] Figure 14 provides real sales values (actual and 12-month rolling average) for TAs in the Otago region. These figures aggregate 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. 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. Central Otago has been consistently more expensive than Dunedin City since 2003.

[31] Small dips at the end of the period reflect the impacts of Covid which have since been largely reversed (based on REINZ data – see Figures 15 and 16). Across Otago, there has been an average 22% year on year increase for Median House prices as at March 2021. Comparing figures 14 and 15 indicate that apart from QLDC, average values are lower than the New Zealand Average, but rates of value change are considerably higher, except for Queenstown-Lakes. While it is difficult to determine a cause from this data, economic commentary highlights that this is potentially driven by first home buyer and investor activity focussing on lower valued areas and properties. For investors, rapid relaxation of LVR requirements followed by long lead times for their reintroduction may have led to the bringing forward of purchasing decisions even in spite of other signalled changes to disincentivise this behaviour. This may also highlight a previously under-investigated role of interest rates (monetary policy) as a significant driver of assets (including housing) prices, particularly alongside large increases in funds (quantitative easing and other Covid related stimulus) looking for returns.

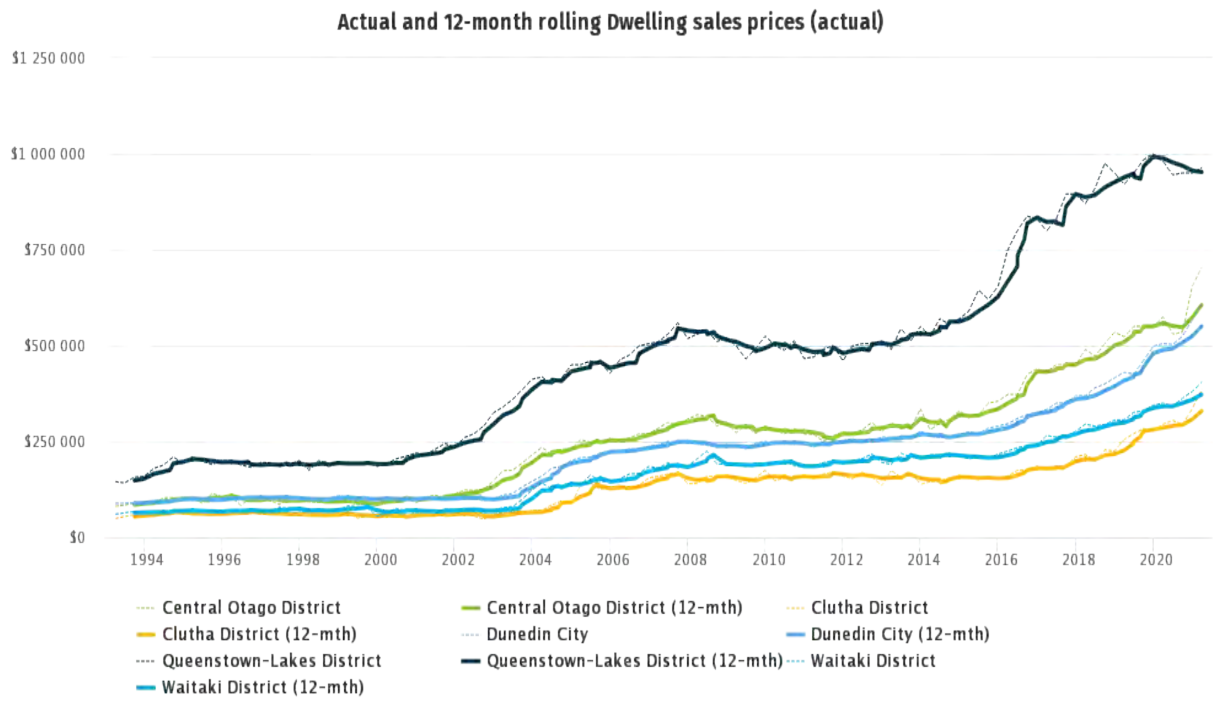


Figure 14: Dwelling Sale Prices (actual) by TA: Source: Urban Development Dashboard, HUD

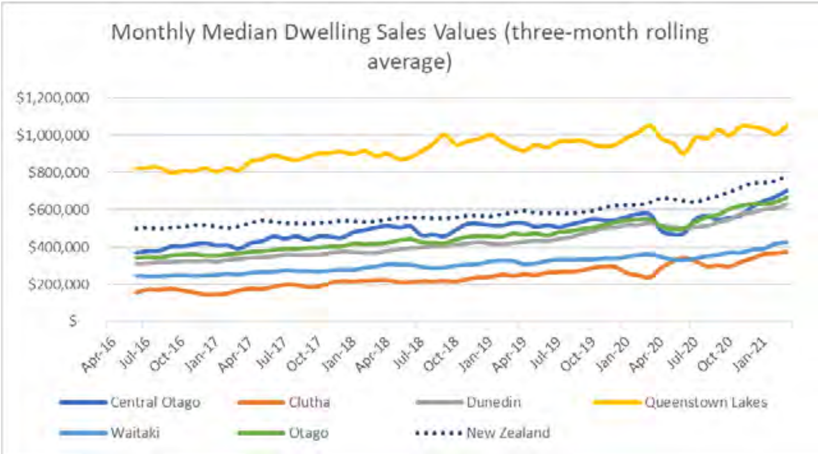


Figure 15: Monthly Median Sales Values (three-month rolling average) – 2016-2021 by TA: Source: REINZ

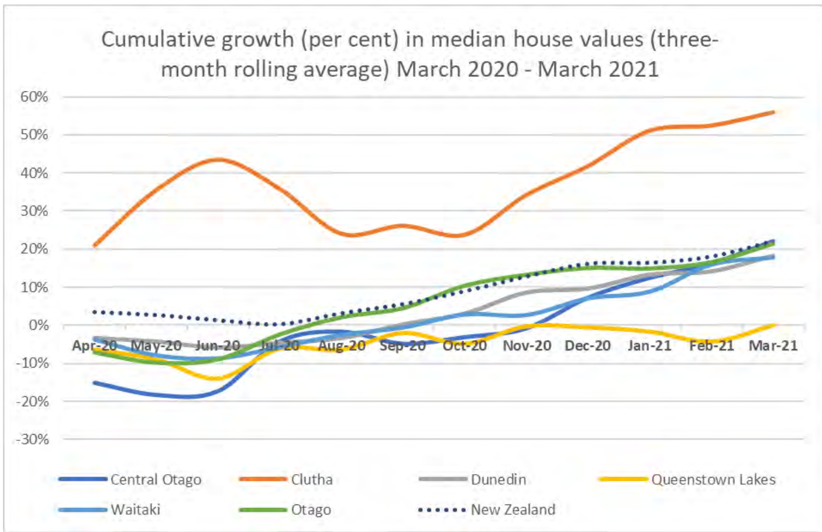


Figure 16: Cumulative percentage growth in median sales values (three-month rolling average) March 2020 - March 2021 by TA: Source: REINZ

<u>Volumes</u>

[32] Sales volumes provide an indication of churn in the market. Figure 17 shows the three-month rolling average for the total number of monthly sales. Sales are dominated by Dunedin, as it has the largest pool of houses. Significant decreases in sales in early 2020 reflect the impact of Covid (including lockdown and transfer restrictions). However, more recent sales indicate these impacts, in terms of number of sales, were short-lived.

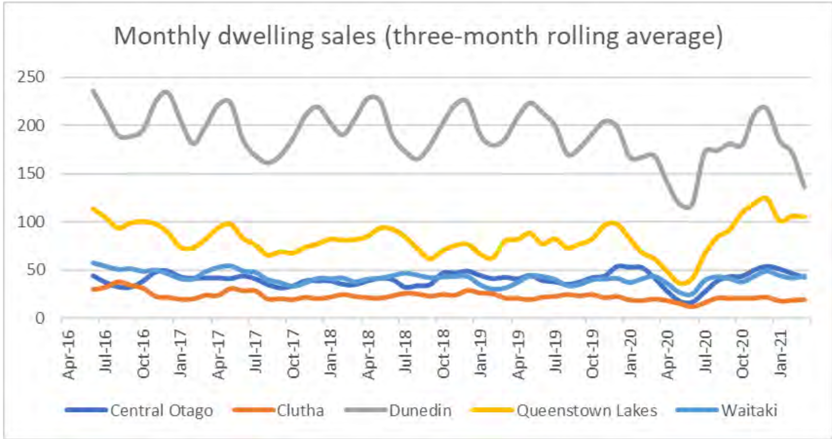


Figure 17: Three-month rolling average for the total number of monthly sales *by TA: Source: REINZ*

[33] Figure 18 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.

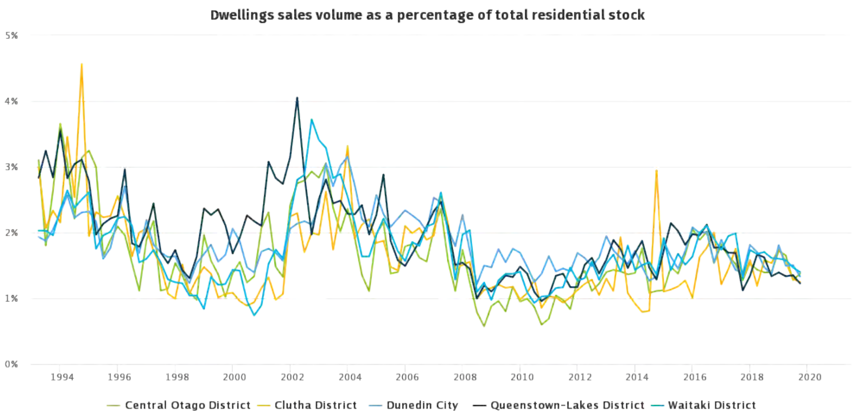


Figure 17: Monthly dwellings sold as a proportion of total dwelling stock, by TA: Source Urban Development Dashboard, HUD/Corelogic

Rents:

[34] Rental data shown in Figure 19 is based on bond lodgements from new tenancies recorded with Tenancy Services which are calculated as multiples of weekly rents.

[35] 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 slightly 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.

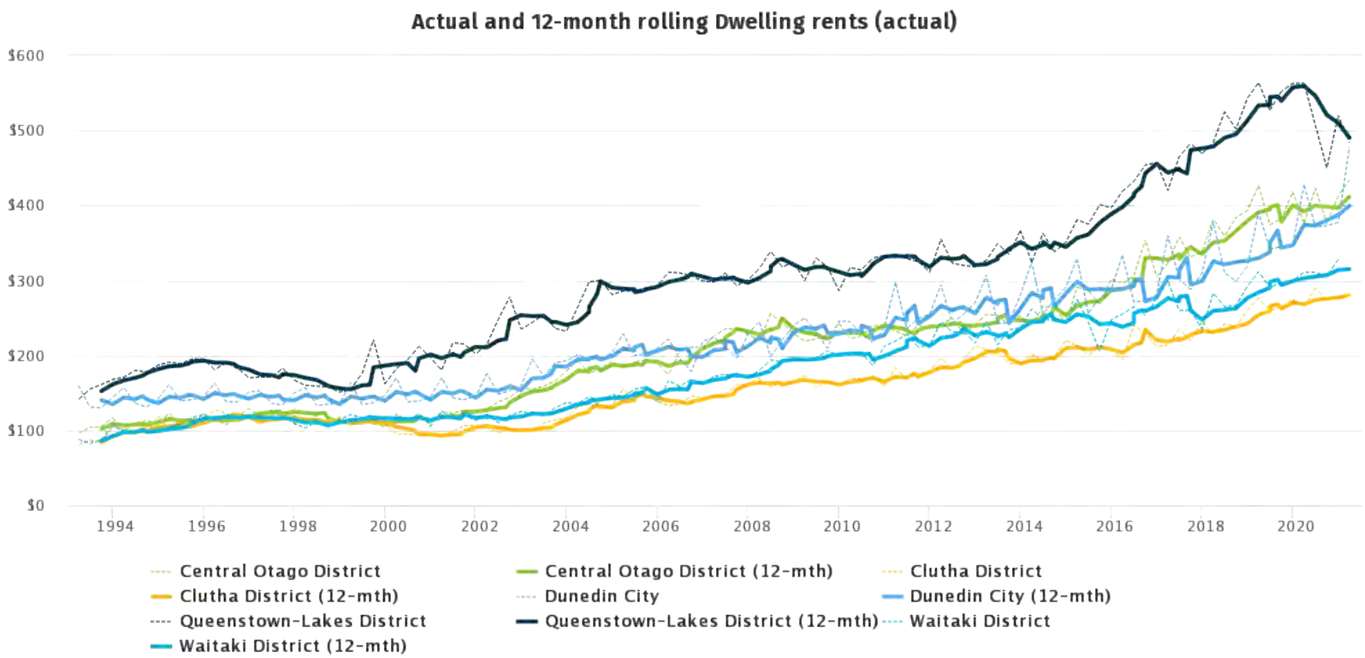


Figure 19: Monthly dwelling rents, by TA: Source Urban Development Dashboard, HUD/MBIE

Price Cost Ratio

[36] The Price cost ratio provides a ratio of the estimated costs to construct a standalone dwelling, including a reasonable profit (that being the cost of 1.0) but excluding the land, compared to the final sales price (being a figure indexed to 1.0 cost). 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). To put it another way, this reflects a 'rule of thumb' that when building new, the value of the house should be approximately 2x the value of the land.

[37] In effect this measure can be considered the degree to which land or construction costs influence (standalone) house prices. The measures imply 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. Measures focussing on standalone houses also miss the potential signal 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 suitable for higher density redevelopment, and which 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, below 1.5, albeit all on an increasing trend from around 2015/2016 in particular Dunedin City, potentially indicating pressure for more intensive redevelopment and/or additional housing land.

[38] Note that the Price cost ratio has not been updated on the Urban Development Dashboard since the last Quarterly Monitoring Report.

Housing Affordability

[39] Housing affordability measures are essentially ratios between a household's 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.

[40] The Ministry for Housing and Urban Development publish various Housing Affordability Measures (HAMs) on the Urban Development Dashboard. The most recently published data having been published and analysed in the first Quarterly Monitoring Report. New data will be analysed as and when it is published.

Housing Capacity Realisation

[41] No reportable data at time of writing.

Recent Government Housing Policy Announcements

[42] In March 2021, Government introduced a package of measures intended to take some of the heat out of the housing market in owing to concerns about the implications of rapid house price inflation on housing affordability. The stated aim of the measures is to 'increase the supply of houses and remove incentives for speculators, to deliver a more sustainable housing market'. Government anticipate the measures will advantage owner-occupiers over investors. The Government expects these measures will contribute towards lower annual house price growth and forecast and average house price growth rate of 0.7% over the coming year. There are three main elements to the package of measures.

[43] Firstly, government extended the 'bright line test' from 5 to 10 years on 27 March 2021. The bright line test determines which investment properties (i.e. not the family home) will be subject to capital gains tax upon sale and is a clarification of the existing 'intention' test. The test taxes capital gains from property appreciation as income if the intention was to profit from the purchase and later sale of the property. Effectively, this means that investment properties sold before the bright line test time threshold are deemed to be intended to be sold for profit, and will therefore attract a capital gains tax upon sale. Government is consulting on whether new build properties will continue to be subject to a 5-year bright line test threshold.

[44] Secondly, Government has indicated it intends to phase out the provision whereby property investors may deduct interest on loans for residential properties from rental revenue for tax purposes. These provisions should apply 1 October 2021 for loans used to acquire residential property (unless it's newly built property) on or after 27 March 2021. Interest deductions will be allowed for property acquired before 27 March 2021, and the deduction rate will be reduced in a staged manner, reaching zero after 4 years. The Government will consult on the detail of these proposals and legislation will be introduced shortly thereafter. Consultation will cover the details of an exemption for new builds acquired as a residential investment property, and whether all people who are taxed on the sale of a property (for example under the bright-line tests) should be able to deduct their interest expenses at the time of the sale.

[45] Thirdly, Government has allocated an additional $3.8 billion to the Housing Acceleration Fund. The $3.8 billion is additional to the $350 million that has already been committed to the Residential Development Response Fund. The Fund aims to increase the supply of houses, particularly affordable homes that low to moderate income households can afford (whether for rent or home ownership). The fund will also be used to unlock more land for housing development, particularly in locations close to jobs, public transport, and amenities, and support the provision of critical infrastructure needed to accelerate that development. The Fund will be focused on priority locations where high housing need has been identified including Kāinga Ora large scale projects. Cabinet will make decisions on the detailed design of the Fund components by 30 June 2021, thereafter Government will start detailed implementation discussions with respective councils.

[46] Future monitoring reports will provide further updates on the Government's demand-side and supply-side packages and attempt to evaluate whether the introduction of these measures coincides with any notable changes to housing demand and/or supply in Otago. In particular, the Housing Acceleration Fund may significantly alter the nature, location and scale of housing and infrastructure delivery if diverted towards enabling

housing growth in any of Otago's regions. Ongoing Covid uncertainty makes predicting trends in housing supply and demand, and identifying the likely reasons for such trends, more difficult than usual.

Business Land Data

[47] No reportable data at time of writing.

7.6. Active faults in the Dunedin City and Clutha Districts

Prepared for:	Data and Information Committee
Report No.	HAZ2106
Activity:	Safety & Hazards: Natural Hazards
Author:	Sharon Hornblow, Natural Hazards Analyst
Endorsed by:	Gavin Palmer, General Manager Operations
Date:	9 June 2021

PURPOSE

[1] To inform the Committee of the outcome of the GNS Science review of active faulting and folding in the Dunedin City and Clutha districts.

EXECUTIVE SUMMARY

[2] As part of a regional assessment of active faulting commissioned by the Otago Regional Council, GNS Science has undertaken a review of the locations and characteristics of active geological faults and folds in the Dunedin City and Clutha districts. Twenty-six active or potentially active faults have been identified at the ground surface. The existence of most of these faults was already known, and they have previously been shown on published geological maps, although many were classified as 'inactive'.

[3] The 2010 Darfield and 2016 Kaikōura earthquakes caused widespread damage and demonstrated the potential effects of ground surface rupturing earthquakes on communities, buildings, and infrastructure. New research is continually adding to the available scientific evidence of active tectonic deformation and the potential consequences of fault rupture.

[4] The new map dataset provided through this review is not intended for use in property-specific risk assessment or hazard zoning, but should assist in land-use planning, risk reduction, and hazard zoning prioritisation relating to active faults. It will also enable the identification of areas where more detailed mapping and site-specific fault avoidance zonation should be considered. The updated mapping and new fault recurrence interval data for coastal and offshore faults (for example parts of the Akatore Fault) allow ORC to update coastal hazard data and risk assessments in the future.

RECOMMENDATION

That the Committee:

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

2) ***Notes** that this information will be publicly available through ORC's Natural Hazards Database.*

3) ***Notes** this information will be provided to Dunedin City and Clutha District councils for incorporation into building control, utility infrastructure and land use planning decisions.*

4) ***Directs*** *that a report be provided to the Strategy and Planning Committee by 31 December 2021 on options for incorporating this information and other fault information held by ORC into planning frameworks across Otago.*

BACKGROUND

[5] The Otago Regional Council has undertaken a systematic review of active geological faulting and folding across Otago to increase awareness and improve management of earthquake ground surface deformation hazards. The review was an annual plan target under Natural Hazards activity. Faults in the Queenstown Lakes District and Central Otago were assessed in 2019[1] by GNS Science, and faults in the Waitaki District were assessed with Environment Canterbury in a 2016 study[2]. The Clutha and Dunedin City faults report brings this work programme to completion and replaces the previous active faults dataset which was last updated in 2005[3].

[6] Research in recent years, especially the 'Active Faults Under Cities' Natural Hazards Research Platform project[4], funded after the Canterbury Earthquakes, has developed understanding of active faults in Dunedin City and the Clutha District. Detailed investigations of topographic LiDAR[5] data and aerial imagery over the past two decades, and invasive ground investigations such as fault trenching, have improved fault recurrence estimates, mapping of multiple fault splays, and understanding of fault rupture behaviour.

[7] This 2020 assessment of active faults and folds was undertaken by David Barrell, an Engineering Geologist and Geomorphologist at GNS Science's Dunedin office. The study scope was to undertake a desktop review of locations and characteristics of known or suspected active faults in the study area. The primary purpose of this work is to identify locations where active faulting or folding may be a hazard through ground surface rupture or deformation.

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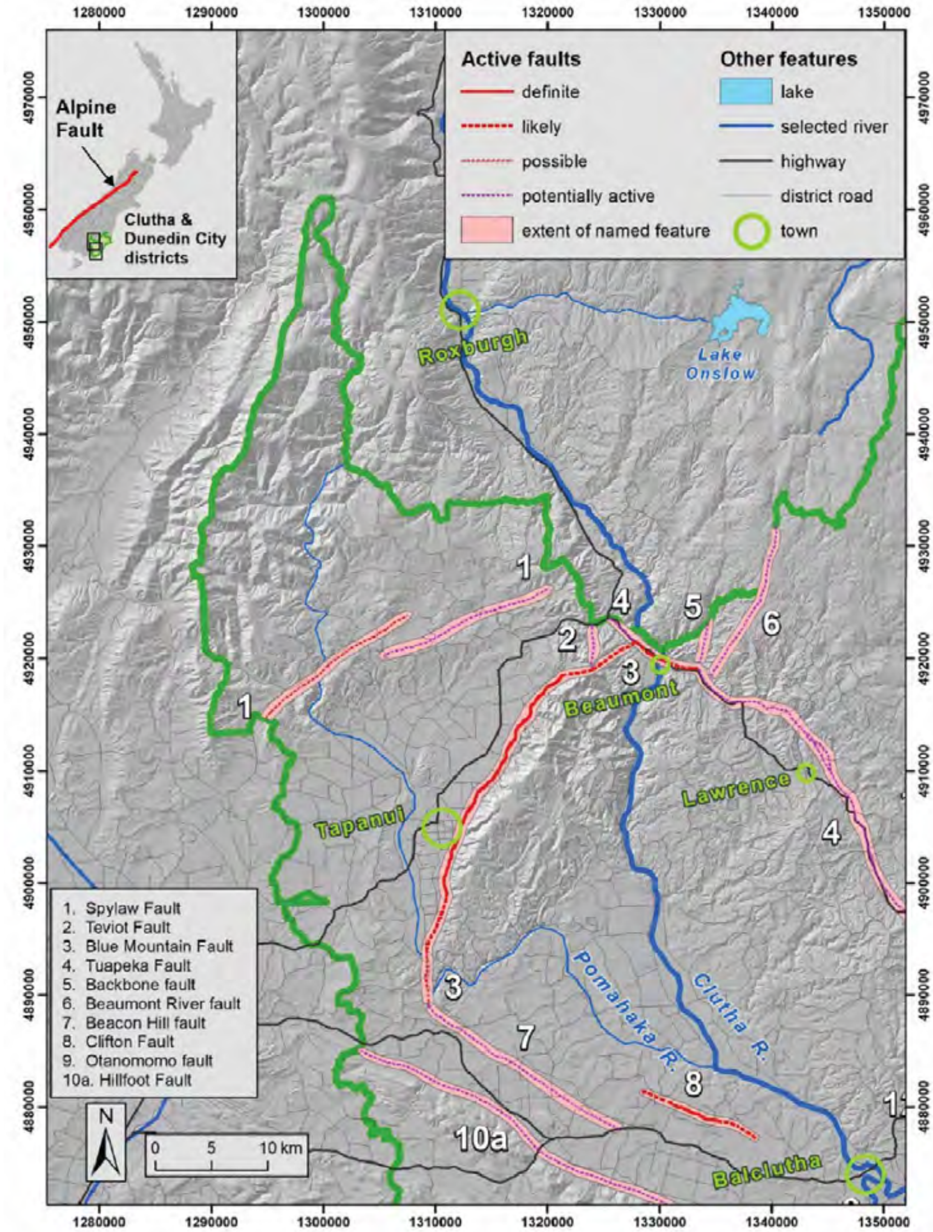
[1] Barrell DJA. 2019. General distribution and characteristics of active faults and folds in the Queenstown Lakes and Central Otago districts, Otago. Dunedin (NZ) GNS Science. 99 p. Consultancy report 2018/207. Prepared for ORC.

[2] Barrell DJA. 2016. General distribution and characteristics of active faults and folds in the Waimate District and Waitaki Ristrict, South Canterbury and North Otago. Dunedin (NZ) GNS Science. 124 p. Consultancy report 2015/166. Prepared for Environment Canterbury; Otago Regional Council.

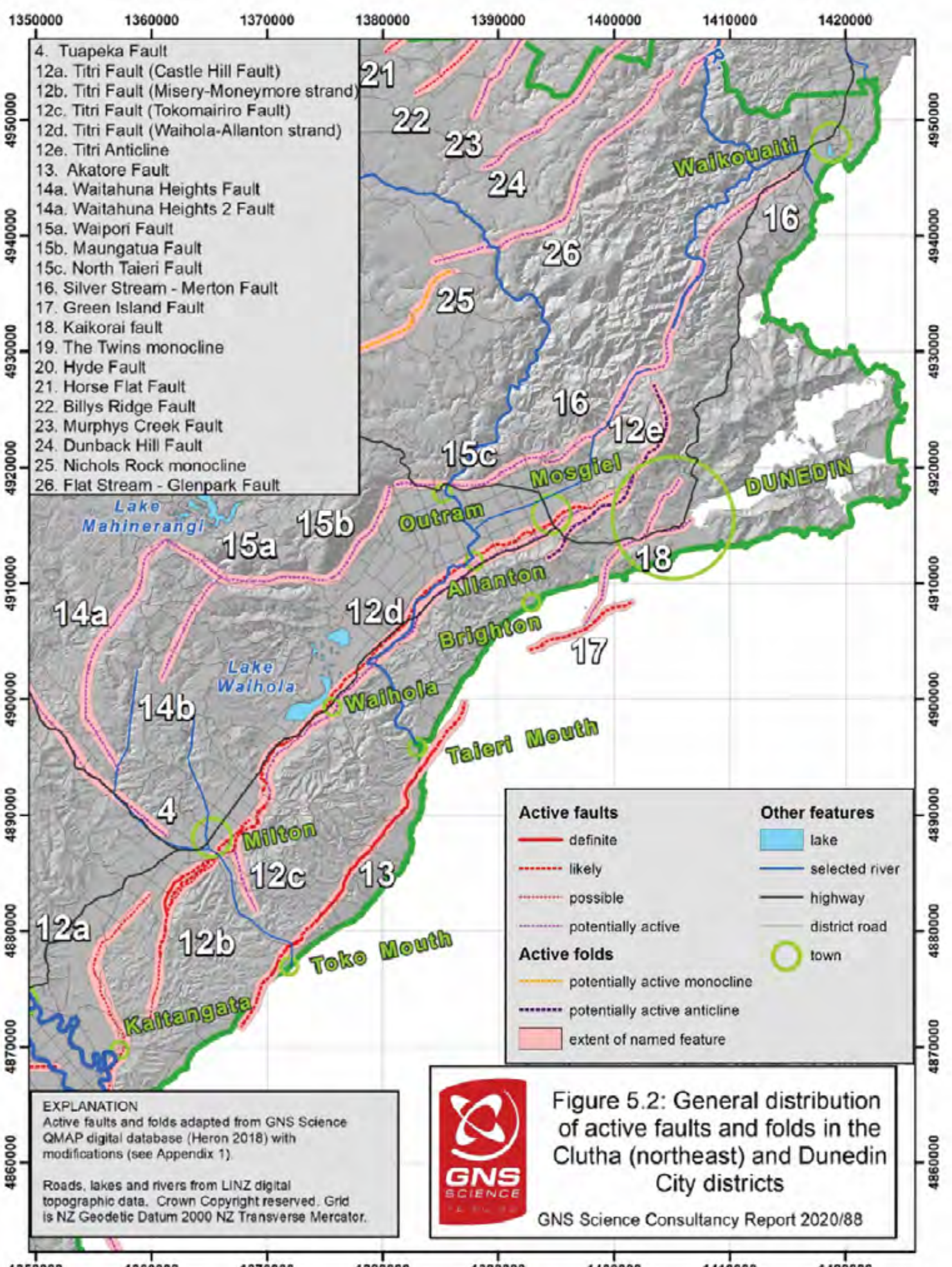
[3] Seismic Risk in the Otago Region. 2005. Study report prepared by Opus International Consultants for Otago Regional council 2019.

[4] Villamor P, Barrell DJA, Gorman A, Davy B, Fry B, Hreinsdottir S, Hamling I, Stirling M, Cox S, Litchfield N, Holt A, Todd E, Denys P, Pearson C, Sangster C, Garcia-Mayordomo J, Goded T, Abbott E, Ohneiser C, Lepine P. Caratori-Tontini, F. 2018. Unknown faults under cities. Lower Hutt (NZ): GNS Science. 71p. (GNS Science miscellaneous series 124). doi:10.21420/G2PW7X

[5] Light Detection and Ranging



[8] **Figure 1a**. General distribution of active faults and folds in the western part of the Clutha District (Barrell, 2020).



[9] **Figure 1b**. General distribution of active faults and folds in the eastern part of the Clutha District and the Dunedin City district (Barrell, 2020).

[10] The GNS Science study was reviewed internally by GNS Science in 2020. It was peer reviewed by Golder Associates in early 2021; there was some discussion of further work on tsunami hazard and multi-fault rupture scenarios, which was outside the scope of this report, but other minor comments were adopted, and the review was overall favourable. Datasets were reviewed by natural hazards analysts at ORC to ensure they are fit for purpose, for example, their use in our online Natural Hazards Database.

REPORT CONTENT AND STRUCTURE

[11] The report is titled *General distribution and characteristics of active faults and folds in the Clutha and Dunedin City districts, Otago*. The introduction describes the geologic and seismic setting of the study area. It describes how faults and folds are classified and how the system used aligns with the national active fault database and standard scientific definitions.

[12] The surface trace of each fault has been reviewed and, where necessary, fault traces or characteristics have been updated. Fault characteristics include the likelihood of a feature (such as a terrace observed in the landscape) being a fault, rupture recurrence interval (statistically calculated time between fault ruptures) and slip rate (how many millimetres the fault moves each year, if movement is averaged over long timescales).

[13] The report also includes a discussion of fault activity near population centres in the Clutha and Dunedin City districts. An appendix gives a detailed description of each fault, outlining justifications for classification and activity status. Associated with the report is a geodatabase of mapped faults and the attributes intended for use with GIS (mapping) software.

DISCUSSION

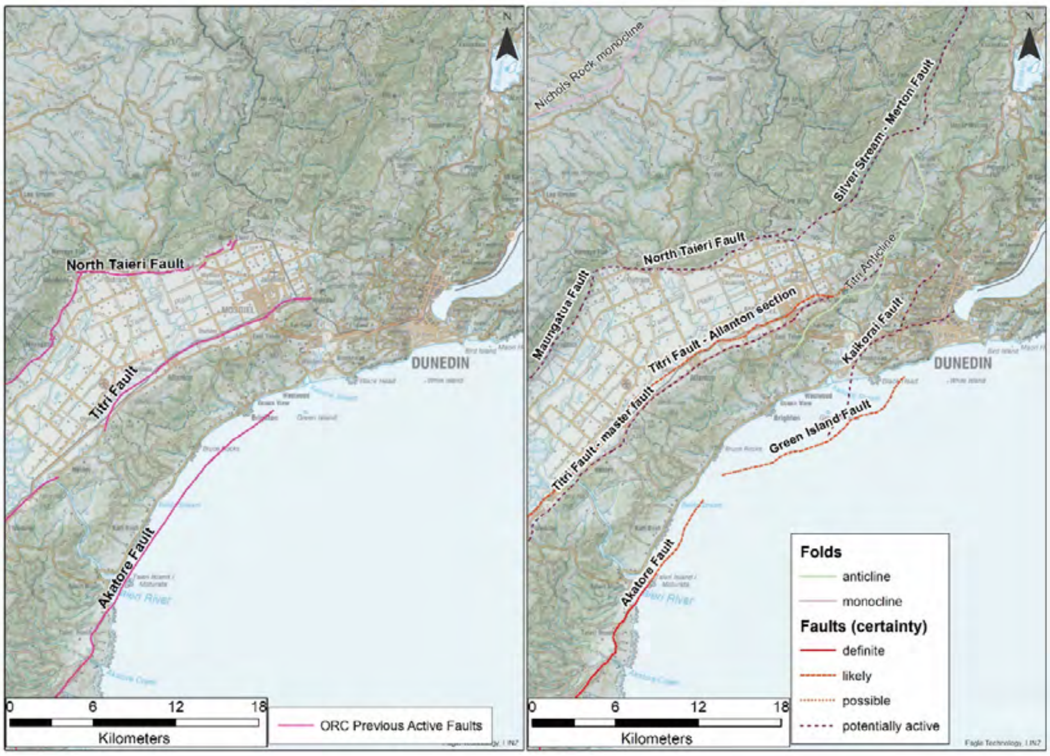
[14] The updated fault database presented here summarises the degree of activity of each feature including an average slip rate, a common way to compare the activity level of a fault or fold. This can also be expressed as an average recurrence interval for deformation events, aided by some assumptions. The recurrence interval estimates provide a linkage to Ministry of Environment (MfE) active fault planning guidelines. Compared to other regions of New Zealand, the seismic hazard in the Dunedin City and Clutha districts is relatively low. Only two faults were assessed as having a recurrence interval of less than 5,000 years (Settlement and Akatore Faults). The rest have recurrence intervals of greater than 10,000 years.

[15] The Akatore Fault, one of the most active faults in Otago, is mapped just to the south of the city with the trace running offshore to the north of the Taieri Mouth settlement. This fault is regarded as being in a state of heightened activity compared to its long-term average slip rate and has ruptured twice in the past ~1300 years. It can produce earthquakes with moment magnitudes of 6.8-7.4[6], depending on whether the total length of the fault ruptures in an earthquake event.

[16] There are several newly classified or mapped active faults near central Dunedin (Figure 2). The Kaikorai Fault has two main branches which are classified as 'possibly active' based on geological indicators such as offset of Dunedin Volcanic Group and older rocks. In addition to following the Kaikorai valley floor from Waldronville, a branch of the fault is inferred to run along the Caversham Valley into South Dunedin. There is no evidence for geologically recent (<125,000 years) offset on the Kaikorai Fault and it is classified as potentially active with a very low activity level. Although the impact of potential seismic activity of the Kaikorai Fault on the overall seismic risk for Dunedin has not yet been assessed, it is likely to be minimal due to the fault's assessed low level of activity.

[6] Taylor-Silva, B. I., Stirling, M. W., Litchfield, N. J., Griffin, J. D., van den Berg, E. J., & Wang, N. (2020). Paleoseismology of the Akatore Fault, Otago, New Zealand. New Zealand Journal of Geology and Geophysics, 63(2), 151-167.

[17] The Green Island Fault runs offshore of South Dunedin and observations from young sea floor sediments indicate it is more active than the Kaikorai Fault (mapped as 'likely'). The detailed appendix of the GNS report discusses the certainty and observations which have led to the different classification of the active faults in the study area. Research into faults beneath Dunedin and the Otago Harbour is ongoing and ORC staff plan to ensure any ground investigations carried out for groundwater monitoring (e.g., drilling and pump testing in South Dunedin planned for August 2021) are well communicated to researchers, so that any data relevant to seismic hazard in the central city are disseminated appropriately.



[18] **Figure 2**. Active Faults in the Taieri Plain and central Dunedin on shown on digital elevation model. Left panel shows previous ORC Natural Hazards Database active faults. Right panel shows faults and folds mapped by Barrell (2020).

[19] The data published in this report are relevant to coordinated national programmes aimed at understanding and publishing scientific reports on seismic hazard and risk in New Zealand. The National Seismic Hazard Model (NSHM) is a collection of many different models that are combined to estimate future earthquake shaking in New Zealand. These models represent the broad range (and uncertainty) of our knowledge about how earthquakes occur, and about how earthquakes cause the surface of the earth to shake[7]. The model results help earthquake scientists to understand the expected shaking in, for example, the next 10, 50 or 100 years. The first version of the

[7] https://www.gns.cri.nz/Home/Our-Science/Natural-Hazards-and-Risks/Earthquakes/National-Seismic-Hazard-Model-Programme

NSHM was published in 2002 and ORC utilised this in 2005 reporting on seismic hazard in Otago. A 2012 update presents the most up to date current publication of the model[8].

[20] Assessment of how likely and how strong earthquake shaking is likely to be at different locations throughout the region for different return periods is called probabilistic seismic hazard (PSH) assessment. ORC is due to update seismic hazard work and, assessment of secondary hazards associated with active faults in coming years, for which the pending 2022 version of the NSHM is well-timed. ORC is currently beginning work on rockfall risk assessment for Otago; PSH assessment is an important component of such work.

[21] Several of the more active faults are fully or partially offshore, such as the ends of the Akatore Fault and the entire Green Island Fault. Uplift of the sea floor associated with rupture on any of these faults would likely generate a local-source tsunami, and there is scope for ORC to renew tsunami hazard modelling for local-source events, the last version of which was completed in 2007 by NIWA. Tsunami and other elevated sea level hazards are part of ORC's upcoming coastal hazard and risk assessment.

[22] 2003 MfE guidance[9] recommends detailed mapping of active faults and the creation of Fault Avoidance Zones to aid land use planning. The now complete Otago Active Faults and Folds dataset allows ORC to work towards this next step in active fault risk management in Otago. ORC can now work to identify areas where an active fault ground deformation hazard indicates site-specific investigation and Fault Avoidance Zoning would be beneficial. It is proposed that a paper on options for Fault Avoidance Zoning across Otago be brought to the Strategy and Planning Committee for consideration. It would draw on the information presented in this paper along with the information previously reported by ORC for Central Otago, Clutha, Queenstown-Lakes and Waitaki Districts. ORC can also proceed with secondary seismic hazard investigation planned for the coming years such as rockfall risk assessment.

CONSIDERATIONS

Strategic Framework and Policy Considerations

[23] There are no immediate policy considerations for ORC.

[24] The information presented and discussed in this report contributes to inform Council's Strategic Directions where our vision states: communities that are resilient in the face of natural hazards, climate change and other risks.

Financial Considerations

[25] Not applicable.

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[8] Stirling, M., McVerry, G., Gerstenberger, M., Litchfield, N., Van Dissen, R., Berryman, K., Barnes, P., Wallace, L., Villamor, P., Langridge, R., Lamarche, G., Nodder, S., Reyners, M., Bradley, B., Rhoades, D., Smith, W., Nichol, A., Pettinga, J., Clark, K., Jacobs, K., 2012. National seismic hazard model for New Zealand: 2010 Update: Bulletin of the Seismological Society of America, v. 102(4), pp. 1514−1542.

