7.1. Natural Hazards Adaptation in the Head of Lake Wakatipu

Prepared for:	Council
Report No.	HAZ2105
Activity:	Safety & Hazards: Natural Hazards
Author:	Tim van Woerden, Natural Hazards Analyst Jean-Luc Payan, Manager Natural Hazards
Endorsed by:	Gavin Palmer, General Manager Operations
Date:	27 May 2021

PURPOSE

[1] This paper updates Council on progress with the Head of Lake Wakatipu natural hazards adaptation project. The project area includes the communities of Glenorchy and Kinloch.

EXECUTIVE SUMMARY

[2] The area at the head of Lake Wakatipu is exposed to a complex range of hydrological, slope-related and seismic hazard events.

[3] In this dynamic alpine environment, many of the natural hazard risks are not static, but are subject to continual adjustment in response to geomorphic (landscape) and climatic changes. Although the timing and magnitude of future changes may be uncertain, both geomorphic and climatic changes are expected to cause increases in the severity and likelihood of natural hazard impacts to this area – particularly for hydrologically-driven hazards such as flooding.

[4] The area has a total population of about 400. The main hazard impacts are flooding of Rees River/Lake Wakatipu impacting on the low-lying residential area of Glenorchy township, and Dart River erosion and flooding causing disruption to Kinloch Road. The road provides vehicle access to Kinloch settlement, and further southwards to the Greenstone/Caples area and amenities.

[5] Given the very dynamic nature of the physical environment in the area, engineering works provide temporary benefits, but they do not fully deal with the problems permanently and are unlikely to be sustainable financially or environmentally in the long run.

[6] A strategic and holistic approach is needed to address these natural hazards issues in the longer term, which needs to also consider future climate change, landscape changes, and multiple and cascading natural hazards.

[7] The approach selected by Otago Regional Council (ORC) to develop a holistic, longer-term natural hazards management plan is a method known as 'Adaptation Pathways', which has been developed by the Ministry for the Environment as a blueprint for community-led decision making in areas affected by natural events and climate change. This approach has been developed specifically to help plan and adapt for situations where the future is uncertain. It allows for flexible and adaptive decision-making, and

for planning under conditions of uncertainty regarding the rate, timeframes and magnitude of future changes.

[8] This report describes the selected approach in more detail and summarises the work completed to-date by ORC in collaboration with other organisations in order to develop, and in the future implement, an adaptation strategy to address natural hazards issues in the longer term.

RECOMMENDATION

That Council:

1) ***Acknowledges*** *the need for natural hazards adaptation planning in the head of the Lake Wakatipu project area.*
2) ***Notes*** *the program of work completed to date.*
3) ***Endorses*** *the use of the Adaptation Pathways approach.*
4) ***Supports*** *the continued collaboration with project partners.*

BACKGROUND

Physical environment and natural hazard overview

[9] The area at the head of Lake Wakatipu (Figure 1) is subject to a number of natural hazards that have potential serious implications, being exposed to a complex range of hydrological, slope-related and seismic hazard events.

[10] The communities in the head of the lake area (including Glenorchy and Kinloch) have been regularly impacted by natural hazard events throughout the duration of settlement, as a consequence of development in locations potentially exposed to these hazard impacts such as floodplains and alluvial fan surfaces.

[11] In recent decades, these hazard impacts have included flooding of lower-lying parts of Glenorchy's residential area in December 1999 and February 2020, and frequent flooding and erosion impacts disrupting or threatening the road access to Kinloch.

[12] This area is also exposed to a number of lower-likelihood hazard events, which may also have severe consequences for parts of this community, including debris flows, dambreak flooding, liquefaction or lateral spreading triggered by a major earthquake, or a tsunami event triggered by landsliding or a collapse of delta sediments.[1]

[1] Tonkin + Taylor (2021). Head of Lake Wakatipu Natural Hazards Assessment. Report prepared for ORC.

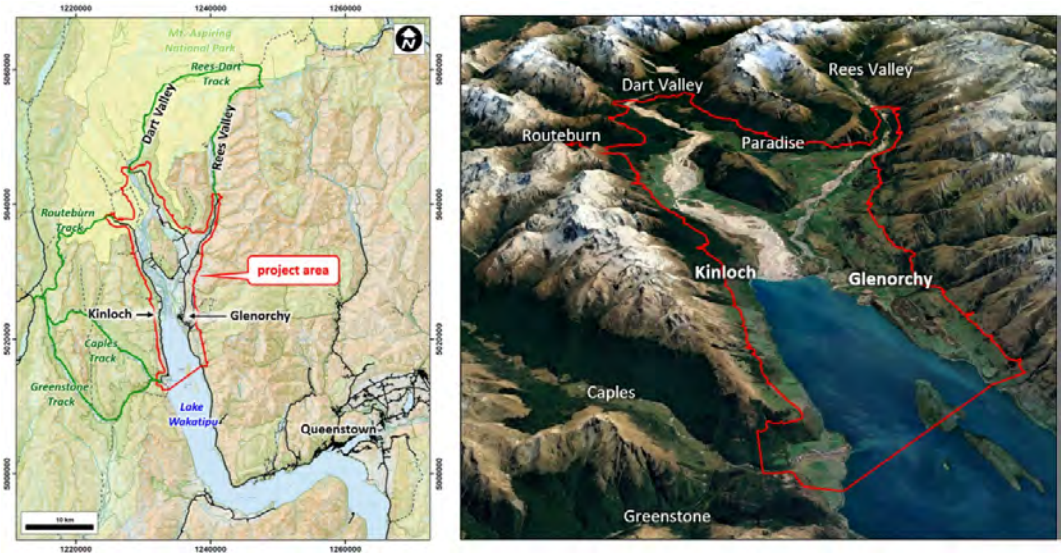


Figure 1: Overviews of the head of Lake Wakatipu project area, showing the relationship to the wider Lake Wakatipu and National Park area (left), and showing the project area comprising largely of the Dart and Rees floodplains between the Humboldt and Richardson Mountains to the west and east respectively (right-hand image).

[13] In this dynamic alpine environment, many of the natural hazard risks are not static, but are subject to continual adjustment in response to geomorphic (landscape) and climatic changes. Although the timing and magnitude of future changes may be uncertain, both geomorphic and climatic changes[2] are expected to cause increases in the severity and likelihood of natural hazard impacts to this area – particularly for hydrologically-driven hazards such as flooding.

[14] The braided riverbeds, delta and floodplains of the Dart and Rees rivers are undergoing inevitable and irreversible geomorphic changes[3] such as riverbed aggradation, delta growth, and lateral channel migration, due to the ongoing natural processes of water and sediment movement through these systems.

[15] These geomorphic changes are expected to increase the frequency and severity of future flooding impacts for both the Dart and Rees river floodplains. For the Dart and Rees floodplains, riverbed aggradation will escalate flood hazards through reducing the flood capacity of the river channels, in turn reducing available freeboard[4] to riverbanks and floodbank structures, while also increasing lateral migration of the braided riverbed's active channels.

[16] For the Glenorchy area, river bed aggradation will also increase the likelihood of a severe outbreak flood event from the Rees River channel through the topographically-lower lagoon area adjacent to the township's northern margin, while also magnifying the backwater effects which may impede floodwater drainage from this lagoon area during flood events (Appendix A).

[2] NIWA (2019), Climate change projections for the Otago Region. Report prepared for ORC.
[3] Wild (2013), Growth dynamics of braided gravel-bed river deltas in New Zealand, PhD thesis, University of Canterbury; Brasington (2021), Fluvial hazards at the top of the lake, presentation to the Glenorchy community, April 2021.
[4] The elevation difference between the water surface to the top of a riverbank, or to a floodbank crest.

[17] In 2019, NIWA analysed projected climate changes in Otago, for mid-century (2031-2050) and late-century (2081-2100) timeframes, and for several climate change scenarios.[5]

[18] For the head of Lake Wakatipu catchments, this modelling shows significant future increases in mean annual rainfall and its seasonality, with mean winter rainfall projected to increase by >40% by 2090 (under the RCP8.5 scenario).[6] Extreme, rare rainfall events are also projected to increase in magnitude, for example NIWA's HIRDS[7] model projections for the 'Dart at Paradise' and Dart Hut locations show increases by late-century of 22-33% in rainfall totals for 100-year (0.01 Annual Exceedance Probability, AEP) rain events (RCP8.5 scenario). These changes to precipitation variables are likely to also result in an increase in the rivers' mean discharges and flood magnitudes, and thus the resulting flood hazard. For the head of the lake catchments, by late-century timeframes, NIWA projects 20-50% increases in mean discharge, and 50-100% increases in the mean annual flood (RCP8.5 scenario).

[19] The area has a total population of about 400. The main hazard impacts are flooding of Rees River/Lake Wakatipu impacting on the low-lying residential area of Glenorchy township and Dart River erosion and flooding causing disruption to Kinloch Road. The road provides vehicle access to Kinloch settlement, and further southwards to the Greenstone/Caples area and amenities.

[20] Otago Regional Council (ORC) and Queenstown Lakes District Council (QLDC) have previously undertaken localised engineering works to address some of the flooding and river erosion (e.g. Figure 2).

Figure 2: Examples of erosion protection and river management works. At left, rock armouring of a section of the Dart river banks at Kinloch Road (completed by QLDC). Right-hand image shows work undertaken by ORC at the Rees Delta to realign the main Rees River channel.

[21] Since the start of the 2018 calendar year, ORC and QLDC have spent a combined total in the order of $1M on river management, flood mitigation and response activities to address the flooding and erosion issues that have arisen during that very short time period.

[5] NIWA (2019), Climate change projections for the Otago Region. Report prepared for ORC.

[6] Future climate change projections are considered under four emission scenarios, called Representative Concentration Pathways (RCPs) by the IPCC.

[7] High Intensity Rainfall Design System.

[22] In the past few years, these activities have included gravel removal, channel realignments, willow control, management of flood-related road closures, construction of erosion control and flood mitigation structures, repairs to roads and structures, and work to raise sections of roadway.

[23] Given the very dynamic nature of the physical environment in the area, engineering works provide temporary benefits, but they do not fully deal with the problems permanently and are unlikely to be sustainable financially or environmentally in the long run.

Natural Hazard Adaptation

[24] A strategic and holistic approach is needed to address these natural hazards issues in the longer term, which needs to also consider future climate change, landscape changes, and multiple and cascading natural hazards.