[9] Kerr, J., Nathan, S., Van Dissen, R., Webb, P., Brunsdon, D., King, A. 2003. Planning for development of land on or close to active faults: A guideline to assist resource management planners in New Zealand. Ministry for the Environment, July 2003. ME Number: 483; GNS Client Report 2002/124.

Significance and Engagement Considerations

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

Legislative and Risk Considerations

[27] Providing the information presented in this paper helps the community and interested stakeholders and organisations understand and manage the seismic risks.

Climate Change Considerations

[28] Not applicable.

Communications Considerations

[29] Refer to the next section.

NEXT STEPS

[30] It is proposed to make this information publicly available through ORC's Natural Hazards Database and allow earthquake scientists to incorporate any new active fault mapping and recurrence interval data into national research ventures such as the NSHM.

[31] It is also proposed to provide this information to Dunedin City Council and Clutha District Council for incorporation into building control, utility infrastructure and land use planning decisions.

[32] ORC will discuss, in partnership with TAs, the next steps toward reducing risk from seismic hazard, such as fault avoidance zoning.

[33] Implications for emergency management and readiness and risks to lifelines utilities will also be considered.

ATTACHMENTS

1. Active Faults in Clutha and Dunedin Districts GNS Science consultancy report 2020-88 [**7.6.1** - 80 pages]
2. Golder Peer Review of GNS Report [**7.6.2** - 6 pages]
3. GNS Peer Review response Final [**7.6.3** - 6 pages]

General distribution and characteristics of active faults and folds in the Clutha and Dunedin City districts, Otago

DJA Barrell

GNS Science Consultancy Report 2020/88
April 2021

BIBLIOGRAPHIC REFERENCE

Barrell DJA. 2021. General distribution and characteristics of active faults and folds in the Clutha and Dunedin City districts, Otago. Dunedin (NZ): GNS Science. 71 p. Consultancy Report 2020/88.

Project Number 900W4088

CONTENTS

FIGURES

TABLES

APPENDICES

EXECUTIVE SUMMARY

This report presents a general outline of the locations and character of active geological faults and folds in the Clutha and Dunedin City districts. The work described in this report is based on a desktop review of information from regional-scale geological mapping and from more detailed published or open-file geological studies relevant to understanding active faults in the two districts. This project involved the compilation of a Geographic Information System (GIS) dataset that gives the locations of active faults and folds delineated in the two districts. The interpretations and geographic positionings of the fault and folds were aided, where available, by topographic information from airborne LiDAR scans (laser radar) and from satellite, aerial or ground-based photographic archives.

A fault is a fracture within the rock of the Earth's crust along which movement has occurred. Commonly, strain builds up in the rock of the Earth's crust and is released suddenly by a slip event (rupture) on a fault, causing an earthquake. Folds represent bending or buckling of rock and are usually associated with an underlying fault. A fault or fold is termed 'active' where it has moved in the geologically recent past (within the past few tens of thousands of years), particularly where the movement has been sufficiently large to have emerged at the ground surface, forming offset and breakage of the ground (fault), or buckling or tilting of the ground (fold). Old landforms of uniform character, such as river terraces formed during the last ice age that ended about 18,000 years ago, are well suited for revealing the presence of active faults or folds, because they may be old enough to have experienced several rupture events and display large offsets or buckles. In areas where the land surface is younger than the most recent fault or fold movements, the presence and location of any active faults or folds may be 'concealed' from view beneath the landform. In this way, active faults or folds are most easily recognised where the landforms are old (e.g. ice-age river terraces) but much more difficult to recognise in areas where landforms are young (e.g. river floodplains).

Commonly, an active fault reaches the ground via a zone of splintering, which, in some cases, may be as much as several kilometres wide. Individual splinters (strands) can be expressed as fault offsets of the ground surface, as ground-surface folds and, commonly, as a mixture of both. Although some individual strands have been named separately, the GIS dataset applies an overall specific name to each active fault structure, whose movements at depth have produced an array of ground-surface fault and/or fold strands. Many of the faults have been named previously, and those names are used here unless reasons exist for applying a different name. As described in this report, a total of 26 named active, possibly active or potentially active faults have been delineated at the ground surface in the Clutha and Dunedin City districts.

The levels of certainty in recognising an active fault and fold, and their clarity of expression at the ground surface, are included in the GIS dataset. The report contains a tabulation of estimated average slip rate and surface-deformation recurrence interval for each fault in relation to Ministry for the Environment guidelines on planning for development of land on or close to active faults. Also highlighted in the report is increasing recognition that, in the Otago region, many of the faults undergo long periods without movement, which makes it difficult to estimate their level of activity. This difficulty is accommodated by the addition of a classification category of 'potentially active' to encompass faults that, despite showing no indications of geologically recent activity, have characteristics that mean the possibility of future activity should not be ruled out.

Potential hazards associated with active faults include: (i) sudden ground-surface offset or buckling at the fault that may result in, for example, the destruction or tilting of buildings in the immediate vicinity; (ii) strong ground shaking from locally centred large earthquakes; and (iii) related earthquake-induced effects, such as landsliding and liquefaction in areas susceptible to such processes. No large, ground-rupturing, earthquakes have been centred within the Clutha or Dunedin City districts since European settlement in the mid-1800s. However, the nature of hazards posed by active faults was well demonstrated during the 2010 Darfield and 2016 Kaikōura earthquakes, both of which caused ground-surface rupture and land shift along faults, and the effects of severe ground shaking were experienced across wide areas. The landform record shows definitive evidence for prehistoric fault deformation having occurred at various locations in the Clutha and Dunedin City districts. This highlights that active fault or fold features in the Otago region should be assessed for their hazard potential.

The GIS map of active faults and folds in the Clutha and Dunedin City districts is derived from regional- (~1:250,000) scale geological information and is of a generalised nature, with details omitted to aid the clarity of presentation. Information in this report and in the companion GIS dataset highlights areas potentially affected by active fault or fold hazards, and the information is intended to help the targeting of any future active fault investigations that may be deemed necessary. This report provides the most up-to-date information available on the locations and nature of active faults and folds in the Clutha and Dunedin City districts. It is intended to create general awareness of the existence of the potential hazards, but the level of detail in the GIS dataset is not sufficient by itself for use in site-specific zoning to avoid fault-generated ground deformation hazards.

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1.0 INTRODUCTION

1.1 Background

The geologically active nature of New Zealand reflects our position astride the active boundary between two large slabs (plates) of the Earth's crust (Figure 1.1). The forces involved in plate movement (tectonic forces) are immense and cause the rock of the Earth's crust to buckle (fold) and fracture (fault) in the general vicinity of the boundary between the plates. The plate boundary through the South Island is marked, at the ground surface, by a sideways tear, the Alpine Fault and, in the northern South Island, by a companion set of tears, the Marlborough Fault System. Although these large faults accommodate most of the plate motion, the remainder is distributed over a wider zone across much of the South Island. The Clutha and Dunedin City districts lie within this wider zone of tectonic deformation.

Movement on the Alpine Fault is predominantly sideways, with the western side of the fault moving northeast and the eastern side moving southwest, as well as a little bit upwards, which has produced the Southern Alps. The technical term for a sideways-moving fault is 'strike-slip', while a fault where the movement is mostly up-down is called 'dip-slip'. In the southeastern South Island, including the Clutha and Dunedin City districts, the relatively small proportion of the plate movement not accommodated on the Alpine Fault is distributed on a series of predominantly dip-slip faults, which are the focus of this report.

Although the movement along the plate boundary is continuous over geological time and can be measured by ground and satellite (GPS) surveying, rock of the Earth's crust is remarkably elastic and can accommodate a lot of bending before letting go and breaking suddenly (rupturing) along a fault, causing an earthquake. On large faults, the break may be big and extend up to the Earth's surface, causing sudden offset and breakage (faulting) and/or buckling and warping (folding) of the ground surface, accompanied by a large earthquake. The 2010 Darfield and 2016 Kaikōura earthquakes provided good examples of the nature and effects of large, ground-surface-rupturing earthquakes on geological faults (e.g. Barrell et al. 2011; Litchfield et al. 2018; Figure 1.2).

In favourable settings, prehistoric fault offsets and/or fold buckles of the ground may be preserved by way of distinctive landforms, and these landforms allow us to identify the locations of active faults and folds. In New Zealand, an active fault is commonly defined as a fault that has undergone at least one ground-deforming rupture within the last 125,000 years or at least two ground-deforming ruptures within the last 500,000 years. An active fold may be defined as a fold that has deformed ground surfaces or near-surface deposits within the last 500,000 years. Unfortunately, there are few reliable 'clocks' in the natural landscape (i.e. deposits or landforms with a known age) and, for practical purposes, it is common to identify as active any fault or fold that can be shown to have offset or deformed the ground surface, or any unconsolidated near-surface geological deposits (Figures 1.2, 1.3). This approach for identifying active faults or folds is used on most geological maps published in New Zealand and is followed in this report. It is also common to assess the significance of hazards associated with an active fault or fold by estimating how often, on average, it has undergone a ground-deforming rupture or deformation event (recurrence interval). The average recurrence interval is a primary consideration in Ministry for the Environment guidelines for the planning of land use or development near active faults (Kerr et al. 2003; referred to henceforth as the MfE active fault guidelines).

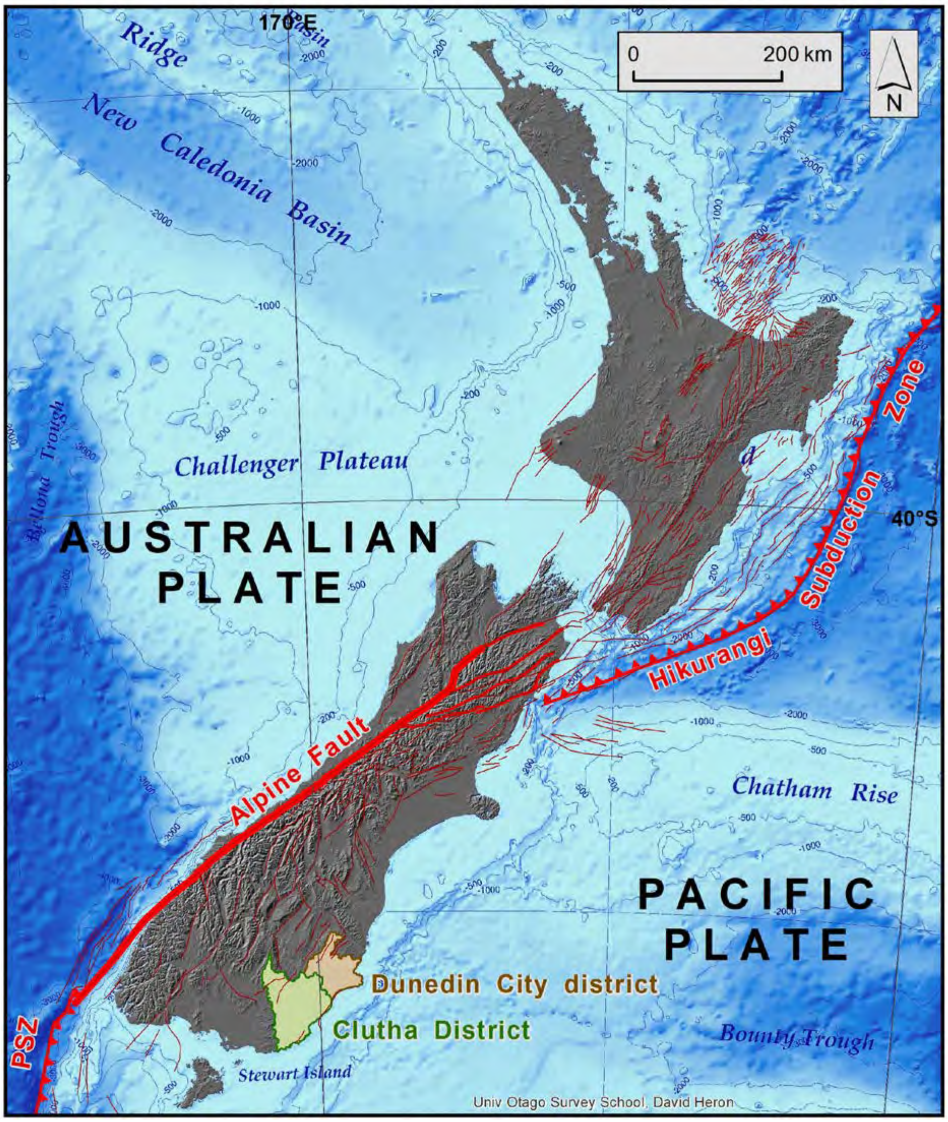

Figure 1.1 The tectonic setting of the Clutha and Dunedin City districts. The junction between the Australian and Pacific plates of the Earth's crust passes through New Zealand. The Pacific Plate pushes westward against, and under, the Australian Plate at the Hikurangi Subduction Zone while, at the Puysegur Subduction Zone (PSZ), the Australian Plate is being pushed down alongside the southwestern South Island. The Alpine Fault (thick red line) and the Marlborough Fault System (medium thickness red lines) transfer most of the plate motion between the two subduction zones, with the remainder accommodated across a wider zone of deformation marked by other active faults (thin dark red lines; from Litchfield et al. 2014). The offshore image is the New Zealand Continent map (GNS Science), showing shallower water in light blue and deeper water in darker blue. Bathymetric contours are in metres below sea level.

In the southeastern South Island, including the Otago region, there are indications that many of the faults undergo episodes of several successive ruptures, interspersed with periods without rupture (e.g. Beanland and Berryman 1989; Litchfield and Norris 2000). This part of New Zealand also lies somewhat away from the locus of plate boundary deformation, and rates of strain on the Earth's crust are relatively slow. Recent research has shown that only half of the large historic earthquakes in New Zealand have occurred on faults that would have been recognised as 'active' under today's criteria (Nicol et al. 2016). A recent research study in coastal Otago advocated the consideration, in a seismic hazard context, of faults that have been active within the past few million years (Villamor et al. 2018). Accordingly, the present project has incorporated all faults that show substantial offset of the Otago peneplain, a prominent landscape feature that is the remains of an ancient land surface that was, originally, nearly flat and low-lying (see Section 3.1 for additional information).

There are many active geological faults and associated folds recognised in the Otago region. As part of ongoing improvements in the recognition and mitigation of natural hazards, Otago Regional Council engaged the Institute of Geological and Nuclear Sciences Limited (GNS Science) to summarise the state of knowledge regarding active faults in the Clutha and Dunedin City districts. This report presents that summary and is a companion to a similar report that addresses the Waitaki District (Barrell 2016) and the Queenstown Lakes and Central Otago districts (Barrell 2019).

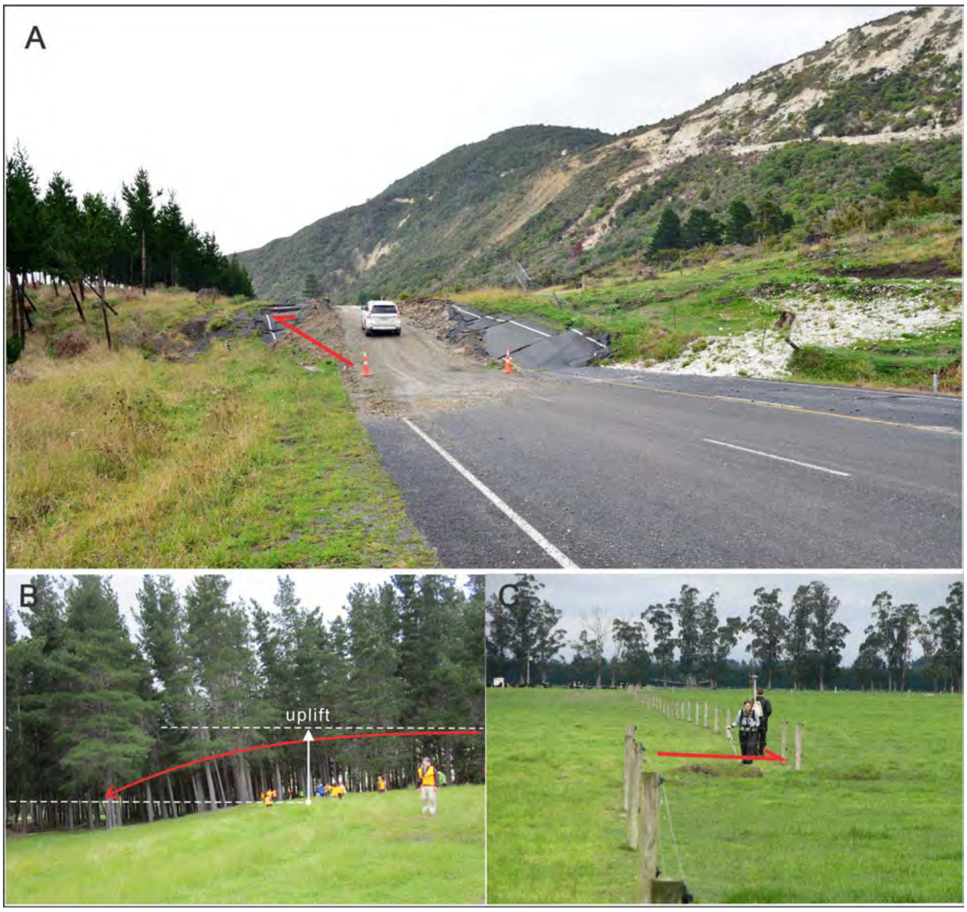

Figure 1.2 Illustrations of recent historical fault rupture deformation of the ground surface in New Zealand. A: Offset of State Highway 1 across the Papatea Fault, north of Kaikōura, that occurred during the 2016 Kaikōura Earthquake. The movement included several metres of upthrow and also several metres of sideways shift to the left, as indicated by the red half-arrow. Photo: GNS Science, VML ID: 210453; DB Townsend. B: Monoclinal fold associated with the Papatea Fault rupture during the Kaikōura Earthquake, illustrated well by the tilting of the pine trees. The ground here was flat prior to the earthquake. The white lines indicate the amount of uplift, and the red arrow shows the breadth and curvature of the monocline. Photo: GNS Science; DJA Barrell. C: A fence offset sideways by ~4.5 m of strike-slip rupture on the Greendale Fault during the 2010 Darfield Earthquake. Photo: GNS Science, VML ID: 137457; NJ Litchfield. The red half-arrow shows the amount of relative displacement, which here involved a shift to the right.

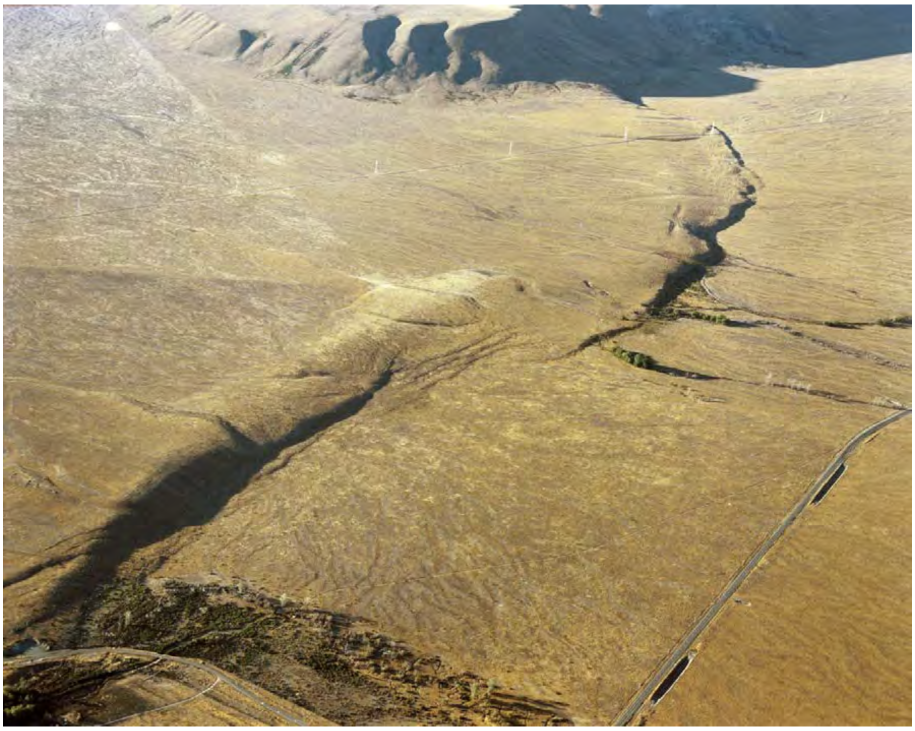

Figure 1.3 A northward oblique aerial view of ground-surface deformation across the Ostler Fault Zone, in the Waitaki District in the Canterbury region, about 12 km southwest of Twizel. The fault zone runs from lower left to upper right and has offset and buckled a ~22,000-year-old glacial meltwater outwash plain with well-preserved relict braided channels. This location is one of the best expressed examples of fault deformation in New Zealand because it is entirely across old landforms. This view shows complicated elements of main and subsidiary fault offsets and folds across a zone that is several hundreds of metres wide. All of these elements form part of a single entity, the Ostler Fault Zone. This figure is taken from Barrell (2016), where a more detailed description of the features in this view is provided. Photo: GNS Science, CN576/B and VML ID: 5151. DL Homer, taken 1995.

1.2 Scope and Purpose

This project comprised an office-based review of existing information, focused on delineating the locations and evaluating the characteristics of known or suspected active faults and folds in the Clutha and Dunedin City districts. The main product of the project is a Geographic Information System (GIS) map dataset that includes information on the certainty of identification of an active fault or fold feature and the clarity of its topographic expression at the ground surface. The report includes tabulated information on estimated degree of activity, expressed as average slip rate and earthquake recurrence interval, for each fault (see Section 5). Also indicated are relationships between information in this dataset and the MfE active fault guidelines (Kerr et al. 2003) for fault complexity categories (well defined, distributed or uncertain) and estimated recurrence interval classes.

The main aim of the work is to provide datasets that highlight locations in the Clutha and Dunedin City districts where active faulting may be a hazard to look for and be aware of. The information in this report is intended to assist local authorities in delineating the general areas of the Clutha and Dunedin City districts that are potentially subject to active fault and fold hazards, particularly those hazards related to ground-surface fault rupture and/or folding deformation.

The precision of regional-scale fault mapping is not sufficiently accurate for site-specific use (e.g. at property boundary scales), and specific hazard zonation was outside the scope of the project. The dataset presented here is not intended to be used directly for hazard zoning but rather to serve as a tool for hazard zoning prioritisation. Thus, a goal of the dataset is to enable the identification of areas where more detailed mapping and site-specific fault avoidance zonation should be considered if substantial building or other infrastructural development is proposed.

2.0 INFORMATION SOURCES

At least four different nationwide datasets in New Zealand provide information on active faults. One is the GNS Science 1:250,000 scale QMAP (Quarter-Million scale map) regional geological map digital database (Heron 2018), which provides, via mapped lines, the general locations and geological characteristics of active faults and folds. Another is the publicly available New Zealand Active Faults Database (NZAFD; see reference list and also Langridge et al. 2016), which represents the locations of past active fault surface deformation at a nominal scale of 1:250,000 and indicates the general degree of fault activity. In the southeastern South Island, the NZAFD is based mainly on the QMAP dataset. A third dataset is a national-scale model of active faults (New Zealand Active Fault Model; NZAFM), described by Litchfield et al. (2013, 2014). The NZAFM shows highly generalised locations of active faults at a nominal scale of about 1:1,000,000. The main purpose of the NZAFM is to quantify the kinematics of near-surface permanent deformation across New Zealand resulting from plate motion. A fourth dataset is the New Zealand National Seismic Hazard Model (NSHM; Stirling et al. 2012), which employs highly generalised locations and characteristics of active faults as earthquake sources for estimating probabilities of levels of earthquake ground-shaking at locations throughout New Zealand. The NSHM linework depicting the locations of active fault earthquake sources is approximately the same as in the NZAFM. At the time of writing, a comprehensive revision of the NSHM is underway (Van Dissen et al. 2021). A fifth type of active fault dataset comprises information of district or regional extent held by territorial or regional governmental authorities; for example, as described by Barrell et al. (2015). The active fault dataset described in this report is of the fifth type.

The five types of active fault datasets have differing purposes, and some are more locationally accurate at different scales. Most of the datasets have differences in regard to fault locations and extents. The locations of active faults represented geographically in the NZAFM and NSHM are much less detailed and less accurate than in the other datasets. The purpose of the dataset described here is to assist local authorities in land-use and development planning and provide an indication of areas where site-specific hazard assessments may be desirable.

The project described here used the QMAP dataset as a primary information source because it encompasses active faults and folds, whereas the NZAFD dataset is confined to active faults. The QMAP digital dataset (Heron 2018) is derived from a sheet-by-sheet series of published geological maps, represented in the Clutha and Dunedin City districts by the Dunedin map (Bishop and Turnbull 1996; southeastern parts of both districts), Murihiku map (Turnbull and Allibone 2003; southwestern Clutha District) and the Waitaki map (Forsyth 2001; northern and western parts of the Dunedin City district). Appendix 1 presents a brief description of the GIS structure of the active fault and fold dataset that forms a companion to this report. Additions and refinements to the QMAP input dataset are described in Appendix 2 of this report. Some more detailed studies have contributed to the information provided in this report and the companion digital dataset. Where relevant, those studies are discussed in Appendix 2, along with general commentary on aspects of the existing information and explanations of the interpretations adopted in this report for each active fault. The interpretation and geographic positioning of the fault and fold features was aided, where available, by topographic information from airborne LiDAR scans (laser radar) and by information from satellite, aerial or ground-based photographic archives, including Street View accessible through Google internet services.

Although the work described in this report did not include site investigations or field inspections, the writer has extensive experience of the assessment area, arising from previous geological investigations and inspections over the past 25 years.

3.0 GEOLOGICAL OVERVIEW

3.1 Rocks and Landforms

In the southeastern South Island, including the Clutha and Dunedin City districts, the oldest underlying rock (basement rock) consists mainly of hard sedimentary rock (‘greywacke’) and its metamorphosed equivalent (schist). These ancient rocks, of Permian to Jurassic age (between 300 and 145 million years old), were buried by a blanket of younger sedimentary rocks (cover rocks), including coal measures, quartz sands, mudstones, limestones and gravelly conglomerates, and some volcanic rocks, ranging in age from ~110 million years ago (middle of the Cretaceous Period) to about 2.5 million years ago. Collectively, the basement and cover rocks constitute what may be called ‘bedrock’. The cover rocks provide useful reference markers for identifying faults and folds. The well-developed sedimentary layering readily shows offsets due to faulting, while the tilting of these layers may reveal the effects of folding. In much of the hill to mountain terrain of Otago, uplift and erosion has stripped away large areas of the cover rock blanket, exposing the underlying basement rock that forms the main ranges. In many places, remnants of the cover rocks lie preserved on the downthrown, low-lying, sides of major faults. The cover rocks are more widely preserved in eastern Otago.

A valuable reference landform in Otago is the exhumed boundary between the basement and cover rocks (Otago peneplain) that is extensively preserved across inland Otago. Part of a widespread ancient land surface (Waipounamu Erosion Surface; Landis et al. 2008), the Otago peneplain was originally nearly flat and of gentle relief, but, following the development and propagation of the Australia-Pacific plate boundary through New Zealand about 20 million years ago, the Otago peneplain has been progressively offset and buckled by fault movement and fold growth associated with plate boundary deformation. In the Catlins area, there is a general accordance of summit elevations that appear to be the remnants of an ancient erosion surface, but it is not known whether it is the same as the Otago peneplain. In this report, it is referred to as the Catlins erosion surface.

Across the region, in many cases it is not clear when fault movement began, but there is evidence that uplift and erosion was underway by the Middle Miocene epoch, sometime between 11 and 19 million years ago, as illustrated in the area west of Dunedin where Dunedin Volcanic Group strata overlie an erosion surface cut across older cover rocks and, locally, the schist basement rock (Bishop and Turnbull 1996). As another example, uplift and exhumation of the peneplain had occurred on the northeast side of the Waihemo Fault System (Waitaki District) by ~15 million years ago, shown by the dating of volcanic rocks that rest directly on basement rock (Coombs et al. 2008). General indications are that the northeast-striking faults, such as the Dunstan Fault Zone, developed after the north-northwest-striking faults, as at least some of the latter faults have been deformed or offset by movement on the northeast-striking faults. It is suspected that most of the movement of the northeast-striking faults, with formation of the basin and range relief of inland Otago, has occurred in the past few million years, though evidence for this is patchy and uncertainties remain (Villamor et al. 2018).

The youngest deposits of the districts are unconsolidated sediments whose nature and distributions are primarily a consequence of tectonic uplift and erosion of the mountain ranges and fluctuating climatic conditions during the latter half of the Quaternary Period (from about one million years ago to the present day). Uplift and erosion produced voluminous sediment that has been laid down in the basins, valleys and plains on top of the basement or cover rocks. A major feature of the Quaternary Period has been a cycle of large-scale natural shifts in global climate, with periods of generally cool conditions (glaciations, or ‘ice ages’) separated by periods of warmer climate ('interglaciations'), such as that existing today. Ice-age glaciers formed in the Southern Alps but did not reach into the Dunedin or Clutha districts. However, the near-coastal reaches of rivers and streams were affected by variations in global sea level that accompanied the expansion and recession of Northern Hemisphere ice sheets.

3.2 Recognition of Active Faults and Folds

The key evidence for recognising active faults or folds is the offset or buckling of landforms or young geological deposits. This is seen most clearly on old river terraces or river plains, where the original channel and bar patterns of the former riverbed are 'fossil' landforms dating from when the river last flowed at that location. Topographic steps or rises that run across such river-formed features could not have been created by the river, and therefore result from subsequent deformation of the ground. If factors such as landsliding can be ruled out, these topographic features may confidently be attributed to fault or fold movements (e.g. Figure 1.2, Figure 1.3 and Figure 3.1).

In this report, and the companion GIS dataset, a distinction is made between the style of active deformation, whether predominantly by fault offset of the ground (fault scarp) or by folding (buckles, tilts or flexures) of the ground. Folds are subdivided into 'one-sided folds', or monoclines, and 'two-sided folds', either up-folds (anticlines) or down-folds (synclines) (Figure 3.1). Monocline is the only class of active fold included in the companion GIS dataset.

Two end-members of fault movement type are shown in Figure 3.1: a dip-slip fault that has up-down movement and a strike-slip fault that has horizontal (sideways) movement. In practice, it is not uncommon for a fault to display a combination of both types of movement; such faults are called 'oblique-slip' and have movement that is partly up-down and partly sideways (see Figure 1.2A). Most dip-slip fault planes are inclined (i.e. are not vertical), and there are two basic types of movement. Where the rock on the upper side of the inclined dip-slip fault shifts upwards along the fault, it is called a reverse fault and results from compressional forces. Where the rock on the upper side of the inclined dip-slip fault shifts downwards along the fault, it is called a normal fault and results from tensional forces.

The fault and fold styles illustrated in Figure 3.1 are idealised examples. They do not show the range of variations and complexity that may exist (e.g. see Figure 1.3). To find such simple examples in nature as displayed in Figure 3.1 would be an exception rather than a rule. The steepness of inclination (dip) of the fault may vary considerably (Figure 3.1). Where a fault has a gentle dip (i.e. is closer to horizontal than vertical), each successive movement commonly results in the upthrown side 'bulldozing' outward, over-riding the ground and encroaching over anything in its immediate vicinity. The destroyed building in the upper diagram of the lower panel of Figure 3.1 attempts to convey an impression of a bulldozer effect.

There is rarely an exact distinction between a fault and a monocline at the ground surface. Fault scarps are commonly associated with some buckling of the ground and near-surface layers, particularly on the upthrown side of a reverse fault scarp (Figure 3.1; also see Figure 1.3). In some cases, part of the fault movement may have broken out on a series of smaller subsidiary faults near the main fault. In the case of monoclines or anticlines, subsidiary faults may also occur over buried faults that underlie these folds, resulting in small ground surface offsets. An important message is that, on any active fault or fold, there are commonly elements of both faulting and folding close to the ground surface (Figure 3.2). The amount of deformation due to faulting, relative to the amount expressed as folding, may vary over short distances (Figure 1.3).

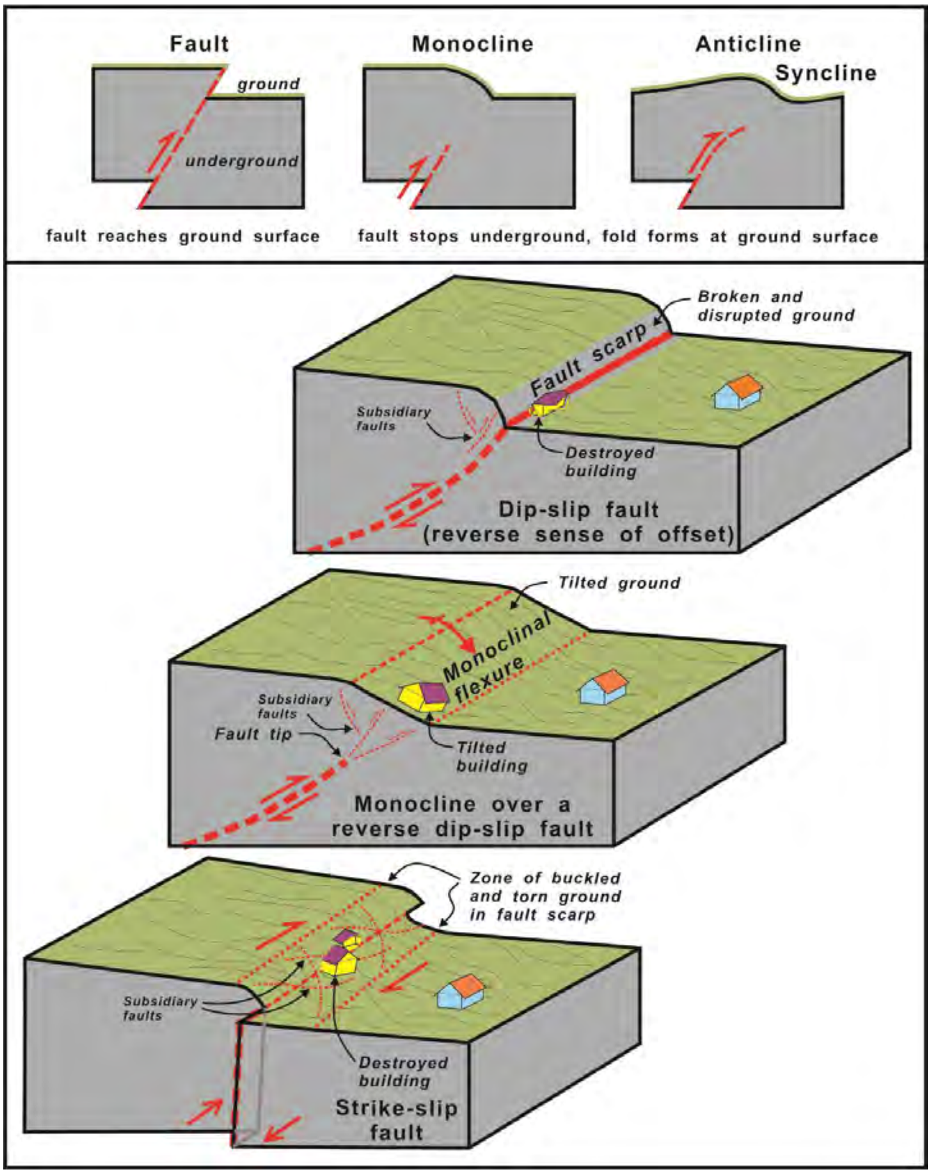

Figure 3.1 Diagrams illustrating styles of active faults and folds. The diagrams show general concepts rather than actual details and are not drawn to an exact scale. Upper panel: Cross-section (vertical slice) diagrams illustrating an active fault, active monocline and active anticline and syncline. Most folds are, as shown here, thought to have formed over faults whose ruptures have not made it all the way to the ground surface. Lower panel: perspective block diagrams showing typical ground-surface expressions of faults and monoclines. The diagrams include hypothetical examples of effects on buildings of a fault rupture or monocline growth event.

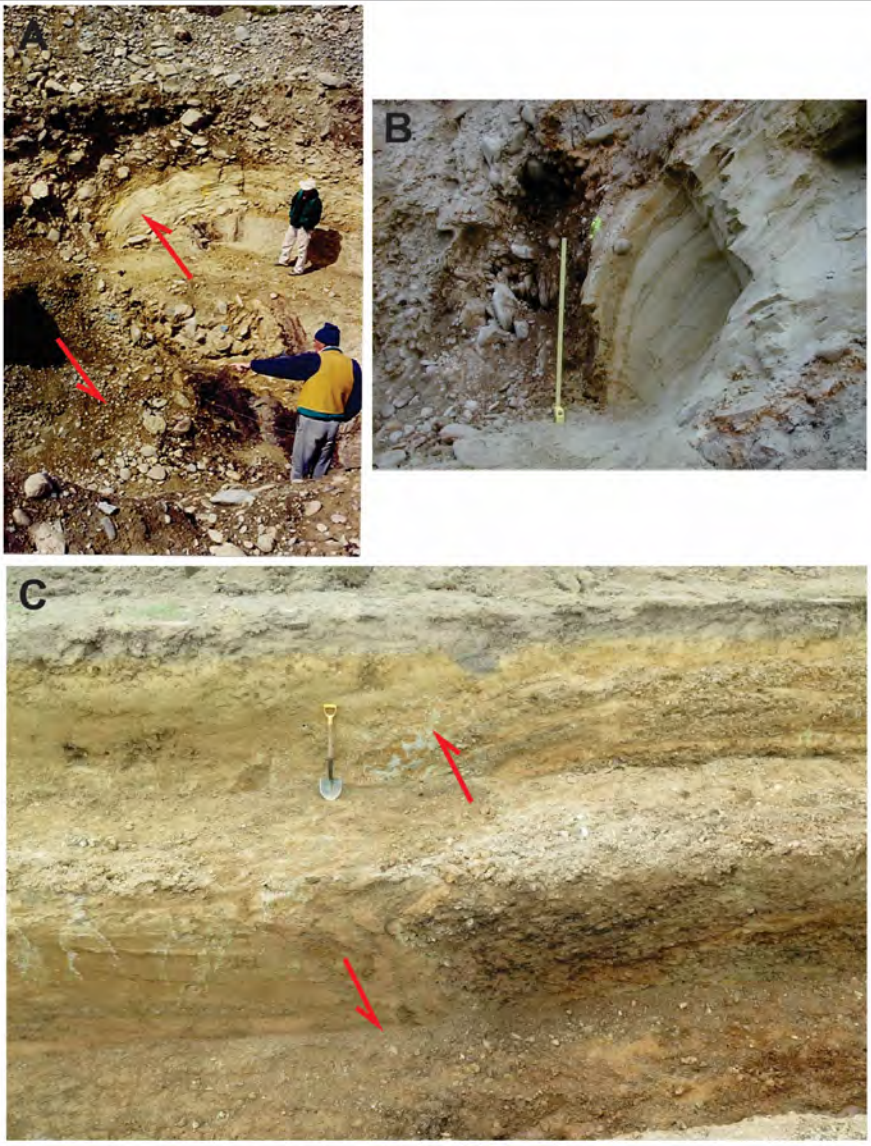

Figure 3.2 Illustrations of faults exposed in investigation trenches. Red half-arrows indicate the relative sense of fault displacement. A and B: The Waitangi Fault exposed in 1999 in a trench 700 m downstream of Aviemore Dam, Waitaki District of Canterbury (Barrell et al. 2009). A: the fault runs upper left to lower right, and a bed of yellow sand has been pushed up and buckled over against river gravel to the left. B: detail of the fault contact after further excavation and cleaning. The yellow tape measure (extended 1 m) provides scale. Layering in the sand has been dragged down nearly vertical against the fault, while elongate river stones immediately left of the sand bed have been dragged up into vertical alignments. C: A view of the wall of a trench excavated across the Titri Fault near Milton in coastal Otago, Clutha District, in 2016. Yellow-brown stream gravel (right of centre) has been thrust up and buckled over against yellow-brown silt (loess) to the left. Detailed examination and mapping of the materials, and dating of the sediments, provides evidence for at least two separate rupture events here within the past ~38,000 years. The 1-m-long shovel illustrates scale. Photos: GNS Science, DJA Barrell.

In practice, where the zone of ground deformation is quite narrow, it is interpreted as a fault, and, where it is broad, it is interpreted as a fold (e.g. monocline; see Figure 3.1). The only way to determine the accuracy of this interpretation is to excavate a trench across the deformed zone to see whether, or to what extents, the near-surface deposits have been offset or merely folded (Figure 3.2). Sometimes, natural exposures in stream banks provide the necessary information. This highlights a key issue; without detailed work involving examination of what lies within the first few metres beneath the ground surface, we can at best only make informed guesses about the exact locations, form and likely future consequences of fault or fold activity.

It is common to find some surprises as a result of more detailed geological examination of active faults or folds. For example, a broad fault scarp, which might be expected to include a considerable amount of folding may, upon excavation, turn out to have a well-defined fault offset with very little folding. This could occur because, after a surface deformation event, natural landscape processes tend to smooth-over the effects. For instance, a steep face of bare broken ground in a fault scarp will settle, subside and compact due to factors such as rainstorms, frost heave and soil formation. Over longer periods, wind-blown dust (loess) emanating from riverbeds tends to accumulate most thickly in hollows and depressions, further smoothing any irregularities produced by fault offset of the ground.

An important message is that, while landforms provide important clues as to the general location of active faults or folds, many details of these features that may be relevant to land use, development and hazard mitigation cannot be obtained without more detailed site-specific investigations (e.g. Figure 3.2).

3.3 Seismicity

The Otago region has experienced very little locally centred seismicity since European settlement. Most of the earthquakes that have been felt in Otago since European settlement have been centred outside the region, mainly originating in the Fiordland area, close to or on the plate boundary.

The local-magnitude 5.0 Dunedin Earthquake on 9th April 1974[1] was the largest earthquake reported for the Dunedin City or Clutha districts since European settlement. The epicentre was assessed as being offshore, about 10 km south of central Dunedin, with a suspected focal depth of 20 km (Adams and Kean 1974). Damage to masonry, particularly chimneys, resulted in 3000 claims to the Earthquake Commission, totalling $250,000 (Bishop 1974). The Dunedin Earthquake highlights that, despite the low historical seismicity, Otago is undoubtedly subject to earthquake activity.

1 The Richter, or local, magnitude (ML) is based on the largest size of ground motions recorded on seismographs. Richter magnitude is difficult to estimate accurately for strong earthquakes, because the seismographs have difficulty recording the full amplitude of very large ground motions. A more commonly used measure of earthquake size is the moment magnitude (MW), which is a measure of the total seismic energy released in an earthquake and is usually calculated from low-frequency waveforms recorded on seismographs.

4.0 CLASSIFICATION OF ACTIVE FAULTS AND FOLDS

4.1 Descriptive Classification

The original information on the active faults and folds of the Clutha and Dunedin City districts was extracted from the QMAP digital dataset (Heron 2018). The QMAP was compiled for presentation at 1:250,000-scale, where 1 cm on a map represents 2.5 km on the ground. For this report, the existing mapping has been re-examined and additions, and some refinements, have been made to the mapping of active faults and folds. These modifications include addition of some previously unmapped features and the reclassification of some existing mapped features. Appendix 2 provides commentary on the mapping and interpretations of the active faults and folds.

Following the approach used in the QMAP digital data structure, faults and folds are separate entities (feature classes) within the GIS dataset. Three data fields (also known as 'attribute' fields) have been added to the active faults and folds feature classes (see Appendix 1 and Table 5.1). The names of these fields are:

- ORC_name (local names for the mapped fault/fold feature; see below)
- Certainty (likelihood that the mapped feature is an active fault/fold; see below)
- Surf_form ('Surface form', indicating how well defined the surface expression of the mapped feature is; see below).

The GIS dataset provides the following information: (i) whether a feature is a fault or a fold, (ii) the level of the certainty with which each feature is recognised as active (definite, likely or possible) or as potentially active and (iii) an interpretation of the surface distinctiveness of each feature at the ground surface (well expressed, moderately expressed, not expressed, unknown). Commonly, a single active fault at depth is expressed at the ground surface as a zone of splintering. An individual line of splinters (fault strand) may comprise fault offsets of the ground surface (fault scarps) or ground-surface folds (fold scarps) and, commonly, a mixture of both. A fault zone may include several lines (traces) of semi-parallel strands, and a fault zone can, in some cases, be several kilometres wide. Some strands have previously been named separately, and this name is retained in the GIS dataset, but the various strands that comprise an active fault are grouped under a common name (ORC_name). This is done to highlight that, collectively, the strands are regarded as part of a single active fault structure whose movements at depth have produced an array of ground-surface fault and/or fold deformation.

Many of the active or potentially active faults have been named previously, and those names are used in this dataset unless reasons exist for applying a different name, as explained in Appendix 2. The QMAP dataset only included names for faults or folds where a name had previously been published, and this is the main reason for adding an attribute that assigns a local name to all mapped features (ORC_name). By and large, the local name corresponds to any previously used name (in QMAP or the NZAFD). In places where no name has previously been given to an active fault/fold feature, the ORC_name has been taken from a nearby named topographic feature or locality. Where names are newly proposed in this report, and thus regarded as informal, the term fault or fold is in lower case type (e.g. Otanomomo fault). For previously published names, a capital 'F' is used. The basis of all new names is explained in Appendix 2. In this and subsequent sections of the report, the term 'fault' is used to encompass faults as well as any associated folds, unless in specific reference to a fold feature. Any references to individual fault or fold strands are identified as such, and the term 'fault' pertains to an overall active fault structure.

The purpose of the Certainty field is to indicate the level of confidence in the interpretation of the deformation features. In the Certainty field, the term ‘definite’ is applied to those features whose existence can only be explained by active fault deformation. Features designated as ‘likely’ are most probably due to active fault deformation, but it is not possible to rule out other origins, such as having been formed by erosion. In instances where there is some reason to suspect the presence of an active fault, but there is a lack of direct evidence because, for example, the landforms are unsuitable (e.g. too young) to have preserved any direct indications of young movement, the feature is designated as ‘possible’. Another category is added in this project for faults that could possibly move in the future (‘potentially active’), even though they have not done so in the recent geological past. Features identified as having a Certainty of ‘possible’ or ‘potentially active’ should not be treated as delineated active faults unless further positive information is obtained. They are identified to highlight areas that are worth a closer look for the possible existence of active fault hazards.

Several of the active faults of the Clutha and Dunedin City districts have been subject to close examination in the field, whereas other faults have been identified primarily using aerial photographs or other imaging, such as Google Earth, or in reconnaissance walkover. In all cases, the geometries and locations of active faults as depicted in the QMAP-based datasets are very generalised. At the scale of QMAP, none is located more accurately than plus or minus (±) 100 m, at best, and ± 250 m as a general rule. The Surf_form field provides a preliminary estimate of how well defined the surface expression of a feature is likely to be, were it to be subjected to a detailed, site-specific, examination. Features that are ‘well expressed’ should be able to be located to better than ± 50 m. Those that are identified as ‘moderately expressed’ should be able to be located to better than ±100 m. Those labelled as ‘not expressed’ do not have any known physical expression on the ground, because they lie in areas of landforms that are probably younger than the most recent deformation. Features are labelled as ’unknown’ if it is unclear whether or not there may be physical evidence that would aid in locating the position of the fault. The purpose of the Surf_form field is to assist in the planning and targeting of future investigations aimed at a more rigorous characterisation of active fault hazard, should any further work be proposed. For example, features designated as ‘well expressed’ are likely to be able to be mapped and delineated more quickly, and to greater precision, than features identified as ‘moderately expressed’.

4.2 Activity Classification

Two common ways of expressing the degree of activity of an active fault (and any related folding) are average slip rate and average recurrence interval. Either of these parameters provides a way to compare the levels of activity of faults across a wide area (e.g. Clutha and Dunedin City districts). In this report, an activity estimate is assigned to a fault as a whole. The one activity estimate applies to its component fault strands and any associated monoclinal fold strands. This assumption may not be true in detail, for example, if one strand of a fault were to rupture in an earthquake while another strand does not. However, a single activity estimate is regarded here as the appropriate approach to use, because at present there is little, if any, information on the past rupture behaviour of individual fault strands.

The behaviour of any particular active fault comprises a relatively long period of no movement, during which strain slowly builds up in the subsurface rock until the fault moves (ruptures) in a sudden slip event, causing an earthquake. For a fault whose largest slip events are sufficient to produce ground-surface rupture (as applies to all mapped active faults in this report), each slip event typically involves sudden movement on the fault of as much as several metres (see Figure 1.2). The amount of fault offset of a geological deposit or a land surface feature, such as a river plain, divided by the estimated age of the deposit or the land surface feature provides an average slip rate, usually expressed in millimetres per year (mm/yr). This does not mean that the fault moves a certain amount each year but is simply a way of assessing its degree of activity. A fault with a larger (faster) slip rate (say 2 mm/yr) generally experiences a ground-surface-rupturing earthquake more frequently than does a fault with a smaller (slower) slip rate (e.g. 0.2 mm/yr).

In most cases throughout Otago, the precise ages of geological deposits and landforms are not known. Instead, geologists usually rely upon provisional age estimates based on regional geological comparisons. By this approach, ages obtained by geological dating of a specific type of landform somewhere in New Zealand are applied to landforms of similar characteristics in another region. The estimated age of a landform or geological deposit, together with the amounts that the landform or deposit has or has not been offset, are used to calculate fault activity rates. The approach and reasoning used to estimate the activity of each fault addressed in this report is explained in Appendix 2.

Average recurrence interval is the average length of time that elapses between ground-surface-rupturing earthquakes and is a more explicit measure of how frequently surface-rupture earthquakes occur. Recurrence interval is an important quantity because it forms the basis for risk-based evaluation of ground-surface fault rupture hazard in relation to the MfE active fault guidelines, which aim to minimise the risks of building across active faults (Kerr et al. 2003). Recurrence intervals range from being as short as a few hundred years for the most active faults in New Zealand (e.g. Alpine Fault), to as much as many tens of thousands of years for other faults. This means that the historically documented record of earthquakes is too short to be of use for evaluating the average recurrence interval of an active fault. Instead, the geological record of deformation of young deposits and landforms is the main source of evidence for defining a recurrence interval for an active fault.

Recurrence interval is more difficult to quantify than slip rate because the direct determination of a recurrence interval depends on the ability to establish the ages of at least two, preferably more, past surface-rupture earthquakes on a fault. Determining recurrence intervals, as well as obtaining accurate values for slip rates, requires detailed geological investigations on a fault, with measurement of past offsets and dating of geologically young deposits. However, few faults in the Otago region have been investigated in that amount of detail.

Another approach for estimating recurrence interval has been developed from research into historical ground-surface fault ruptures internationally and in New Zealand. That work has identified generally applicable relationships that allow one fault parameter to be calculated from another parameter. For example, the size of a single-event fault rupture displacement can be estimated from the length of the fault. That methodology provides a means for estimating fault activity characteristics for faults where detailed geological investigations have not been carried out and has been applied to such faults in the 2010 version of the NSHM (2010 NSHM; Stirling et al. 2012). The 2010 NSHM methodology calculates, among other things, values for recurrence interval and single-event displacement from estimates of fault length, fault dip (the inclination from horizontal of the fault plane) and slip rate; those estimates are usually determined by an expert panel of geoscientists, drawing on available geological information.

The present project, and one recently completed for the Central Otago and Queenstown Lakes districts (Barrell 2019), used the 2010 NSHM approach to estimate provisional recurrence interval values for newly defined active and potentially active faults not currently in the 2010 NSHM. This differs from the recurrence-interval approach used previously for the Waitaki District (Barrell 2016), which applied a method that assumed a fixed representative value for single-event displacement size and used that, along with estimated slip rate, to calculate an inferred recurrence interval. An important point is that, except in the case of the few faults that have been investigated in detail with useful results obtained, the slip rate and recurrence interval estimates presented in this report should be regarded as preliminary until more direct estimates are obtained from site-specific geological investigations of the fault. The estimates in this report are intended primarily to indicate an approximate recurrence interval that may be expected for each fault, allowing the activity of a fault to be placed into general context with the MfE active fault guidelines (Kerr et al. 2003).

This project differs from the fault classification approach used for the Waitaki District (Barrell 2016), which only included faults displaying physical evidence for geologically recent activity, thus according with existing definitions of 'active fault' (Langridge et al. 2016). However, recent research in coastal Otago (Villamor et al. 2018) has led to a recommendation for including all faults that have experienced substantial movement in the wider geological past, specifically within the past 20 million years, as the present plate boundary has been active through the New Zealand region. The inclusion of many more faults in the dataset has little impact on seismic hazard estimation in Otago for faults that have experienced considerable movement in the deeper past but little, if any, in geologically more recent times. Those faults are assessed as having very slow slip rates and therefore long recurrence intervals; thus, they statistically contribute little to the overall earthquake hazard in the region.

There is considerable uncertainty in the estimated fault activity parameters, but the level of uncertainty is difficult to quantify. This is because there is uncertainty in estimating the size of fault offset of a landform (e.g. estimated from aerial photos) and uncertainty in the age assigned to the landform (e.g. inferred from regional geological comparison – see earlier paragraph). It is not considered meaningful for the present report to try and quantify activity uncertainties, for example, by giving a range of estimated values for slip rate or recurrence interval. That would be a desirable goal of future assessments of specific active faults where detailed geological investigations have been undertaken. However, the present report just gives a single best-estimate value for slip rate, from which a single recurrence interval is calculated using 2010 NSHM methodology. Should anyone wish to apply a level of uncertainty to those values, an uncertainty of ±50% of the stated slip rate or recurrence interval is deemed here to be a useful working representation of the uncertainty.

It is important to appreciate that all of the fault activity estimates in this report, and in preceding datasets, are no more than working best estimates. The main use of those estimates is for enabling comparison of the relative activities of different faults and providing context for identifying and managing associated hazards, typically via the derived parameter of recurrence interval. A last point to note is that the information on degree of fault activity in this report, notably, the extended reviews and discussions in Appendix 2, is more comprehensive than that contained in the NZAFD, as it stood in August 2020, and also builds on and refines information and estimates presented by Van Dissen et al. (2003), Stirling et al. (2012) and Litchfield et al. (2013, 2014) and references therein.

4.3 As-Yet Undetected Active Faults

The Canterbury earthquake sequence of 2010–2011 occurred on a series of previously unknown faults. There are two main reasons why nothing was known about those faults. First, they have a low rate of activity (the average time between surface-rupture earthquakes is many thousands of years) and, second, the Canterbury Plains consist of relatively young deposits and landforms, which mask most of the underlying geology, including faults

(Hornblow et al. 2014). The 2016 Kaikōura Earthquake involved the rupture of multiple faults, several of which were not previously known to be active faults (Litchfield et al. 2018). Somewhat different circumstances prevail in Otago, where most areas are not buried by young sediments, and many of the faults are clearly expressed in the geology and topography, especially where hard basement rock has been uplifted to form a range of hills or mountains on one side of the fault. Nevertheless, it is conceivable that there may be other active faults in areas of relatively young landforms, whose presence is yet to be detected. This means that the active faults of the Clutha and Dunedin City districts that have a preserved record of previous ground-surface deformation of young deposits or landforms should be regarded as a minimum representation of the active faults of these districts.

The active faults and associated folds that are known about can be taken into account in planning, engineering and hazard mitigation or avoidance. Although little can be done to avoid hazards from faults whose presence/location is unknown, modern building and design standards in regard to earthquake shaking do make allowance for minimising adverse effects of a large, nearby, earthquake, even if there is no known active fault nearby. However, there is good confidence that the more active faults of the two districts have been identified and characterised in this report. This is because such faults are likely to have left distinctive landform indicators of their presence. The more active faults present the largest hazard statistically, because they have a greater chance of rupturing again in the geological near-future than faults of lesser activity. However, and unfortunately, that does not necessarily mean that a higher activity fault will be the next one(s) to rupture. This is because there are many more low activity faults than there are high ones.

4.4 Earthquake Magnitudes

For an active fault to be recognisable at the ground surface, it indicates that past ruptures must have been sufficiently large to have broken through to the ground surface. For the types of faults that occur in the eastern South Island, the amount of slip required for a fault to rupture the ground surface will generate a large earthquake of magnitude somewhere between the high sixes and mid-sevens (e.g. Pettinga et al. 2001).

Active folds indicate the presence of underlying active faults whose ruptures have not reached the ground surface. Conceivably, subsurface ruptures sufficient to generate surface folds may produce earthquakes of lesser magnitudes (e.g. in the low to mid-sixes). These considerations were borne out in the Darfield Earthquake, where the surface-rupturing Greendale Fault movement had an estimated magnitude of 7.0, while the subsurface Charing Cross and Hororata fault ruptures had estimated magnitudes of 6.4 and 6.3, respectively, and did not cause surface rupture but produced subtle, instrumentally measurable, ground shifts (Beavan et al. 2012). Surface fold growth resulting from non-surface-rupturing faults does not necessarily mean that the earthquakes were not large. For example, a gently inclined non-surface-rupturing fault may be able to generate an earthquake at least as large as one generated by a steeply inclined, surface-rupturing fault, such as the Greendale Fault.

Each of the active faults identified in this report should be assumed to be capable of generating earthquakes with magnitudes between the high sixes to mid-sevens, depending on the length of the fault, with longer faults having potential to generate larger earthquakes within this magnitude range.

5.0 DISTRIBUTION AND CHARACTERISTICS OF ACTIVE FAULTS

5.1 Overview

A regional-scale map of the active and potentially active faults delineated in the Clutha and Dunedin City districts is presented in Figures 5.1 and 5.2, which collectively provide overlapping panels of the assessment area. Descriptions of the representative characteristics of the categories of active faults and associated active folds used in this report, as well as indicative correlations to the fault complexity classification of the MfE active fault guidelines (Kerr et al. 2003), are presented in Table 5.1. Table 5.2 summarises the main features of each of the delineated active and potentially active faults. The table includes an assessment of the degree of activity of each fault. Appendix 2 provides extended descriptions of the mapping, geological interpretations and activity estimations for each fault.

In many cases, rupture on an active fault may have broken out discontinuously, or in multiple places, on the ground. Some individual faults may converge, or abut one another, and some faults comprise a zone of surface deformation, in which some fault strands have been given individual names. To aid clarity of illustration, each named fault in Figures 5.1–5.2 has been accentuated by a coloured area ('extent of named area'). In the cases where a fault comprises multiple strands, this helps show which strand belongs to which active fault.

Of the 26 active faults (comprising a total of 34 named fault features in Figures 5.1–5.2) identified in the Clutha and Dunedin City districts, nine are classified as comprising 'definite' or 'likely' components and can be regarded, respectively, as known or suspected active faults. Of the remaining faults, three are classed as 'possible' active faults and another 14 are classified as 'potentially active'. The classification of 'possible' indicates that there is reason to think of those faults as having a greater likelihood of future activity than faults classified as 'potentially active'.

Only two faults are assessed as having an average recurrence interval of less than 10,000 years: the Akatore Fault and the Settlement Fault, with estimated recurrence intervals of ~1700 years and 1800 years, respectively. These estimates reflect that both faults have displayed evidence for episodes of greater and lesser activity. Definitely the Akatore Fault, and possibly the Settlement Fault, have had greater activity in the geologically recent past compared to their longer-term average, with at least two surface surface-rupturing earthquakes indicated as having occurred on each fault within the past few thousand years. It is considered prudent to assume that they remain in a heightened state of activity.

A further six faults are assessed as having an average recurrence interval of between 10,000 and 20,000 years, including the Blue Mountain, Hyde and Titri faults. For many of the active or potentially active faults identified in this report, there is no information on when the most recent ruptures occurred, and this means that there is little or no information on where the faults are currently sitting within their rupture cycles.

In the active fault assessment for the Waitaki District (Barrell 2016), the focus was on faults designated as active in the NSHM and NZAFM. Subsequently, in the southern Waitaki District, Villamor et al. (2018) delineated several more faults assessed as potentially active. All extend into the Dunedin City district, and, in the dataset described in this report, the full extent of those faults across both districts is included. The additional faults are the Murphys Creek, the Dunback Hill and the Flat Stream – Glenpark faults (Figure 5.2).

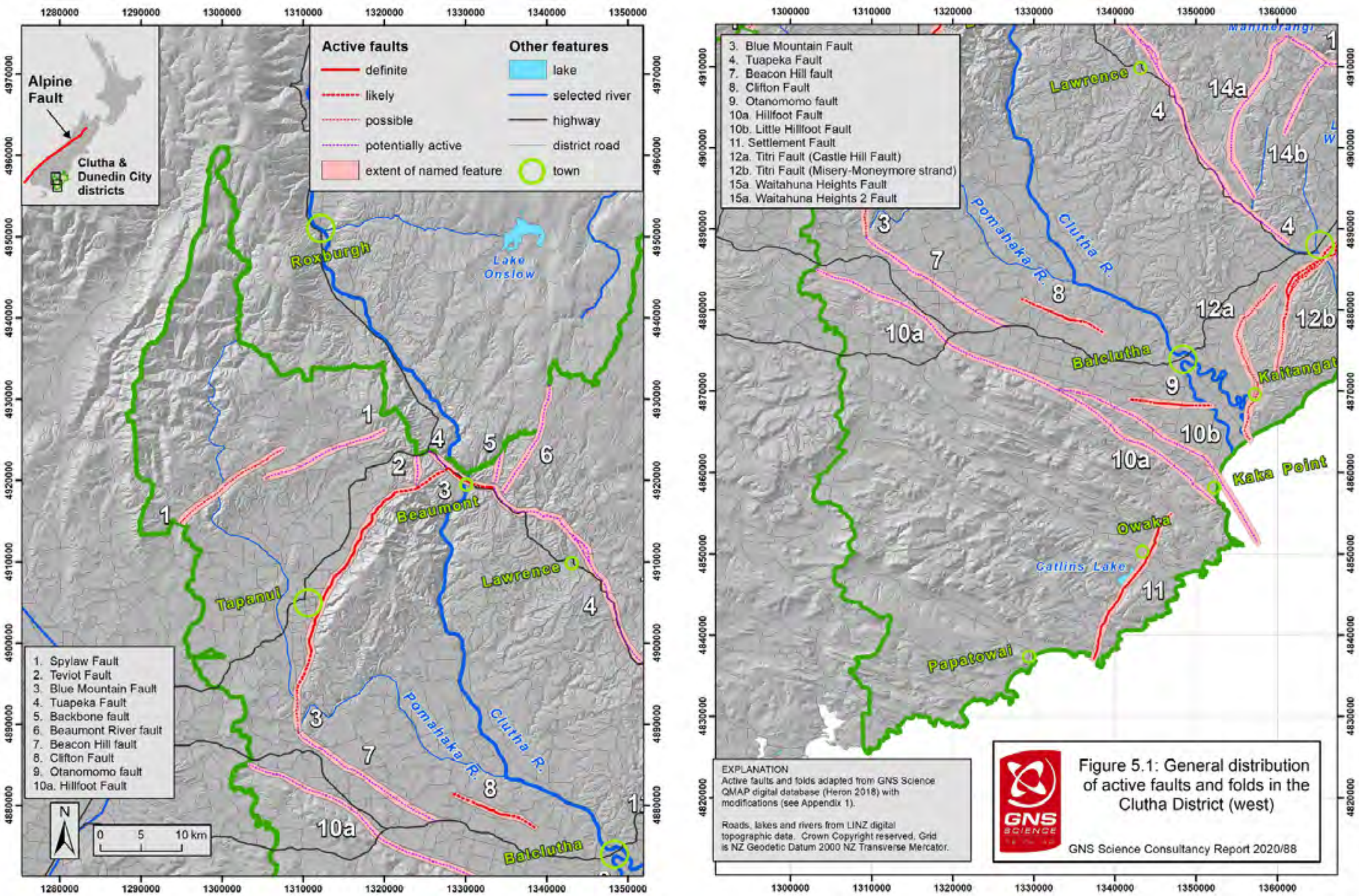

Figure 5.1 General distribution of active faults and folds in the western part of the Clutha District. The pink areas indicate groupings of fault or fold strands that collectively form part of a single numbered active fault. The pink areas are purely illustrative and do not imply anything about the location or extent of fault-related ground deformation. Each fault that intersects the outer boundary of the combined districts (thick green line) extends into a neighbouring district. The location of the overlapping map panels is shown in the inset at top left.

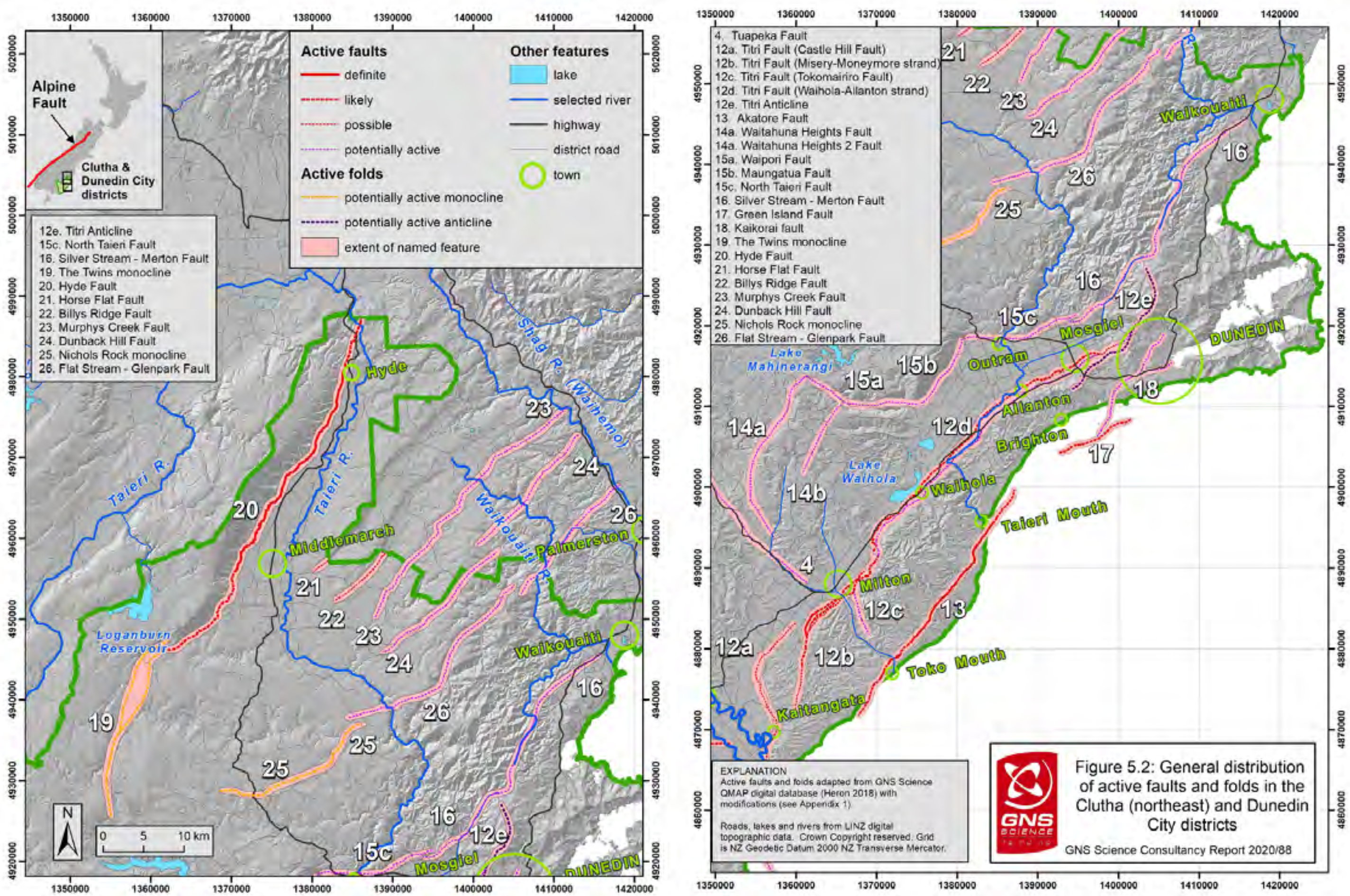

Figure 5.2 General distribution of active faults and folds in the eastern part of the Clutha District and the Dunedin City district. The pink areas indicate groupings of fault or fold strands that collectively form part of a single numbered active fault. The pink areas are purely illustrative and do not imply anything about the location or extent of fault-related ground deformation. Each fault that intersects the outer boundary of the combined districts (thick green line) extends into a neighbouring district. The location of the overlapping map panels is shown in the inset at top left.

Table 5.1 Categories and terms used in this report to describe active faults and folds in the Clutha and Dunedin City districts.

Category	Characteristics	Certainty	Surface Form	Nature of Evidence	Fault Complexity (based on definitions in Kerr et al. [2003])
Active fault	Deformation predominantly in the form of breakage and offset of the ground surface. This is presumed to occur in sudden events accompanied by a large earthquake. May also include some monoclinal or anticlinal folding.	Definite	Well expressed	Sharp step in ground surface that cannot be attributed to other geological factors (e.g. river erosion or landslide movement).	Well-defined deformation
		Definite	Moderately expressed	Poorly defined step(s) in ground surface that cannot be attributed to other geological factors	Well-defined or distributed deformation
		Definite	Not expressed	No surface expression (i.e. evidence concealed or eroded away) but lies along trend from nearby definite active fault.	Uncertain deformation
		Likely	Well expressed	Sharp step(s) in the ground surface that cannot readily be attributed to other geological factors.	Well-defined deformation
		Likely	Moderately expressed	Poorly defined steps in the ground surface that cannot readily be attributed to other geological factors.	Uncertain deformation
		Likely	Not expressed	No surface expression, but lies along trend from nearby likely active fault.	Uncertain deformation
		Possible	Moderately expressed	Coincides with a definite or likely fault in bedrock, along trend from nearby definite or likely active fault; includes steps or topographic features that may possibly relate to fault activity, but other origins are reasonably likely.	Uncertain deformation
		Possible	Not expressed	No surface expression (i.e. evidence concealed or eroded away) but lies along trend from nearby likely or possible active fault.	Uncertain deformation
		Potentially active	Not expressed	Little or no information from which to estimate the specific location of a potentially active fault.	No recognised deformation
Active monocline	Deformation in the form of one-sided tilting or buckling of the ground surface. Fold growth assumed to occur in sudden events accompanied by a large earthquake. May include some subsidiary fault offsets.	Potentially active	Moderately expressed	Coincides with a known or suspected monocline in bedrock or the peneplain surface, with no definitive evidence of geologically recent movement. The line marking the feature is positioned at the foot of the fold.	Uncertain deformation
Active anticline	Deformation in the form of broad up-doming of the ground surface. Fold growth assumed to occur in sudden events accompanied by a large earthquake. May include some subsidiary fault offsets.	Potentially active	Moderately expressed	Coincides with a known or suspected anticline in bedrock or the peneplain surface, with no definitive evidence of geologically recent movement. The line marking the feature is positioned along the axis (i.e. crest) at the foot of the fold.	Uncertain deformation

Definite = clear evidence for the existence of an active fault or fold
Likely = good reason to suspect the existence of an active fault or fold
Possible = some reason to suspect the existence of an active fault or fold
Potentially active = a known or suspected fault without identified geologically recent activity, but which could conceivably experience activity in the future

Well expressed = likely to be able to be located to better than ± 50 m in site-specific investigations
Moderately expressed = likely to be able to be located to better than ± 100 m in site-specific investigations
Not expressed = able to be located only by large-scale subsurface site-specific investigations

Table 5.2 Summary of evidence and estimated deformation characteristics of active faults and folds recognised in the Clutha and Dunedin City districts. Refer to text and appendices for further information. In the 'Name' column, a lower case last term (e.g. 'fault') indicates a newly applied name (this report) while upper case (e.g. 'Fault') indicates a previously published name. Calculated recurrence interval (RI) values are rounded to the nearest hundred years for values <10,000 years, to the nearest thousand years for values <30,000 years and to the nearest 5000 years for longer RIs.