[25] The complex, dynamic alpine environment of the head of Lake Wakatipu poses several challenges for assessing, defining and communicating natural hazard risk levels. The future risks resulting from ongoing changes to the geomorphic and climatic environments form a 'moving baseline' of risk levels, which is reliant on projections and modelling of future scenarios and will develop as further information on these processes becomes available.

[26] The risk levels of some natural hazard event types cannot be well defined based on the current data available. These less-frequent, and often cascading, natural hazard events such as debris flows, dambreak flooding, liquefaction/lateral spreading, or lake tsunami may have the potential for major impacts to the local communities, but their event likelihood or consequences are not yet known with enough confidence to define these risks probabilistically.

[27] It is very important that this strategic approach is developed collaboratively with the local community and other project stakeholders and partners, and that their values and views are incorporated into this planning.

[28] The approach selected by ORC to develop a holistic, longer-term natural hazards management plan is a method known as 'Adaptation Pathways', which has been developed by the Ministry for the Environment[8] as a blueprint for community-led decision making in areas affected by natural events and climate change. This approach has been developed specifically to help plan and adapt for situations where the future is uncertain – it allows for flexible and adaptive decision-making, and for planning under conditions of uncertainty regarding the rate, timeframes and magnitude of future changes. This work is an Annual Plan activity for ORC.

[29] The Adaptation Pathways guidance is structured as an iterative 10-step decision cycle, organised around five key questions (Figure 3);

- What is happening?
- What matters most?

[8] Ministry for the Environment (2017), Coastal Hazards and Climate Change: Guidance for local government.

- What can we do about it?
- How can we implement the strategy?
- How is it working?

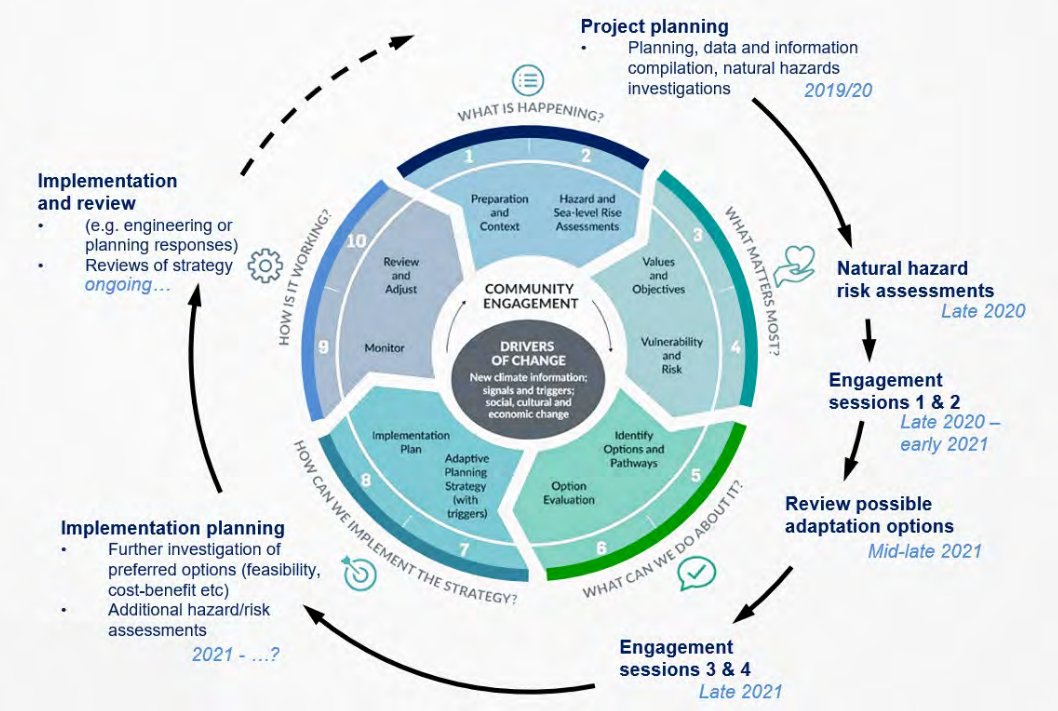


Figure 3: Overview of the 10-step decision cycle of the MfE Adaptation Pathways approach, showing the proposed timelines for the head of Lake Wakatipu natural hazard adaptation project.

[30] Adaptation is a response strategy to anticipate and adjust to actual and expected changes in environmental conditions. An adaptation strategy for the head of Lake Wakatipu will probably include a mix of short, medium, and long-term (100 years and longer) adaptation options or pathways, selected from a range of option types available.

[31] Adaptation options can be summarised in four types (accommodate, defend, retreat, and avoidance). The 'status quo' is also an option, not taking any proactive action to address natural hazards, and accepting that their impacts may increase in severity.

[32] The approach relies on pre-defined decision points, or triggers, where the first options or pathway can be revisited, depending on how the future evolves (refer to Appendix A for more details).

[33] ORC is leading this natural hazard adaptation project in collaboration with our project partners; Queenstown Lakes District Council (QLDC), Department of Conservation (DOC) and Kai Tahu, represented by Aukaha and Te Ao Marama. We have also relied on technical advice and specialist expertise from Tonkin and Taylor (T+T), University of Canterbury (UC), NIWA and Aukaha.

[34] The adaptation strategy being developed, and its successful and enduring implementation will need the strategy to be embedded in existing (such as the Regional Policy Statement, the District Plan, annual and long-term plans) or future planning documents, legislation or regulations (such as the outcome of the Resource Management System Reform currently underway, Figure 4 below).

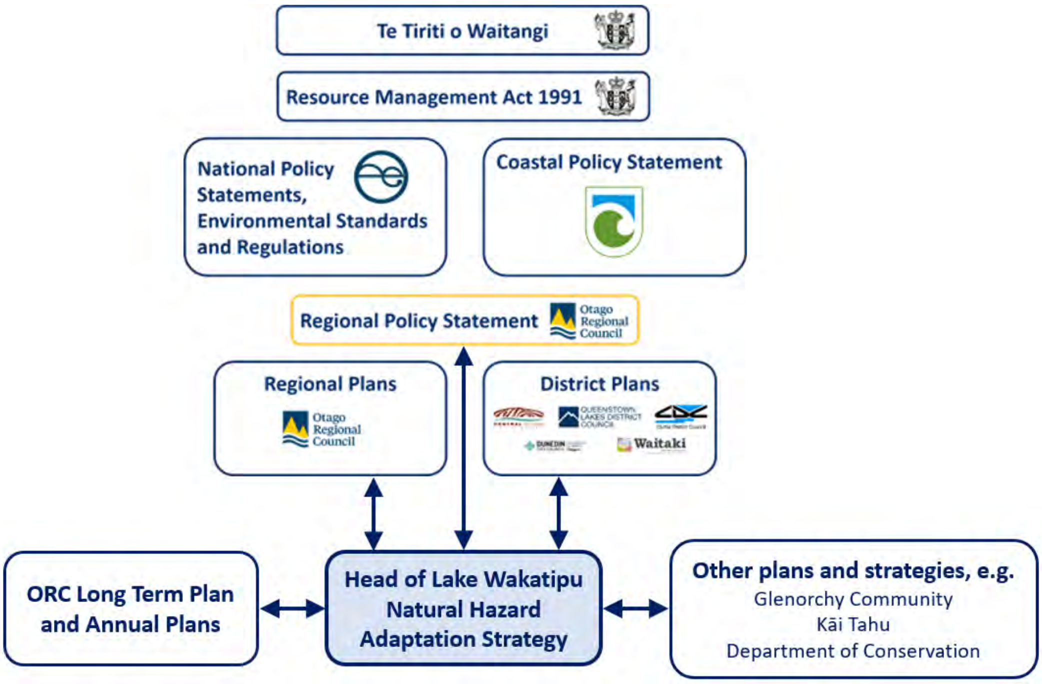


Figure 4: Hierarchy of policies and plans and relation with the Head of Lake Wakatipu Natural Hazard Adaptation Strategy.

[35] The Milton 2060 Flood Risk Management Strategy (2012) is a relevant example of how a strategy was used to guide planning considerations through the Clutha District Plan[9].

Work Completed

[36] A detailed description of the work completed to date is presented in Appendix A.

[37] This adaptation project for the head of Lake Wakatipu was commenced in mid-2019, and initially intended as a 2-year project. Project work to date has included capture of updated datasets such as river bed and LiDAR[10] surveys, implementation of additional environmental monitoring (Figures 5 and 6), compilation of existing natural hazards datasets, project planning and selection of the project approach, development of

partner and community relationships, and engaging external expertise to undertake new investigations.

Figure 5: The recently installed water level monitors installed at the Glenorchy lagoon (left) and the Glenorchy marina (right). Data for both of these monitoring stations is available in near real-time on ORC's WaterInfo web page.

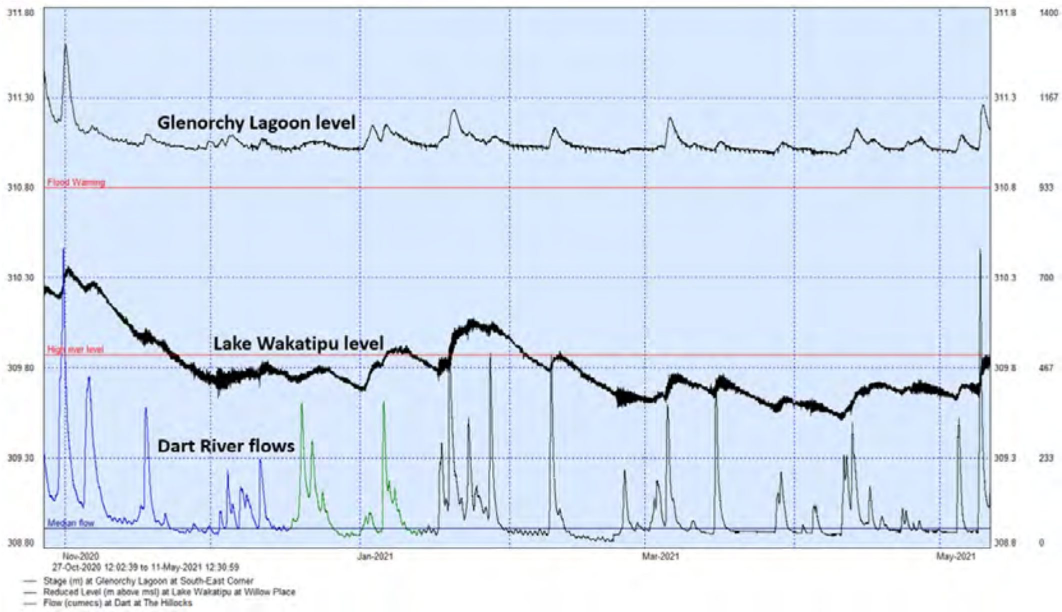


Figure 6: Initial monitoring data for the Glenorchy Lagoon, showing the relationships with the level of Lake Wakatipu and Dart River flows. Over this time the lagoon levels have fluctuated within a range of ~0.6m, with the highest lagoon level of 311.6m associated with a high-flow event in early November (Dart River peak flow of ~780 cumecs).

[38] While progressing the adaptation project, ORC has also continued with responses to flooding events and river management issues, carrying out inspections, investigations and surveys, and undertaking river management works.

[39] The last two years have seen several significant flood events in the head of Lake Wakatipu area; the Dart River has recorded the two highest river flows since monitoring commenced in 1996 (March 2019, February 2020; Figure 7), and Lake Wakatipu has reached the 7th and 8th highest lake levels recorded since 1962 (December 2019, February 2020; Figure 8).

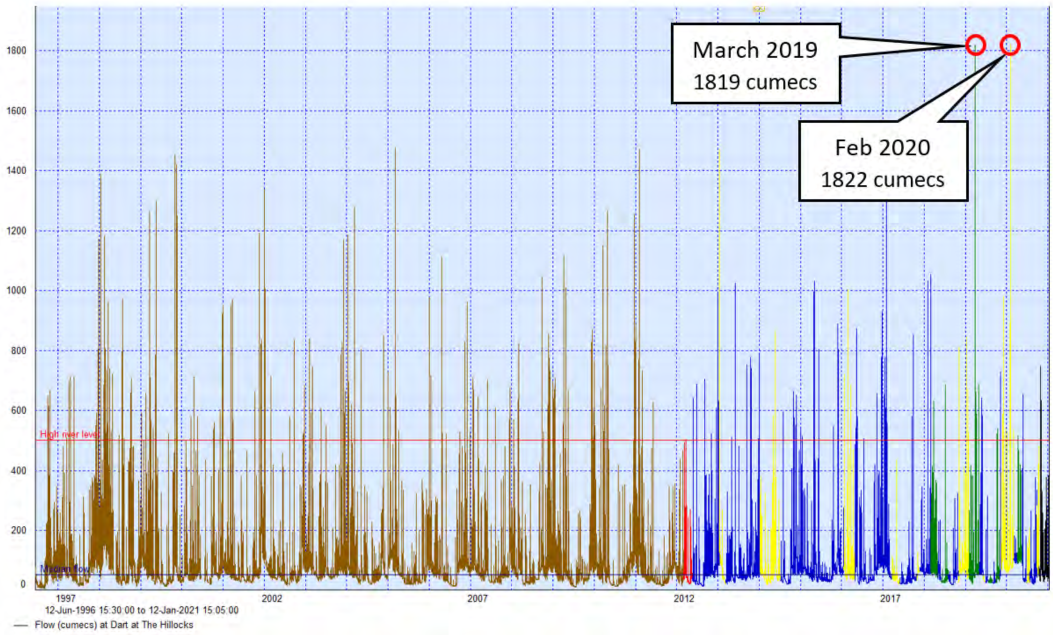


Figure 7: The Dart River flow record 1996-2021. Prior to the high flows (about 1820 cumecs) of March 2019 and February 2020, the four highest flows previously recorded were in the range of 1450-1480 cumecs (Nov 1999, March 2005, Feb 2011, Jan 2013).

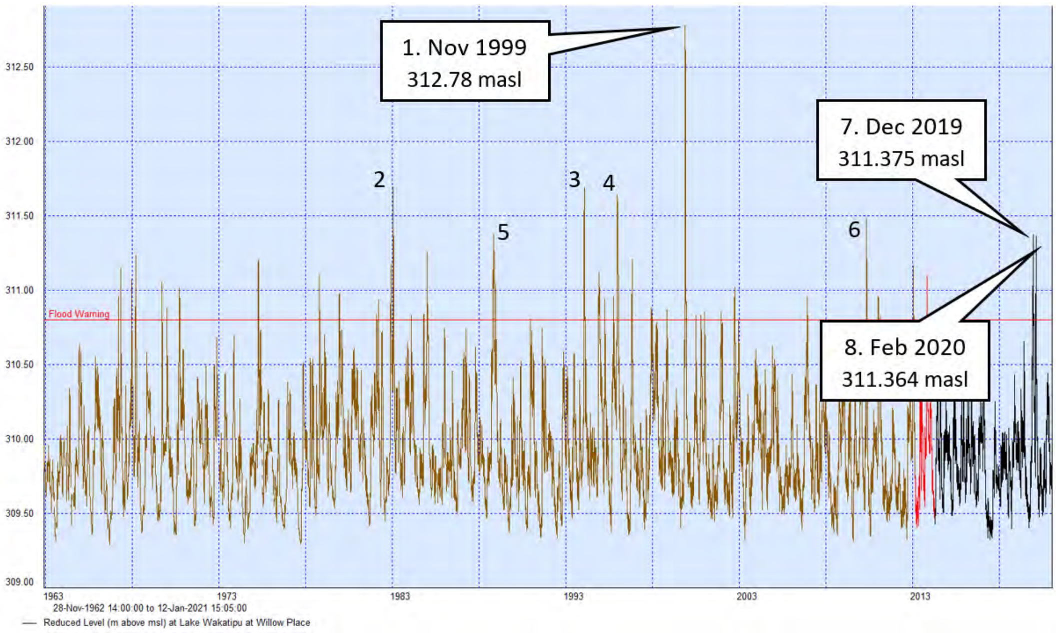


Figure 8: Lake Wakatipu levels 1962-2021. The eight highest flood peaks within this record are numbered.

[40] ORC engaged the University of Canterbury to complete a river morphology assessment which analysed river and floodplain processes and historic changes, the drivers of geomorphic change, and expected future changes to the landscape and flooding hazards. The project was led by Professor James Brasington (Director of the Waterways Centre for Freshwater Management).

[41] This work is a key component of the adaptation project as it provides the scientific basis demonstrating the expected future increases to the flood hazard as a result of geomorphic and climatic changes, reinforcing the need for adaptation to these changes.

[42] ORC engaged Tonkin and Taylor (T+T) to complete a review of the natural hazards' risks for this project area, based on all currently available information[11].

[43] The report provides an improved risk understanding for the area, showing the spatial extent of potential natural hazard events, and illustration of the potential event consequences. This report has included completion of the first risk mapping for the head of the lake area, showing natural hazard uncertainty and risk rating.

[44] This risk mapping illustrates the higher risk areas as being those subject to potential floodplain hazards (flooding, erosion and channel avulsion), elevated lake levels, and active or potentially active alluvial fan surfaces.

[45] A NIWA team lead by Dr Paula Blackett have collaborated in the co-design of the community engagement activities of this project. NIWA's valuable social science expertise has helped to guide development of an engagement process designed to ensure dialogue and participation with the community.

[46] Consistent with the MfE guidelines, the engagement process is intended to enable the community to be heard and participate in the decision-making process, and for ORC to gather feedback regarding the community's concerns and preferred directions for adaptation approaches (refer to next section).

[47] Aukaha have compiled a cultural values statement for the project area on behalf of Kāi Tahu. This report emphasises the significance of the wider Whakatipu-wai-Māori (Lake Wakatipu) area to mana whenua, providing an overview of the cultural values and mana whenua associations of this project area and its surrounding landscapes. This resource will be one used to ensure iwi values are considered in project direction and assessment of any adaptation options or pathways.

Community Engagement

[48] Over the last two years, ORC has worked to develop strong working relationships with members of the local community directly and through the Glenorchy Community Association (GCA).

[49] In that time, ORC has presented to three GCA meetings to provide updates on natural hazards activities[12], has provided emailed monthly project updates[13] (since August 2020), has created a project webpage[14], and has organised two community engagement events as part of this adaptation project (December 2020, April 2021).

[11] https://www.orc.govt.nz/media/9784/head-of-lake-wakatipu-natural-hazards-assessment.pdf
[12] Presentation slides located within '*Presentation and other resources*' tab on the project webpage, link below.
[13] These newsletters saved at '*Newsletter archives*' tab on the project webpage, link below.
[14] https://www.orc.govt.nz/managing-our-environment/natural-hazards/head-of-lake-wakatipu

[50] The first community engagement event of this adaptation project was held in Glenorchy in early December 2020. This event was titled "What is happening now, and how does this affect you?" and was structured as a drop-in session, attended by around 35 members of the local community.

[51] This session was intended as an introduction to the natural hazards and historical landscape changes and allowed for discussion of residents' experiences and observations of past natural hazards events and landscape changes, and concerns regarding future natural hazard impacts.

[52] The second community engagement events for this project were held in early April 2021, and were titled "What could happen in the future, and what might we do?"

[53] The first part of these events was a public presentation by James Brasington to present the findings of the river morphology assessment and natural hazards implications; 'Fluvial hazards at the top of the lake - living with rivers on the edge.'[15] This talk was attended by about 40 community members.

[54] The following day a drop-in session was held to continue discussions, focusing on two key areas; what might future geomorphic and climate changes mean for the natural hazards of this area, and what might adaptation to those changes look like?

Next Project Steps

[55] ORC and NIWA are currently compiling and assessing information collected from community discussions and are working to develop plans for the next phases of this project. These next steps will involve reviews and discussions with our project partners, evaluation of the need for additional natural hazards and risk information, and for assessments of feasibility of adaptation options or pathways.

[56] The immediate next steps proposed for technical studies are to undertake a climate change modelling project to provide a more specific and detailed understanding of the hydrological effects of climate change for this area, an initial assessment of the feasibility of possible river management options, and to commence scoping for a series of proposed studies to provide improved understanding of the risks posed by flooding, debris flow/dambreak flood and alluvial fan events, and liquefaction/lateral spread susceptibility.

[57] The next phase of community engagement activities is intended for late 2021, although the design and content of these sessions are yet to be finalised, and it is likely that the engagement approach for these next steps will need to be different in form than the 'drop-in' format utilised to date.

[58] Planning for these next engagement activities will consider review of community feedback to date, discussions with project partners, and ongoing development of the project direction.

[15] Presentation slides and audio recording saved within '*Presentation and other resources'* tab on the project webpage, link above.

[59] In the interim, before these next in-person engagement activities, we will continue to provide the community with project updates via email and through making material available on the ORC website.