Name	**Observed Characteristics**	**References**	**Deformation Estimates**					
Name of feature (number in Figures 5.1–5.2)	*Description of feature(s)*	*Main source(s) of information on character or activity of feature*	*Basis of estimates*	*Classification*	*Assigned net slip rate (mm/yr)*	*Estimated recurrence interval (RI) – years*	*Comments*	*Indicated RI Class (following Kerr et al. [2003])*
Akatore Fault (13)	Fault in bedrock with offset of peneplain and offset of geologically young sediments and landforms	Taylor-Silva et al. (2020); this report	Air photo interpretation, field inspection and surveying, trenching and dating, LiDAR data, regional geologic mapping	Definite active fault	Between 0.3 and 6.0	1700	The fault displays episodic rupture recurrence and may be in a more active phase, which is why a relatively short RI is applied.	Class I (<2000 years)
Backbone fault (5)	Inferred fault zone(s) in bedrock, with indicated offset of peneplain	Barrell (2019)	Air photo interpretation, geomorphologic interpretation	Potentially active fault	0.05	35,000	No known evidence for geologically young fault movement.	Class VI (>20,000 years)
Beacon Hill fault (7)	Fault in bedrock, with indicated offset of peneplain	Turnbull and Allibone (2003); this report	Air photo interpretation, regional geologic mapping, geomorphologic interpretation	Potentially active fault	0.05	29,000	No known evidence for geologically young fault movement.	Class VI (>20,000 years)
Beaumont River fault (6)	Inferred fault zone(s) in bedrock, with indicated offset of peneplain	Barrell (2019)	Air photo interpretation, geomorphologic interpretation	Potentially active fault	0.05	50,000	No known evidence for geologically young fault movement.	Class VI (>20,000 years)
Billys Ridge Fault (22)	Fault in bedrock, with offset of peneplain	Litchfield et al. (2013); Villamor et al. (2018); Barrell (2016)	Air photo interpretation, regional geologic mapping, geomorphologic interpretation	Possible active fault	0.05	45,000	No known evidence for geologically young fault movement.	Class VI (>20,000 years)
Blue Mountain Fault (3)	Fault zone(s) in bedrock, with offset of peneplain and offset of geologically young landforms	Turnbull and Allibone (2003); Pace et al. (2005); this report	Air photo interpretation, regional geologic mapping, geomorphologic interpretation, geological dating	Definite, likely and possible active fault	0.22	11,000	-	Class V (>10,000 to ≤20,000 years)
Clifton Fault (8)	Inferred fault in bedrock, indicated offset of peneplain and offset of geologically young landforms	Turnbull and Allibone (2003); this report	Regional geologic mapping, LiDAR data, geomorphologic interpretation	Definite and likely active fault	0.09	20,000	Suspected to rupture together with Otanomomo fault. Activity estimates from Otanomomo fault.	Class V (>10,000 to ≤20,000 years)
Dunback Hill Fault (24)	Fault in bedrock, with offset of peneplain	Forsyth (2001); Villamor et al. (2018); this report	Air photo interpretation, regional geologic mapping, geomorphologic interpretation	Potentially active fault	0.05	50,000	No known evidence for geologically young fault movement.	Class VI (>20,000 years)
Flat Stream – Glenpark Fault (26)	Fault in bedrock, with offset of peneplain	Forsyth (2001); Villamor et al. (2018); this report	Air photo interpretation, regional geologic mapping, geomorphologic interpretation	Potentially active fault	0.05	65,000	No known evidence for geologically young fault movement.	Class VI (>20,000 years)
Green Island Fault (17)	Inferred fault zone(s) in bedrock, offshore of Kaikorai Estuary	Holt (2017); Villamor et al. (2018); this report	Offshore bathymetric and geophysical surveys	Likely active fault	0.05	22,000	Evidence for geologically young offset of the sea floor.	Class VI (>20,000 years)
Hillfoot Fault (10a, 10b)	Fault zone(s) mapped in bedrock, with indicated offset of peneplain	Bishop and Turnbull (1996); Turnbull and Allibone (2003); this report	Air photo interpretation, regional geologic mapping, geomorphologic interpretation	Potentially active fault	0.05	110,000	No known evidence for geologically young fault movement.	Class VI (>20,000 years)
Horse Flat Fault (21)	Fault in bedrock, with offset of peneplain	Forsyth (2001); Litchfield et al. (2013); Villamor et al. (2018); Barrell (2016)	Air photo interpretation, regional geologic mapping	Possible active fault	0.05	50,000	Also known as Taieri Ridge Fault. Equivocal evidence for geologically young fault movement.	Class VI (>20,000 years)
Hyde Fault (20)	Fault zone(s) in bedrock, with offset of peneplain and deformed geologically young sediments and landforms	Norris et al. (1994); Norris and Nicolls (2004); Litchfield et al. (2013); this report	Air photo interpretation, field inspection and surveying, trenching and dating, LiDAR data, regional geologic mapping	Definite, likely and possible active fault	0.25	14,200	Data from recent trenching and dating by University of Otago provided by M Stirling and J Griffin (personal communication) .	Class V (>10,000 to ≤20,000 years)
Kaikorai fault (18)	Inferred fault zone(s) in bedrock, with indicated offset of cover rock strata	Villamor et al. (2018); this report	Air photo interpretation, regional geologic mapping, geomorphologic interpretation	Potentially active fault	0.05	22,000	No evidence for geologically young fault movement.	Class VI (>20,000 years)

Name	Observed Characteristics	References	Deformation Estimates					
Name of feature (number in Figures 5.1–5.2)	*Description of feature(s)*	*Main source(s) of information on character or activity of feature*	*Basis of estimates*	*Classification*	*Assigned net slip rate (mm/yr)*	*Estimated recurrence interval (RI) – years*	*Comments*	*Indicated RI Class (following Kerr et al. [2003])*
Murphys Creek Fault (23)	Fault in bedrock, with offset of peneplain	Forsyth (2001); Villamor et al. (2018); this report	Air photo interpretation, regional geologic mapping, geomorphologic interpretation	Potentially active fault	0.05	50,000	No known evidence for geologically young fault movement.	Class VI (>20,000 years)
Nichols Rock monocline (25)	Inferred monoclinal fold in bedrock, with indicated deformation of peneplain	Villamor et al. (2018); this report	Air photo interpretation, regional geologic mapping, geomorphologic interpretation	Potentially active monocline	0.05	28,000	No known evidence for geologically young fault or fold movement.	Class VI (>20,000 years)
Otanomomo fault (9)	Inferred fault in bedrock, with offset of geologically young landforms	This report	Air photo interpretation, regional geologic mapping, LiDAR data, geomorphologic interpretation	Definite and likely active fault	0.09	20,000	Suspected to rupture together with the Clifton Fault.	Class V (>10,000 to ≤20,000 years)
Settlement Fault (11)	Fault zone in bedrock, with indicated offset of peneplain and offset of geologically young landforms	Bishop and Turnbull (1996); Turnbull and Allibone (2003); Litchfield et al. (2013); this report	Air photo interpretation, regional geologic mapping; geological dating, geomorphologic interpretation.	Definite active fault	Between 0.08 and 0.79	1800	May display episodic rupture recurrence and may be in a more active phase, which is why a relatively short RI is applied.	Class I (<2000 years)
Silver Stream – Merton Fault (16)	Fault zone(s) in bedrock, with indicated deformation of peneplain	Bishop and Turnbull (1996); Forsyth (2001); Villamor et al. (2018); this report	Air photo interpretation, regional geologic mapping, geomorphologic interpretation	Potentially active fault	0.05	50,000	No known evidence for geologically young fault movement.	Class VI (>20,000 years)
Spylaw Fault (1)	Fault in bedrock, with offset of peneplain and possible offset of geologically young landforms	Turnbull and Allibone (2003); Pace et al. (2005); Litchfield et al. (2013); this report	Air photo interpretation, regional geologic mapping, field inspection, geological dating, geomorphologic interpretation	Possible and potentially active fault	0.11	19,000	Evidence for geologically young fault movement is equivocal.	Class V (>10,000 to ≤20,000 years)
Teviot Fault (2)	Inferred fault zone in bedrock, with indicated offset of peneplain	Barrell (2019); this report	Air photo interpretation, regional geologic mapping, geomorphologic interpretation	Potentially active fault	0.01	225,000	No known evidence for geologically young fault movement.	Class VI (>20,000 years)
The Twins monocline (19)	Monoclinal fold in bedrock, with deformation of peneplain	Bishop and Turnbull (1996); Forsyth (2001); Villamor et al. (2018); this report	Air photo interpretation, regional geologic mapping, geomorphologic interpretation	Potentially active monocline	0.13	13,000	No known evidence for geologically young fault or fold movement.	Class V (>10,000 to ≤20,000 years)
Titri Fault (12)	Fault zone in bedrock; offset of peneplain and offset of geologically young landforms and deposits	Litchfield (2001); Barrell et al. (2020); this report	Air photo interpretation, regional geologic mapping, field inspection and surveying, trenching and dating, LiDAR data	Definite, likely, possible faults; potentially active faults and anticline	Between 0.1 and 0.2	19,000	Possibility of episodic rupture recurrence and may be in a less active phase. A long-term average RI is applied.	Class V (>10,000 to ≤20,000 years)
Tuapeka Fault (4)	Fault zone in bedrock, with offset of geologically young landforms	Els et al. (2003); Villamor et al. (2018); this report	Air photo interpretation, regional geologic mapping, geomorphologic interpretation	Likely and potentially active fault	0.04	95,000	-	Class VI (>20,000 years)
Waipori – Maungatua – North Taieri Fault (15)	Faults in bedrock, with offset of peneplain	Bishop and Turnbull (1996); Barrell et al. (1998); this report	Air photo interpretation, regional geologic mapping, geomorphologic interpretation	Potentially active fault	0.05	50,000	No known evidence for geologically young fault movement.	Class VI (>20,000 years)
Waitahuna Heights Fault (14)	Faults in bedrock, with offset of peneplain	Villamor et al. (2018); this report	Air photo interpretation, regional geologic mapping, geomorphologic interpretation	Potentially active fault	0.05	30,000	No known evidence for geologically young fault movement.	Class VI (>20,000 years)

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5.2 Comparison with Previous Assessments

The present project has delineated 26 active and potentially active faults thought to be potentially capable of generating ground-surface-rupturing earthquakes, noting that the total of 34 named fault features in Figures 5.1–5.2 and Table 5.2 includes several regarded as only able to rupture together with other faults. In comparison, the 2010 NSHM identifies a total of seven active fault earthquake sources partly or entirely within the limits of the combined Clutha and Dunedin City districts, and the same seven active fault features are delineated in the NZAFM. The NZAFD, which in the assessment area is based largely on interpreted active fault scarps from the QMAP dataset, mostly shows scattered, disconnected, active fault strands rather than entire active fault structures, as are portrayed in the NZAFM, for example. The active fault dataset described in this report provides a full update of information on active faults in the combined Clutha and Dunedin City districts. The information on active faults in this report is more comprehensive than the current version (August 2020) of the NZAFD.

Most of the additional faults identified in the dataset described in this report were included in the assessment by Villamor et al. (2018) as potential active fault earthquake sources. The dataset described here provides more detailed delineations of the fault features identified by Villamor et al. (2018).

5.3 Assessment of Fault Activity Estimates

The delineation of many more faults in the dataset described here, compared to previous assessments, presents an issue for fault activity estimation. The estimation of fault slip rates for the 2010 NSHM and the NZAFM took account of the inferred strain from plate convergence across the South Island. In both of those datasets, fault characterisation parameters based on geological investigation or landform interpretation evidence were adjusted to achieve a satisfactory accord with predicted plate deformation strain.

Mirroring the approach used by Barrell (2019), this issue is considered for the new fault dataset described in this report. For each of the potentially active faults, for which there is no recognised evidence of fault deformation of geologically young landforms, a nominal slip rate of 0.05 mm/yr has been assigned. In the southeastern South Island, faults with a slip rate of about 0.1 mm/yr generally show some landform indicators of fault deformation, such as uplifted old terraces, or elevated foothill terrain, on the upthrown side of the line of the fault, for example, the Titri Fault (Barrell et al. 2020). A nominal slip rate of 0.05 mm/yr is considered here to be a first-approximation value that is compatible with an absence of preserved landform evidence of geologically recent fault deformation. A 'reality-check' comparison can be made by summing the slip rates of all the faults partly or entirely in the combined districts in the 2010 NSHM, the NZAFM and the new dataset. While this approach is not a good measure of plate deformation strain relative to the plate boundary, it does give an approximation of internal deformation rate within a three-dimensional block of the Earth's crust in the combined area of the two districts. In the 2010 NSHM, the summed slip rate is ~3.1 mm/yr. The NZAFM assigns each modelled fault three slip rate estimates: a minimum, maximum and most likely ('best') value. The NZAFM summed slip rates have a range of 1.5 to 7.6 mm/yr (minimum to maximum) and 4.2 mm/yr 'best' estimate. The summed slip rate for the 26 faults in the new dataset is ~2.7 mm/yr. If the nominal 0.05 mm/yr slip rate were increased to 0.07 mm/yr, the summed slip rate would be ~3.0 mm/yr, equivalent to the 2010 NSHM value. Both sum estimates lie within the range from the NZAFM and indicates that the slip rates applied in the new dataset are broadly in overall accord with those of the 2010 NSHM and NZAFM datasets.

5.4 Discussion of Fault Activity Close to Population Centres

5.4.1 Southwestern Otago

In southwestern Otago (Figure 5.1), the two faults assessed as being most active in this area are the Blue Mountain Fault, about 1 km southeast of Tapanui, and the Settlement Fault, within ~1 km of Owaka. The Blue Mountain Fault is assessed as having a recurrence interval of ~11,000 years, similar to the value in the 2010 NSHM (Stirling et al. 2012), though it is not known when it last moved. There is some evidence to indicate that the Settlement Fault has experienced greater activity over the past few thousand years than in the preceding ~125,000 years or so. As discussed in Appendix 2, there is clear evidence for a surface-rupturing earthquake having occurred ~3600 years ago, with possibly another one ~1000 years ago. Based on the assumption that the fault has recently entered a more active phase, its recurrence interval is assessed at ~1800 years, somewhat shorter than the 4000 years given in the 2010 NSHM (Stirling et al. 2012).

There is evidence for past rupture on the Tuapeka Fault, which passes under Beaumont village and lies ~1.5 km northeast of Lawrence. Based on landform interpretation, the most recent rupture(s) are assessed as having occurred sometime between 20,000 and 65,000 years ago, and its recurrence interval is assessed as being ~95,000 years, making it a very low activity fault.

The recognition of several potentially active faults only minimally increases the chance of fault rupture and related hazards occurring due to a local-source earthquake in southwestern Otago, because their rates of activity (if any) are very low. The villages of Clinton and Kaka Point lie within a kilometre or so of the Hillfoot Fault, but there is no landform evidence of the fault having moved in geologically recent times (e.g. several tens of thousands of years) and its recurrence interval is assessed as being well in excess of 20,000 years.

5.4.2 Northern Dunedin City District

In the northern part of the Dunedin City district (Figure 5.2; left panel), the small population centres of Middlemarch and Hyde lie within 4 km and 1 km, respectively, of the Hyde Fault. The Hyde Fault has an estimated recurrence interval of ~14,000 years, with the most recent surface rupture ~10,000 years ago. Similarly to southwestern Otago, the recognition of several potentially active faults only minimally increases the chance of fault rupture and related hazards occurring due to a local-source earthquake in the northern part of the Dunedin City district, because their rates of activity (if any) are very low.

5.4.3 Coastal Hills and Basins North of Clutha River

The Tokomairaro and Taieri basins, and the coastal range of hills, are occupied by the main population centres of the assessment area (Figure 5.2; right panel). The most prominent feature is the Titri Fault, whose movement over time has been responsible for uplift that has raised the coastal hills. The fault has complexity of surface expressions, with step-overs from one fault strand to another and, in places, curved to sinuous surface break-up scarps (Figures 5.3–5.5). In several places, notably near Milton, Henley and Mosgiel, the exact location of the most recent fault break-outs are uncertain because stream action has removed or buried the fault-diagnostic landforms. In the south, there is a good geological and topographic basis for positioning the Titri Fault (Castle Hill Fault component) along the foot of the hills on the eastern edge of Kaitangata township, rather than farther west under the Inch Clutha plain as previously mapped. Further north, Milton lies about 2 km northwest of the Titri Fault, which is mapped as passing along the foot of higher ground immediately southeast of its Tokoiti suburb.

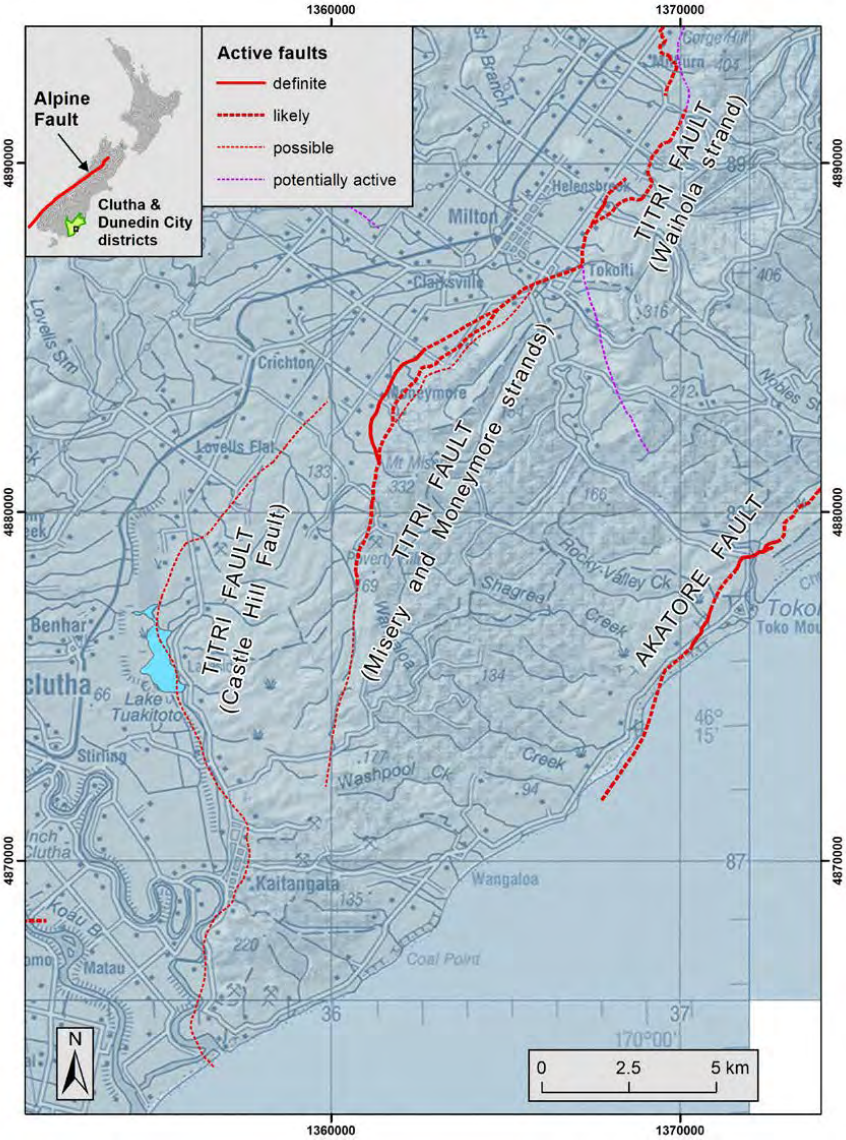

Figure 5.3 Active faults in the southwestern sector of the coastal hills. The background is the Topo 250 topographic map draped transparently over a hillshade digital elevation model. The location of the map panel is shown in the inset at top left.

The village of Waihola is built on low, hilly, terrain immediately on the southeastern, uplifted, side of the Titri Fault, with the fault inferred to lie approximately beneath the position of the railway line. Similarly, the villages of Allanton and East Taieri are on low, hilly, terrain immediately on the southeastern, uplifted, side of the fault. Through Mosgiel, the fault is inferred to lie approximately beneath the railway line and on the eastern side of Mosgiel, approximately along the course of Owhiro Stream. Near Wingatui, the fault is inferred to divert eastward through the village to join the position of the fault as mapped on bedrock relations north of the Chain Hills. For the most part, there are very few houses built directly on the inferred position of the fault, and the main infrastructure close to the line of the fault between Clarendon and Mosgiel are the railway line and State Highway 1. The Titri Fault has an estimated recurrence interval of ~19,000 years and, at least near Milton, last ruptured more than 18,000 years ago. However, it is not known whether the fault ruptures with a regular frequency or in bursts separated by periods of inactivity.

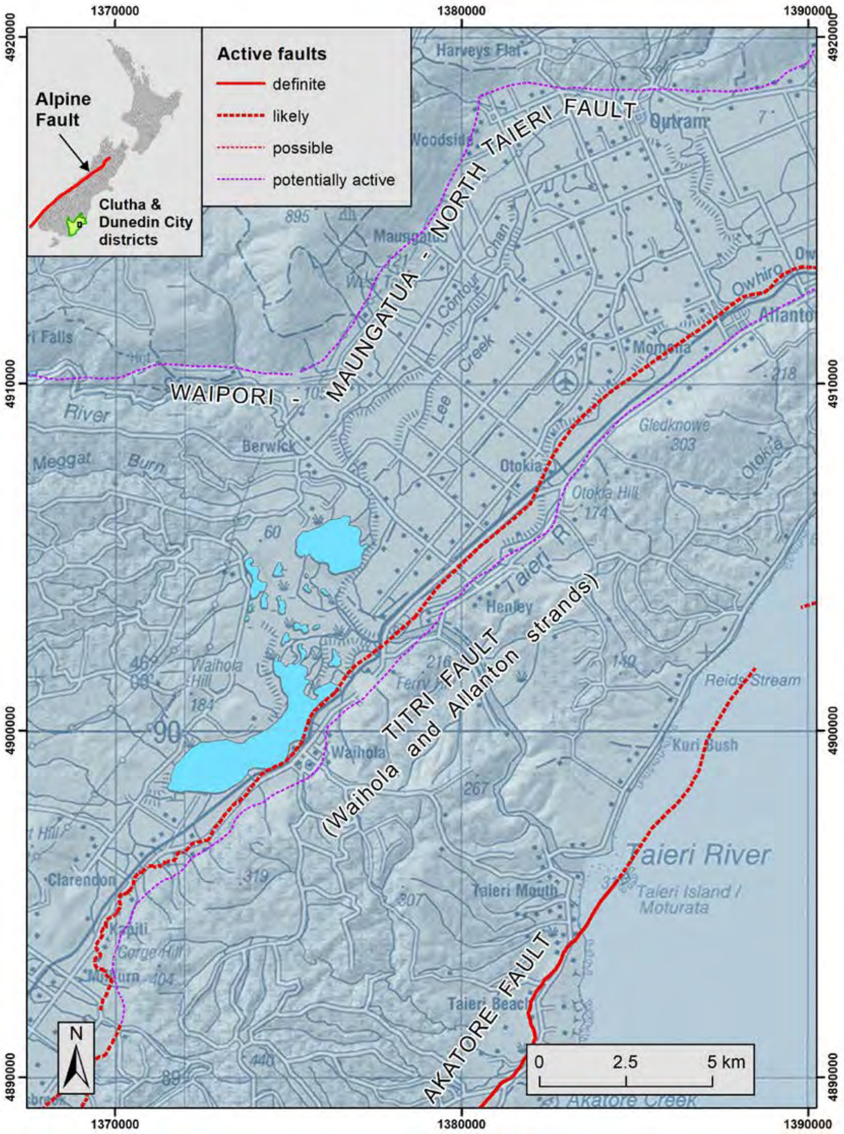

Figure 5.4 Active faults in the central sector of the coastal hills and the Taieri Plain. The background is the Topo 250 topographic map draped transparently over a hillshade digital elevation model. The location of the map panel is shown in the inset at top left.

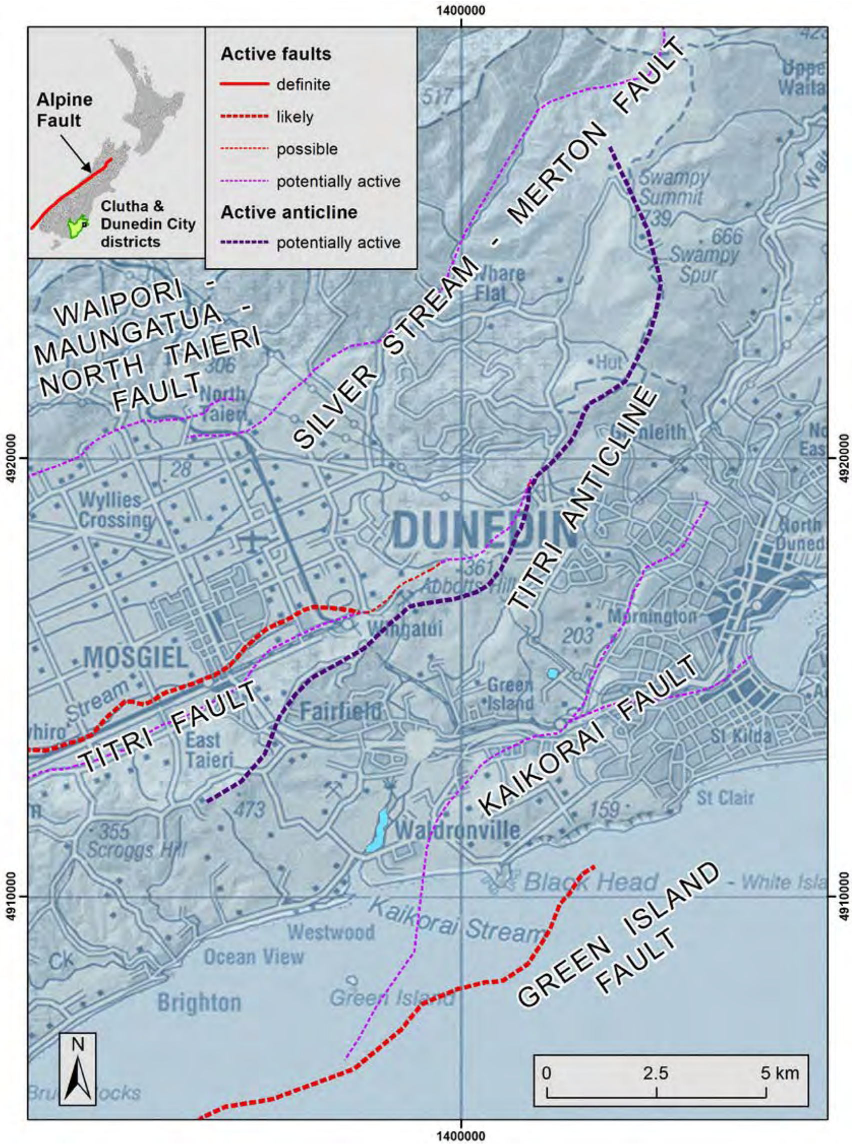

Figure 5.5 Active faults in the northern sectors of the coastal hills and Taieri Plain. The background is the Topo 250 topographic map draped transparently over a hillshade digital elevation model. The location of the map panel is shown in the inset at top left.

The northwestern side of the Taieri Plain is marked by the Waipori – Maungatua – North Taieri Fault, which has, over time, uplifted the hills on that side of the plains (Figures 5.4–5.5). The village of Outram lies within ~1 km southeast of the inferred mapped line of the fault, but none of the built-up area lies directly on the mapped position. Previously, sections of the fault had been interpreted as having had geologically recent activity, based on landform evidence. However, as part of the present assessment, that interpretation has been revised, and those landform features are now interpreted as being unrelated to fault activity. This fault is interpreted as potentially active with an assessed recurrence interval of ~50,000 years. It is not known when it last ruptured.

The Akatore Fault runs close to the coast and has, over time, uplifted a prominent ridge on its southeastern side. It is regarded as likely being in a state of heightened activity, has ruptured twice in the past ~1300 years and is assigned a recurrence interval of ~1700 years. The small village of Toko Mouth lies about 1 km southeast of the fault, on its uplifted side, while, where the fault goes offshore to the northeast, the village of Taieri Beach is within 1 km of the fault on its northwestern side.

The Kaikorai fault is an inferred potentially active fault that is mapped, on the basis of indicative geological relationships, from the coast near Waldronville along the eastern side of the Kaikorai valley floor and the western side of the Roslyn to Maori Hill ridge. A branch of the fault is inferred to extend through Lookout Point and down Caversham Valley into South Dunedin (Figure 5.5). The fault, if its existence as drawn is correctly diagnosed, is upthrown to the southeast and there is no evidence for geologically recent offset of the ground surface. The fault's exact location is mostly uncertain, and it is drawn in the best estimated position from sparse geological outcrop information and topographic considerations. As positioned in this dataset, the fault passes under the eastern fringe of Waldronville and through the eastern part of the Green Island suburb. From Burnside, the fault is drawn under the Kaikorai valley floor at approximately the location of Kaikorai Valley Road and/or Kaikorai Stream. The only significant fix on its location is ~100 m southeast of the Kaikorai Valley Road / Brockville Road intersection, where Benson's (1968) geological map explicitly shows a fault upthrown to the southeast, at the foot of the hill. Northeast of there, the fault is positioned along the axis of the broad valley through the Balmacewan area.

The possible branch of the fault extending east across the Lookout Point saddle has several likely position fixes. As far as is known, it is not crossed by the railway tunnels (the original tunnel north of the motorway through Caversham valley, or the new one south of the motorway), and it is not on the northern side of the Lookout Point motorway overbridge. Saturated very weak materials possibly associated with the geological boundary between Caversham Sandstone and Dunedin Volcanics were exposed in the motorway foundations east of Barnes Drive and south of the overbridge at the Glen, and it is inferred that the possible fault lies close by to the south. East from there, the fault is extrapolated through South Dunedin to the margin of the Otago Harbour.

5.4.4 Tsunami Generation

Several of the more active faults extend offshore, such as the southern end of the Settlement Fault, both ends of the Akatore Fault, the southern end of the Titri Fault and the entirely offshore Green Island Fault. Uplift of the sea floor associated with the rupture of any of those faults would likely generate a local-source tsunami, affecting nearby coasts and estuaries within a matter of minutes. Lowest-lying parts of the settlements at Pounawea, Kaka Point, Toko Mouth, Taieri Mouth and Brighton may be particularly exposed to such a hazard.

6.0 IMPLICATIONS FOR HAZARDS

Since European settlement in the Clutha and Dunedin City districts, there have been no known ground-surface fault rupture events. The geological record and landforms show clear evidence for zones of geologically recent (though pre-dating European settlement) fault deformation of the ground surface. This highlights that it would be prudent to treat the active fault or fold features of the Clutha and Dunedin City districts as potentially hazardous. Figures 1.2 and 1.3 illustrate examples of the types of ground-surface deformation hazards associated with active faults or active monoclines, noting that, at any location, elements of both faulting and folding may be present within a deformation zone. Faults present the most focused form of ground deformation, in regard to direct rupture, while monocline movement involves broader tilting of the ground surface. Monocline growth is likely to occur in a sudden event, associated with rupture of an underlying fault.

The geological estimates presented in this report indicate that only two of the faults in the Clutha and Dunedin City districts have a recurrence interval of less than 5000 years, and all of the rest have assessed recurrence intervals of more than 10,000 years. For many of those inferred low-activity faults, there is uncertainty as to whether they should in fact be considered active, but their potential for future activity cannot be ruled out. Nonetheless, there are several undoubtedly active faults in the Clutha and Dunedin City districts, notably the Akatore Fault, Blue Mountain Fault, Hyde Fault, Settlement Fault and Titri Fault, and every reason for authorities and residents to be prepared for the occurrence of ground-surface-rupturing fault movements, and resulting large, locally damaging earthquakes, over future decades to centuries. It is important to appreciate that the mapped delineation of the active faults and folds of the Clutha and Dunedin City districts presented in this report has been done at a regional scale (1:250,000). The level of precision is not adequate for any site-specific assessment of hazards (e.g. planning for building or other infrastructure developments). In addition, several of the fault/fold features that have been mapped have not yet been proven to be active. For features classed as ‘likely’, or ‘possible’, it would be desirable to prove one way or the other whether they are hazardous active faults/folds before undertaking any hazard planning, zonation or mitigation in respect to these features.

It is reiterated that the information presented in this report, and the accompanying GIS layers, is primarily intended for indicating general areas where there may be an active fault ground-deformation hazard to look for and where site-specific investigations may be necessary prior to development. In addition, the issue of local-sourced tsunami is raised as a matter that may warrant consideration.

7.0 CONCLUSIONS

1. Regional geological mapping has identified a number of active fault and fold features in the Clutha and Dunedin City districts. In total, 26 known, suspected, possible or potentially active faults are delineated. The existence of most of these faults was already known, and they have previously been shown on published geological maps, for example, although many were classified as ‘inactive’.
2. A GIS dataset of information on the active and potentially active faults and folds accompanies this report. For each mapped fault and fold, an attribute of ‘certainty’ indicates the level of confidence in the mapping of the feature, whether ‘definite’, ‘likely’ or ‘possible’. Also included is a classification of ‘surface form’, whether ‘well expressed’, ‘moderately expressed’, ‘not expressed’ or ‘unknown’. The surface form classification provides a provisional estimate of how easy it would be to pinpoint the location of the particular fault or fold feature on the ground.
3. Table 5.2 summarises what exists in the way of geological evidence for the degree of activity of each feature. Average slip rate is a common way to compare the level of activity of a fault or fold. This can also be expressed as an average recurrence interval for deformation events, aided by some assumptions. The recurrence interval estimates provide a linkage to Ministry for the Environment active fault planning guidelines.
4. The information presented here is not sufficiently precise for site-specific hazard assessment. Instead, the information is intended to highlight those areas which, at the current state of knowledge, are potentially affected by active fault or fold hazards. The information may help to target site-specific investigations that may be desirable, or required, prior to development and allow identification of lifeline vulnerabilities and emergency management response plans.

8.0 ACKNOWLEDGEMENTS

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APPENDICES

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APPENDIX 1 GIS DATASET

The GIS dataset referred to in this report comprises an ArcGIS file geodatabase, containing three Feature Classes:

- Clutha_Dunedin_active_faults_September2020
- Clutha_Dunedin_active_folds_September2020
- Clutha_Dunedin_fault_entity_area_September2020

The original attribute fields for the first two feature classes were extracted from the QMAP (Quarter-Million-scale geological mAP) 'seamless' dataset (Heron 2018), sourced from map data represented in the Clutha and Dunedin City districts by the Dunedin map (Bishop and Turnbull 1996; southeastern parts of both districts), Murihiku map (Turnbull and Allibone 2003; southwestern Clutha District) and the Waitaki map (Forsyth 2001; northern and western parts of the Dunedin City district).

In the active faults feature class of the dataset prepared as part of this project, the 'DOWN_QUAD' attribute field of the QMAP dataset is retained, and, for the folds feature class, the QMAP fields of 'TYPE' and 'FACING' are retained.

For this project, three new attribute fields are added:

- ORC_name (local names for the mapped features)
- Certainty (see report text)
- Surf_form (see report text)

Unless indicated otherwise, all of the data have been compiled at a regional scale (1:250,000), and the locations of active faults and folds should be regarded as having a general accuracy of ± 250 m and, at best, ± 100 m. The geographic coordinate system for the data is New Zealand Geodetic Datum 2000.

Interested readers can examine and query the QMAP digital database (Heron 2018) online at GNS Science, www.gns.cri.nz, search term < QMAP digital data webmap >.

The dataset is based largely on broad-scale inferences and should not be used in isolation for any purposes requiring site-specific information. The main purpose of the dataset is to delineate areas where active or potentially active fault features may warrant further scrutiny for future planning and development activities.

APPENDIX 2 COMMENTARY ON ACTIVE FAULT MAPPING

A2.1 Background Information

The information in this Appendix is largely of a technical nature and written for a technical audience. Its primary purpose is to set out the knowledge basis for the interpretation of faults and folds in this report. Readers of this Appendix may find it of benefit to refer to Google Earth, Google Maps and topographic maps, such as may be accessed from www.topomap.co.nz.

The source of information on active faults and folds described in this report is from the 1:250,000-scale Geological Map of New Zealand, dubbed 'QMAP' because the map is at 'quarter-million' scale. Compiled between the mid-1990s and 2010, the maps were published as ~160 km by ~160 km individual sheets in a nationwide cut-up. The Clutha and Dunedin City districts are encompassed by three published map sheets, with accompanying descriptive booklets, by the Dunedin map (Bishop and Turnbull 1996; southeastern parts of both districts), Murihiku map (Turnbull and Allibone 2003; southwestern Clutha District) and the Waitaki map (Forsyth 2001; northern and western parts of the Dunedin City district). Subsequently, all of the digital datasets from which these maps were generated were compiled into a nationwide 'seamless' dataset, published in digital form (Heron 2018). The subsets of 1:250,000-scale faults and folds that form the Clutha and Dunedin City district dataset presented in this report were extracted from the Heron (2018) seamless QMAP dataset.

The classification of active faults and folds in the QMAP dataset, especially in the eastern South Island sheets, is largely evidence-based. Where there is observed evidence for geologically recent movement, such as offset landforms or offset young deposits, the fault, and closely adjacent sections of the fault, were attributed as 'active', whereas other, more distant, sections of the same geological fault were attributed as 'inactive'. While the subdivision of a fault into active and inactive sections is somewhat artificial (a fault structure is commonly regarded as active or inactive), it provided a way of emphasising evidence of recent activity on a fault in a particular area (attributed as 'active') and distinguishing that from faults whose existence is identified on geological criteria, but for which there is no specific evidence for or against recent movement. Thus, in the QMAP dataset, particularly in the eastern South Island, the attribution of a fault as 'inactive' means that, rather than the fault being definitively 'inactive', there is no known evidence demonstrating that it is active. Much of the QMAP delineation of faults classified as 'active' in the central to lower South Island has been taken up, with little modification, into the New Zealand Active Faults Database (NZAFD; Langridge et al. 2016).

A generalised nationwide interpretation of active faults (the New Zealand Active Fault Model [NZAFM]) was published by Litchfield et al. (2013, 2014). In the South Island, the information in the NZAFM is largely derived from reviews undertaken by the GNS Science earthquake geology team between 2005 and 2008, as described in Litchfield et al. (2013, 2014). The NZAFM datasets indicate the generalised location (at a scale of the order of 1:1,000,000) of faults that are known or inferred to be active, based on a range of geological considerations. In similar vein, many of the generalised faults depicted by Litchfield et al. (2013, 2014) are incorporated, again in highly generalised form, in the current version, compiled in 2010, of the National Seismic Hazard Model (NSHM; Stirling et al. 2012). The 2010 NSHM dataset focuses on identifying the location of faults that are considered to be potential sources of large earthquakes. The 2010 NSHM dataset is used primarily to generate statistical estimates of the likely maximum intensity of earthquake motions at any specified location in New Zealand over specified time ranges (e.g. 500 years, 2500 years). For simplicity, any references made henceforth to the Litchfield et al. (2013) detailed report and the Stirling et al. (2012) paper and associated datasets are, respectively, the NZAFM and 2010 NSHM.

The dataset presented in this report is based on the 1:250,000-scale QMAP fault and fold dataset, unless indicated otherwise. In a number of places, refinements have been made to fault locations using LiDAR data or high-resolution colour aerial imagery, the latter accessed through the Google Earth platform, and through an imagery base map service delivered with the ArcGIS mapping software used for this project. In some cases, archival black and white aerial photography held by the GNS Science Dunedin Research Centre was examined, interpreted geomorphologically by the writer and used to assist improved locational mapping of fault-related landforms. Commentary on these refinements, and the addition of any newly identified, or re-interpreted, fault features, is provided in this appendix.

Extensive reference is made to the ‘Otago peneplain’, which is a key geological reference entity for assessing tectonic deformation in the eastern to southeastern South Island. It is part of the Waipounamu Erosion Surface (Landis et al. 2008), which marks a major unconformity on top of Mesozoic-age rock and at the base of younger sedimentary cover strata that were deposited on the older rock. In the project area, the peneplain is recognised as the top of schist or greywacke rock, where formerly overlying cover strata have been largely or completely eroded away, but with little erosional modification of the underlying rock (e.g. denudation of less than a few tens of metres). An extensive erosion surface in the Catlins area, of uncertain affinity to the Otago peneplain, is referred to here as the Catlins erosion surface.

The methodology of the 2010 NSHM was used for this project to calculate recurrence intervals for faults not previously in the 2010 NSHM, or for faults whose lengths have been revised. The 2010 NSHM methodology calculates, among other things, values for recurrence interval and single-event displacement from estimates of fault length, fault dip (the inclination from horizontal of the fault plane) and slip rate. Those estimates are usually determined by an expert panel of geoscientists, drawing on available geological information. For the present report, they were undertaken by the writer in order to produce preliminary estimates, as explained for each fault in this appendix. It is expected that a panel approach would be used if new faults identified here are in future taken into the NSHM environments.

In this appendix, faults are discussed in alphabetical order. The adopted slip rate and recurrence interval estimates are compiled in Table 5.2 in the body of the report.

A2.2 Akatore Fault (feature 13, Figure 5.2)

This northeast-striking fault, upthrown to the southeast, lies onland from near Toko Mouth in the southwest to Taieri Mouth in the northeast. It has offset the peneplain by as much as ~100 m, with the offset greatest midway along the fault at Big Creek, with offset diminishing both northeast and southwest. Conspicuous geologically young landform offsets have long been recognised near Taieri Beach and the Tokomairaro River valley.

To the southwest and northeast, the fault goes offshore, creating uncertainty as to how far it extends. A previous interpretation extrapolated the fault as much as ~30 km to the northeast, inferring that it comes back onland near Waldronville, and continues to South Dunedin (Bishop and Turnbull 1996). Villamor et al. (2018) noted that, near Taieri Mouth, the offset on the peneplain is diminishing northeastward. Offshore seismic reflection surveys indicate that the fault continues for ~6.5 km northeast of Taieri Island / Moturata before transitioning into an anticlinal fold (Holt 2017). That interpretation is adopted in this report, confining the offshore mapping to the fault as interpreted by Holt (2017).

To the southwest, previous maps have shown the fault going directly offshore, but, in this dataset, the fault is drawn along the beach zone for ~1.4 km before diverting offshore near Measly Beach along a sharp landward margin of two offshore reefs. This interpretation raises the possibility of a fault-related origin for the surprising course of the coastal reach of Shagree Creek, whose channel extends southwest for several hundred metres behind the dune barrier. Northeastward diversion of near-shore reaches of streams is more common, in keeping with the prevailing direction of longshore drift. It is possible, though, that the course of Shagree Creek is a quirk of coastal processes rather than being fault-related.

As mapped in this dataset, the Akatore Fault has an onland length of ~23 km, with likely offshore extensions of at least ~5 km to the southwest and ~9 km to the northeast, giving an indicative length of ~37 km. A trenching investigation at Big Creek (Taylor-Silva et al. 2020) exposed the fault, showing evidence for at least three surface rupture events with total vertical offset of between ~4 and ~5 m. The investigation also showed that the near-surface fault dip is between ~30 and ~50° SE. Previous estimates of overall dip for the fault structure of 45° and 55° given by Stirling et al. (2012) and Litchfield et al. (2014) are compatible with the new data.