DISCUSSION

[60] As this adaptation project develops through the iterative approach being utilised, it is expected that the project scale and complexity will increase. As we commence planning for the next steps in this project, we have identified a number of technical investigations which are required for providing an increased understanding of natural hazard risks, and for initial assessments of potential adaptation options. It is becoming clear that to undertake these investigations thoroughly, the project timeline and scale may need to be extended beyond that initially proposed for this project.

[61] Following completion of this project phase to identify and develop a strategy of preferred adaptation options and pathways approaches, the next phase will consist of planning towards implementation of those options and pathways. Implementation of any larger-scale adaptation options will require significant investment in further investigations, for example these may include feasibility studies, cost-benefit analysis and business case development, investigations of potential funding options, and consideration of environmental, legal, technical and planning factors.

[62] Attaining the level of natural hazard risk definition (e.g. risks to life, or risk to property) which may be needed for decision-making will require continued research and technical investigations.

[63] Climate change is a key factor is this project, along with geomorphic change. These two influences being causes of expected increases to many of the natural hazard risks, and therefore driving the need for development of a natural hazards adaptation response.

[64] The Adaptation Pathways approach to natural hazards adaptation is relatively new and most past or current applications have been in coastal hazard environments,[16] rather than in an alpine environment or with a multi-hazard scope.

[65] The lessons from the use of this process will have wider benefits for ORC's other natural hazards adaptation projects within Otago.[17]

[66] ORC will also communicate these findings to Otago's territorial authorities and any other interested organisations. Members of the natural hazards team are planning to meet with staff at the Dunedin City Council to provide a review of this adaptation project, and to discuss challenges and lessons which may have benefit for adaptation in the South Dunedin/Harbourside areas.

[67] Continued collaboration and development of project partner relationships will be critical to the successful development of an adaptation pathway strategy, and future implementation of these adaptation actions.

[16] E.g. the 'Clifton to Tangoio coastal hazard strategy 2010' developed by the Hawke's Bay Regional Council (https://www.hbcoast.co.nz/strategy-development/)

[17] For example adaptation work in the South Dunedin-Harbourside area, and at the Clutha Delta.

CONSIDERATIONS

Strategic Framework and Policy Considerations

[68] The currently operative Regional Policy Statement for Otago provides for regional, city and district councils the opportunity to prepare strategies or other similar documents to assist in the management and reduction of natural hazard risk and adaptation to, and mitigation of climate change.

[69] It also encourages regional, city and district councils to develop community relevant responses to the impacts of natural hazards and climate change, in collaboration with the relevant local authority, key stakeholders and affected community (Method 6, Non-RMA strategies and plans, Otago Regional Policy Statement, 2019).

[70] The adaptation approach discussed in this paper reflects 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

[71] The project is included in the draft ORC 2021-30 Long Term Plan with funding of $120,000 (excluding staff time) in the next financial year and $70,000 (excluding staff time) for the two following years.

[72] However, as noted previously, the scale and complexity of this project is expected to evolve due to the iterative nature of the adaptation process. The number and scope of supporting investigations required to support this process will become clearer as this program of work progresses. This may require further funding in the coming years.

[73] The need for additional work will be reflected in the preparation of the next Annual Plans and Long-Term Plans.

Significance and Engagement

[74] Refer to the description in the Background and Discussion sections.

Legislative and Risk Considerations

[75] The work described in this paper helps ORC fulfil its responsibilities under sections 30 and 35 of the RMA.

[76] The likely reforms of the Resource Management Act and strengthening of provisions to do with local authority leadership for climate change adaptation are noted.

Climate Change Considerations

[77] Climate change considerations are discussed above.

Communications Considerations

[78] ORC's communications for this project have included development of a project webpage, compilation of an email contact list used to provide monthly project updates to community members, and several in-person events and meetings with the head of Lake Wakatipu community, and with the Glenorchy Community Association.

NEXT STEPS

[79] Next steps are presented in the Next Project Steps section above.

ATTACHMENTS

1. Natural Hazards Adaptation in the Head of Lake Wakatipu [**7.1.1** - 43 pages]

Appendix A: Natural hazards adaptation in the Head of Lake Wakatipu:

1. INTRODUCTION

The paper presented to the committee provides a formal update on ORC's natural hazards adaptation project for the head of Lake Wakatipu area. This appendix provides supporting information summarising ORC's natural hazards activities within this project area over about the last two years. The overall objective of these activities has been to work towards development of a natural hazards adaptation strategy. These project activities have included;

- project planning and design of the project approach,
- development of working relationships with our project partners; QLDC, DOC and Iwi, as well as the local community,
- capture of survey information to enable assessment of geomorphic changes,
- completion of technical studies to provide greater understanding of the natural hazards and risks of this project area,
- design and commencement of the community engagement phase for development of a natural hazards adaptation strategy, and
- response to natural hazards events, of which the most disruptive have been the Glenorchy flood event of 4th February 2020, and regular flooding impacts and erosion threats to Kinloch access.

2. BACKGROUND

2.1. Natural Hazard Overview

The head of Lake Wakatipu is subject to a number of natural hazards that have potential serious implications, being exposed to hydrological, slope-related and seismic hazard events (Figure 1). The communities in the head of the lake area are highly exposed and vulnerable to natural hazard events, and consequently these natural hazard events have had regular impacts throughout the duration of settlement.

A number of previous natural hazards investigations have been undertaken in the study area, however these have typically been focused on a localised area of interest (e.g. Glenorchy[1]), or focused only a single hazard type (e.g. seismic hazards[2], flooding and river morphology[3], alluvial fans[4] and delta growth[5]).

Glenorchy township is located on a low-elevation alluvial fan landform at the lake margin, between the Rees River and Buckler Burn drainages, and adjacent to the actively growing Rees delta (Figures 2

[1] URS (2007) *Glenorchy Area Geomorphology and Geo-hazard Assessment*; ORC (2010) *Natural Hazards at Glenorchy*.

[2] Barrell (2019) *General distribution and characteristics of active faults and folds in the Queenstown Lakes and Central Otago districts, Otago*; and Barrell (2019) *Assessment of liquefaction hazards in the Queenstown Lakes, Central Otago, Clutha and Waitaki districts of the Otago Region.*

[3] URS (2007) *Glenorchy Floodplain Flood Hazard Study*; ORC (2013) *Channel morphology of the Rees River, Otago*; Geosolve (2016) *Flood Protection – Kinloch Road / Dart River.*

[4] Opus/GNS (2009) *Otago Alluvial fans project*, and GNS (2009) *Otago Alluvial Fans Project: Supplementary maps and information on fans in selected areas of Otago*.

[5] Wild MA (2012) *Growth dynamics of braided gravel-bed river deltas in New Zealand*. PhD thesis, University of Canterbury.

and 3). The lower parts of Glenorchy have been flooded on multiple occasions (e.g. November 1999, Figure 4; and February 2020, Figure 20), and other possible natural hazard threats to the township include activation of the Buckler Burn alluvial fan, debris flows or dambreak flooding, a major earthquake triggering liquefaction or lateral spreading of the saturated lake and alluvial and sediments, or a lake tsunami generated by landsliding or delta collapse. The Glenorchy wetland is located at lower elevation than the adjacent Rees River channel, and an inevitable future avulsion of the river flow into this wetland flow path will increase the flooding hazard to Glenorchy.

The Dart-Rees floodplain has been formed of alluvial sediments deposited by the braided Dart and Rees Rivers. As is typical of braided rivers, these are highly active systems, frequently overtopping their banks to inundate their adjacent floodplains during flood events, and continually evolving through erosion and deposition processes. With large portions of the road network constructed on this floodplain and the tributary alluvial fans, there is a long history of roading disruptions due to flooding, riverbank erosion and alluvial fan activity. Within the project area, there is a legacy of historic, engineered flooding and erosion protection structures, however these have provided only limited or temporary protection, and have been regularly damaged or completely destroyed by flood events.

The head of Lake Wakatipu is within ~50 kilometres of the Alpine Fault and other known active faults, so is also exposed to seismic hazards, with lake-side sedimentary deposits vulnerable to liquefaction and slumping, and potential for earthquake-triggered landslides from steep slopes.

The Dart-Rees Delta formed by the Dart and Rees Rivers, and the smaller Buckler Burn and Stone Creek deltas, are continually growing as sediments are deposited into, and gradually infill the head of Lake Wakatipu. Much of this delta shoreline has advanced lakeward by 200-250 metres since the earliest European records (Figure 3). Early surveys at Glenorchy show the present-day wetland area was a large lagoon in the 1860-70s, and at Kinloch, delta growth has infilled the bay and now rendered the Kinloch jetty inaccessible, limiting boat access as an alternative access option to Kinloch and leaving the community vulnerable to road closures. Modelling of future delta growth[6] indicates that over the next 100-120 years the delta will advance an average of ~165 metres, with actual advances across the delta shoreline ranging from 40 to 300 metres (Figure 3). Increases to the upstream sediment supply rate would accelerate this rate of riverbed aggradation and delta growth, such as would result from events such as the widespread coseismic landsliding expected to result from a major earthquake event (e.g. on the Alpine Fault)[7], or as a consequence of failure of a major landslide dam.[8]

As a result of delta growth and associated riverbed aggradation, the Head of the Lake landscape will experience ongoing and irreversible change, as noted by Wild[9], "*Although there is uncertainty in the timing, it is inevitable that the Rees-Dart delta will eventually overwhelm both Glenorchy and the Dart River true-right bank as the delta continues to advance*."

Flooding hazards already pose a substantial threat to Glenorchy, due to the combination of the frequency of these events, and the number of buildings exposed to potential flooding damages. Future

[6] Wild MA (2012) *Growth dynamics of braided gravel-bed river deltas in New Zealand*. PhD thesis, University of Canterbury.
[7] Robinson et al, 2016. *Coseismic landsliding estimates for an Alpine Fault earthquake and the consequences for erosion of the Southern Alps, New Zealand*. Geomorphology 263, pp. 71-86.
[8] For example, the aggradation and river avulsions resulting from the 1999 failure of the Poerua River landslide dam. Hancox et al, 2005. *The October 1999 Mt Adams rock avalanche and subsequent landslide dam-break flood and effects in Poerua River, Westland, New Zealand*. New Zealand Journal of Geology and Geophysics 48 (4): 683-705.
[9] Wild, 2012. *Growth dynamics of braided gravel-bed river deltas in New Zealand*. PhD thesis, University of Canterbury.

delta growth and riverbed aggradation will continue to increase this flooding hazard, as these will raise the riverbed levels adjacent to Glenorchy and Kinloch. In addition to the future geomorphic changes which will increase the flood hazard at the head of the lake, continued changes to climatic and hydrological factors are also projected to cause significant increases in the flood hazard.

NIWA[10] has analysed projected climate changes in Otago, for mid-century (2031-2050) and late-century (2081-2100) timeframes, and for several climate change scenarios[11]. This modelling shows significant future increases in mean annual rainfall and its seasonality, with mean winter rainfall projected to increase by >40% by 2090 (under the RCP8.5 scenario). Extreme, rare rainfall events are also projected to increase in magnitude, for example NIWA's HIRDS[12] model projections for the 'Dart at Paradise' and Dart Hut locations show increases by late-century of 22-33% in rainfall totals for 100-year (0.01 AEP) rain events (RCP8.5 scenario). These changes to precipitation variables will also result in an increase in the rivers' mean discharges and flood magnitudes, and thus the resulting flood hazard. For the head of the lake catchments, by late-century timeframes, NIWA projects 20-50% increases in mean discharge, and 50-100% increases in the mean annual flood (RCP8.5 scenario).

2.2. Natural hazards issues exacerbated by geomorphic and climate change

Many of the hazard events in the area are a function of the dynamic geomorphic nature of the rivers, deltas and floodplains. These hazards will be exacerbated by the inevitable, ongoing and irreversible processes of aggradation and delta growth. These hazard events will also be influenced by climate change, where higher magnitude and more frequent flood events will occur, and will also transport greater sediments loads through the river systems.

- The Glenorchy flooding hazard will continue to increase, meaning that the likelihood and severity of flooding to the residential area will be increased. The effectiveness of the protection provided by the QLDC floodbank at the Glenorchy lagoon will also decrease.
- A channel breakout (avulsion) of the lower Rees River becomes increasingly likely as aggradation continues. If this flood overtops the floodbank protection, this will impact on the Glenorchy residential area, and potentially with greater floodwater depths and velocities than have been observed in past flood events.
- The section of the Rees River bed at the road Rees bridge has also been aggrading, although the rate is not well defined. Continued aggradation at the bridge may begin to increase the likelihood and severity of erosion or flood impacts to the bridge.
- Aggradation of the lower Dart riverbed reduces the flooding threshold – increasing frequency and severity of flood events on the dart floodplain and closures of Kinloch Road.
- Westwards erosion of the Dart floodplain has been ongoing for >50 years, and is already directly impacting Kinloch Road through erosion at several locations. This has required localised protective rock armouring at several locations in last few years, but is eroding over riverbank lengths of many kilometres (e.g. Figures 22 and 23).

---

[10] NIWA, 2019. *Climate change projections for the Otago Region*. Report prepared for Otago Regional Council.

[11] Termed RCP's (Representative Concentration Pathways) and based on IPCC projections.

[12] High Intensity Rainfall Design project.

ORC has previously undertaken river management engineering works to address natural hazards issues such as flooding and erosion. While engineering works provide temporary benefits, they do not fully deal with the problems permanently and are unlikely to be sustainable financially or environmentally in the long run.

A strategic and holistic approach is needed to address these issues in the longer term, which needs to also consider future climate change, landscape changes, and multiple and cascading natural hazards. It is very important that this strategic approach is developed collaboratively with the local community and other project stakeholders and partners, and that their values and views are incorporated into this planning.

Figure 1: *The hazardscape of the head of Lake Wakatipu, illustrating the range of potential natural hazard events with potential to impact this area.*

Figure 2: *A view of Glenorchy township, looking over Lake Wakatipu and towards the Richardson Mountains in the background. The Rees River enters the lake at left forming the Rees Delta, and Buckler Burn is at right. Glenorchy is located on the low-relief alluvial fan deposits deposited by Buckler Burn.*

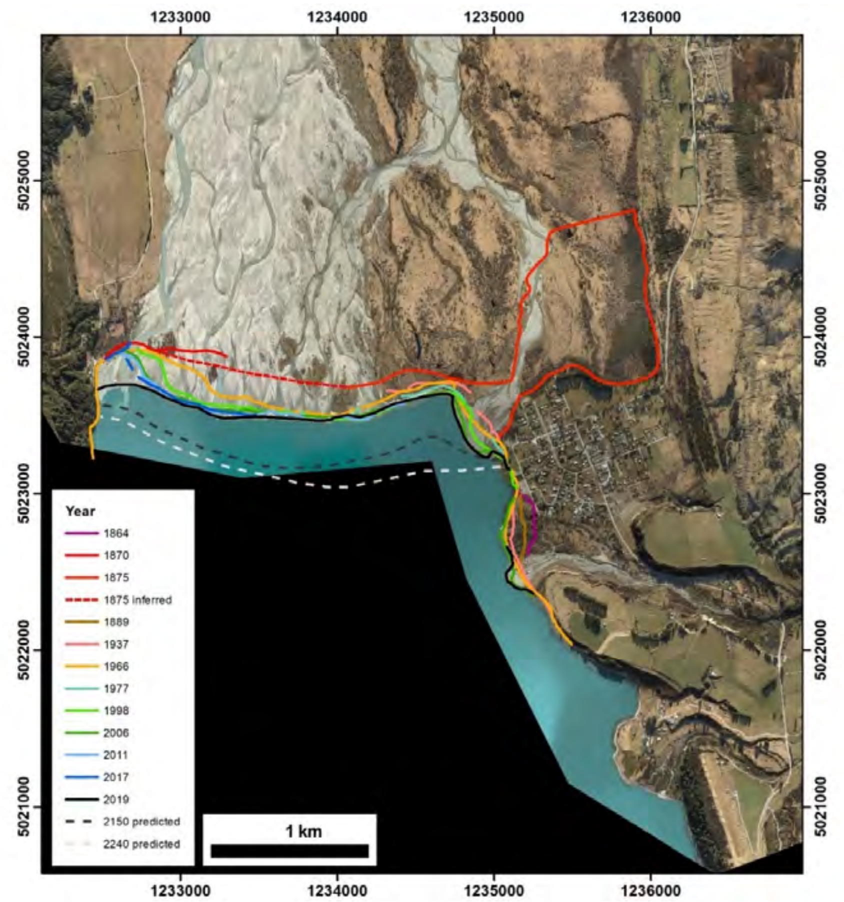


Figure 3: *Historical and predicted shoreline positions of the Dart-Rees delta, based on compilations of historical maps and photographs by URS (2007) and Wild (2012). Projected delta growth based on modelling by Wild (2012).*

Figure 4: *Flooding in Glenorchy during the November 1999 flood event, showing significant inundation of the residential area.*

Figure 5: *Flooding of the lower Dart floodplain in a moderate 2019 flood event. This shows the Kinloch Road closed due to flooding of sections between Glacier Burn and Turner Creek.*

3. COMPLETED PROJECT WORK

3.1. Capture of Lidar surveys and aerial imagery

LiDAR topography and high-resolution aerial imagery were captured in June 2019. The survey area included the majority of the Dart and Rees floodplains, and was of greater extent than the only previous LiDAR survey (2011). This detailed LiDAR topographic information has been used in geomorphic analysis to compare changes to the river and floodplains since the previous survey (e.g. Figures 9 and 11), and can be used as a base for hydraulic modelling of flood events.

Regular reconnaissance helicopter flights are also carried out by ORC to inspect river morphology and flooding impacts. In the last two years, these have been undertaken in May 2019, October 2019, December 2019, and October 2020.

3.2. Riverbed cross-section surveys

A series of riverbed cross sections for the Dart and Rees rivers have been regularly surveyed since the 1990's, providing information to monitor change and inform river management decisions. The constantly changing morphology of the river channels and floodplains, and the sparse cross sections, means it is difficult to make definitive conclusions regarding bed level trends, but it appears most cross sections have undergone net aggradation, a conclusion supported by analysis of LiDAR surveys.

The most recent full survey of Dart and Rees River cross sections was carried out in June 2019. A selection of lower Rees cross sections were then re-surveyed in May 2020 (RR3A, RR4A, RR5, and part DR1) to investigate riverbed changes following the February 2020 flood event, and a single survey line (RR3A) was also re-surveyed in November 2020 to review effects of river management works at the Rees Delta.

3.3. Environmental monitoring

In response to community requests following the February 2020 flood event, ORC has installed two new water level monitoring stations in the Glenorchy area (Figure 6).

At the Glenorchy Lagoon, a recently installed water level monitoring station shows water levels, and height relative to the floodbank crest level (Figure 6a). This provides near real-time monitoring of water levels for local residents, and provides data enabling ORC to better understand the relationships between the lagoon behaviour in response to other influences (e.g. rainfall, river flows and lake levels, Figure 7) which to date have relied largely on visual observations and anecdotal reports.[13]

A telemetered water level sensor was installed and operating in Lake Wakatipu at the Glenorchy marina in late January 2021 (Figure 6b).[14] Assessment of the initial monitoring dataset from this temporary install will assist with determining the value in potential upgrade of this station to provide permanent collection of telemetered real-time monitoring information. The level of Lake Wakatipu has been recorded at Willow Place in Queenstown since 1962, and it has been previously assumed that this lake level measured in Queenstown approximates the lake level at the head of the lake,

[13] Near real-time monitoring lagoon level data available online at ORC's WaterInfo page, the site is named 'Glenorchy Lagoon at south-east corner'.

[14] Near real-time monitoring lake level data available online at ORC's WaterInfo page, the site is named 'Lake Wakatipu at Glenorchy boat ramp'.

~45km distant. The relationship between lake levels at these two locations has not previously been investigated, so this new data will be an important dataset in investigating potential differences in lake levels under a range of river flow conditions.

One key environmental factor not presently recorded is monitoring of the Rees River flows, and this dataset would help significantly with understanding the hydrology and flood hazard in this area. Our current understanding of Rees River flood peaks is based only on comparison with observed flows in the adjacent Dart catchment. However, there is known to be a relatively poor correlation between the magnitude of high flow events between these catchments, based on a flow dataset obtained by NIWA in 2009-2011. ORC is proposing to re-establish a Rees River flow monitoring station at a similar location as the previously acquired dataset, near the Invincible Mine. This is planned to be installed and operational in 2021, and will be an important dataset in increasing the understanding of the flood hazards in Glenorchy.