The Taylor-Silva et al. (2020) investigation has shown that the Akatore Fault has experienced at least three surface ruptures since ~15,000 years ago, with total net slip in the range of 4.8 to 7.4 m. Before that, no surface ruptures had occurred since at least ~125,000 years ago, which indicates that the Akatore Fault experiences episodic rupture behaviour. This implies an indicative long-term slip rate of ~0.05 mm/year. The two most recent ruptures have occurred since ~1300 years ago. From the investigation data for the recent episode of activity, Taylor-Silva et al. (2020) calculated a recent slip rate in the range of 0.3 to 6.0 mm/year and recurrence interval in the range of 450 to ~5100 years, noting that the larger slip rate and shorter recurrence interval are extreme values.

Two additional considerations can be used to refine the Taylor-Silva et al. (2020) estimates. One is that, on the coast near the mouth of Big Creek, there is an uplifted Holocene sea cliff, with the base of the cliff and adjoining uplifted shore platform standing at ~4 to ~5 m above sea level. This is approximately the same as the vertical component of throw at the Big Creek trench and indicates that the last three ruptures recorded in the Big Creek trench must all have all occurred after the culmination of the post-glacial sea-level rise ~7000 years ago (Clement et al. 2016). Following the culmination of sea-level rise, sufficient time must have elapsed for coastal erosion to have cut a shore platform and sea-cliff in the schist bedrock along the coast, prior to the uplift events. A nominal estimate for the duration for the pre-uplift erosion of ~2000 years is assumed here. Taking an age of ~5000 years and dividing it by three rupture events that occurred since that time gives an indicative average recurrence interval of 1700 years (rounded to the nearest hundred years). That value is adopted for the purposes of this report.

A2.3 **Backbone fault** (feature 5, Figure 5.1)

The north-striking Backbone fault lies mostly in the Central Otago District and was identified and described by Barrell (2019). A summary description of the fault from the appendix of that report is presented below.

The Backbone fault is identified from an indicated up-to-the-west vertical separation of the peneplain of between ~100 and 200 m and is assumed to be a west-dipping reverse fault. There is no known geological exposure of the fault, and the line denoting its position is drawn along the foot of the topographic escarpment. It is assumed to be a west-dipping reverse fault. Only the southern 3.5 km of the fault lies in the Clutha District, and the fault is mapped as stopping at the Tuapeka Fault.

There are no known offsets of geologically young landform features, and the Backbone fault is classified as 'potentially active'. For the estimation of activity parameters, Barrell (2019) assigned a dip of 60°, length of 24 km and a nominal slip rate of 0.05 mm/year, from which a recurrence interval of ~35,000 years was calculated using the 2010 NSHM methodology.

A2.4 **Beacon Hill fault** (feature 9, Figure 5.1)

The northwest-striking Beacon Hill fault is from the QMAP dataset, where it is an unnamed fault within the Livingstone Fault System. This fault system is interpreted to be a major geological feature of New Zealand, separating different types (terranes) of basement rock, and has an overall steep dip to the northeast (e.g. Cawood 1987; Mortimer et al. 2002; Tarling et at al. 2019).

The Beacon Hill fault coincides with a notable topographic escarpment in the peneplain surface, up to the northeast, and is named here after a hill on its upthrown side. At the south end of the Blue Mountains range, the escarpment is ~150 m high but progressively diminishes southeastward to a few tens of metres high. It is up to the northwest. Because its northwestern end coincides with the end of the Blue Mountain Fault, the Beacon Hill fault is interpreted in this dataset as 'potentially active' and could possibly pick up slip transfer from the Blue Mountain Fault. Also a factor in this interpretation is that the Beacon Hill fault is nearby, and approximately parallel, to the Clifton and Otanomomo faults, which have experienced definite geologically young surface rupture.

There are no known offsets of geologically young landform features on the Beacon Hill fault. For the estimation of activity parameters, a dip of 70°, length of 21 km and a nominal slip rate of 0.05 mm/year were applied, from which a recurrence interval of ~29,000 years was calculated using the 2010 NSHM methodology.

A2.5 **Beaumont River fault** (feature 6, Figure 5.1)

The north-striking Beaumont River fault extends from the Central Otago District into the Clutha District and was identified and described by Barrell (2019). A summary description of the fault from the appendix of that report is presented below.

The Beaumont River fault is identified from an indicated up-to-the-east vertical separation of the peneplain of between ~100 and 200 m and is assumed to be an east-dipping reverse fault. There is no known geological exposure of the fault, and the line denoting its position is drawn along the foot of the topographic escarpment. It is assumed to be a west-dipping reverse fault. The southern ~15 km of the fault lies in the Clutha District, and the fault is mapped as stopping at the Tuapeka Fault.

There are no known offsets of geologically young landform features and the Beaumont River fault is classified as 'potentially active'. For the estimation of activity parameters, Barrell (2019) assigned a dip of 60°, length of 36 km and a nominal slip rate of 0.05 mm/year, from which a recurrence interval of ~50,000 years was calculated using the 2010 NSHM methodology.

A2.6 Billys Ridge Fault (feature 22, Figure 5.2)

This northeast-striking fault is ~35 km long and upthrown to the northwest, with vertical separation of the peneplain of as much as ~250 m but more commonly between ~50 and 100 m. In detail, it comprises two strands, the north-eastern one identified as the Macraes Fault and the southwestern one as the Billys Ridge Fault (Barrell 2016). The Macraes Fault is known to be a northwest-dipping reverse fault, and the Billys Ridge Fault is inferred to also be a northwest-dipping contractional fault. Only the southwestern ~9 km of the Billys Ridge Fault lies in the Dunedin district; the remainder is in the Waitaki District fault dataset, described by Barrell (2016).

Although not classified as active in the original QMAP dataset (Forsyth 2001), it has been reclassified as active in the QMAP database (Heron 2018). It is included in the NZAFD, NZAFM and NSHM (Litchfield et al. 2013). Previous estimates of fault activity parameters are discussed by Barrell (2016).

There are no known offsets of geologically young landforms or deposits. The fault is classified as a possible active fault in this dataset, following the reasoning presented by Barrell (2016). Villamor et al. (2018) identified it as an earthquake source. They considered various estimates for slip rate, ranging from 0.12 to 0.003 mm/year, and calculated corresponding average recurrence intervals in the range of ~18,000 years to more than 600,000 years. For the estimation of activity parameters for this report, a dip of 45°, a length of 34 km and nominal net slip rate of 0.05 mm/year were applied and a recurrence interval of ~47,000 years was calculated using the 2010 NSHM methodology.

A2.7 Blue Mountain Fault (feature 3, Figure 5.1)

The northeast-striking Blue Mountain Fault is one of the most topographically prominent faults of the Clutha District, with the Blue Mountains range having been uplifted on the southeast side of the fault. The vertical separation of the peneplain is as much as ~700 to ~800 m at the highest part of the range, east of Tapanui.

The fault is drawn along the foot of the range. There are no known exposures of the fault plane, but it is assumed to be a southeast-dipping reverse fault. At the north-eastern end of the fault, the fault has previously been interpreted as breaking into two strands, the main strand (Blue Mountain No. 1 Fault) and an east-northeast-striking short strand to the east (Blue Mountain No. 2 Fault) (e.g. Beanland and Berryman 1986; Turnbull and Allibone 2003). The ‘No. 1’ strand, classified as ‘active’ by Turnbull and Allibone (2003) has been depicted as terminating northeast against the Teviot Fault, while the Teviot Fault is depicted as terminating southward against the ‘No. 2’ strand (this strand was classified as ‘inactive’ by Turnbull and Allibone [2003]). That interpretation is regarded here as being unlikely kinematically.

There is no known geologically young offsets of landforms at the north-eastern end of the Blue Mountain Fault ‘No. 1’ strand (Pace et al. 2005). The likely reason that Turnbull and Allibone (2003) classified this strand as ‘active’ was because the main strand of the fault farther south is identified as the ‘No. 1’ strand. However, the main topographic expression of the Blue Mountain Fault (i.e. peneplain offset) follows the ‘No. 2’ strand, and that strand is regarded here as the main strand. From the point that the ‘No. 1’ and ‘No. 2’ strands diverge, ~16 km northeast of Tapanui, the ~3.5 km extension of the ‘No. 1’ strand is deleted and the ‘No. 2’ strand is retained. In the dataset, no distinction is made between the ‘No. 1’ and ‘No. 2’ strands, and the name ‘Blue Mountain Fault’ is applied collectively.

For a ~18 km section of the Blue Mountain Fault, between ~3.5 km south and ~15 km northeast from Tapanui, there are discontinuous steps at the front of medium- to high-level alluvial fan remnants along the foot of the range, and these have been interpreted as fault scarps (Beanland and Berryman 1986; Pace et al. 2005). In some cases, younger fan surfaces have been built out around the front of the steps, meaning that the surfaces either side of the scarp are not necessarily the same age. Stream drainage emerging from the range-front continues northwest away from the fault for as much as several kilometres. This means that the elevated steps at the foot of the range cannot be attributed to fluvial erosion but rather must have been elevated tectonically. For that reason, the fronts of the steps are identified as 'definite', 'moderately expressed' fault features, connected along strike by 'definite', 'not expressed' sections.

The section of the range-front with upfaulted alluvial fan remnants conforms with the interpretation of Pace et al. (2005), and stereoscopic examination of archival aerial photographs has been used to refine the position of the fault scarps compared to how the fault position was depicted in the QMAP.

Pace et al. (2005) report a luminescence age of 98,500 ± 10,300 years for the deposits of an alluvial fan, interpreted to have been offset ~20 m vertically across the Blue Mountain Fault. The typical scarp height on the old fans is between 10 and 20 m, and, for the purpose of this assessment, the mean age was taken as the time elapsed for an average of ~15 m vertical displacement. For the estimation of activity parameters, a dip of 45° and fault length of 35 km were assigned. This length value approximates the northeast-southwest length of the Blue Mountains range. The calculated vertical slip rate is ~0.15 mm/year. When resolved onto a 45° dipping fault plane with an inferred pure dip-slip motion, this equates to a net slip rate of 0.22 mm/year. From those values, a recurrence interval of ~11,300 years was calculated using the 2010 NSHM methodology. This is approximately the same as the recurrence interval of ~12,700 years calculated by Stirling et al. (2012) from the data provided by Pace et al. (2005). That value differed from the 'best estimate' of ~20,000 years determined by Pace et al. (2005). Balancing of slip rates across the wider region was a consideration in the Stirling et al. (2012) estimates but necessitated applying a fault length of 51 km, which is more than can be supported from geological data. In any case, all of the past estimates of recurrence interval indicate that Blue Mountain Fault has a relatively low level of activity, as assessed by recurrence interval.

The Blue Mountain Fault is mapped as 'likely' at its northeast end, close to its intersection with the Tuapeka Fault. Refer to the section on the Tuapeka Fault for discussion of possible transfer of slip from the Blue Mountain Fault to the Tuapeka Fault.

A2.8 Clifton Fault (feature 8, Figure 5.1)

This west-northwest-striking fault is identified solely on the basis of landform offsets. The fault has no general topographic expression across downlands terrain. It was first identified several decades ago and is named after the Clifton rural locality. In QMAP, it is identified as part of the Livingstone Fault System. This fault system is interpreted to be a major geological feature of New Zealand, separating different types (terranes) of basement rock, and has an overall steep dip to the northeast (e.g. Cawood 1987; Mortimer et al. 2002; Tarling et at. 2019).

There is no LiDAR in the area of this fault, and its position and characteristics were reviewed using archival black and white aerial photos. The review found that the position of the fault was depicted in QMAP, and the NZAFD, with poor precision. As part of this project, it has been accurately repositioned, at ~1:10,000-scale, resulting in it being shifted as much as 400 m south of where it was previously shown.

Only the central ~4 km of the fault has a fairly continuous, undoubted fault scarp, up to several metres high, and is classed as ‘definite’. It appears to be quite a broad scarp in many places, so is classified as ‘moderately expressed’. The remainder is classified as ‘likely’.

With a total identified length of 11 km, the Clifton Fault is probably too short to account for the presence of several-metre-high surface offsets. This same problem exists for the Otanomomo fault, farther to the southeast, which has similar expression in the landscape to that of the Clifton Fault. For the estimation of activity parameters, the interpretation is made that those two faults are the surface expressions of the rupture of an unidentified fault at depth. The collective distance between the eastern end of the Otanomomo fault and the western end of the Clifton Fault is 27 km. Assuming both faults are reverse faults with dips of 70°, and pure dip-slip motion, the Otanomomo fault scarp height of 4 m with an adopted age of 45,000 years equates to a 0.09 mm/year net slip on the fault plane, and a recurrence interval of ~19,900 years was calculated using the 2010 NSHM methodology. These parameters are also applied to the Clifton Fault.

A2.9 **Dunback Hill Fault** (feature 24, Figure 5.2)

This northeast-striking fault is upthrown to the northwest, with vertical separation of the Otago peneplain of as much as ~150 m but mostly between ~50 and ~100 m. It is inferred to be contractional, with a dip to the northwest.

Similarly to the Flat Stream – Glenpark Fault, there is a step-over in central section of the Dunback Hill Fault, comprising a ~2 km step to the southeast. The north-eastern strand of the fault is named ‘Dunback Hill Fault’ in the QMAP, while the southwestern strand was un-named. The peneplain offset implies that the two faults are closely associated, and the name ‘Dunback Hill’ is applied to both strands in this dataset.

The fault strands were shown as inactive in the QMAP dataset, and are not in the NZAFD, NZAFM or NSHM. There are no known offsets of geologically young landforms or deposits, and the fault is classified in this dataset as potentially active. Villamor et al. (2018) identified what they called simply the Dunback Fault as a potential earthquake source. They considered various estimates for slip rate ranging from 0.07 to 0.002 mm/year and calculated corresponding average recurrence intervals in the range of ~34,000 years to more than 1 million years. For the estimation of activity parameters for this report, a dip of 45°, a length of 37 km and nominal net slip rate of 0.05 mm/year were applied, and a recurrence interval of ~52,000 years was calculated using the 2010 NSHM methodology.

A2.10 **Flat Stream – Glenpark Fault** (feature 26, Figure 5.2)

This northeast-striking structure, upthrown to the northwest, comprises the ~35 km long Flat Stream Fault in the southwest, which steps over to the ~20 km long Glenpark Fault in the northeast. At its southwest end on the Barewood plateau, the Flat Stream Fault has a ~10–20 m vertical separation of the peneplain (Villamor et al. 2018), which increases to as much as ~200 m before petering out towards Switchback Hill. At that location, the Glenpark fault becomes evident ~1.5 km southeast of the Flat Stream Fault. Vertical separation of the peneplain across the Glenpark fault is between ~50 and ~100 m. The Nichols Rock monocline (separate section) commences at the southwest end of the Flat Stream Fault.

The Flat Stream – Glenpark Fault is inferred to be contractional, with a dip to the northwest. The fault is shown as inactive in the QMAP dataset and is not in the NZAFD, NZAFM or NSHM. There are no known offsets of geologically young landforms or deposits, and the fault is classified in this dataset as potentially active. Villamor et al. (2018) identified the Flat Stream – Glenpark Fault as a potential earthquake source. They considered various estimates for slip rate ranging from 0.05 to 0.001 mm/year and calculated corresponding average recurrence intervals in the range of ~68,000 years to more than 2 million years. They also considered a scenario in which the Flat Stream – Glenpark Fault ruptures together with the fault underlying the Nichols Rock monocline, and that scenario has an average recurrence interval of more than 100,000 years. For the estimation of activity parameters for this report, a dip of 45°, a composite length of 45 km for the Flat Stream – Glenpark Fault and nominal net slip rate of 0.05 mm/year were applied, and a recurrence interval of ~63,000 years was calculated using the 2010 NSHM methodology.

A2.11 **Green Island Fault** (feature 17, Figure 5.2)

This northeast-striking fault is identified from offshore bathymetric and geophysical surveys (Holt 2017). Although it is wholly an offshore fault, it is included in this dataset because of a possible association with the onshore Kaikorai Fault interpreted by the writer in the Villamor et al. (2018) report. The writer now considers that there is a difficulty with that interpretation. There is evidence, afforded by what appears to be a fault scarp on the sea floor, that the Green Island Fault has experienced a geologically recent surface rupture, probably in the past few thousand years (Holt 2017). In contrast, there is no onland landform evidence for any fault scarp on the hill slope terrain on the line of the Kaikorai Fault, suggesting that it has not experienced a geologically recent surface rupture. It seems more likely that the indicated recent scarp on the Green Island Fault may be more closely associated with that of the Akatore Fault. For example, the Green Island Fault’s most recent rupture(s) may have been triggered by geologically recent Akatore Fault rupture(s) or perhaps may have occurred independently in a similar time frame.

Offshore surveys indicate a length of ~16 km for the Green Island Fault. There is no information on the older geological history of movement of the Green Island Fault, for example, whether its rupture pattern is closely similar to that of the Akatore Fault. For the estimation of activity parameters for the Green Island Fault, a dip of 45° and slip rate of 0.05 mm/year (indicative long-term average rate for the Akatore Fault) are applied, from which a recurrence interval of ~22,000 years was calculated using the 2010 NSHM methodology.

A2.12 **Hillfoot Fault** (feature 10, Figure 5.1)

This west-northwest-striking fault is a major geological feature, separating two different types of basement rock (Mortimer et al. 2002) and is thought to have a near-vertical dip. The fault is marked by a prominent topographic step, up to the southwest. The vertical separation of the peneplain is typically as much as ~300 m. There are no known geologically young offsets of landform features along the fault in the Otago Region, and it is not in the NSHM or the NZAFD. The prominence of the topographic step, sometimes referred to as the Murihiku Escarpment, is the reason why it is included in this dataset as a potentially active fault. The fault continues into the Southland Region, and for the purpose of estimating potential seismic hazard, this part of the Hillfoot Fault is stopped at Gore, where there is a major cross-cutting fault that breaks the continuity of the escarpment. Farther northwest towards Lumsden, about 50 km west of the Otago region, Turnbull and Allibone (2003) did interpret a geologically young offset on a

~14 km long section of the Hillfoot Fault. This was an added factor in the decision made here to classify the Hillfoot Fault in Otago as potentially active.

Towards the southeastern coast, the Hillfoot Fault reduces in topographic prominence, and another strand, the Little Hillfoot Fault, is shown in QMAP as lying up to ~2.5 km northeast of the main strand. The topographic expression of the Little Hillfoot Fault is generally no more than 100 m or so, up to the southwest. It is mapped as extending offshore to about Nugget Point. In this dataset, both fault strands are classified as potentially active, and they are regarded as connected at depth.

For the estimation of activity parameters, a dip of 75°, length of 80 km and nominal slip rate of 0.05 mm/year are applied, from which a recurrence interval of ~110,000 years was calculated using the 2010 NSHM methodology.

A2.13 **Horse Flat Fault** (feature 21, Figure 5.2)

This northeast-striking fault is ~35 km long and upthrown to the northwest, with vertical separation of the peneplain of as much as ~200 m. The Horse Flat Fault (also known as the Taieri Ridge Fault) is inferred to be a northwest-dipping reverse fault. Only the southwestern ~2 km of the fault lies in the Dunedin district; the remainder is in the Waitaki District fault dataset, described by Barrell (2016).

Although not classified as active in the original QMAP dataset (Forsyth 2001); it has been reclassified as active in the QMAP database (Heron 2018). It is included in the NZAFD, NZAFM and NSHM (Litchfield et al. 2013). Previous estimates of fault activity parameters are discussed by Barrell (2016).

Interpretations have been made about possible deformation of geologically young landforms or deposits (Norris and Nicolls 2004), but these were regarded as equivocal by Barrell (2016). The fault is classified as a possible active fault in this dataset, following the reasoning presented by Barrell (2016). Villamor et al. (2018) identified it as a potential earthquake source. They considered various estimates for slip rate, ranging from 0.12 to 0.003 mm/year, and calculated corresponding average recurrence intervals in the range of ~17,000 years to more than 600,000 years. For the estimation of activity parameters for this report, a dip of 45°, a length of 35 km and a nominal net slip rate of 0.05 mm/year were applied, and a recurrence interval of ~49,000 years was calculated using the 2010 NSHM methodology.

A2.14 **Hyde Fault** (feature 20, Figure 5.2)

The northeast-striking Hyde Fault lies along the southeastern foot of the Rock and Pillar Range, which has been uplifted on the northwestern side of the fault. The vertical separation of the peneplain is as much as ~1200 m at the highest part of the range, northwest of Middlemarch. There is LiDAR coverage along most of the range-front. The following description progresses from northeast to southwest.

Northeast of Hyde village, the fault is classified as ‘likely, not expressed’, because its expression has involved an amount of folding. To the southwest, where the range becomes progressively higher, the fault is classified as ‘definite’, ‘not expressed’. At the Hyde gold diggings, the fault location in bedrock is well constrained (Norris et al. 1994) and is classified as ‘moderately expressed’. South of Heeney Creek, the position of the fault as located in the QMAP dataset has been refined with the aid of LiDAR. For about 15 km along the range-front, from Lug Creek in the north (~11 km north of Middlemarch) to the catchment of Doughboy

Creek in the south (~5 km west of Middlemarch), there are moderately to well-expressed fault scarps. The QMAP fault was shifted to accord to the fault scarp locations interpreted from LiDAR. Farther south along the range-front, the fault was repositioned to accord with the toes of landslide terrain at the foot of the slope. The reasoning for this is that the fault is inferred to lie at the foot of the range, that landslides are ubiquitous along this part of the range and that the toes of the landslides approximately define the foot of the range.

The topographic expression of the Hyde Fault diminishes southwest toward the headwaters of Sutton Stream, but thereafter an escarpment of tectonic origin becomes increasingly prominent towards the south (The Twins monocline; see separate section).

Recent geological investigations of the Hyde Fault, the data from which are still undergoing assessment, indicate that at least two ruptures, totalling about 4 m of uplift, have occurred in the past ~60,000 years (Jonathan Griffin, personal communication, July 2020). This implies a long-term vertical slip rate of ~0.07 mm/year. At that rate, it would have taken more than 10 million years to uplift the Rock and Pillar Range. There is also evidence from the geological investigations that the two most recent ruptures occurred in relatively quick succession, the earlier one ~23,000 years ago and the later one ~10,000 years ago. Taking the ~4 m uplift for those events and averaging it over ~23,000 years indicates a vertical uplift rate of 0.17 mm/year, at which rate the Rock and Pillar Range could have formed in the past ~5 million years. Either scenario for initiation of uplift is plausible. For the estimation of Hyde Fault activity parameters, an overall fault dip of 45° is assumed, and the faster vertical slip rate is preferred as it is more conservative from a ground surface tectonic deformation perspective. When the vertical slip rate is resolved onto a fault plane with an inferred pure dip-slip motion, this equates to a net slip rate of 0.25 mm/year. Taking the fault length as 50 km, an average recurrence interval of ~14,200 years was calculated using the 2010 NSHM methodology.

For comparison, Villamor et al. (2018) considered various estimates for slip rate ranging from 0.68 to 0.019 mm/year and calculated corresponding average recurrence intervals in the range of ~5600 to ~200,000 years. Stirling et al. (2012) applied a slip rate of 0.25 mm/year and calculated a recurrence interval of ~12,800 years. Overall, the Hyde Fault is assessed here as being a relatively low activity fault.

A2.15 Kaikorai fault (feature 18, Figure 5.2)

A2.15.1 Kaikorai valley

The existence of this northeast-striking fault is inferred from geological relationships (Villamor et al. 2018). There are differences in the elevations of the base of Dunedin Volcanic Group rocks either side of Kaikorai valley. Near the Southern Reservoir, on the west side of valley, the base of the volcanics is ~80 m asl (Glassey and Barrell 2000) but, on the ridge east of the valley, the base of the volcanics is ~140 m asl (McKellar 1990).

Farther up-valley, near the confluence of Frasers Gully and Kaikorai Stream, Benson’s (1968) map shows a northeast-striking fault at the foot of the southeastern side of Kaikorai valley, with Caversham Sandstone up-faulted to the southeast against volcanics. The geological relationships depicted on Benson’s map, when compared to the LiDAR elevation model, only require a throw of 35 m or so.

The southeastern side of Kaikorai valley is topographically prominent. Geologically, the southwestern side of Kaikorai valley comprises a general dip-slope of ~5° southeast off the crest of the Titri Anticline, approximating the base of Dunedin Volcanic Group. The underlying older geological strata dip a little steeper southeast (~10°), and progressively younger components of those strata are exposed approaching Kaikorai valley. In the Burnside – Green Island suburbs, Caversham Sandstone outcrops on the southeast side of the valley, forming a relatively steep 'scarp-slope' facing into the valley. This is a common landform associated with Caversham Sandstone outcrop in coastal Otago, because the sandstone is relatively stronger and more stable than the older formations. However, the topographic prominence of the southeastern side of Kaikorai valley continues to the northeast, beyond the Caversham Sandstone outcrop. At the head of Kaikorai valley, the prominent Maori Hill – Roslyn ridge is the continuation of this topographic promontory, but has volcanic rocks outcropping both sides of the topographic step. The height of the step decreases progressively northeast and dies out approaching the Leith valley. As the topographic step does not appear to be associated with a particular rock type, it lends weight to the interpretation that the step has a tectonic origin.

Towards the coast, between the Green Island and Waldronville suburbs, there is poor outcrop in the topographic escarpment. All previous geological maps (Ongley 1939; Benson 1968; McKellar 1990) show different outcrop patterns. A case could be developed for either no fault or for a fault with as much as ~100 m throw. If the outcrop pattern on McKellar's (1990) map is correct, it does highlight a difference in geological structure either side of Kaikorai valley. The outcrop pattern implies that, on the southeast side of the valley, the base of Caversham Sandstone has a gentle eastward dip of ~2 or 3°, and the base of Dunedin volcanics is near-flat near Kaikorai valley before developing a gentle eastward dip near St Clair. The contrasts in dip angle and dip direction either side of Kaikorai valley is the strongest evidence for the existence of the Kaikorai fault in the Green Island – Waldronville area.

Uncertainties of geological interpretation limit the confidence in mapping the position of the inferred Kaikorai fault. From the coast through Green Island suburb, the fault is drawn along a change from gentler slopes below to steeper slopes above. This position is compatible with stratigraphic exposure data shown on the Ongley (1939) and McKellar (1990) maps. Near the Burnside southbound off-ramp on the Southern Motorway, the fault is positioned as running out under the valley floor. It is drawn approximately along Kaikorai Valley Road until the Bradford suburb, where it is positioned along the southeastern margin of the valley floor. Near Brockville Road, the fault is drawn in the position of the fault shown on Benson's map. From there, it is continued along the broad valley on the northwestern margin of the Roslyn – Maori Hill ridge. The position there approximates the Kaikorai Stream channel, being as good a place as any to draw it. The fault is stopped at Balmacewan Road, where the ridge loses expression.

A2.15.2 Caversham valley and South Dunedin

Small fault offsets (centimetre to decimetre scale) were observed in the Lookout Point motorway overbridge excavation. They offset weathering colour-bands within highly weathered Caversham Sandstone, but the offsets do not extend up into the overlying loess, implying that the most recent movements occurred at least 100,000 years ago (Barrell and Litchfield 2013). Most of these faults have near-vertical dips, strike east-southeast and are downthrown to the north. There are also some shallow-dipping north-northeast-striking faults that dip gently east, with centimetre to decimetre scale displacements up to the west, implying a reverse component of movement. It was not possible to establish whether these faults are of tectonic origin or, alternatively, are related to slope movements. A subsequent inspection of a nearby deeper exposure found that the small-scale faults there do not extend down into the underlying less-weathered Caversham Sandstone. It was concluded that those small-scale faults were formed by gravitational movements within the highly weathered Caversham Sandstone rather than being fault-related phenomena (Barrell 2014). However, this does not preclude the possibility that a fault does pass through Lookout Point and, if so, most likely lies on the southeastern side of the overbridge (Ioannis Antonopoulos, Opus International Consultants, personal communication, 2013).

In Caversham valley, Caversham Sandstone is present on the southeast side of the valley, as seen in the railway tunnel portal, for example. In the Southern Motorway foundation excavation near the valley floor near Barnes Drive and at the Glen, saturated highly plastic clay was encountered that is suspected to mark the contact between Caversham Sandstone and overlying volcanic rock (personal observation of the writer). This provides a basis for tentatively inferring a fault, upthrown to the southeast by a few tens of metres, down the axis of Caversham valley and just south of the motorway through the Caversham suburb.

From there, the fault is extrapolated east, close to the position of the motorway and railway line, and on across South Dunedin to the margin of Otago Harbour.

A2.15.3 Overall Interpretation

The geological information is tentatively resolved to interpret the presence of a fault, upthrown to the southeast of as much as 50–100 m, along the eastern side of Kaikorai valley, with a splay extending east through Lookout Point and into South Dunedin, with perhaps a few tens of metres throw, up to the south. There are no known offsets or deformation of geologically young landform features or sedimentary deposits across the Kaikorai fault or its Caversham Valley splay.

For earthquake source modelling, Villamor et al. (2018) used a combined length of the Kaikorai fault and the offshore Green Island Fault. A problematic aspect of that approach is that the Green Island Fault is interpreted to have experienced a geologically young surface rupture, because a bathymetric step on the sea floor is interpreted to be a fault scarp (Holt 2017; Villamor et al. 2018). In contrast, there is no evidence for geologically young movement on the Kaikorai fault.

A feature of note is that the Kaikorai fault is broadly parallel to and 4–5 km southeast of the Titri Fault and Titri Anticline. It is conceivable that the Kaikorai fault is a splay at depth off the Titri Fault. If that is the case, then one possibility is that the Kaikorai fault may potentially rupture together with the Titri Fault rather than being an independently rupturing fault. That then raises a question as to whether the Kaikorai fault relates to an earlier phase of Titri Fault development and may no longer be active. Conversely, it could be an ongoing component of Titri Fault evolution. These possibilities are raised here for completeness but cannot be resolved from present information. It is regarded as most prudent to regard the Kaikorai fault as an independent entity for the purposes of this assessment.

Villamor et al. (2018) considered various estimates for combined Green Island / Kaikorai fault slip rate ranging from 0.04 to 0.001 mm/year and calculated corresponding average recurrence intervals in the range of ~35,000 to more than ~1.3 million years. For the estimation of activity parameters for this report, a length of 16 km is applied to the Kaikorai fault by itself (including the Caversham valley splay). Adopting a dip of 45° and a nominal net slip rate of 0.05 mm/year return a recurrence interval of ~22,000 years using the 2010 NSHM methodology.

A2.16 Murphys Creek Fault (feature 23, Figure 5.2)

This northeast-striking fault is ~35 km long and upthrown to the northwest, with vertical separation of the peneplain of as much as ~100 m. It is inferred to be contractional, with a dip to the northwest.

The fault is shown as inactive in the QMAP dataset and is not in the NZAFD, NZAFM or NSHM. There are no known offsets of geologically young landforms or deposits, and the fault is classified in this dataset as potentially active. Villamor et al. (2018) identified it as a potential earthquake source. They considered various estimates for slip rate ranging from 0.05 to 0.001 mm/year and calculated corresponding average recurrence intervals in the range of ~46,000 years to more than 1 million years. For the estimation of activity parameters for this report, a dip of 45°, length of 37 km and nominal net slip rate of 0.05 mm/year were applied and a recurrence interval of ~52,000 years was calculated using the 2010 NSHM methodology.

A2.17 Nichols Rock monocline (feature 25, Figure 5.2)

This north-northeast-striking feature forms a subtle topographic step, up to the northwest. Because it is a broad rather than sharp step, it is assumed to be a monocline rather than a fault at the ground surface. Villamor et al. (2018) characterised this structure as a potentially active fault, on the presumption that the monocline is underlain by a fault whose subsurface rupture would generate an earthquake. This feature was referred to as the ‘Nichols Rock’ active fault earthquake source by Villamor et al. (2018), and the name ‘Nichols Rock monocline’ is applied here after Nichols Rock Road, which crosses the monocline escarpment just east of State Highway 87.

The vertical separation of the peneplain across the monocline is as much as ~60 m. The best evidence of tectonic origin is adjacent to State Highway 87 near ‘Abbotsford’ farm, where a remnant of quartz sandstone, overlain by volcanic rock, is preserved on the peneplain at the foot of the monocline. North from there, the highway ascends the ~800-m-wide monocline, with the schist plateau at the crest of the monocline standing ~55 m higher than it does at ‘Abbotsford’. To the northeast, the monocline’s expression dies out at about the location where the southwestern end of the Flat Stream Fault scarp becomes evident, ~1.5 km to the northeast. To the southwest, the expression of the monocline is lost in irregular dissected terrain of the Lee Stream valley. The line representing the monocline is positioned at the foot of the topographic step.

There are no known offsets or deformation of geologically young landform features. Villamor et al. (2018) considered various estimates for slip rate ranging from 0.04 to 0.001 mm/year and calculated corresponding average recurrence intervals in the range of ~35,000 to more than ~1.3 million years. For the estimation of activity parameters for this report, a dip of 45°, length of 21 km and a nominal net slip rate of 0.05 mm/year return a recurrence interval of ~28,000 years using the 2010 NSHM methodology.

A2.18 Otanomomo fault (feature 9, Figure 5.1)

This east-west-striking fault is identified solely on the basis of landform offsets. It is named after the nearby Otanomomo locality. The fault has no general topographic expression across downlands terrain to the west and runs across two northwest-striking faults in bedrock shown in QMAP as part of the Livingstone Fault System. The fault scarp is most prominent where it is crossed by the Owaka Highway ~2 km south of Finegand meatworks. Previously mapped as a step between a higher and lower river terrace by Barrell et al. (1998), the availability of LiDAR makes it clear that it is a definite fault scarp. The main terrace, previously thought to be two terraces, has an ~4-m-high scarp at the highway, up to the north. About a kilometre to the east, there is a remnant inset terrace about 4 m lower than the main terrace, and it has a ~1- to 2-m-high fault scarp across it. A luminescence age of 134,000 ± 18,000 years was obtained by Barrell et al. (1998) on beach sand underlying the main terrace, indicating it is of last interglacial age. They also obtained a date from the base of a ~3.2-m-thick loess layer overlying the sand of 38,000 ± 7600 years. As it is the terrace surfaces that offset, a reasonable interpretation seems to be that the fault offsets occurred after at least part, if not all, of the loess had accumulated. On that basis, the fault is interpreted to have ruptured at least twice since ~45,000 years (older bound of the loess age).

It is noted that the new information from LiDAR means that the geomorphological map of he Inch Clutha Plains (Figure 4 in Barrell et al. [1998]) is now not correct in the Telford-Otanomomo area due to the new interpretations of fault scarps.

With the aid of LiDAR and aerial photos, the fault can be tracked as a distinct step on the downlands terrain to the west. It is mapped as 'definite', and either 'moderately expressed' or 'not expressed', for 3 km west of the Owaka Highway. Beyond there, its expression is less clear cut and it is classified as 'likely' for a further 3 km, beyond which it cannot be discerned. Towards the east, it is extrapolated as 'not expressed' across the Clutha floodplain and stopped before it meets the mapped location of the Livingstone Fault, on the presumption is does not cross that major geological structure.

With a total identified length of 10 km, the Otanomomo fault is too short to account for the size of surface offsets of as much as 2 m per event. This same problem exists for the Clifton Fault, farther to the northwest, which has similar expression in the landscape to that of the Otanomomo fault. For the estimation of activity parameters, the interpretation is made that those two faults are the surface expressions of the rupture of an unidentified fault at depth. The collective distance between the eastern end of the Otanomomo fault and the western end of the Clifton Fault is 27 km. Assuming both faults are reverse faults with a dip of 70°, and pure dip-slip motion, the Otanomomo fault scarp height of 4 m with an adopted age of 45,000 years equates to a 0.09 mm/year net slip on the fault plane, and a recurrence interval of ~19,900 years was calculated using the 2010 NSHM methodology.

A2.19 Settlement Fault (feature 11, Figure 5.1)

The northeast-striking Settlement Fault displays a vertical separation of the Catlins erosion surface of the order of 100 m, up to the southeast. The fault has uplifted a Holocene sea cliff and adjoining shore platform on the eastern side of Catlins Lake, demonstrating at least one surface rupture since the present sea level was attained in the mid-Holocene, ~7000 years ago (Clement et al. 2016). The villages of Pounawea and at Jacks Bay are built on former shore platforms raised above sea level by recent movement(s) on the Settlement Fault.

A2.19.1 Geological Character

The fault was originally mapped from geological relationships in the Jurassic-age greywacke bedrock that underlies the area (Speden 1971). Those relationships indicate that the geological sense of bedrock offset across the Settlement Fault is down to the southeast, of opposite sense to the current topographic sense of offset.

According to Speden (1971), most of the northeast-striking faults in the north-eastern Catlins area have a ‘normal’ sense of geological throw, and on his map notes the amounts of offset of distinctive stratigraphic contacts, where present. There is only one recorded offset on the Settlement Fault, at Purakaunui valley, of 1200 feet (~370 m) vertical component of offset down to the southeast. The interpretation is made here that the Settlement Fault is a re-activated former normal fault that originally accumulated vertical downthrow of ~500 m to the southeast. Movement has subsequently reversed, with ~100 m of vertical upthrow to the southeast seen across the Catlins erosion surface, which has partly restored the original stratigraphic offset.

A2.19.2 Location and Expression of the Fault

In the southwest, a well-expressed fault scarp is preserved at the south coast on the eastern side of a pocket beach, on the west side of the Irihuka (Long Point) headland. There is an uplifted Holocene sea cliff and shore platform immediately east of the fault scarp, but not to the west. LiDAR analysis indicates the scarp is about 2 m high. This location lies ~4 km west of where the Settlement Fault was previously drawn at the coast, at the eastern end of Tahakopa Bay by Speden (1971) and Bishop and Turnbull (1996), with a north-easterly strike to the Purakaunui River valley. That mapping of the fault was based on bedrock geological relationships, but neither the topographic expression of the Catlins erosion surface offset or the geologically young surface fault scarp follow that trend. The topographic expression and surface fault scarp at the coast instead take a more northerly trend and meet the geologically mapped position of the fault at the Purakaunui River valley. Either the original mapping interpretation was incorrect or the more recent movement on the Settlement Fault near Catlins Lake has diverged southward off the original fault.