Figure 6: *The recently installed water level monitors installed at the Glenorchy lagoon (6a, left) and the Glenorchy marina (6b, right). Data for both of these monitoring stations is available in near real-time on ORC's WaterInfo web page.*

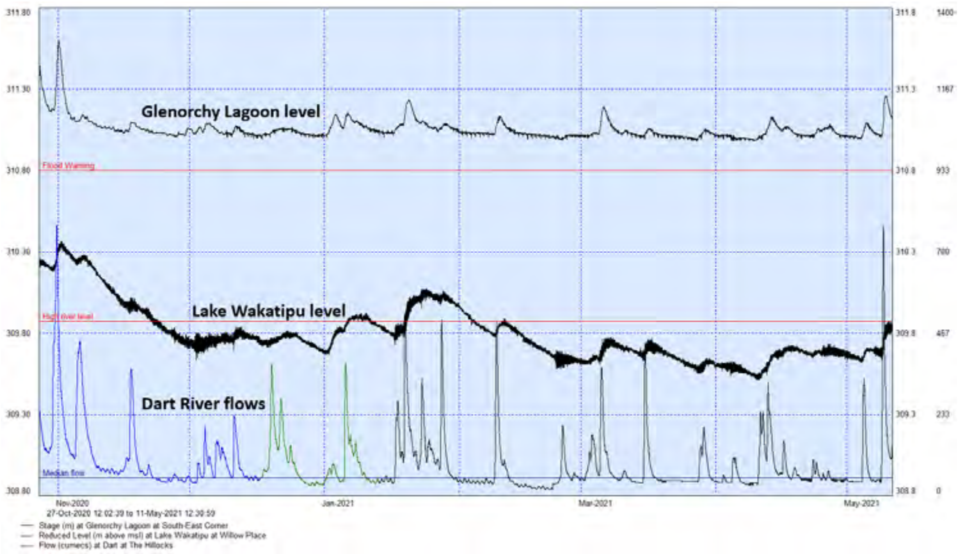


Figure 7: *Initial monitoring data for the Glenorchy Lagoon, showing the relationships with the level of Lake Wakatipu and Dart River flows. Over this time the lagoon levels have fluctuated within a range of ~0.6m, with the highest lagoon level of 311.6m associated with a high-flow event in early November (Dart peak of ~780 cumecs). The Glenorchy floodbank may overtop at level of about 312.5m.*

3.4. Flood forecast modelling

A rainfall-runoff model has been developed by an ORC hydrologist for the Dart River, and this can be used in flood forecasting to provide a modelled estimate of flood peak, based on rainfall forecasts and records. The initial model is being tested for its accuracy during high flow events, and these tests will inform how valuable it can be for providing flood warning. Figure 8 shows an example model output comparing observed and modelled flow hydrographs for a high-flow event in the Dart River. This model for the Dart River can be used to complement the existing ORC flood model for Lake Wakatipu, which enables modelling of lake levels based on recorded and forecast rainfall totals.

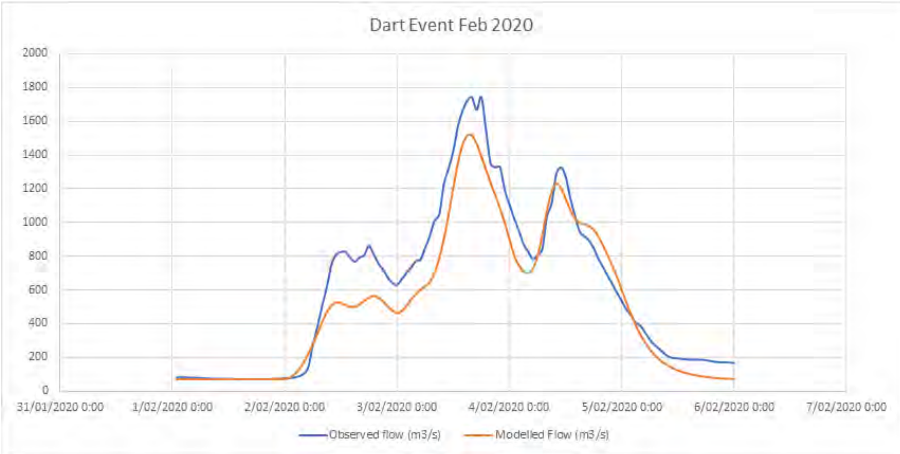


Figure 8: *Example of flood modelling output, showing the observed (blue) and modelled (orange) Dart river flows for the February 2020 flood event.*

3.5. River morphology research (University of Canterbury)

A research project '*Geomorphic Character and Morphodynamics of the Dart-Rees Rivers*' has been carried out by Professor James Brasington of the University of Canterbury. This investigation provides a summary of the river channel dynamics, historic river corridor evolution, and interpretation of these observed changes based on their driving processes. The report also provides detail of the expected future changes to the river systems and how these are likely to affect their natural hazard impacts; giving a scientifically-based review of the need for adaptation to these future challenges, and provides guidance for the management of these river corridors.

The study includes assessment of historical changes to the river systems, based on analysis of satellite imagery archives, and from analysis of repeat LiDAR surveys (Figure 9). These assessments demonstrate the characteristics and scale of changes to the river corridor, both of changes of the river's active channel widths, and of channel migration across the floodplain. LiDAR analysis can be used to identify and quantify changes to the river beds, including locations and rates of erosion and aggradation, and volumetric changes to riverbed sediments. These analyses of net changes consistently indicate system-wide aggradation for both the Dart and Rees Rivers, with a dominant aggradation trend over the last eight years (Figure 10).

There are two key factors identified as drivers of an increasing flood hazard within this project area; geomorphic changes, and climate change. The geomorphic changes were the focus of this research, with the climate changes having been assessed in previous studies by NIWA.[15]

For the Dart and Rees floodplains, the geomorphic changes resulting from aggradation of sediments will reduce the rivers cross-sectional area and gradient, in turn reducing the river channel's flood capacity and increasing the likelihood and severity of flood events. Aggradation will also cause an increase in lateral migration of the rivers active channel belts. At the lower Dart floodplain erosion

[15] NIWA (2019), Climate change projections for the Otago Region. Report prepared for ORC.

rates are already relatively high, with erosion impacts threatening the Kinloch Road access at multiple locations, so any increase in migration rates may lead to increases in the extent and severity of erosion.

For the lower Rees River and Glenorchy, the aggradation of the river bed and growth of the delta will also increase the flood hazard through the impacts of these geomorphic changes. Aggradation will reduce the relative level of the flood stage to the floodbank crests, and also increase erosional and hydrostatic pressures on the floodbank structure. Aggradation on the Rees delta at the confluence of Lagoon Creek, raises the base level of this creek, and impedes drainage from the lagoon. During a flood event, this backwater effect may block or limit lagoon outflows, and contribute to higher lagoon levels or overtopping of the floodbank (as occurred in the February 2020 flood event).

The third, and potentially highest consequence, impact of river bed aggradation on the flood hazard for Glenorchy, is through increasing the risk of channel outbreak flooding (an avulsion event). A section of the active Rees River channel is elevated above the surrounding floodplain and wetlands (Figure 11), and at some point in time, the river flows will inevitably re-route through this steeper flow path. This realignment of the channels is not necessarily triggered by a major high-flow event, but may result from the cumulative effects of aggradation reaching a tipping point. The hazards resulting from a severe avulsion event have been described[16] as being a process which "poses a credible mechanism for a major flood hazard that would overwhelm the existing stopbank near to the Lagoon," and which "could route a significant proportion of the Rees River along this pathway, resulting in fast moving, erosive flood waters flowing through the town."

This research shows the need for adaptation to the flooding hazards in this project area, as they will increase due to both climate change and long-term geomorphic evolution; becoming increasingly difficult to manage through the current management approaches, and posing significant threats to the communities into the future. This research will be presented as a technical report, and was also presented to the community in a public talk on 7th April 2021.[17]

[16] Brasington J, 2020. River science evidence presented at resource consent hearing, 10-11 December 2020, for ORC regarding Blackthorn Lodge Glenorchy Limited (RM191318).

[17] Presentation slides: https://www.orc.govt.nz/media/9816/james-brasington-presentation_-fluvial-hazards-at-the-top-of-the-lake_20210407.pdf
Audio recording: https://www.youtube.com/watch?v=wMWeIhp6GOI

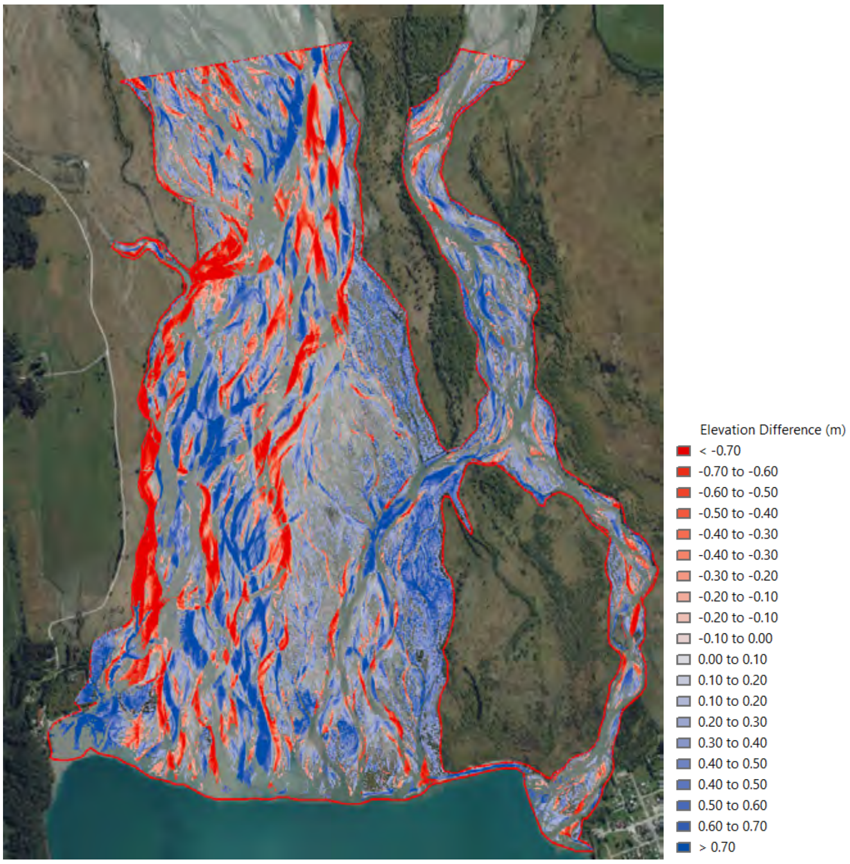
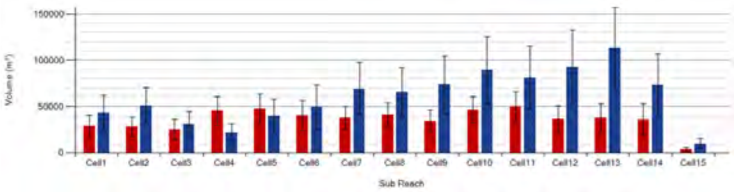