Northeast of the Purakaunui River valley, the fault underlies steep and irregular hill terrain on the northwest side of Hinahina Hill through to the southern margin of the Catlins Lake estuary. There are some topographic anomalies on spurs low on the slope that may mark the fault location, but there is much evidence of past landslide and hillslope erosion activity, that could also account for topographic anomalies. Accordingly, the fault through this area is classified as ‘not expressed’.

At the southwestern shore of Catlins Lake, the position of the fault has been shifted about 150 m west of where it was shown by QMAP to place it west of the Holocene sea cliff. Under Catlins Lake, the exact position of the fault is not known, and it is interpolated between points of geomorphic constraint at the southwestern and northern shores.

On the northern shore of Catlins Lake, Hinahina Rd runs along the foot of the uplifted sea cliff, and the uplift ceases where Hinahina Rd heads inland northeast towards Owaka. At that location, a short segment of the fault is classified as ‘well defined’.

The fault scarp extends past the eastern outskirts of Owaka as a broad topographic step, in a few places with a more distinct break in slope. There is no LiDAR coverage through this area, so high-resolution colour aerial photographs, aided by Street View from the sealed roads, were used to refine the position of the QMAP line representation of the fault to more closely accord with the topographic features. It is classified as ‘moderately expressed’.

Across the Owaka River valley floor northeast of Owaka township, the Owaka Highway is constructed approximately along the crest of the fault scarp. This is evident at the Owaka River bridge, where the valley floor is a wide poorly drained floodplain west of the road, but, east of the road, the valley floor is a terrace, about 1 or 2 m higher than the floodplain to the west, into which the river channel is incised. Due to the good constraint on fault location in this area, it is classed as 'well expressed', even though its detail is obscured by the roading earthworks.

For about 1 km on the northeast side of the Owaka valley, the fault scarp is unusually sharply expressed as a several-metre-high step along the hill slope, parallel to and about 170 m east of the Owaka Highway. Farther northeast towards the saddle where Dans Peak Rd branches off the highway, an alignment of changes in slope near the foot of the hill east of the highway are inferred to mark the fault scarp, classed as 'definite', 'moderately expressed'.

Along strike northeast of there, there is no indication of a fault scarp or notable topographic step. A short 'possible' extension is drawn out into the Ahuriri Flat valley. Whether the most recent deformation on the Settlement Fault stopped at the Ahuriri Flat valley, or stepped elsewhere, is unknown.

A2.19.3 Evidence for Fault Rupture Events / Uplift Events

Based on microfossil faunas from sediment cores, Hayward et al. (2007) reported evidence for three Holocene earthquake events on the Settlement Fault, based on subsidence or uplift either side of the fault (determined by changes in water depth). The indicated events were ~1000 calendar years ago (0.4 m of subsidence – downthrow or compaction – west of the fault), ~3600 calendar years ago (1.2 m uplift of an extensive terrace on the east side of the fault) and an earlier event ~5000–4500 calendar years ago (1 m of abrupt subsidence west of the fault). Figueira and Hayward (2014) subsequently re-interpreted the earlier event as non-tectonic, arising from erosion and reworking of microfossils. At least one, but not necessarily more, Holocene rupture accounts for the uplifted shore platform, with timing of uplift at ~3600 years ago fixed by radiocarbon dating of a cockle shell on the platform (Hayward et al. 2007).

From a landform perspective, in several places where the fault is 'moderately expressed' across hill or downland terrain, the overall topographic step is usually 5 to 10 m high, substantially more than the 1–2-m-high scarp that displaces Holocene shoreline features at Catlins Lake and the south coast. This indicates that previous surface ruptures are preserved in the landscape, but the ages of those hill or downland surfaces are unknown. There are no mapped remnants of previous interglacial marine terraces along the coast southeast of the Settlement Fault (Speden 1971; Bishop and Turnbull 1996). This likely reflects a combination of the highly exposed coast, with an active cliff-line usually several tens of metres high, and relatively slow rates of uplift that means that any previously formed shore platforms have been removed during the Holocene.

There is only one likely remnant of a previous interglacial terrace southeast of the fault, near Catlins Lake about 1 km southwest of the Hinahina Road bridge over the estuary. This terrace remnant is alongside the C7 radiocarbon dating site of Hayward et al. (2007) that furnished the ~3600-year age of the Holocene terrace uplift. The higher terrace remnant is illustrated in Figure 7 of that paper as a suspected last interglacial (~125,000 years old) terrace. This site is just within LiDAR coverage, and the LiDAR data are consistent with that interpretation. LiDAR shows that the ~400-m-long by 400-m-wide terrace remnant is nearly flat, with an elevation of between 10 and 15 m above sea level (asl). Its northern margin is the ~3600-year-old sea cliff at the back of the ~2-m-asl uplifted Holocene shore platform.

In regard to the nature of the 10 to 15 m asl terrace, Figure 77 of Speden (1971) is a detailed inset map of this locality, showing fossil collection sites and bedrock structural data. There is a bedrock fossil collection site at the western edge of this terrace remnant and a bedrock dip and strike measurement in the middle of the terrace remnant. This suggests that the terrace is largely an eroded bedrock platform with little sediment cover.

The last interglacial peak sea level is generally regarded as having been ~5 m higher than present. Assuming that this terrace is ~125,000 years old and stands ~5 to 10 m above its assumed altitude of formation, this implies that between 5 and 10 m of uplift has occurred over the past ~125,000 years.

A2.19.4 Long-Term Slip Rate and Activity Estimates

The nature and estimated age of the 10 to 15 m asl terrace remnant described above implies a long-term uplift rate (including the most recent uplift[s]) of between 0.04 and 0.08 mm/year. The average of the two rate calculations (0.06 mm/year) is therefore taken as a satisfactory long-term uplift estimate at this location.

A longer-term estimate of vertical displacement rate can be made by assuming that the ~100 m offset of the Catlins erosion surface across the Settlement Fault was achieved over the past ~2 million years – an indicative reference age used by Barrell (2019) to calculate nominal slip rates for some faults farther inland in Otago. This implies a net long-term vertical displacement rate of 0.05 mm/year.

Collectively, the generally subdued nature of the fault scarp in most places, and the lack of flights of fluvial or marine terraces on the uplifted side of the Settlement Fault, is consistent with it being a relatively low activity fault over the long-term, but one that has experienced a geologically young rupture or ruptures.

The collective distance over which the ‘definite’ geologically young displacement features are mapped on the Settlement Fault is 19 km, from the south coast to the southwestern margin of the Ahuriri Flat valley. Allowing for small extension of the fault offshore to the south, and into the Ahuriri Flat valley, an overall fault length of 23 km is adopted, the same length as assigned by Stirling et al. (2012).

For a long-term estimation of activity parameters using the 2010 NSHM methodology, a fault dip of 45°, length of 23 km and slip rate of 0.08 mm/year (0.06 mm/year uplift since ~125,000 years ago, resolved onto a 45° dipping fault plane with assumed pure dip slip motion) return a calculated recurrence interval of ~20,000 years.

A2.19.5 Short-Term Slip Rate and Activity Estimates

The activity estimates assigned by Stirling et al. (2012) emphasise the Holocene movement evidence from the data of Hayward et al. (2007). Using an assigned fault dip of 45° and slip rate of 0.4 mm/year, they calculated a recurrence interval of 4000 years. The work of Figueira and Hayward (2014) has discounted the earlier event ~5000–4500 years ago. The uplift event ~3600 years ago is well constrained by geomorphology (raised shore platform and cliff) and radiocarbon dating of a cockle shell on the uplifted shore platform. A subsequent rupture event ~1000 years ago, inferred by Hayward et al. (2007), is regarded here as more equivocal than the evidence of the conspicuously uplifted Holocene terrace. However, it remains possible that the uplifted terrace is the composite result of two recent fault ruptures, an earlier and larger rupture ~3600 years ago and a smaller later one ~1000 years ago. Assuming that an overall vertical separation across the fault of ~2 m has occurred in at least two ruptures since ~3600 years ago indicates an average vertical slip rate of 0.56 mm/year. Resolved onto a 45°-dipping fault plane with assumed pure dip-slip motion indicates a net slip rate of 0.79 mm/year, and, with 23 km fault length, a recurrence interval of 1800 years is calculated.

A2.19.6 Summary

This review of information highlights similarities between the Settlement Fault and the Akatore Fault. Both have a north-easterly strike, similar length and similar total offset of the peneplain, or peneplain-like, surface. The Akatore Fault has well-demonstrated slow long-term slip rate, but a more recent re-activation since ~15,300 years ago, with at least three surface ruptures since that time and the most recent between ~1000 and ~750 years ago (Taylor-Silva et al. 2020). For the current episode of greater fault activity since ~15,300 years ago, they calculated an Akatore Fault slip rate of between 0.3 and 6.0 mm/yr and corresponding recurrence interval range of between 450 and 5110 years. More investigation would be needed to determine whether or not the Settlement Fault Holocene activity involved more than one rupture.

The available evidence indicates that the Settlement Fault has experienced a recent re-activation, possibly involving more than one recent rupture in the late Holocene. If this is the case, the short-term recurrence interval (~1800 years) is much less than the estimated long-term recurrence interval (~20,000 years) and implies an episodicity of fault rupture and a possibility that the fault may currently be in a more active phase. It is therefore regarded here as prudent to adopt the short-term recurrence interval of ~1800 years as the best current working estimate of activity.

A2.20 Silver Stream – Merton Fault (feature 16, Figure 5.2)

This feature extends northeast from the Taieri Plain along the valleys of Silver Stream and Waikouaiti River South Branch and then along the northwestern side of the Merton valley. The terrain is heavily dissected by erosion, and recognition of the fault is based on offsets of geological strata at either end of the fault; mapping of fault crushed rock on the Silver Stream valley floor (GNS Science unpublished data); and tentative reconstruction of the peneplain surface, from summit and ridge height accordance (Villamor et al. 2018). The fault system is upthrown to the northwest and is assumed to have contractional reverse motion.

At the north-eastern end of the Taieri Plain, the fault has produced vertical separation of the peneplain and basal Cretaceous–Cenozoic strata of the order of a few tens of metres. In the Merton valley, the vertical separation is ~100 m, with uplift of the peneplain on the northwestern side of the fault diminishing northeast. The peneplain meets sea level on the western side of the Waikouaiti valley, near the presumed northern end of the fault.

Peneplain reconstruction indicates a maximum vertical separation of about 300 m, at a dome-like structure centred on the Silver Peaks. The picture is complicated by the presence of the Titri Anticline on the southeast side of the fault, which makes the apparent vertical separation across the fault less than would otherwise be the case. The Silver Peaks dome is about the same extent, and of similar height above sea level to the Maungatua dome. Remnants of the tilted peneplain are preserved locally on western parts of the dome at Mt John and Lamb Hill. The Silver Peaks dome has been heavily dissected by stream and gully erosion, giving it a different appearance to the largely undissected Maungatua dome.

The Silver Peaks lie adjacent to a north-northeast-striking section of the Silver Stream – Merton Fault, with lesser throw on northeast to east-northeast-striking sections of the fault. This is similar to the association of fault strike and throw seen on the Maungatua – North Taieri Fault (see separate section) and is suggestive of a component of oblique dextral motion on east-northeast-striking sections of the fault.

It is assumed that the Silver Stream – Merton Fault and the Maungatua – North Taieri Fault are adjacent structures, with one dying out where the other starts. It is also assumed that the fault underlying the Titri Anticline terminates against the Silver Stream – Merton Fault.

The Silver Stream – Merton Fault system is shown as inactive in the QMAP dataset (Bishop and Turnbull 1996) and is not included in the NZAFD, NZAFM or NSHM. There are no known geologically young offsets of deposits or landforms on the Silver Stream – Merton Fault, and in this dataset it is classified as 'potentially active'.

Villamor et al. (2018) identified the Silver Stream – Merton Fault as a potential earthquake source. They considered various estimates for slip rate ranging from 0.16 to 0.004 mm/year and calculated corresponding average recurrence intervals in the range of ~12,700 to more than ~400,000 years. For the estimation of activity parameters for this report, a dip of 45°, length of 35 km and nominal net slip rate of 0.05 mm/year were applied, and a recurrence interval of ~49,000 years was calculated using the 2010 NSHM methodology.

A2.21 Spylaw Fault (feature 1, Figure 5.1)

The northeast-striking Spylaw Fault has prominent topographic expression, having uplifted a peneplain remnant by as much as 200 m on its southeast side. It has long been regarded as an active fault (e.g. Beanland and Berryman 1986; Pace et al. 2005). It is included in the NZAFD, NZAFM and NSHM (Stirling et al. 2012; Litchfield et al. 2013).

The main evidence for geologically recent activity on the Spylaw Fault is the presence of a prominent step on a terrace beside Spylaw Burn, illustrated in Figure 6 of Pace et al. (2005). This terrace is interpreted to have been offset with vertical separation of between 3 and 7 m. Pace et al. (2005) reported a luminescence age of 39,200 ± 3400 years for the interpreted uplifted terrace from near the base of a ~2.7-m-thick silt deposit, interpreted as loess, overlying the stream gravel of the terrace. The low, interpreted downthrown, side of the fault scarp is close to modern stream level. The ~2.7 m loess cover on uplifted side of the interpreted fault scarp implies the stream gravel stands only about half the terrace height above stream level, suggesting that the uplift would only be a little more than half the upthrown terrace height. In addition, loess accumulation requires a land-surface rather than a stream bed, so it is likely that the loess accumulation began after the terrace became elevated above stream level. If the terrace was elevated by faulting, the age for the basal loess may be a minimum age for that uplift. On balance, that is the interpretation preferred here for the data presented by Pace et al. (2005). Assuming a tectonic uplift of ~3.5 m of the stream gravel, and indicative age of ~40,000 years for that uplift, indicates a vertical slip rate of 0.09 mm/year. If resolved onto a fault plane dipping 45° with assumption of pure dip slip motion, this gives an average net slip rate of 0.11 mm/year, which equates to the minimum slip rate estimate provided by Litchfield et al. (2013).

Another possibility is that the elevated terrace at Spylaw Burn owes its origin to stream erosion (i.e. stream downcutting and lateral trimming) rather than fault uplift. Examination of archival air photos indicates that there is no comparable step on alluvial fan terrain to the northeast or southwest on the projected line of the fault. This terrain contains elements of likely similar age to the terrace beside Spylaw Burn, and evidence for a comparable fault scarp should be present across that terrain. There are scattered topographic features to the southwest along the line of the fault that, in isolation, resemble fault scarps. However, they lack continuity across adjacent landforms of similar age, indicating that they are more likely topographic steps formed by river or stream erosion, or in some cases, landslide movement. Most are topographic steps on dissected overlapping alluvial fans, where intersecting and merging stream channels can leave isolated step-like benches.

Overall, this review of information raises questions about the interpretation of landform features along the line of the Spylaw Fault thought to be related to geologically recent fault rupture. In addition, if these features are of fault origin, there are reasons to prefer a slip rate at the lower end of previous estimates.

Near Spylaw Burn, the offset of the peneplain diminishes rapidly in height north-eastwards, but, 2 km to the southeast, another fault offset of the peneplain commences, and the offset grows in size towards the northeast. This en-echelon relationship between the two faults is interpreted as them both being branches (splays) of a single fault at depth. Although the northeast splay fault is given a different name in QMAP (Turnbull and Allibone 2003; Heron 2018), the ‘Park Hill – Dunrobin Fault’, they are both called Spylaw Fault in this dataset. The north-eastern splay has no known indications of geologically young landform offsets (Pace et al. 2005). Both of these en-echelon strands are included in the Spylaw Fault entity as delineated in the NZAFM and NSHM, while only the western strand is included in the NZAFD.

Based on the considerations above, the western strand of the Spylaw Fault (proper) is classified as ‘possible’, the possible fault scarp at Spylaw Burn is classified as ‘moderately expressed’ and the remainder of the fault is classified as ‘not expressed’. The eastern strand (Park Hill – Dunrobin Fault) is classified as ‘potentially active’, ‘not expressed’.

In both the NSHM and NZAFM, the Spylaw Fault entity is given a length of ~50 km. This is achieved by extending the Spylaw Fault, as delineated in QMAP, southwest for ~20 km along mapped bedrock faults that have an opposite sense (upthrow to the northwest) to that of the Spylaw Fault. It is preferred in this report to restrict the Spylaw Fault to the geological structure that has upthrown the peneplain to the southwest, which has an overall length of ~30 km. For the estimation of activity parameters for this report, a dip of 45°, length of 30 km and re-estimated net slip rate of 0.11 mm/year were applied and a recurrence interval of ~19,000 years was calculated using the 2010 NSHM methodology. This is somewhat more than the ~12,400-year recurrence interval given in the NSHM (Stirling et al. 2012).

A2.22 Teviot Fault (feature 2, Figure 5.1)

The north-northwest-striking Teviot Fault lies mostly in the Central Otago District, with only the southern 3 km of the fault extending into the Clutha District. The fault characteristics were described by Barrell (2019), and a summary of the description of the fault from the appendix of that report is presented below.

The peneplain has an indicated up-to-the-west vertical separation of as much as ~300 m across the Teviot Fault. It is assumed to be a west-dipping reverse fault, with no known offsets of geologically young landform features, and is classified as 'potentially active'. Based on similarities to the nearby Old Man Fault, the Teviot Fault was assigned the same slip rate as the Old Man Fault (0.01 mm/year) and a length of 32 km, from which a recurrence interval of ~225,000 years was calculated using 2010 NSHM methodology.

The Teviot Fault is mapped here as ending southward at the Blue Mountain Fault. However, see the section on the Blue Mountain Fault for discussion of this interpretation.

A2.23 The Twins monocline (feature 19, Figure 5.2)

This north-northeast-striking feature forms a prominent topographic step, up to the west. It is shown in the QMAP dataset as a monocline that is expressed in the foliation (layering) in the schist rock. The vertical separation of the peneplain across the monocline is as much as ~400 m. The northern half of the structure comprises two parallel monocline strands. The western one was the one shown in QMAP, and the eastern one is inferred from topographic expression. Villamor et al. (2018) characterised the structure as a potentially active fault, on the presumption that the monocline is underlain by a fault whose subsurface rupture would generate an earthquake. In this dataset, the feature is represented as a monocline as befits its surface geological character. The lines representing the monocline are positioned at the foot of the topographic step. This feature was referred to as the 'Hyde South – The Twins' earthquake active fault source by Villamor et al. (2018). Here, the surface geological structure is referred to as 'The Twins monocline', after a peak on the elevated side named on the Topo 50 map.

There are no known offsets or deformation of geologically young landform features. Villamor et al. (2018) considered various estimates for slip rate ranging from 0.25 to 0.007 mm/year and calculated corresponding average recurrence intervals in the range of ~5900 to more than ~200,000 years. Because it is essentially contiguous with the Hyde Fault, but the topographic expression is only about half of that of the Hyde Fault, a net slip rate for The Twins monocline structure of 50% of that applied to the Hyde Fault (i.e. 0.125 mm/year) is inferred. For the estimation of activity parameters, a dip of 45°, length of 23 km and net slip rate of 0.125 mm/year return a recurrence interval of ~12,700 years using the 2010 NSHM methodology.

A2.24 Titri Fault (feature 12, Figure 5.2)

The Titri Fault is a major northeast-striking system of faults. Uplift on the southeastern side of the fault has elevated a range of coastal hills, which separates the low-lying Taieri and Tokomairaro plains from the coast. It is sometimes referred to as the Titri Fault System or Titri Fault Zone, but the simpler term 'Titri Fault' is preferred in this report.

The Titri Fault and geological relationships either side of it have been much studied since the 1950s, and the background is set out in the publicly available paper by Litchfield (2001) and report by Barrell et al. (2020), to which an interested reader should refer. In summary, the Titri Fault was originally a normal fault, with displacement down to the southeast during the mid- to late Cretaceous Period, ~100 million years ago. Contractional deformation in the Late Cenozoic (within the last ~20 million years) has re-activated the Titri Fault with reversal of movement that has uplifted the southeast side, forming the coastal hills.

In the southwest, the north-striking Castle Hill Fault was also a Cretaceous normal fault whose movement allowed a thick sequence of Taratu Formation coal measures to accumulate on the eastern, downthrown side of the fault at the Kaitangata Coalfield, with a much thinner sequence of Taratu Formation strata to the west (Harrington 1958). The Castle Hill Fault has also experienced reversal of movement in the Late Cenozoic and is regarded as a component of the re-activated Titri Fault (Litchfield 2001).

The dataset described in this report is based on the QMAP dataset. The original QMAP linework depicting the fault was compiled by Bishop and Turnbull (1996) from existing geological map information. Considerable refinements to the fault mapping and interpretation were made by Litchfield (2000, 2001). Those refinements were subsequently incorporated into the QMAP dataset (Heron 2018). In the late 2010s, further mapping, trenching and dating along the Titri Fault, aided greatly by the availability of LiDAR coverage, introduced further refinements to the mapping and interpretation (Barrell et al. 2020), which are compiled into the dataset described in this report.

The LiDAR, coupled with the identification of definite fault scarps from trenching, has provided a strong interpretive basis for focusing on topographic features in the mapping of the fault. The QMAP dataset placed more reliance on identifying fault locations from geological relationships, because few fault scarps were previously identified. The recent recognition of more scarps raises the confidence of placing faults along the foot of prominent topographic steps.

A2.24.1 Background on Fault Mapping and Interpretation

The terminology follows that provided by Litchfield (2001). In the north, the Titri Fault structure is characterised predominantly by a large anticline, the Titri Anticline, which is evident northwards from the Saddle Hill / Chain Hills area. The central section of the fault is characterised by what has been referred to as the ‘master fault’, at the foot of the main hills, and is regarded as the location where the bulk of previous fault movement has occurred and which, over long geological time (e.g. several million years), has elevated the coastal hills. At the northwestern foot of the main hills is a strip of low rounded hills and terraces. The northwest margin of that strip is regarded as the location where the most recent movements of the Titri Fault have broken out at the ground surface. That movement zone has been referred to as the ‘frontal strand’ of the fault. Geographically, the frontal strands are divided into three sections. From north to south, these are the Allanton section from about Three Mile Hill southwest to near Henley, the Waihola section from near Henley southwest to the Tokomairaro River (note recently gazetted revision of spelling) and the Misery section from the Tokomairaro River to the hill country north of Kaitangata. The Misery section has a parallel component to the northwest, approximated by the Castle Hill Fault, which lies along the southwestern margin of the coastal hills.

The Titri Fault had previously been extrapolated through the western side of the Dunedin urban area in the upper part of the Water of Leith catchment by Bishop and Turnbull (1996). The assessment by Villamor et al. (2018) found that the geological structure in the upper Leith catchment could not be reconciled by that model, as there was no clear indication of continuity between that structure and that of the Titri Fault to the southwest in the Taieri basin. Instead, they highlighted that the Titri Anticline structure is also evident in the geological structure of the Dunedin Volcanic Group rocks of the high ridge that includes the summits of Flagstaff and Swampy Summit, a point previously identified by Barrell (2002). That interpretation is adopted in this dataset.

A2.24.2 Commentary on Fault Mapping and Interpretation

This commentary on fault mapping and interpretation proceeds from southwest to northeast.

At Kaitangata township, two points of information bear upon the location of the Castle Hill Fault. A shaft at the former Castle Hill Mine, about 215 m east of the Eddystone Street / Bembridge Street intersection, according to location coordinates in Harrington (1958), encountered a major reverse fault at ~80 m depth, dipping 60° east (Castle Hill Reverse Fault, as named by Harrington [1958]), which has emplaced Taratu Formation coal measures up over younger marine strata of likely early Eocene age and correlated with the younger part of the Wangaloa Formation. At Kaitangata Mine, the main shaft (also known as Shore's Shaft), about 280 m east of the Selcombe Street / Start Street intersection, passed through at least 200 m of steeply west-dipping coal measures strata, presumably beneath which lies a major reverse fault. Its location approximates the edge of the uplifted coastal hills. It is classified as 'possible', 'not expressed'. The position of the fault through Kaitangata shown on Harrington's (1958) map does not accord with the location or information provided by Harrington for the Castle Hill Mine shaft. The fault has been repositioned along the foot of the hills at the eastern margin of Kaitangata township. There is no indication of offset of any geologically young landforms. Northeast from Lake Tuakitoto, the fault coincides with a topographic step of as much as a few tens of metres, up to the east. This is inferred to be fault-related topography, and the fault is classified as 'moderately expressed'.

East of the Castle Hill Fault, there is another prominent, up to the east, topographic step, extending through hill terrain from the southern end of the Tokomairaro basin south to near Kaitangata. It coincides with mapped faults and is referred to here as the 'Misery section' of the Titri Fault, after Mt Misery near Moneymore. It was referred to in part as the Hillfoot Fault by Litchfield (2001), but a more generic name is applied here to save any confusion with the previous nomenclature for specific faults in the Kaitangata Coalfield. The topographic step is as much as 200 m high in the north, decreasing to a few tens of metres in the south. In the north it is classified as 'likely', due to proximity of 'likely' and 'definite' fault scarps near Moneymore (Moneymore 1 and Moneymore 2 traces) and 'possible' farther south. Because the topographic step is not sharp and lies in terrain generally dissected by erosion, it is classed as 'not expressed'.

The Moneymore traces comprise two parallel scarps, one at the foot of the range (Moneymore 1), classed as 'likely', and one ~0.5 km to the northwest out in the basin (Moneymore 2), classed as 'definite'. In the Moneymore area, the master fault at the range-front is identified as the Misery section, with which it has continuity to the south. However, adjacent to the 'likely' and 'definite' Moneymore traces, the Misery section at the range-front is classed as 'possible', on the presumption that the geologically more recent activity has migrated to the Moneymore traces.

On the Waihola section, offsets of geologically young deposits due to rupture of the Titri Fault have been identified by trenching at two locations, one at Glenledi Road ~2 km east of Milton and the other at the Clarendon rural locality ~8 km northeast of Milton (Barrell et al. 2020). That information provides a basis for mapping the approximate position of the fault along the foot of topographic steps at the northwest margin of low hill terrain and terraces in a similar setting to that present near Moneymore. Only the locations where fault offsets have been demonstrated by trenching are identified as 'definite'. Other locations where topography indicates the presence of the fault are classed as 'likely'. Southwest of Lake Waihola, where the northwestern margin of the low hill and terrace terrain is generally continuous, the fault is classified as 'moderately expressed'. Where the continuity is disrupted by stream valley erosion and adjacent to Lake Waihola and the Taieri-Waipori river plains, where erosion has trimmed the northwest edge of the low hill/terrace terrain, the fault is classed as 'not expressed'. Throughout the area northeast of the Tokomairaro River, the master fault is classified as 'potentially active', on the presumption that the geologically more recent activity has been on the frontal topographic step.

At Tokomairaro River, there is an apparent discontinuity of the character of the range-front. It has been suggested that this represents a kinematic break in the Titri Fault, with those parts of the fault northeast and southwest of the Tokomairaro River rupturing independently, at least on some occasions (Villamor et al. 2018; Barrell et al. 2020). There is prominent topographic relief on the east side of the Tokomairiro Fault, which strikes south down the river valley, and it is classified as 'potentially active' in recognition that it could conceivably accommodate movement were the Titri Fault northeast of there to rupture independently of the Moneymore section.

On the Allanton section, Litchfield (2001) drew the frontal strand northeast of the lower Taieri gorge near Henley as merging with the master fault at the foot of the range. This dataset follows QMAP in drawing the fault as 'not expressed' ~0.5 km northwest of the foot of the range. The reasoning is that, near Waihola and between Allanton and Wingatui, the frontal strand is consistently about that distance out from the foot of the range. The interpretation is that, in the general area of Henley, erosion has removed the distinctive hill and terrace terrain that elsewhere lies southeast of the frontal strand of the fault.

From Allanton northeast to Wingatui, the northwest margin of the low hill and terrace terrain is partly continuous, broken by minor stream valleys draining northwest into the basin. Drainage of this sector of the Taieri Plain is to the southwest, creating potential for stream action to have eroded the margin of the terrain. However, the margin of the terrain shows a somewhat sinuous form, similar to that seen southwest of Lake Waihola where the fault escarpment is thought to have suffered little if any erosion. Therefore, the interpretation is made that the Allanton section frontal strand lies just northwest of the low hill and terrace terrain but is classified as 'not expressed' to signal some uncertainty regarding fault location. There is no evidence as to whether the most recent ruptures on the Waihola section extended along the Allanton section, but it is assumed that they did, and the Allanton section is classed as 'likely'.

Northeast of Wingatui, the Titri Fault projects into hill terrain. Its position there is taken from geological mapping, and it is classified as a 'possible' active fault because it is not known whether the most recent surface ruptures have extended that far northeast along the fault. In this area, the Titri Anticline is the most prominent aspect of the Titri Fault structure, providing further reason to consider that past ruptures may not have reached the ground surface in this area. At Three Mile Hill Road, unpublished mapping by Liggett (1975) documents the character of the fault by the nature and attitude of bedding in the Dunedin Volcanic Group.

The mapping places the anticline axis ~0.5 km north of the intersection between Three Mile Hill Rd and Halfway Bush Rd. The anticline has a gentle southeast limb and a steep northwest limb. About 60 m northwest of the axis, the strata are overturned, and Liggett's (1975) cross-section interprets a fault at that location. This is included in the dataset as a 'possible' fault. Probably this is not the Titri Fault as a whole, but it could be regarded as a splay off of it. To indicate the probable association, a 'potentially active' connection is drawn between this fault and the end of the 'possible' Titri Fault ~3 km to the southwest near Abbotts Hill.

A2.25 Estimation of Titri Fault Activity

On the northern side of the mouth of the Clutha River / Matau Branch is an elevated flat bench, interpreted to be a marine terrace, near the locality of Summer Hill. A modern river-cut cliff at the terrace margin shows bedrock outcrop extending at least half to two-thirds of the height of the cliff (personal observation of the writer). The terrace surface is 30 m asl, based on LiDAR information. These general observations suggest the marine-erosion surface on bedrock is between ~15 and 20 m asl, and Bishop and Turnbull (1996) map it as being of last interglacial age (~125,000 years ago). It is generally regarded that, at the time, the sea level was ~5 m higher than today. That implies that the marine erosion surface has been uplifted by between 10 and 15 m, which equates to a long-term average uplift rate of ~0.1 mm/year. Because of the assumptions used, this should be seen as no more than an indicative estimate.

Data from the trenching and dating investigations on the Waihola section indicate that the Titri Fault has ruptured at least twice in the past ~38,000 years (Barrell et al. 2020). The earlier rupture occurred sometime between ~38,000 and ~28,000 years ago, followed by another one sometime before ~18,000 years ago. The collective vertical separation from those ruptures was ~3.5 m. Barrell et al. (2020) concluded that the Titri Fault has a slip rate in the range of 0.1–0.2 mm/yr and recurrence interval in the range of ~7000 to ~19,000 years, with a preference towards the longer end of that range.

The question remains as to whether the Titri Fault experiences episodicity of rupture activity similar to what has been shown for the Akatore Fault. The data from the Titri Fault are inconclusive in that regard. In combination with the tentative information from the uplifted terrace at the Clutha River mouth, the net fault slip over the past ~38,000 years from the Waihola section suggest the vertical component of movement (approximating uplift) from that time period is similar to the average uplift rate since ~125,000 years ago. This could be interpreted to mean that the Titri Fault ruptures are relatively regular, or that periods of quiescence are relatively shorter than the >100,000 years found for the Akatore Fault by Taylor-Silva et al. (2020).

Using data from the Titri Fault rupture history investigations reported by Barrell et al. (2020), Villamor et al. (2018) considered a range of fault segmentation scenarios and slip rates and calculated recurrence intervals in the range of ~5000 to more than ~40,000 years.

For the purpose of this assessment, an average slip rate of 0.15 mm/year and an indicative average recurrence interval of 19,000 years (based on two ruptures in the past ~38,000 years) are adopted for the Titri Fault.

A2.26 Tuapeka Fault (feature 4, Figure 5.1)

The northwest-striking Tuapeka Fault is a prominent geological feature of the Lawrence to Waitahuna areas. The Tuapeka Fault is a southwest-dipping normal fault of Cretaceous age (Els et al. 2003), mapped as extending from Raes Junction in the north for ~55 km southeast to near Milton. The crushed zone of the Tuapeka Fault is exposed on the western side of the Beaumont Highway (State Highway 8), about 3 km north of the Beaumont Hotel, marked by barriers to keep debris from falling onto the road. The plane of the Tuapeka Fault is extensively exposed in the Gabriels Gully historic gold mining area near Lawrence (Els et al. 2003), who found that the fault dip ranges from 26° to 60°.

A2.26.1 Evidence for and Interpretation of Geologically Young Fault Offsets

Near the northwestern end of the fault near Beaumont, ~0.8 km west of the Beaumont Hotel, there is a several-metre-high topographic step crossing remnants of medium- to high-level river terraces on the western side of the Clutha River valley. This suspected fault scarp is on the projected line of the Tuapeka Fault and is up to the southwest, indicating reversal of the original Cretaceous sense of fault movement. There are two closely spaced river terrace levels, and the scarp height is about the same on both terraces. On trend immediately to the northwest is a similar, though broader, step on the axis of a ridge separating a minor stream catchment from the Clutha valley. Nowhere else on the Tuapeka Fault is there any known evidence for geologically young offsets.

The Clutha River terraces west of Beaumont are fortuitously preserved remnants of old landforms, in a setting where they have largely escaped erosional modification. Elsewhere along the Tuapeka Fault, the terrain is mostly moderate to steep hill country, subject to much more recent, and ongoing, natural landscape evolution. It is therefore possible that only at Beaumont have the most recent movement(s) of the Tuapeka Fault been preserved. Another possibility is that the fault scarp at Beaumont is the result of slip having transferred onto part of the Tuapeka Fault during rupture(s) of another nearby active fault. The Blue Mountain Fault is the most likely contender, as it has experienced geologically recent ruptures, whereas no geologically recent activity is known on the Teviot Fault. This possibility contributes to the interpretation of fault activity below.

A 4-km-long section of the fault is shown as 'active' on QMAP (Turnbull and Allibone 2003) and the remainder of the fault classified as 'inactive'. The 'active' section of the Tuapeka Fault is included in the NZAFD, but the Tuapeka Fault is not included in either the NZAFM or 2010 NSHM. In compiling the dataset described in this report, the line depicted in QMAP for the 'active' section of the fault has been refined in position to accord better with the fault-related landform features evident in high-resolution photographic resources (aerial imagery and Google Street View). The topographic step near Beaumont runs transverse to the Clutha River terrace features and affects several different-age landform features. However, there is a faint possibility that the topographic step could be due to some sort of slope instability, and so it is classified as 'likely' fault scarp, although it is close to qualifying as 'definite'. The classification of likely' is extended ~3.5 km east of Beaumont, with the fault classified as 'not expressed' under the low terraces of the Clutha River and the broad valley floor of its Low Burn tributary. From there, the fault takes a more southeasterly strike and is classified as 'potentially active', due to an absence of direct evidence for any geologically recent surface offsets of landforms. The reasoning is that slip transfer is unlikely to extend much beyond the uplifted Blue Mountains fault block, if there is validity to the possibility that the Blue Mountain Fault is the origin of the primary slip (see paragraph above). The section of the Tuapeka Fault north of the intersection with the Blue Mountain Fault is also classified as 'potentially active'.

A2.26.2 Estimation of Tuapeka Fault Activity

The lowest (i.e. youngest) terrace that displays the suspected fault scarp at Beaumont was interpreted to be of Penultimate Glaciation age (i.e. older than ~130,000 years) by Turnbull and Allibone (2003), and the adjacent next lowest terrace that is not displaced was assigned an age of Early Last Glaciation (~60,000 to 70,000 years). There is a view that the ages used in QMAP for the glacial moraines and meltwater outwash terraces of the upper Clutha valley have been overestimated (Barrell 2011), and the writer considers this is also the case in the Beaumont area. A key geomorphological consideration is the lowest river terrace of the Beaumont basin, which stands only a few metres above river level and to which QMAP assigned an age of Late Last Glaciation (~20,000 years). Sizeable tributary streams drain onto the western margin of this broad terrace surface but have constructed only small alluvial fans, much smaller than would be expected if the terrace were really that old. On that basis, the broad lowest terrace is interpreted here to be of post-glacial age, probably no older than ~10,000 years. The next higher terrace, on which the Beaumont Hotel is built, is not offset by the fault and is suggested here to be Late Last Glaciation (~20,000 years old). The lowest faulted terrace is suggested to be of Early Last Glaciation age (~65,000 years old). The adjacent ridge, whose crestline has what appears to be an offset of similar size to that on the next lower terrace, is indicated by Turnbull and Allibone (2003) to be a remnant of a much older river terrace. The ridge stands ~50 m above Clutha River level, and, based on information on terrace ages from the upper Clutha valley (Barrell 2011; GNS Science unpublished data), the writer estimates that ridge landform to be at least 200,000 years old.

Based on the inferences above, the Tuapeka Fault at Beaumont is estimated to have experienced at least one surface rupture between ~20,000 years ago and ~65,000 years ago but, before that, no surface rupture back to at least ~200,000 years ago. Taking the scarp height as a nominal ~5 m high, accrued since ~200,000 years ago, implies a long-term vertical slip rate of no more than 0.025 mm/year (rounded to 0.03 mm/year). In regard to the interpretation that the Tuapeka Fault offsets are due to slip transfer from another fault, likely the Blue Mountain Fault, which has a vertical slip rate of ~15 mm/year, it implies either a relatively small slip transfer onto the Tuapeka Fault, or that that transfer does not occur during every rupture.

The Tuapeka Fault was assigned a recurrence interval in the range of ~250,000 to ~680,000 years by Villamor et al. (2018) through the application of a slip rate of 0.01 mm/year. The slip rate estimated above for the Beaumont area can be considered a maximum for the Tuapeka Fault as a whole, if the slip transfer interpretation is correct. Assuming an average fault dip of 45° and pure dip-slip motion, a vertical slip of 0.03 mm/year translated to a net slip rate of 0.04 mm/year. In conjunction with a fault length of 55 km, a recurrence interval of ~95,000 years is obtained using the 2010 NSHM methodology.