Figure 9: *Geomorphic change for the lower Dart and Rees rivers (2011-2019), where blue is sedimentation, red is erosion. This shows westwards erosion of the lower Dart floodplain, and widespread aggradation in the lower reaches of the Dart and Rees rivers.*



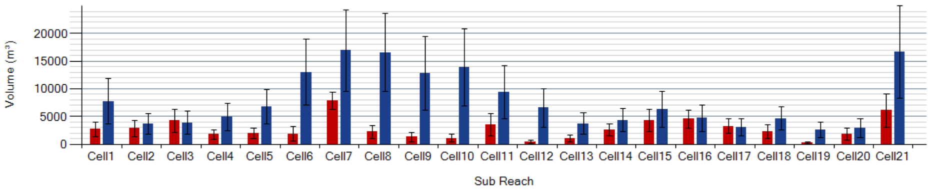


Figure 10: *Sediment volume changes (2011-2019) for the Dart (upper) and Rees (lower), where change is analysed over cells of 200m length, with Cell 1 starting from lake edge. Sedimentation volumes (blue) are of greater magnitude than erosion (red), indicating net aggradation over the lower reaches of both rivers.*

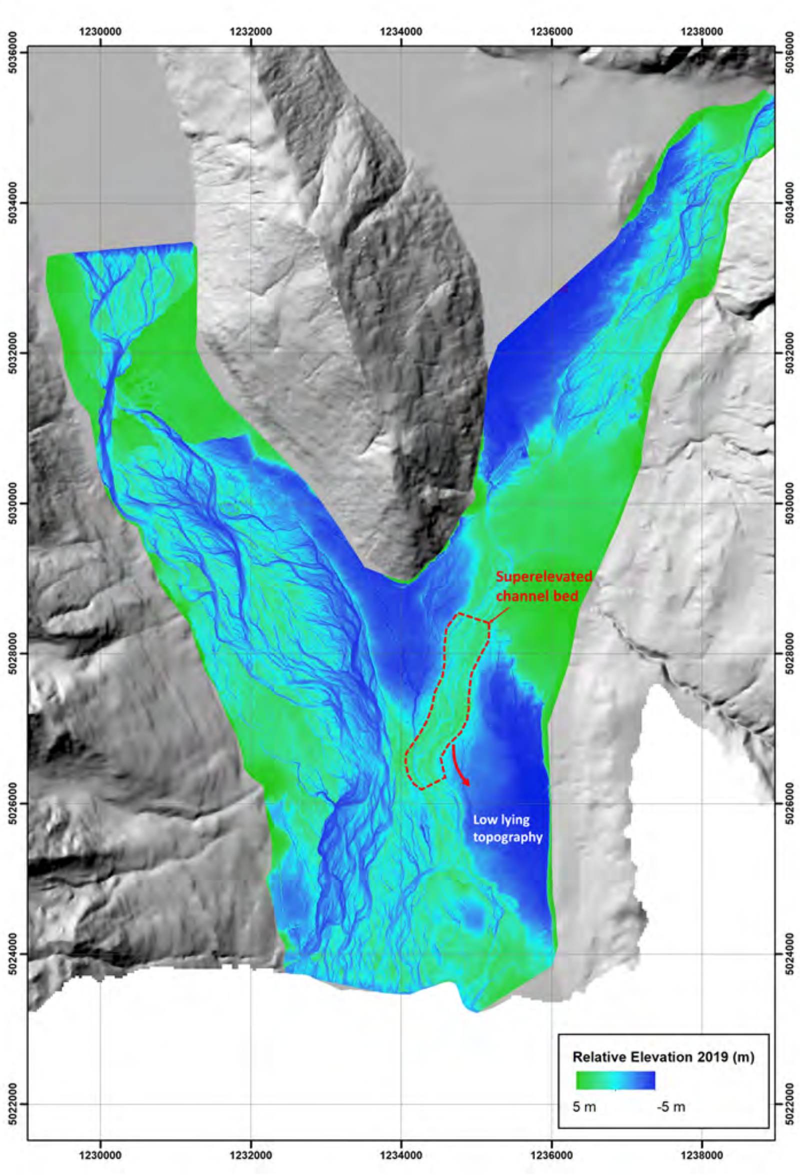


Figure 11. *Relative elevation model of the Rees-Dart valley floor. This is computed by comparing the valley floor elevations to the adjacent average level of the river bed. The section of super-elevated*

river bed highlight is the likely source for a potential channel breakout flood eastwards into the lower-lying topography of the wetland and lagoon area. The analysis is based on a 1 m resolution lidar topographic dataset acquired in 2019.

3.6. Hazard and risk assessments (Tonkin + Taylor)

Tonkin and Taylor (T+T) have completed a review of the natural hazards risks for this project area, based on all currently available information[18]. The report provides an improved risk understanding for the area, showing the spatial extent of potential natural hazard events, and illustration of the potential event consequences. This report has included completion of the first risk mapping for the head of the lake area, showing natural hazard uncertainty and risk rating.

Many of the natural hazard events in the project area are not independent, but may interact in cascades or sequences of hazard events. Figure 12 shows an example to illustrate the complexity of natural hazard interactions, showing the range of potential natural hazard impacts which may be triggered by a major earthquake.

The hazards analysis identifies that the current levels of natural hazards knowledge for the project area are not sufficiently detailed for undertaking of a probabilistic risk assessment approach. As it is difficult to define or assign risk classifications due to limited confidence in knowledge of likelihood and potential consequences. The risk information is instead presented by showing the spatial extent of potential natural hazard events, and through illustration of the potential event consequences. Risk mapping was developed to show natural hazard uncertainty and risk rating. This risk mapping illustrates the higher risk areas as being those subject to potential floodplain hazards (flooding, erosion and channel avulsion), elevated lake levels, and active or potentially active alluvial fan surfaces (Figure 13).

This report has provided ORC with an independent, expert review of the natural hazard risks, ensuring all hazards are identified and taken into account. As a broad-scale review coving the entire project area, this study will be supplemented by continued investigations at those locations identified as being of higher risk.

[18] Tonkin + Taylor (2021). Head of Lake Wakatipu Natural Hazards Assessment. Report prepared for ORC. Report is available at: https://www.orc.govt.nz/media/9784/head-of-lake-wakatipu-natural-hazards-assessment.pdf

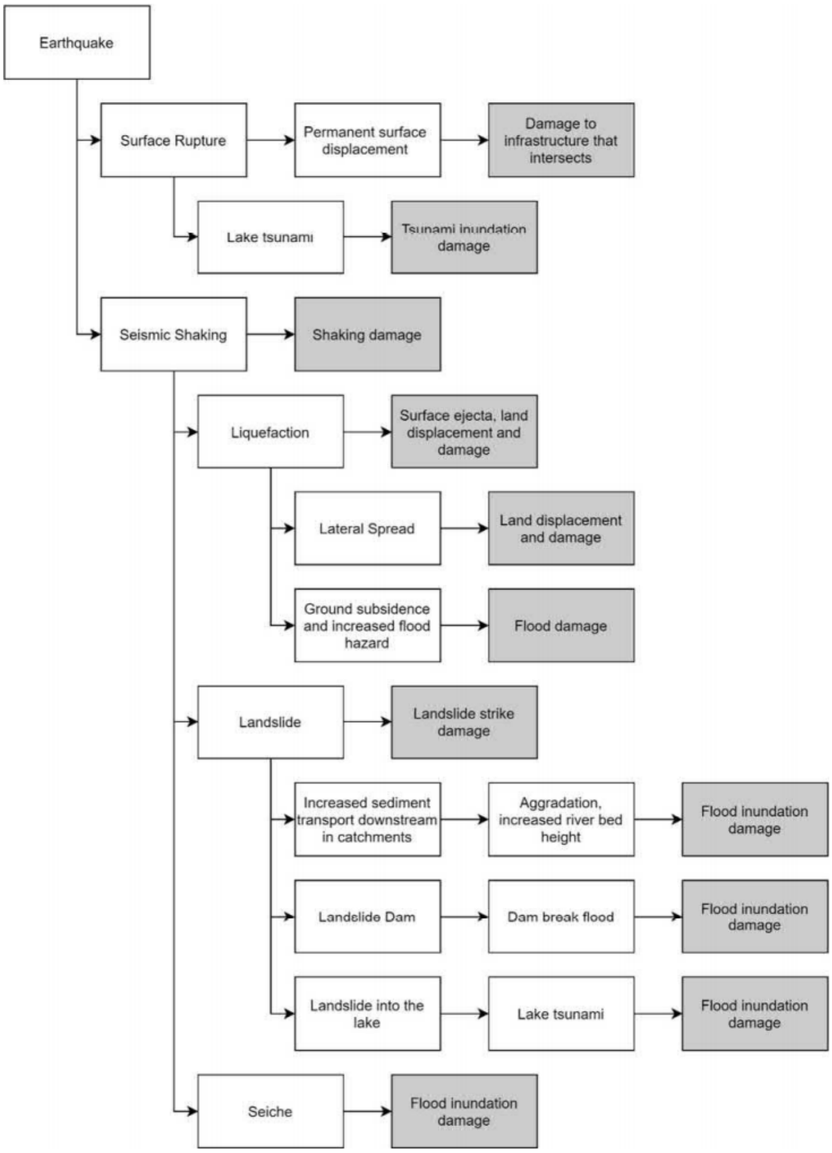


Figure 12: *Example of the cascading natural hazard events which may be initiated by the triggering event of a major earthquake.*