A2.27 Waipori – Maungatua – North Taieri Fault (feature 15, Figure 5.2)

These faults form a prominent escarpment along the northern margin of the Taieri Plain. As defined in this dataset, this entity comprises three separately named components from the QMAP dataset, from west to east: the southeast- to east-striking Waipori Fault, the northeast-striking Maungatua Fault and the east-striking North Taieri Fault. Upthrow is to the northwest and north, respectively. Uplift reaches a maximum at Maungatua hill, where the peneplain has been up-domed to as much as ~900 m above sea level with uplift diminishing both to the east and west. At the eastern end, near North Taieri, uplift of the peneplain and locally preserved overlying Late Cretaceous to Cenozoic strata diminishes rapidly, with the peneplain surface descending to as little as 100 m above sea level. This is interpreted to mark the eastern limit of this fault structure. At about the same location, another fault structure, identified as the Silver Stream – Merton Fault, becomes evident and increases in throw northeastwards (see separate section).

This system of faults is inferred to be contractional, and the maximum uplift, being adjacent to the northeast-striking Maungatua Fault, raises the possibility that the east-striking Waipori and North Taieri faults may be oblique-slip with a component of right-lateral motion. Structurally, the western component, the Waipori Fault, is likely to accommodate any slip differential between the northwest-facing Waitahuna Heights Fault and the southeast-facing Maungatua Fault.

All these faults were shown as inactive in the original QMAP dataset (Bishop and Turnbull 1996). Using aerial photos, Barrell et al. (1998, 1999) interpreted discontinuous topographic steps along the southeastern foot of Maungatua hill, and on old alluvial fan terraces at the foot of the North Taieri Fault escarpment, as Late Quaternary fault scarps. These were subsequently incorporated into the QMAP digital dataset (Heron 2018) and the NZAFD.

However, recent field observations and examination of LiDAR datasets has led the writer to revise his previous interpretation that these features are fault scarps. There is insufficient lateral continuity across adjacent similar-age landforms to support a fault origin for these topographic steps. Instead, it is more likely that they are fluvial erosion features or, in some cases, possibly toe thrusts of landslides. An important consideration is that the Taieri River system has tended to erode down into its valley floor during episodes of glacial climate due to lowered sea level (Barrell et al. 1999), and its tributary streams would have responded similarly. This likely would have imparted a stronger southwesterly drainage grain down the Taieri Plain than prevails in today's regime of generally impeded drainage, as well as the building of broad alluvial fans out towards the axis of the plains. Under a glacial climate fluvial regime, the main tributaries of the north-eastern part of the Taieri Plain, Mill Stream and Silver Stream would likely have episodically eroded the foot of the North Taieri Fault escarpment, creating overlapped and terraced alluvial fans that have topographic anomalies superficially resembling fault scarps.

The writer considers that there is currently no convincing evidence for geologically young fault offsets of landforms along the Maungatua or North Taieri faults or along the Waipori Fault. This system of faults is therefore classified in this dataset as 'potentially active'. It remains a possibility that some evidence for fault activity may come to light in the future and so may warrant a change in classification.

Villamor et al. (2018) identified the Maungatua – North Taieri Fault (including the Waipori Fault) as a potential earthquake source. It has not previously been included in the NZAFM or NSHM, although the previously interpreted fault scarps (now interpreted otherwise) are included in the NZAFD. Villamor et al. (2018) considered various estimates for slip rate for the Maungatua – North Taieri Fault ranging from 0.39 to 0.01 mm/year and calculated corresponding average recurrence intervals in the range of ~5900 to more than ~200,000 years. For the estimation of activity parameters for this report, a dip of 45°, length of 35 km and nominal net slip rate of 0.05 mm/year were applied, and a recurrence interval of ~49,000 years was calculated using the 2010 NSHM methodology.

A2.28 Waitahuna Heights Fault (feature 14, Figure 5.2)

The north- to northeast-striking Waitahuna Heights Fault has produced an up-to-the-southeast vertical separation of the peneplain of as much as ~250 m. It is assumed to be a southeast-dipping reverse fault, with no known offsets of geologically young landform features, and is classified as 'potentially active'. The fault name comes from the QMAP dataset (Bishop and Turnbull 1996). Villamor et al. (2018) identified this fault as a potential earthquake source. It has not previously been included in the NZAFD, NZAFM or NSHM. About 4.5 km to the southeast, there is a shorter parallel fault with up to 50 m vertical separation of the peneplain, also up to the southeast. This fault was not shown in the QMAP dataset, but its topographic expression on the peneplain surface is strong evidence for its existence. This fault was referred to as the Waitahuna Heights 2 Fault by Villamor et al. (2018), who also identified it as a potential earthquake source. However, in this report, it is considered to be a splay at depth off the Waitahuna Heights Fault and not an independent fault structure.

As part of the Villamor et al. (2018) assessment, the writer used topographic considerations to interpret that the Waitahuna Heights Fault extends 4 km farther northeast than was shown on QMAP to the southwest margin of Lake Mahinerangi. As part of this review, and upon wider consideration of nearby faults, the writer now prefers the QMAP interpretation. Upon reconsideration, the topographic features used to reinterpret the fault extent can adequately be accounted for by erosional rather than tectonic processes. Further, it is easier to reconcile the kinematic relationships between the Waitahuna Heights Fault and the Maungatua – North Taieri Fault nearby to the east, the former upthrown to the southeast and the latter upthrown to the northwest, with the QMAP depiction of faults.

In this dataset, the Waitahuna Heights Fault extends north to northeast from near the Tuapeka Fault for 23 km to intersect the Waipori Fault at the southwest margin of the Waipori river valley (refer to Maungatua – North Taieri Fault section for information on the Waipori Fault). The Waitahuna Heights 2 Fault has a length of 10 km and is ended north-eastward at the Waipori Fault. There are no known offsets of geologically young landforms along either fault.

Villamor et al. (2018) considered various estimates for slip rate for the Waitahuna Heights Fault ranging from 0.14 to 0.004 mm/year and calculated corresponding average recurrence intervals in the range of ~11,300 to more than ~400,000 years. For the estimation of activity parameters for this report, a dip of 45°, length of 23 km and nominal net slip rate of 0.05 mm/year were applied, and a recurrence interval of ~32,000 years was calculated using the 2010 NSHM methodology.

A2.29 Appendix 2 References

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03 February 2021 Reference No. 18113122_7407-004-LR-RevA_DRAFT

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PEER REVIEW OF GNS SCIENCE CONSULTANCY REPORT 2020/88 (BARRELL, 2020)

Dear Ben

At the request of Otago Regional Council (ORC), Golder Associates (NZ) Limited (Golder) has reviewed the supplied draft version of Barrell 2020[1]. The draft report was communicated to Golder by email (Ben Mackey to Jeff Fraser, dated 14 February 2019). Our review findings are summarised in this letter report[2].

Background and Purpose of the Report

GNS Science (GNS) has previously prepared a series of reports for districts throughout New Zealand documenting current knowledge of active faults and folds, to increase awareness and improve management of earthquake ground surface deformation hazards through planning rules implemented by district councils. However, we understand that similar summary reports have not previously been developed for Clutha and Dunedin City Districts. The 2010 Darfield earthquake and 2016 Kaikoura earthquake caused widespread damage and demonstrated the potential effects of ground surface rupturing earthquakes on communities, buildings and infrastructure. New research is continually adding to the available scientific evidence of active tectonic deformation and the potential consequences of fault rupture. Barrell 2020 attempts to summarise the currently available information about the *'locations and nature of active faults and folds in the Clutha and Dunedin districts'* (page v).

Golder has reviewed the report but has not independently verified the findings. However, we have specific experience of some of the geological structures described in the report, general knowledge of the regional geology and experience in tectonic geomorphology, paleoseismology, earthquake ground surface deformation hazard assessment and seismic hazard assessment.

The primary author of Barrell 2020 is an engineering geologist who has many years of experience and considerable knowledge of the geology and tectonic development of the subject area.

[1] Barrell DJA. 2020. General distribution and characteristics of active faults and folds in the Clutha and Dunedin City districts, Otago. GNS Science consultancy report 2020/88.

[2] This letter report is provided subject to the attached Report Limitations.

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Dr Ben Mackey | Manager Natural Hazards
Otago Regional Council

Reference No. 18113122_7407-004-LR-RevA_DRAFT
03 February 2021

Review Findings

Severe damage was observed to occur where fault rupture occurred beneath buildings during recent New Zealand earthquakes. Identification and documentation of active faults and avoidance of building on known faults using planning rules is acknowledged to be an appropriate approach to managing fault rupture hazard.

The report is of a high standard and relevant concepts, project specific constructs, and the scientific limitations of the work are very well described. The following comments and recommendations are provided constructively and the authors of this review are happy to discuss any points with ORC or GNS.

Minor comments:

1) Table 5.2, extra zero included in the recurrence interval for the Akatore fault.
2) Page 14 second paragraph, 'certainty' is capitalised unnecessarily.
3) The term "plate boundary deformation" is used. The region is well away from the main plate boundary and activity rates are an order of magnitude, or more, lower than plate boundary faults. We suggest using the term "tectonic deformation" rather than "plate boundary deformation". E.g., Page 8 paragraph 2, near the end of the second sentence and all other instances in the report.
4) Conclusion, bullet point 2 second sentence, needs to be updated with the additional term "potentially active" as described on page iv and mentioned on page 13.
5) The term "sector" is used throughout the report where usually we would expect the term "section" to be used. The meaning of the term is clear (a portion of a fault plane) but conventionally "section" is used. On page 39, 3rd paragraph, 3rd sentence, "sector" should be "sections". Perhaps this is an auto correct issue.
6) Page 39, 4th paragraph, full stop missing from end of second sentence.
7) Page 41, 4th paragraph, 4th sentence, "…seal-cliff…" should be "…sea-cliff…".
8) Capitalisation of the word "district" is not consistent throughout the report. E.g., page 47, Section A2.13, first paragraph, last sentence. Suggest checking throughout.
9) Page 52, 3rd paragraph 4th sentence, "and" should be "end".
10) Page 52, last paragraph, 2nd sentence, "There is only one recorded…" should read "There is only one offset recorded…". In the following sentence "…the Settlement Fault is a reactivated former normal fault…"
11) Page 54, 5th paragraph, last sentence, "suggest" should be "suggests".
12) Page 55, 2nd paragraph, first sentence, "~~that~~ that".
13) Page 55, last paragraph, last sentence, "3" should be "three".
14) Page 56, 3rd paragraph, last sentence, "…and ~~are~~ is assumed to have…"
15) Page 57, last paragraph, first sentence, "…raises question concerning the interpretation of landform…".
16) Page 58, second paragraph, end of first sentence needs a full stop in place of the comma.

17) Page 59, 5th paragraph, "Litchfield 2001" cited but not in Appendix 2 reference list.

18) Page 60, last paragraph, 5th sentence, "…shown on Harrington's (1958) does not…" word missing after "Harrington's", "map"?

19) Page 65, second paragraph, third sentence, "Upthrow is the north or northwest…" reword.

Recommendations:

a) Section 2 paragraph 1 documents the various sources of fault information. A paper is in preparation presenting the New Zealand Community Fault Model and it might be valuable to acknowledge this new source that will soon be available. GNS are leading the development of the community fault model. It may be valuable to note that the community fault model is a seismic source model; therefore, has simplifications in fault geometry and a different approach to assigning activity rates and maximum magnitudes.

b) Page 39, 3rd paragraph, 3rd sentence, "...(a fault is either entirely active or it is not)…". We do not believe this statement to be correct and it contradicts several classifications within the report where different levels of activity or certainty are inferred along contiguous, or semi-contiguous, fault structures. We recommend the quoted section is removed or reworded.

c) Page 47, last sentence. "…the mapped trace of the fault was repositioned to accord with the toes of landslide terrain at the foot of the slope.". This statement seems unjustified, perhaps some additional information would be useful. We assume you are inferring that geological changes across the fault are manifest in the geomorphology which seems a reasonable basis for locating the fault trace.

d) Page 48, second paragraph. Regarding: "…and the faster vertical slip rate is preferred as it is more conservative from a seismic hazard perspective." Recommend re-wording, perhaps replacing "seismic" with "tectonic ground surface deformation".

e) The method for determining the recurrence interval assumes that mapped faults will rupture alone. The Darfield and Kaikoura earthquakes demonstrated that multi-fault rupture may be more common than previously thought in New Zealand. To some degree this brings into question the validity of the MFE guideline criteria as it makes it difficult to estimate magnitude that is used to estimate the recurrence interval. This may be further complicated by the revised national seismic hazard model which may include multi-fault ruptures in seismic hazard assessment as has been adopted in California, USA.

While the report makes a case for not including the uncertainty in the recurrence interval estimate (e.g., Section 4.2) it is arguable that incorporation of uncertainty is as important as the estimate itself. The basis for identifying and characterising hazards is so that society can make risk-based decisions. Risk is often considered as the product of hazard and consequence, but it is also defined as the effect of uncertainty on objectives (e.g., AS/NZS ISO 31000:2009, Risk Management – Principles and Guidelines). We consider both definitions are applicable to fault rupture risk management. While the general advice is +/-50 % (page 16), it would not be difficult to include an estimated range based on the uncertainty in the parameters used to estimate the recurrence interval including: fault length uncertainty, fault width uncertainty (dip and crustal thickness), magnitude scaling equation uncertainty, and slip rate estimate uncertainty. This information could be used by ORC to assess the likelihood that a fault meets the MFE active fault criteria, and on that basis plan for suitable mitigation measures (e.g., do nothing, avoidance or further investigation). There seems to be a desire to present a definitive recurrence interval value perhaps because the active fault criterion is definitive. In reality, we do not know the recurrence interval on most of the faults in these districts; therefore, computing the recurrence interval as a probability distribution function would be more faithful to the data and analysis. Further, this approach would allow incorporation of the uncertainty in how faults behave during different seismic cycles (i.e., nearly all faults have variable inter-event times).

Computing a probability distribution function of the recurrence interval would allow computation of the probability that a fault is or is-not above or below the MFE active fault criterion. We suspect some of the faults assigned a long recurrence interval would have a possibly-significant probability of meeting the MFE active fault definition.

For example, the Spylaw Fault (pg. 57) has a large degree of uncertainty and two strands that could either rupture together or independently. An assumption has been applied that the strands form one fault and are therefore only capable of making one larger magnitude earthquake. If the assessment also considered the ability of these faults to rupture independently, and the uncertainty in the slip rate estimate we suspect there would be a significant probability that the Spylaw Fault would meet the MFE active fault criteria.

We note that the approach adopted is defensible and well explained. This recommended approach would, in our opinion, be an improvement that brings the results in-line with the scientific understanding described well in the report.

f) Paragraph 2 on page 30 discusses coastal settlements near the junction of the Akatore Fault trace and the coastline. Given the relatively short assessed recurrence interval is it worth considering the potential inundation hazard associated with coastal tectonic deformation? The inundation hazard at Toko Mouth and Taieri Beach, is separate, but related to the tsunami hazard described briefly in Section 5.4.4 Pg 30.

g) The potential for mapped faults to generate tsunami is noted in Section 5.4.4 (page 300). It may be valuable to note that these local tsunami sources are likely to have little influence on the tsunami hazard since much more frequent tsunami can be generated far away from the East Otago coast and travel long distances to impact the region (e.g., Hikurangi-, Puysegr-, South American-subduction trenches). It is noted that the local sources of tsunami are important given the lack of warning time relative to far-field generated tsunami.

Closure

We trust this letter meets your needs at this stage. Please do not hesitate to contact us if you wish to discuss this matter further.

Yours sincerely
GOLDER ASSOCIATES (NZ) LIMITED

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14 April 2021

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Attention: Ben Mackey
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Dear Ben,

General distribution and characteristics of active faults and folds in the Clutha and Dunedin City districts, Otago – final report

Further to the external review comments provided by Golder Associates (letter to Otago Regional Council, dated 03 February 2021, reference no. 18113132_7407-004-LR-RevA"), provided by you to GNS Science, the report has been revised and finalised. The majority of editorial comments and broader recommendations from the review have been acted upon. Below are summary points relating to editorial comments and recommendations from the review that have not been adopted in the final report.

Minor editorial comments not adopted:

- The capitalization of 'Certainty' on page 14 is retained, because it is used in a formal sense to refer to the name of an attribute field in the GIS. I consider the text in question would lose clarity without the capitalization.
- The suggestion to replace 'plate boundary deformation' with 'tectonic deformation' has not been actioned. I consider that the context in which the term is used in the text is has clear meaning, and it emphasises that the tectonic features discussed for these two districts of Otago relate to a wider perspective than just those two districts.
- Capitalization of district vs District. Apart from two inconsistencies, the variable capitalization is intended, and correct. Lower case is used where two or more districts are referred to collectively, and also for the Dunedin City district, which is administratively a 'district' in a regulatory sense (i.e. it has a District Plan) but district in not part of its formal name (Dunedin City). The two errors have been fixed.

Recommendations not adopted:

- Recommendation e) – Incorporation of uncertainties in recurrence interval. The review presents valuable perspectives on this topic, while also acknowledging that the approach used in the report is valid. There are two reasons for not acting upon this suggestion. The main reason is to ensure consistency with the two other previous companion reports addressing of districts of Otago. A key purpose of the reports is to present complete and consistent maps of active and potentially active faults and folds of Otago, and via the slip rate and recurrence interval estimates, provide an indication of their relative levels of activity. Recommendation e) represents a proposal for a different approach, of nationwide applicability and likely improved effectiveness over current approaches. However, it is considered to be beyond the scope of the present report.
- Recommendations f) and g) both relate to provision of further information on potential tsunami hazards. Tsunami implications are mentioned in passing where relevant in the present report, but are not a focus, and I consider it beyond the scope of the report to expand into discussion of specific tsunami inundation hazards.

The PDF of the final report is attached to the email that also attaches this letter. Fifteen printed and bound copies are expected to be available within the next few days, and will be sent to your office.

Kind regards,

David Barrell
Senior Scientist, GNS Science

7.7. Queenstown and Dunedin Q3 FY21 Patronage Report

Prepared for:	Data and Information Committee
Report No.	PPT2110
Activity:	Transport: Public Passenger Transport
Author:	Julian Phillips, Implementation Lead Transport
Endorsed by:	Gavin Palmer, General Manager Operations
Date:	9 June 2021

PURPOSE

[1] The purpose of this report is to update the Committee on the performance of its public transport and total mobility services for the three quarters of the 2020/21 financial year, together with Super Gold Card patronage.

[2] Monthly statistics comparing the previous two financial years are also provided. It also addresses customer enquiries and complaints, presents the results of the Queenstown customer satisfaction survey and provides information on the Total Mobility scheme and use of the Real Time information system.

EXECUTIVE SUMMARY

[3] COVID-19 has had a significant effect on our public transport activity.

[4] In Dunedin, January to April 2021 patronage is tracking significantly higher, at 32% overall, than the corresponding periods in 2020, due to the 2020 period being affected by COVID travel-restrictions.

[5] Fare revenue for the same period is significantly lower due to the impact of the $2 fare trial; however, April 2021 is significantly higher compared to April 2020, due to April 2020 being the first full month of fare-free COVID travel in Dunedin.

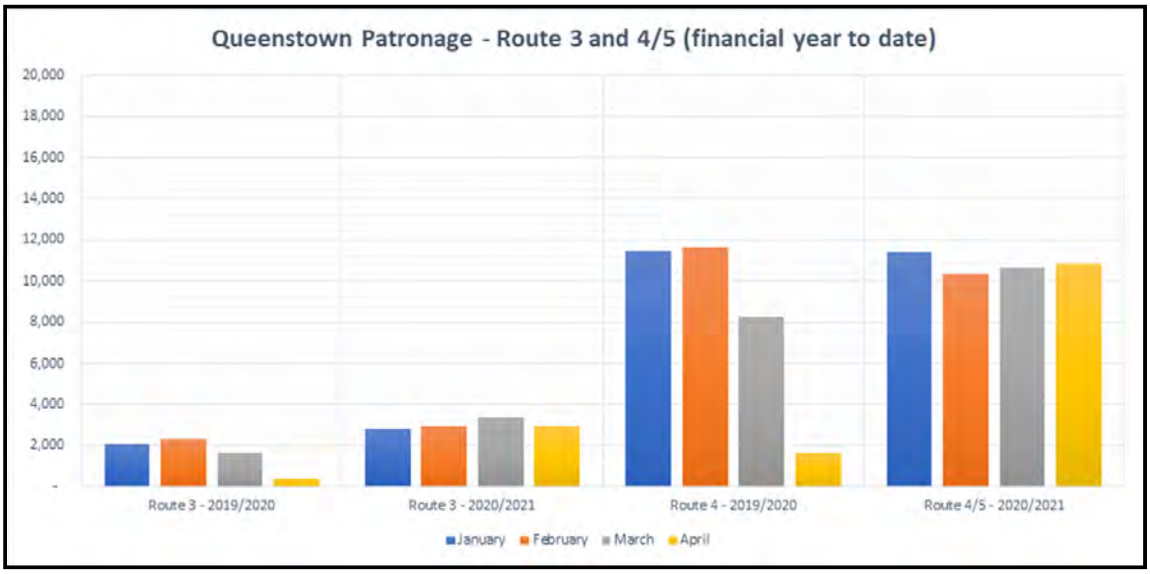
[6] Contrasting April 2021 with pre-COVID April 2019, patronage is marginally (1%) lower and indicative of the strong recovery of the Dunedin network post-COVID.

[7] Queenstown public transport activity remains significantly affected by COVID-19. For the period January to April 2021 patronage is tracking significantly lower, at -30% overall, compared to the corresponding periods in 2020, reflecting the unprecedented impact of COVID 19 on the social and economic wellbeing of the Queenstown Lakes District

[8] From January to April 2021, Queenstown Routes 3 and 4/5 have seen increases of 86% and 31% respectively, noting that these are more commuter/residential oriented services. This is somewhat skewed by the impact of COVID in late-March/April 2020, but nevertheless, comparing pre-COVID January/February 2020 vs 2021 patronage for these routes shows that patronage has been increasing year-on-year in 2021 prior to COVID affecting 2020 patronage (see Figure 1 below).

Routes 1 and 2 have seen patronage fall by 41% and 27% respectively compared to the previous financial year.

Figure 1: Queenstown route 4/5 patronage 2019/20 vs 2020/21



[9] 696 complaints were received in the period November 2020 to May 2021, representing 0.035% of the nearly 2 million trips taken during that time.

[10] The WKNZTA-ORC Customer Satisfaction surveys are in progress, with the Queenstown Survey completed and the Dunedin survey to completed in June. This report presents the results of the Queenstown survey, specifically the Overall Satisfaction with Service result of 96%, which exceeds the Annual Plan target of 85%.

[11] The Dunedin Real Time Tracking service (RTI) launched in May, together with the introduction of the Transit app for both Dunedin and Queenstown.

[12] Reception to both RTI for Dunedin and the Transit app has been very positive, with detailed statistics provided later in the report.

[13] Total Mobility usage has increased by 13.29% for period YTD 2020/21, accompanied by a 16.91% increase in 'hoist' (wheelchair accessible) vehicle trips.

[14] Increases are driven primarily by the effect of COVID on demand for services in the 2019/20 FY.

RECOMMENDATION

That the Committee:

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

BACKGROUND

[15] The Council (ORC) contracts public transport services in Dunedin and Queenstown to two transport operators; Ritchies and Go Bus. Network coverage is shown in Figures 2 and 3.

[16] 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 2,199,254 passengers (2,548,330the year before).

[17] 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 1,249,503 passengers (1,468,057 the year before).

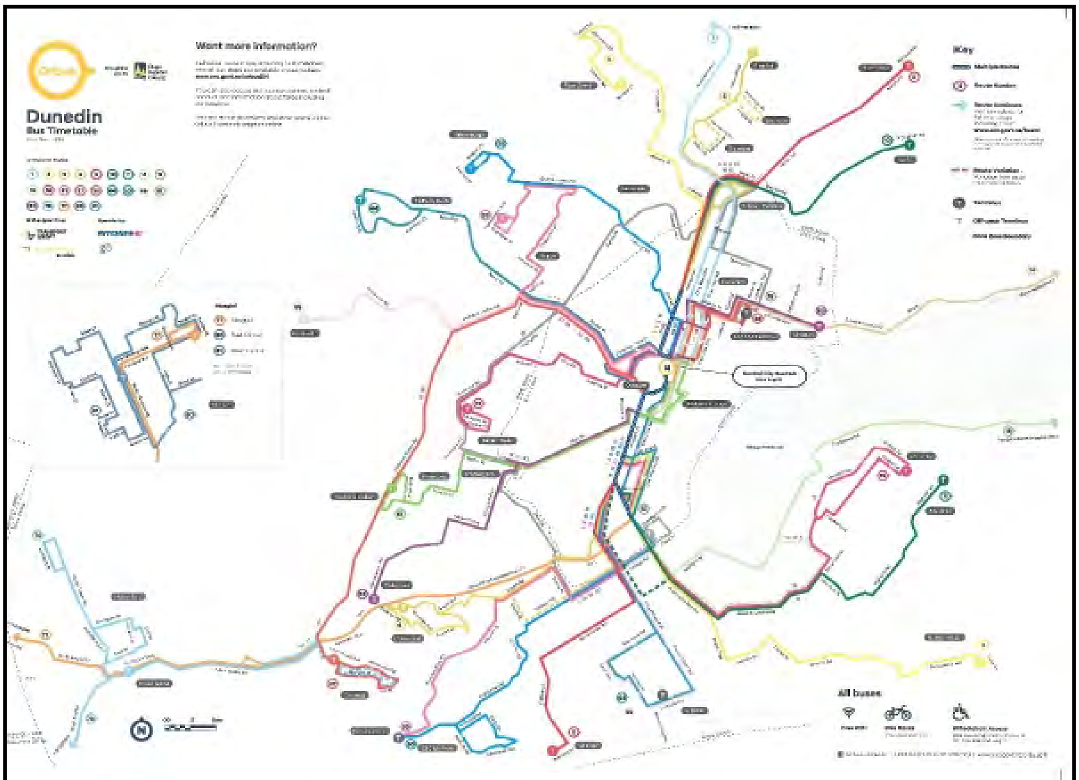


Figure 2: Dunedin Bus

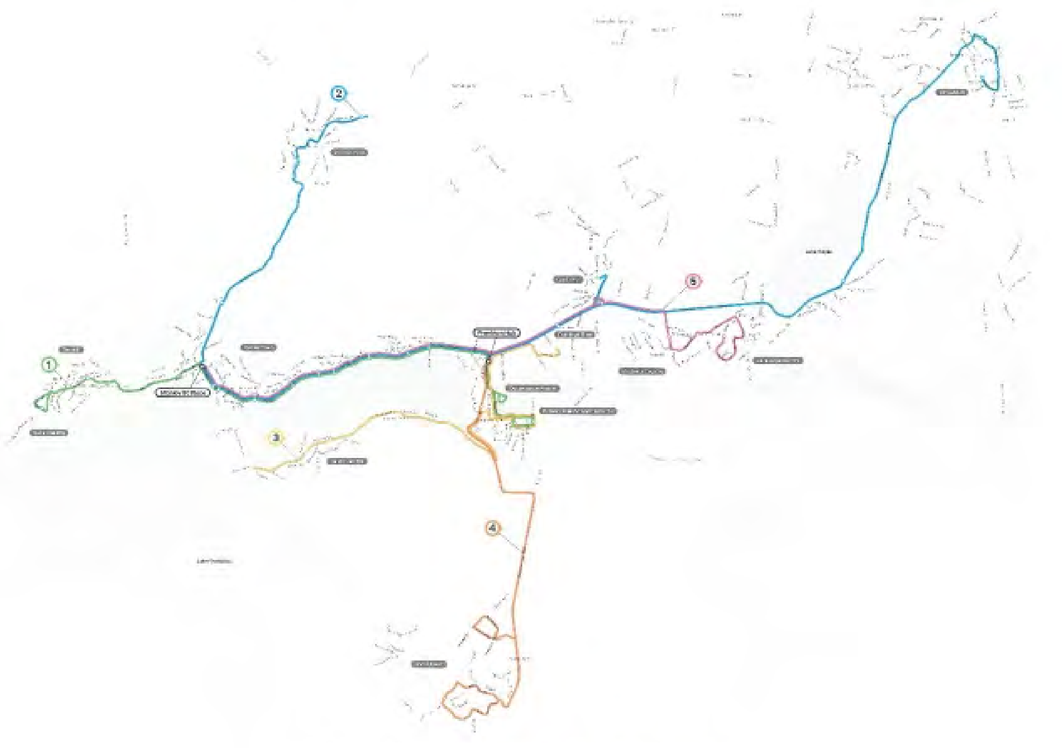


Figure 3: Queenstown Bus Network

[18] Council contracts Public Transport in Dunedin and Queenstown to two Transport Operators, Ritchies and Go Bus.

[19] Each Transport Operator is contracted to operate ‘PTOM Units’ (each unit being a collection of routes contracted to an operator, as defined by the 2014 Regional Public Transport Plan. PTOM stands for Public Transport Operating Model).

[20] There are 7 Units in total, 2 in Queenstown, both operated by Ritchies; and 5 in Dunedin, operated by both Ritchies and Go Bus.

The following report summarises patronage trends across both networks, comparing Quarters 1 - 3 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 enquiries and complaints, presents the results of the Queenstown customer satisfaction survey and provides information on the Total Mobility scheme and use of the Real Time information system.

PUBLIC TRANSPORT - DUNEDIN

[21] Dunedin fare revenue for April is up compared to April 2020 (when fares were not being charged), but showing a decrease of 37% compared to April 2019, primarily due to the trial flat $2 fare.

[22] Patronage for the April is showing a 631% increase compared to April 2020 and a 1% decrease from April 2019.

[23] Patronage for the financial year is 15% above the same period last year.

[24] Patronage for each PTOM Unit in April 2021 has increased compared to April 2020. Revenue has increased for all units also; Noting that April 2020 is when New Zealand was in Alert Level 4 lockdown – patronage was very low and fares were free.

Figure 4: Dunedin Patronage and Revenue, YTD April 2021

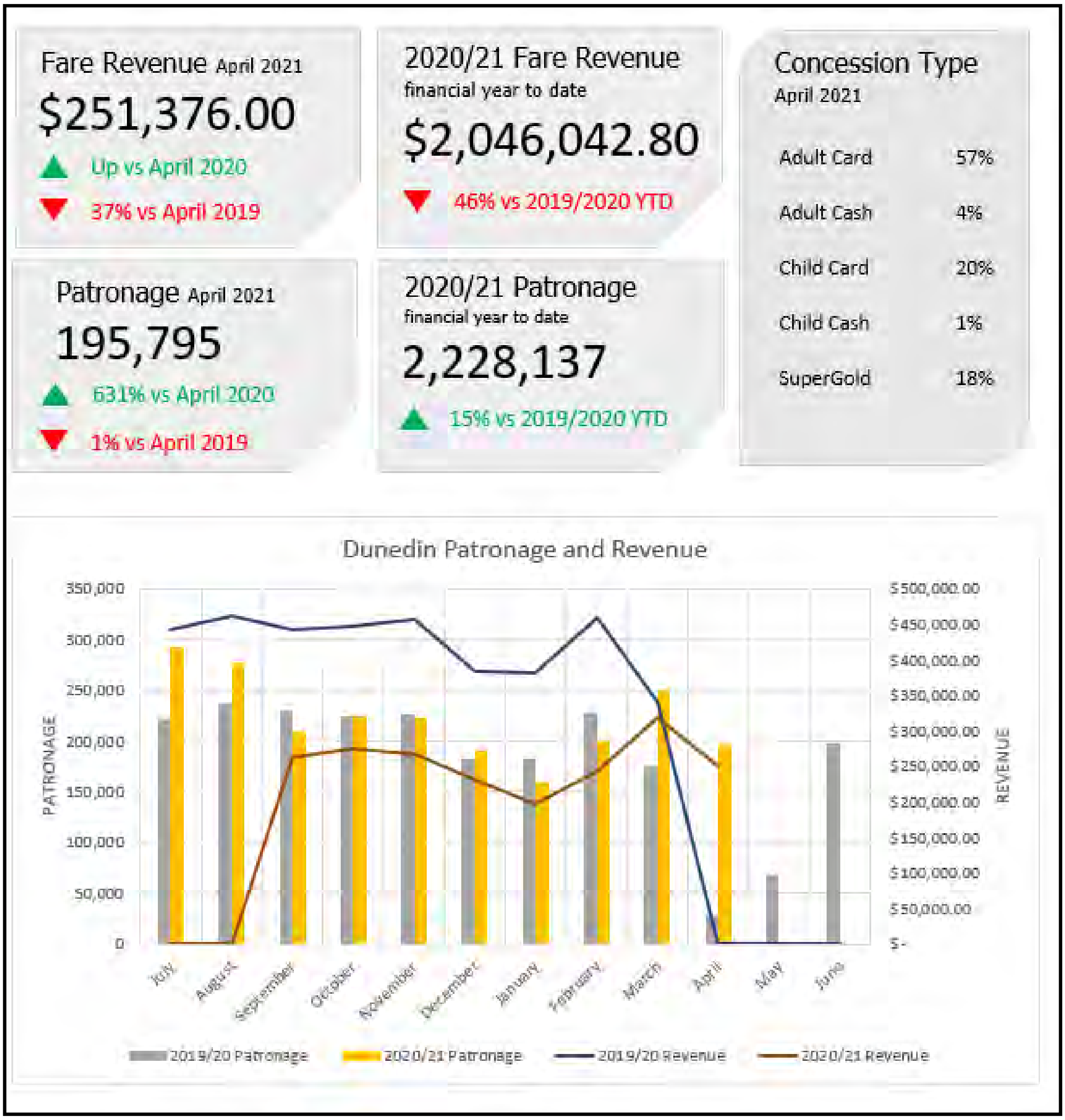


Figure 5: Dunedin weekly patronage, Unit Revenue and Unit Patronage

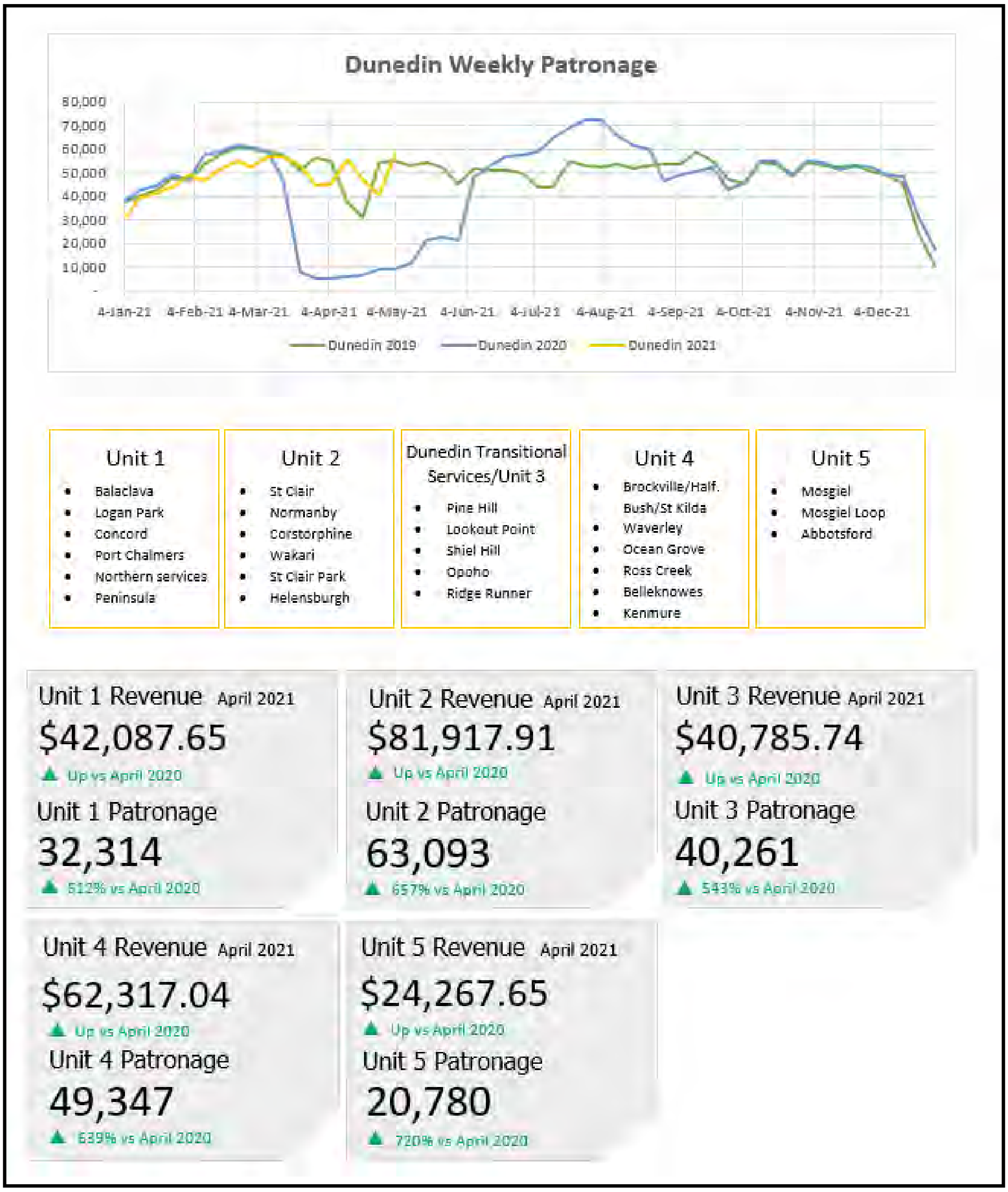
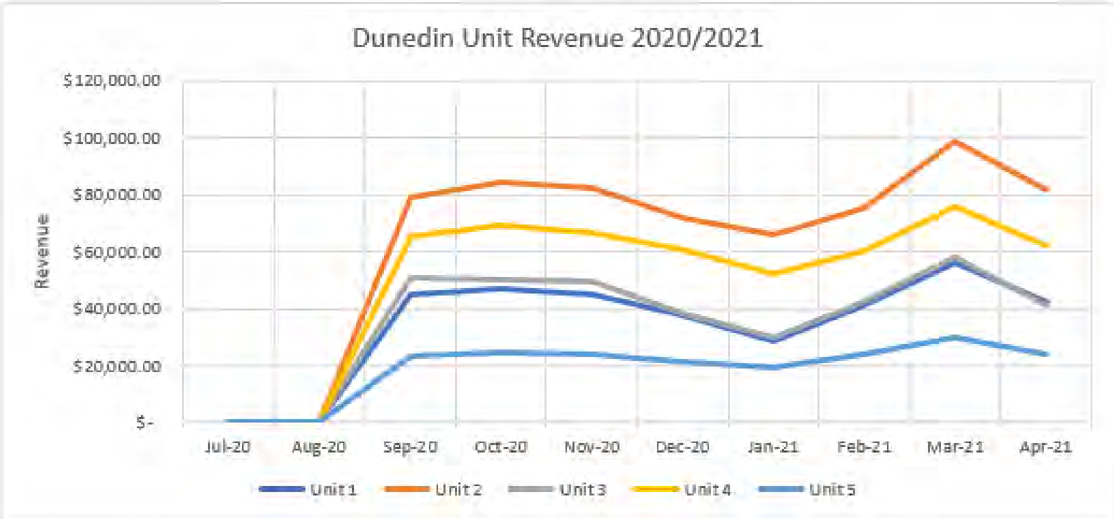
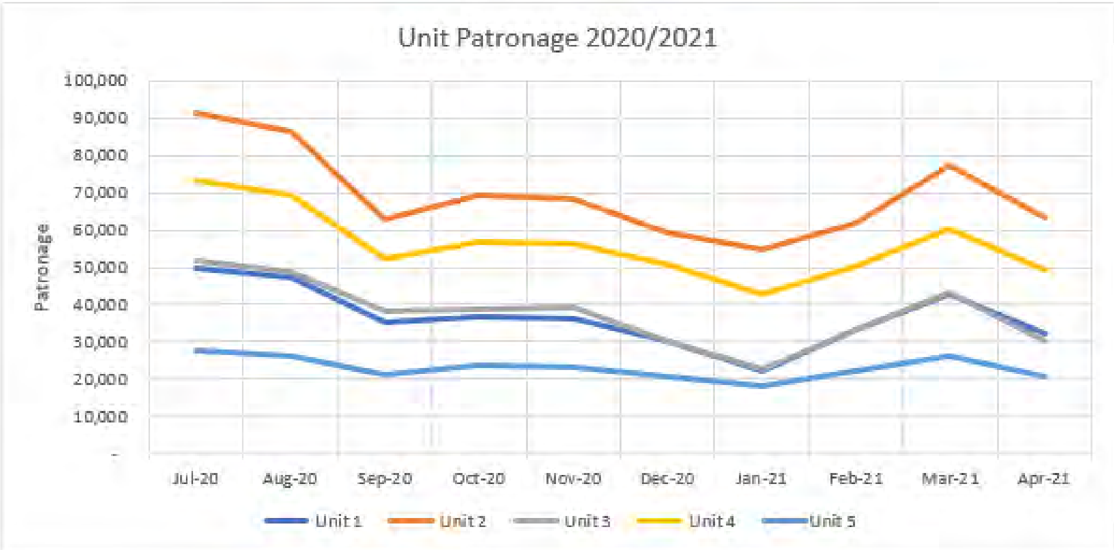


Figure 6: Dunedin Unit Revenue and Patronage





PUBLIC TRANSPORT - QUEENSTOWN

[25] Queenstown patronage and revenue continues to be low, a significant impact being the reduced level of airport/tourist activity and the impact of COVID on the local economy.

[26] Revenue is up compared to April 2020, when there was fare-free travel, and patronage up by 565% compared to April 2020 due to Alert Level 4 restrictions.

[27] From September 2020 to April 2021, Queenstown Routes 1 and 2 have seen patronage fall by 51% and 41% respectively compared to the previous financial year. However, the more commuter/residential oriented Routes 3, 4/5 have seen significant increases of 43% and 19%.

Figure 7: Queenstown Patronage and Revenue, YTD April 2021

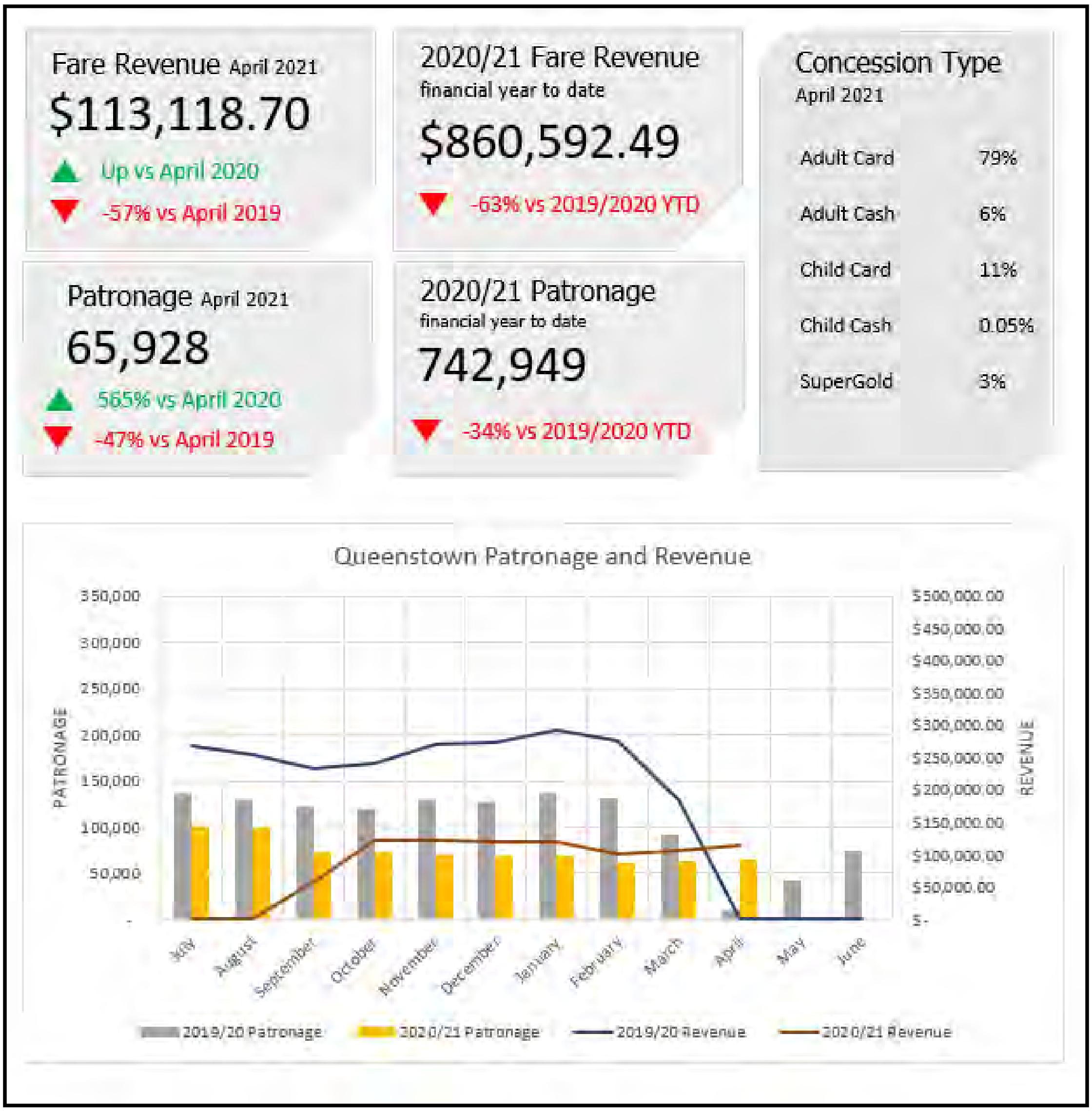
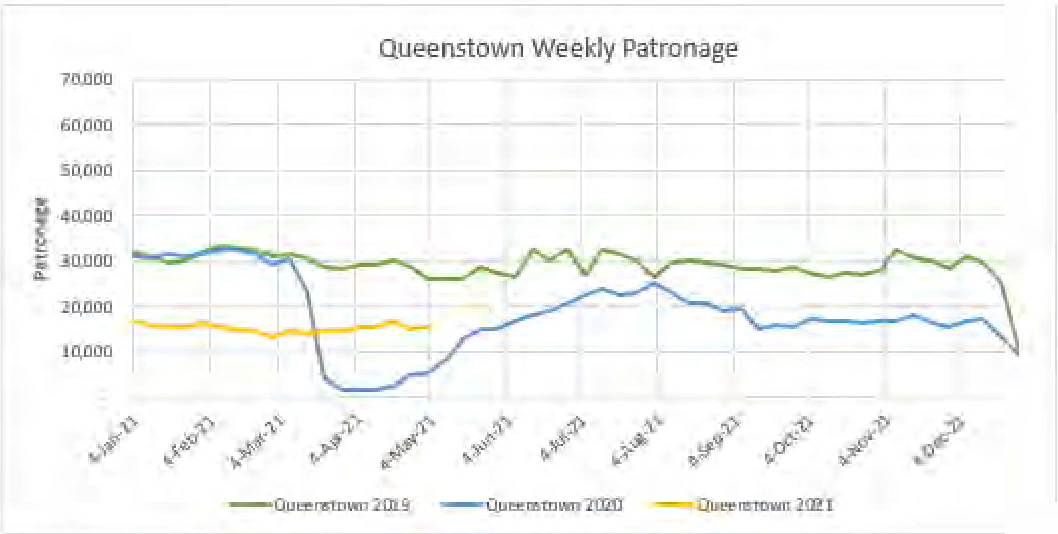


Figure 8: Queenstown weekly patronage, Unit Revenue and Unit Patronage



The weekly patronage graph above shows us the full calendar year view of patronage per week.

Unit 6	Unit 7
• Fernhill – Remarkables Park • Jacks Point – Frankton Hub • Lake Hayes - Queenstown	• Arthurs Point – Arrowtown • Kelvin Heights – Frankton Flats

Unit 6 Revenue April 2021

$86,503.04

▲ Up vs April 2020

Unit 6 Patronage

49,797

▲ 561% vs April 2020

Unit 7 Revenue April 2021

$26,615.65

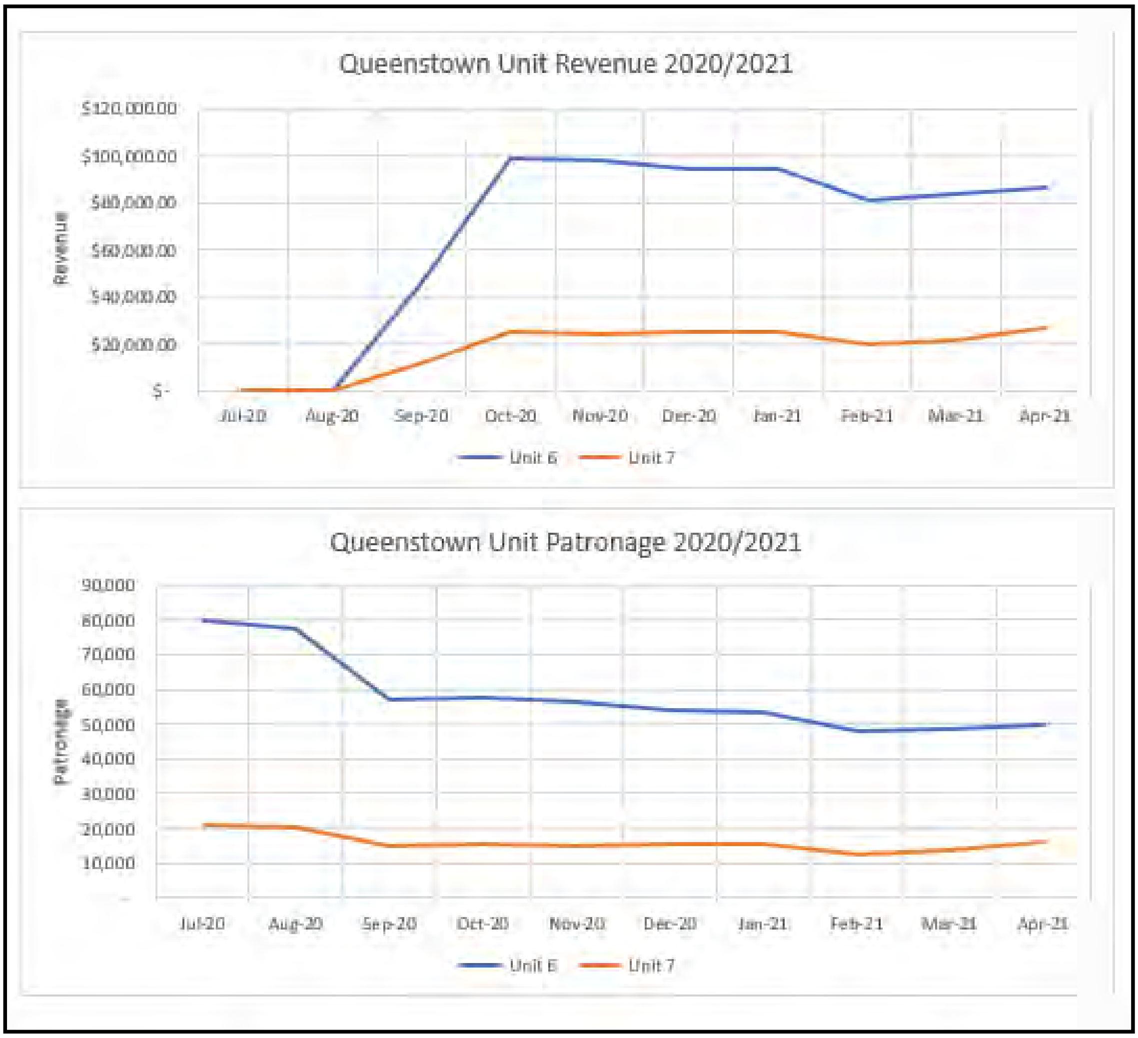
▲ Up vs April 2020

Unit 7 Patronage

16,131

▲ 576% vs April 2020

Figure 9: Queenstown Unit Revenue and Patronage



BEE CARD STATISTICS

[28] As of 1 June 2021, Otago has 47,554 registered Bee Cards. Of the 9 councils in the regional consortium using the Bee Card, the registration numbers are only higher in one council: Waikato, which has a significantly larger population and a greater number of buses.

CUSTOMER FEEDBACK AND COMPLAINTS

[29] The table and chart below capture feedback and complaints data, segregated by enquiry type, for November 2020 to April 2021.

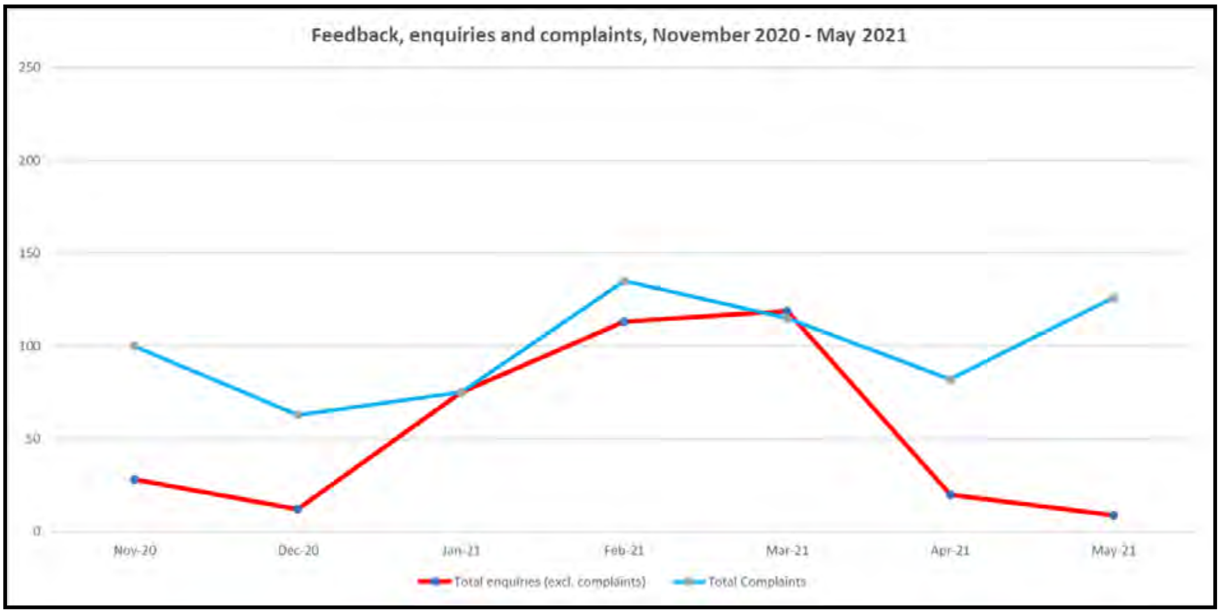
[30] Pre-COVID, the Otago network was reporting in excess of 4.1 million trips per annum. For the period below, 1,931,178 (est.) trips were recorded. 696 of the enquiries below were complaints, equating to 0.036% of the patronage for this period.

[31] Staff continue to follow up all complaints and take operational action where required. For example, recent concerns related to a period of peak travel time trip cancellations in March 2021 on two routes in Dunedin, due to driver illness, resulted in a collaborative approach with the transport operator to resolve the issue. Drivers with regular health concerns were re-rostered to off-peak services, resolving the issue for subsequent months.

FIGURE 10: CUSTOMER FEEDBACK, NOVEMBER 2021-MAY 2021

Detail	**Nov-20**	**Dec-20**	**Jan-21**	**Feb-21**	**Mar-21**	**Apr-21**	**May-21**
Total Escalated enquiries	128	75	150	248	234	100	135
Queenstown	35	17	35	47	38	30	30
Dunedin	93	58	115	201	186	72	105
Unspecified	-	-	-	-	9	-	-
Enquiries split by category							
General	12	11	35	51	56	7	4
Request	13	1	13	12	12	11	2
Praise	2	0	4	8	9	2	3
Lost Property	1	0	23	42	38	-	-
Unspecified	-	-	-	-	4	-	-
Total enquiries (excl. complaints)	28	12	75	113	119	20	9
Total Complaints	100	63	75	135	115	82	126
Complaints breakdown:							
Complaints related to the Bus Hub	2	1	1	2	0	-	-
Complaint about cost	1	1	0	5	2	-	-
Complaints about drivers	39	28	39	43	55	41	46
Complaint about passenger behaviour	1	0	0	5	3	2	5
Complaints about routes and times	17	8	29	24	3	3	5
Complaints about ticketing	4	0	5	4	2	8	2
Complaints about on-street infrastructure	10	2	6	14	1	7	9
Complaints about timeliness	23	20	14	62	40	15	27
Complaints about timetables/schedules	11	2	7	5	0	10	5
Complaint about on-bus wi-fi	1	0	1	0	0	1	-
Complaints related to other unclassified issues	18	13	34	18	5	7	2
Complaints about cleanliness/condition of bus	-	-	-	6	2	2	3
Complaints about transfers	-	-	-	4	0	-	
Complaints about Information/comms	-	-	-	10	2	5	17
Complaints related to app/website	-	-	-	4	0	1	5

Figure 11: Customer feedback, charted, November 2021-May 2021



REALTIME INFORMATION

[32] The previous reported notes a proposal to introduce a new mobile-friendly realtime tracking system, utilising the Transit app and the existing Trackabus system, which has since been implemented.

Figure 12: The Transit app, showing live tracking of the number 8 St Clair Service

[33] The app has been very well received and has had significant uptake in a short period of time. Figures 13 and 14 show app usage in May for Dunedin and Queenstown, detailing tens of thousands of views across the period. Route 8, St Clair-Normanby, shows 26,517 views alone for May 2021.

[34] In Figures 13 and 14, 'Views' refers to opening the app and using it to view services or buses nearest to the user. 'Clicks' refers to the specific action of 'clicking' on a route and using the functionality within the app to plan routes, set reminders, etc.

Figure 13: Transit App usage, May 2021, Dunedin

Line		Views	Clicks
8	St Clair - City - Normanby	26,517	3,121
3	Ross Creek - City - Ocean Grove	19,525	2,030
63	Balaclava - City - Logan Park	19,025	2,326
10	Opoho - Shiel Hill	18,342	1,331
11	Shiel Hill - Opoho	18,190	1,627
50	St Clair Park - City - Helensburgh	17,184	1,720
5	Pine Hill - City - Calton Hill	16,629	948
6	Calton Hill - City - Pine Hill	16,195	798
19	Waverley - City - Belleknowes	16,136	1,669
55	St Kilda - City - Brockville	15,583	1,200
33	Corstorphine - City - Wakari	15,415	1,338
15	Ridge Runner Northbound	15,349	908
44	St Kilda - City - Halfway Bush	15,222	1,149
18	Peninsula - City	13,892	1,501
14	Port Chalmers - City	13,267	1,597
77	Mosgiel - City	12,540	2,373
38	University - City - Concord	12,259	770
37	Concord - City - University	11,212	652
61	City to Kenmure	10,304	514
1	Palmerston - City	4,994	413
70	Brighton - Abbotsford - Green Island	3,308	214
80	Mosgiel East Circuit	1,757	108
81	Mosgiel West Circuit	1,518	68
40	MacAndrew Intermediate to Lookout Point via Kings and Queens	508	21

Figure 14: Transit App usage, May 2021, Queenstown

Line		Views	Clicks
1	Fernhill to Remarkables Shopping Centre	3,886	791
2	Arthurs Point to Arrowtown	3,755	368
5	Queenstown to Lake Hayes Direct	3,404	262
3	Kelvin Heights to Frankton Flats	3,199	232
4	Frankton Hub to Jacks Point	2,256	153

[35] The back end of the RTI system delivers operational benefits, principally in terms of contract management and network reliability. PT staff are utilising this to aid with contract/operator management, specifically Schedule 8 of ORC's PTOM contracts, and network reliability.

[36] Schedule 8 in ORC's PTOM contracts related to KPI's and punctuality. The RTI system allows for the electronic monitoring of all services to monitor reliability and punctuality KPI's. Link to contract schedule: https://www.orc.govt.nz/media/9620/key-performance-indicators-units-1-7.pdf

[37] Reliability and Punctuality are contractually defined by the Number and Percentage of scheduled trips leaving the Terminus (origin stop) between 59 seconds before and 4 minutes and 59 seconds after the scheduled departure time, with a target of 100% without good cause. Good cause can include issues such as heavy congestion, driver health, traffic and weather incidents, etc.

[38] The reports shown in Figures 15 and 16 detail, for Dunedin and Queenstown respectively, average [mean] departure times across all routes and trips for the month of April, at terminus point of origin.

[39] The report also provides for two non-contractual but key additional timing points which are important to the timeliness of the network, being the Bus Hub in Dunedin and the Stanley Street Hub in Frankton, Queenstown.

[40] The data indicates that departures are, on average, well within the Punctuality parameters required by contract.

[41] Note that this does **not** mean that there were zero late or missed trips, these continue to be reviewed and abatements charged where appropriate.

[42] Further analysis will take place in the form of peak trends driven by statistical review of standard deviations (and other measures) which will inform timetabling decisions during busier periods where services may be subject to delays - data which may not be visible in mean monthly statistics due to the weighting by volume of off-peak services which are less likely to experience delays/cancellations.

Figure 15: Dunedin RTI data showing reliability to schedules, April 2021

Operator	Route Name	Start Terminus	Terminus Status	Mid-timing Point (Bus Hub Dunedin & Frankton Hub Queenstown)	Mid-point Status
GoBus	Ross Creek - City - Ocean Grove	2:45	Within Bounds	2:18	Within Bounds
GoBus	Ocean Grove - City - Ross Creek	0:07	On Time	0:55	On Time
GoBus	St Clair - City - Normanby	2:19	Within Bounds	1:58	Within Bounds
GoBus	Waverley - City - Belleknowes	3:14	Within Bounds	1:25	Within Bounds
GoBus	Belleknowes - City - Waverley	2:48	Within Bounds	1:02	Within Bounds
GoBus	Corstorphine - City - Wakari	2:36	Within Bounds	0:46	On Time
GoBus	Wakari - City - Corstorphine	2:52	Within Bounds	1:00	Within Bounds
GoBus	St Kilda - City - Halfway Bush	2:00	Within Bounds	2:00	Within Bounds
GoBus	Halfway Bush - City - St Kilda	2:34	Within Bounds	1:06	Within Bounds
GoBus	St Clair Park - City - Helensburgh	1:02	Within Bounds	1:03	Within Bounds
GoBus	Helensburgh - City - St Clair Park	3:57	Within Bounds	1:21	Within Bounds
GoBus	St Kilda - City - Brockville	2:01	Within Bounds	1:53	Within Bounds
GoBus	Brockville - City - St Kilda	2:01	Within Bounds	1:21	Within Bounds
GoBus	Brighton - Abbotsford - Green Island	1:30	*Green Island is a transfer point, required to hold for passengers from route 77*		
GoBus	Green Island - Abbotsford - Brighton	6:54	*Green Island is a transfer point, required to hold for passengers from route 77*		
GoBus	Mosgiel - City	1:03	Within Bounds	n/a	n/a
GoBus	City - Mosgiel	2:05	Within Bounds	n/a	n/a
GoBus	Mosgiel East Circuit	0:50	On Time	n/a	n/a
GoBus	Mosgiel West Circuit	1:37	Within Bounds	n/a	n/a
Ritchies Dunedin	City - Palmerston	4:05	Within Bounds	n/a	n/a
Ritchies Dunedin	Pine Hill - City - Calton Hill	2:10	Within Bounds	0:27	On Time
Ritchies Dunedin	Pine Hill - City - Calton Hill via Libertor	1:47	Within Bounds	0:13	On Time
Ritchies Dunedin	Pine Hill - City - Calton Hill via Dalmore	0:49	On Time	1:22	Within Bounds
Ritchies Dunedin	Pine Hill - City - Calton Hill via Libertor	1:48	Within Bounds	1:04	Within Bounds
Ritchies Dunedin	Pine Hill - City - Lookout Point via Hills	1:33	Within Bounds	1:03	Within Bounds
Ritchies Dunedin	Calton Hill - City - Pine Hill	2:29	Within Bounds	1:05	Within Bounds
Ritchies Dunedin	Calton Hill - City - Pine Hill via Dalmore	1:34	Within Bounds	1:14	Within Bounds
Ritchies Dunedin	Calton Hill - City - Pine Hill via Libertor	2:11	Within Bounds	2:13	Within Bounds
Ritchies Dunedin	Calton Hill - City - Pine Hill via Dalmore	2:29	Within Bounds	0:30	On Time
Ritchies Dunedin	DNI to Pine Hill	2:00	Within Bounds	n/a	n/a
Ritchies Dunedin	Calton Hill - City - Pine Hill via Hillside	1:18	Within Bounds	2:28	Within Bounds
RItchies Dunedin	Opoho - Shiel Hill	3:57	Within Bounds	0:13	On Time
Ritchies Dunedin	Opoho - Shiel Hill via King Edward St ai	2:18	Within Bounds	1:11	Within Bounds
Ritchies Dunedin	Shiel Hill - Opoho	2:15	Within Bounds	3:21	Within Bounds
Ritchies Dunedin	Shiel Hill - Opoho via Macandrew Rd ai	0:58	On Time	4:09	Within Bounds
Ritchies Dunedin	Port Chalmers - City	1:33	Within Bounds	n/a	n/a
Ritchies Dunedin	City - Port Chalmers	1:30	Within Bounds	n/a	n/a
RItchies Dunedin	Ridge Runner Northbound	2:43	Within Bounds	n/a	n/a
Ritchies Dunedin	Ridge Runner Southbound	2:30	Within Bounds	n/a	n/a
Ritchies Dunedin	Peninsula - City	1:15	Within Bounds	n/a	n/a
Ritchies Dunedin	City - Peninsula	2:17	Within Bounds	n/a	n/a
Ritchies Dunedin	Peninsula - City - via Musselburgh	3:09	Within Bounds	n/a	n/a
Ritchies Dunedin	Concord - City - University	3:28	Within Bounds	1:13	Within Bounds
Ritchies Dunedin	University - City - Concord	1:57	Within Bounds	1:07	Within Bounds
Ritchies Dunedin	Balaclava - City - Logan Park	4:17	Within Bounds	0:46	On Time
Ritchies Dunedin	Logan Park - City - Balaclava	2:46	Within Bounds	0:33	On Time
		2:47		**1:53**	
		Overall [Mean]		**Overall [Mean]**	

Figure 16: Queenstown RTI data showing reliability to schedules, April 2021

Operator	Route Name	Start Terminus	Terminus Status	Mid-timing Point (Bus Hub Dunedin & Frankton Hub Queenstown)	Mid-point Status
Ritchies Queenstown	Fernhill to Remarkables Park	3:54	Within Bounds	1:56	Within Bounds
Ritchies Queenstown	Remarkables Park to Fernhill	2:05	Within Bounds	2:06	Within Bounds
Ritchies Queenstown	Arthurs Point to Arrowtown	0:31	On Time	1:43	Within Bounds
Ritchies Queenstown	Arrowtown to Arthurs Point	0:04	On Time	3:58	Within Bounds
Ritchies Queenstown	Kelvin Heights to Frankton Flats	1:24	Within Bounds	1:12	Within Bounds
Ritchies Queenstown	Frankton Flats to Kelvin Heights	2:38	Within Bounds	1:11	Within Bounds
Ritchies Queenstown	Frankton Hub to Jacks Point	0:25	On Time	n/a	n/a
Ritchies Queenstown	Jacks Point to Frankton Hub	2:35	Within Bounds	n/a	n/a
Ritchies Queenstown	Queenstown to Lake Hayes	1:41	Within Bounds	0:33	On Time
Ritchies Queenstown	Lake Hayes to Queenstown	1:41	Within Bounds	3:11	Within Bounds
		1:41		**1:58**	
		Overall [Mean]		**Overall [Mean]**	

CUSTOMER SATISFACTION SURVEY

[43] The Waka Kotahi NZ Transport Agency (WKNZTA)/ORC customer satisfaction surveys for Queenstown and Dunedin are ongoing, with the Queenstown survey completed and Dunedin due in June.

[44] The survey is mandated by WKNZTA to take place biennially; however, Council has conducted the survey annually since 2013, with the exception of 2020 (due to COVID).

[45] WKNZTA state that for customer satisfaction survey results to be comparable across different operators, modes and regions, the questions, sampling methods and rating scales must be the same. The Transport Agency has developed a list of common questions that form the public transport customer satisfaction survey. This set of questions allows for national statistics to be developed for the purpose of accountability reporting to government and to allow benchmarking between approved organisations and between operators. WKNZTA sets out the question wording, the required rating scale and sampling method and provides guidelines for carrying out surveys (https://www.nzta.govt.nz/assets/resources/procurement-manual/docs/appendix-k-measuring.pdf).

[46]

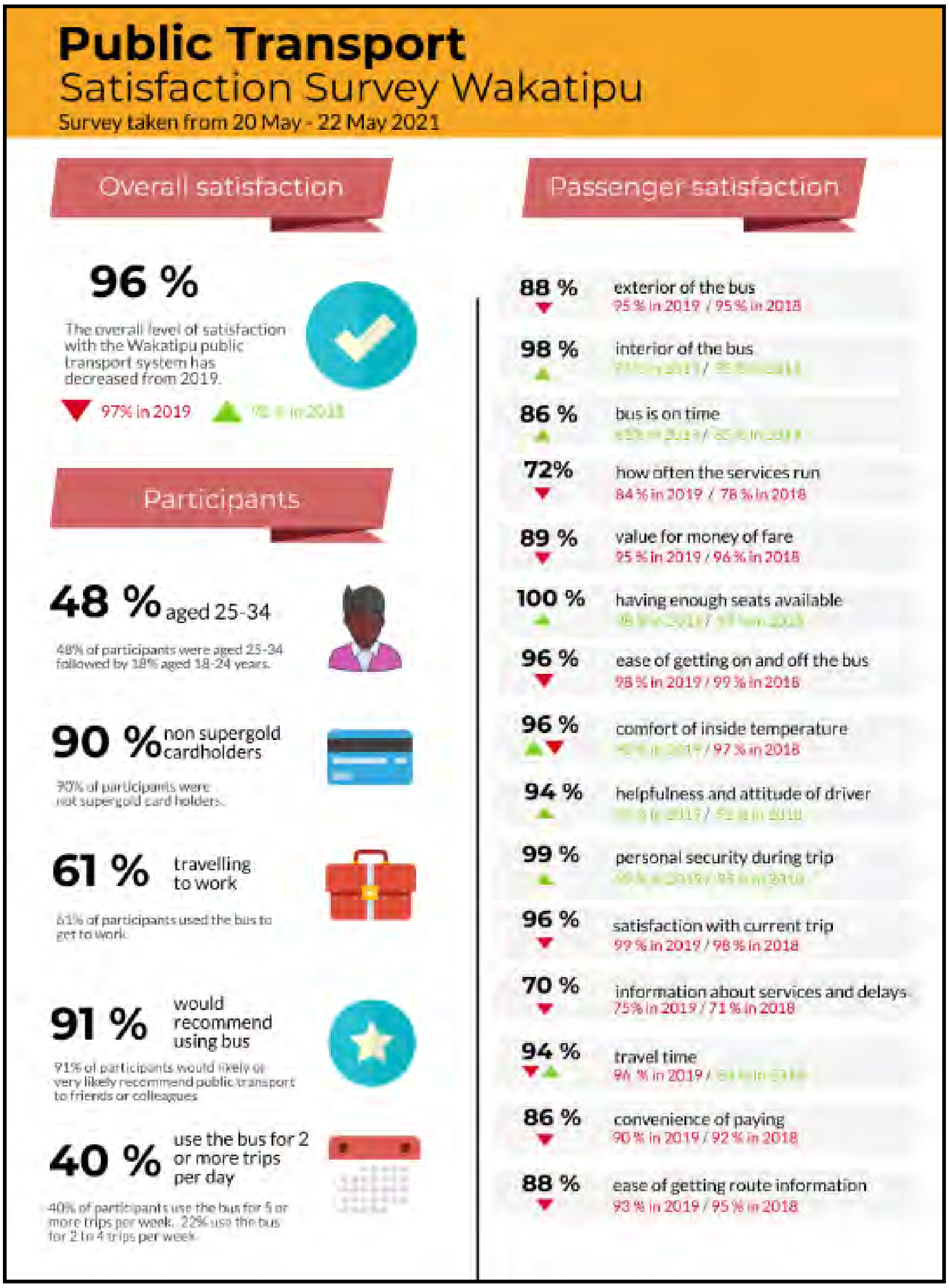
[47] A randomised sample of trips is taken using an approved Excel formula, including peak/off-peak, evening and weekend services. ‘Onboard sampling’ is the WKNZTA approved methodology for ORC surveys, meaning selecting users onboard in-service buses.

[48] Temporary staff travel on selected trips and select every third person entering the bus (excluding those younger than 15 years). Surveys are completed on iPads that are controlled by survey staff use and the results are collated in a surveying tool before collation/analysis by transport staff.

[49] The Queenstown survey was completed 20-22 May 2021, with all surveyed factors in the 80-90% range except for one, ‘information about services and delays’, at 70%. This measure is expected to improve over time due to the introduction of the Transit app.

[50] The 2020-21 Annual Plan, ‘Measures and Targets – Transport’ (Transport section, page 35) states “Public satisfaction – at least 85% of bus users surveyed annually for each network are satisfied with the overall standard of service”. The overall result for the Queenstown network is 96%, which exceeds the target by 11%.

Figure 17: Queenstown Satisfaction Survey Results, 2020/21



[51] Survey points of interest include:

- Bus is on time: an increase of people satisfied from 2019 and 2018;
- Value for money of fare: this decreased from 2019 and 2018;
- Helpfulness and attitude of driver: this increased from 2019 and 2018;
- Personal security: an increase from both years.
- Convenience of paying: This has decreased.

[52] 'The convenience of payment' measure is a disappointing decrease, given the introduction of the Bee Card; anecdotal feedback from the surveyors was passenger expectation of a Paywave-style system.

TOTAL MOBILITY

[53] Total Trips June 2020 to May 2021 are 111,854, of which 15,188 had hoist (wheelchair access) use. The average monthly number of 'Trips' was 9321 and of those 1265 requiring hoist transport.

[54] Comparing YTD 2019-2020 vs the same period 2020-2021, there has been an increase in trips taken and increased hoist use. An additional 13,125 trips were taken in 2021 and of those, 2197 had hoist deployment.

[55] During 2020 COVID-19 Alert Levels 4 and 3 (April and May), there was a decreased level of travel due to government lock down restrictions; however during June there was an increase in trips due to the introduction of free travel on all PT services, and fewer travel restrictions during Alert Level 2.

[56] 85% of trips took place in Dunedin and Mosgiel followed by 12% in Oamaru, 2% in Wanaka and 1% in Queenstown.

[57]

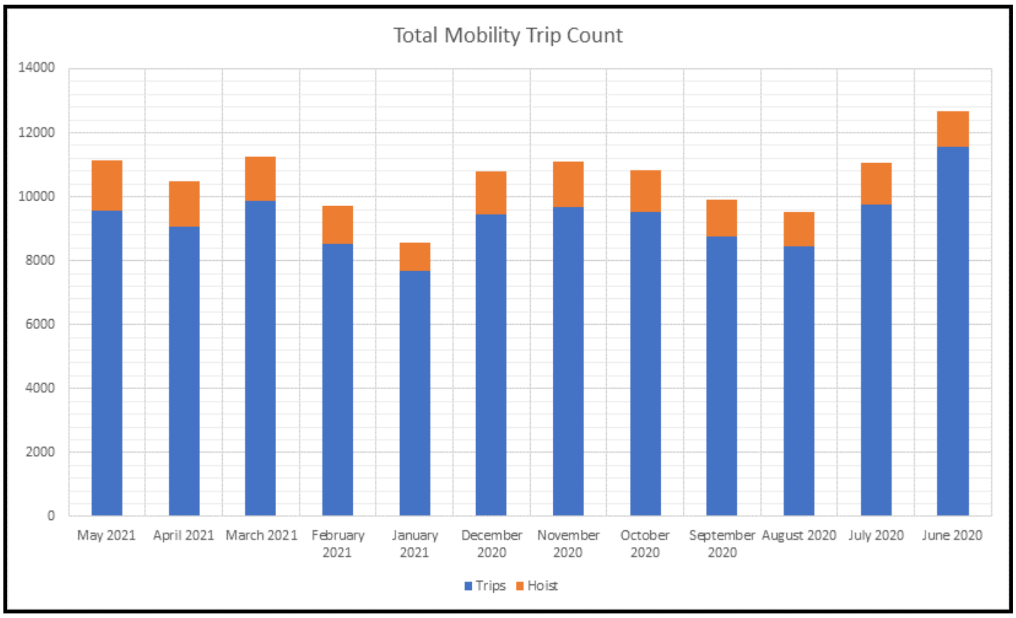


Figure 18: Total Mobility Patronage

NEXT STEPS

[58] 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.
- present the results of the satisfaction survey of our Dunedin bus services in the next committee paper.
- provide an update on the performance to the two public transport networks at the End-FY Data and Information Committee meeting.

ATTACHMENTS

Nil