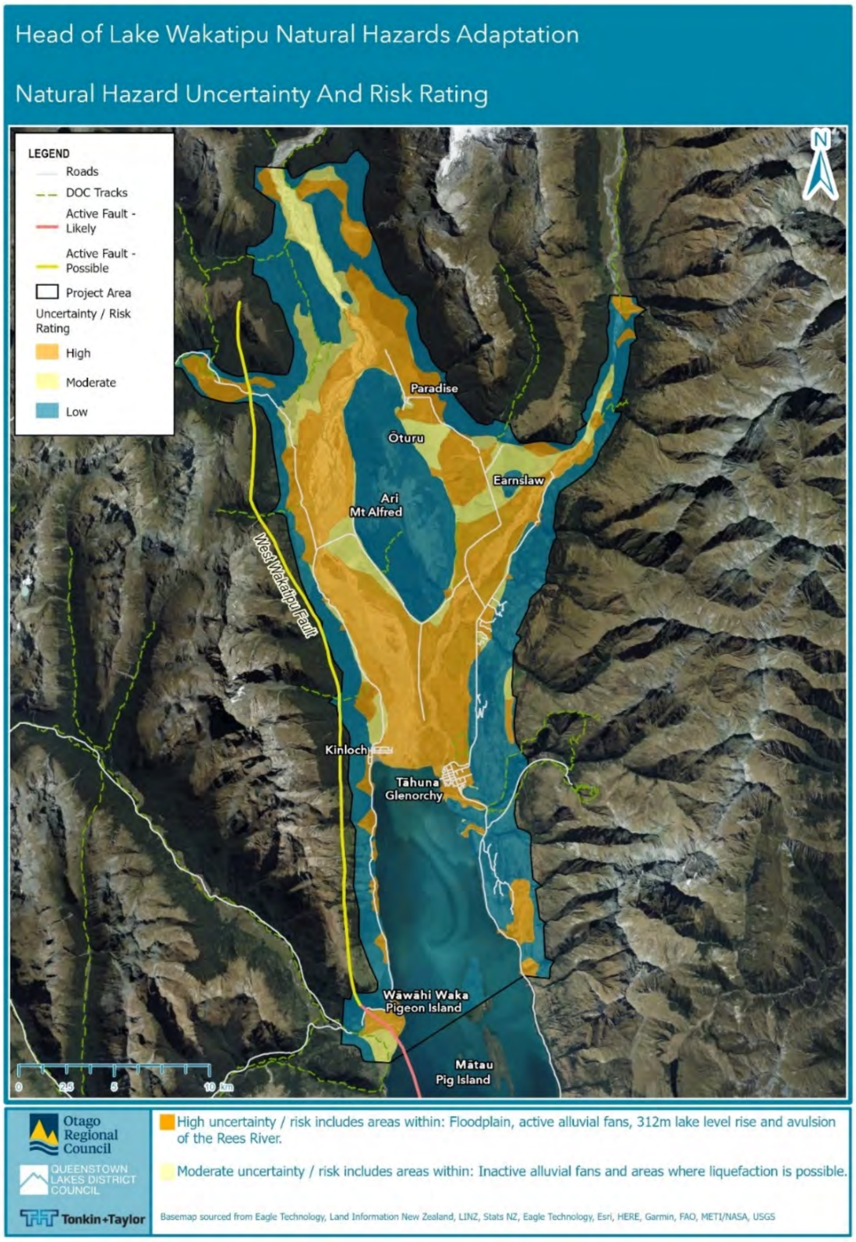


Figure 13: *A risk and uncertainty map compiled for the head of Lake Wakatipu area, showing the higher risk areas located where there is exposure to floodplain, alluvial fan activity and lake flooding.*

3.7. Climate change projections (NIWA)

As part of ORC's Climate Change Risk Assessment project (OCCRA), NIWA[19] have completed projections for climate variables for the Otago region, under a range of future time periods (mid-century and late-century) and emissions scenarios (Representative Concentration Pathways, RCPs). For the head of Lake Wakatipu catchments, these projections show significant increases in both rainfall (Figures 14 and 15) and river flow variables (Figure 16).The existing flood risks for this area are already relatively high, so these projected increases in rainfall and river flows will only increase these risks, and consequently flooding impacts are expected to increase in frequency and severity.

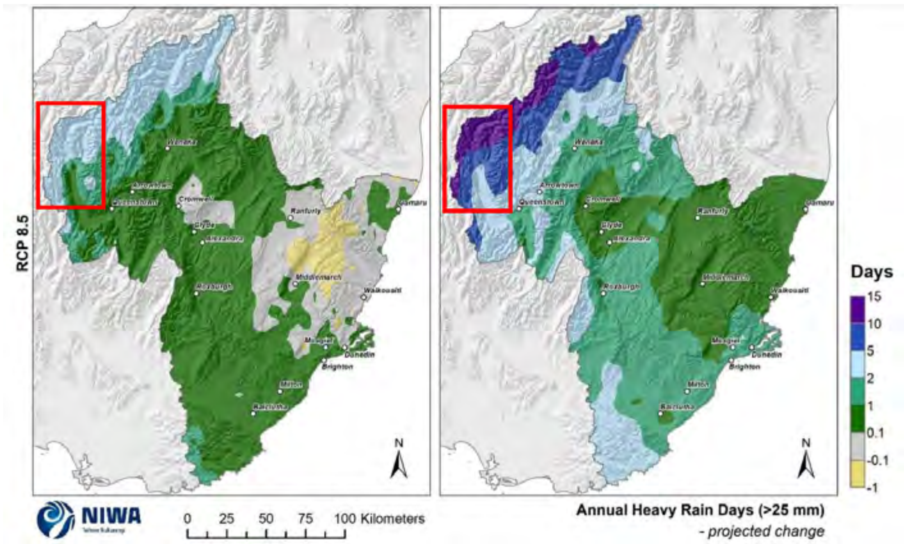


Figure 14: *Projected changes to the annual number of heavy rain days (>25mm) by 2040 (left) and 2090 (right), under the IPCC's RCP8.5 climate scenario. The approximate area of the Dart and Rees catchments are outlined, showing that these are expected to experience a significant increase in heavy rain events.*

[19] NIWA (2019), Climate change projections for the Otago Region. Report prepared for ORC.

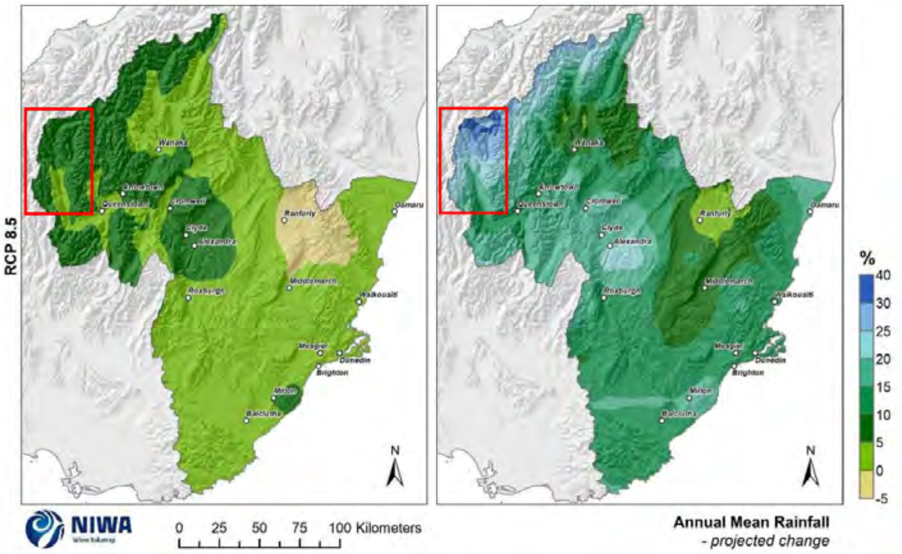


Figure 15: *Projected annual mean rainfall changes by 2040 (left) and 2090 (right), under the IPCC's RCP8.5 climate scenario. The approximate area of the Dart and Rees catchments are outlined, showing that these are expected to experience some of the largest percentage increases in rainfall anywhere in the Otago region.*

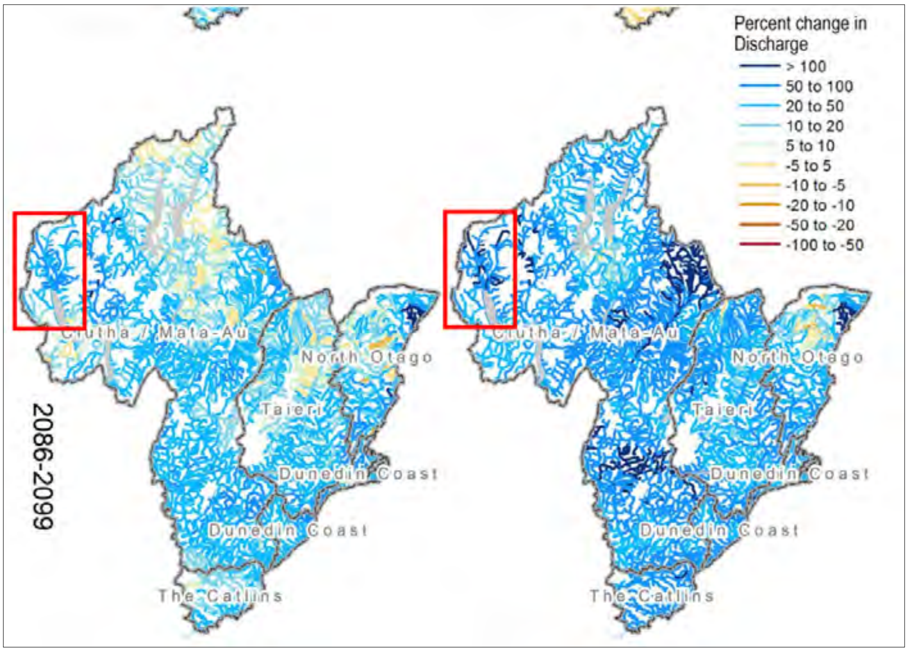


Figure 16: *Projected percent changes to average annual flood discharges for the late 21st century, projected changes shown for the RCP6.0 (left) and RCP8.5 (right) scenarios. The approximate area of*

the Dart and Rees catchments are outlined, showing that these catchments are expected to experience large percentage increases in flood magnitudes.

3.8. Cultural Values Assessment (Aukaha)

A cultural values statement (CVS) has been prepared to provide mana whenua input to this adaptation project. This has been completed by Aukaha and reviewed by the four Otago rūnaka. This CVS covers both the wider Te Wai Pounamu landscape and the area at the head of Whakatipu-wai-Māori (Lake Wakatipu).

The mana whenua associations discussed demonstrate the high significance of the area to mana whenua, showing widespread use, settlement, established travel routes and abundant traditional resources. A large number of traditional names are embedded within the landscape, these are summarised in the report and are also shown online in the Ngāi Tahu Ka Huru Manu Atlas (Figure 17).[20]

This core cultural values of Mana, Mauri and Whakapapa are noted, and a number of additional Kāi Tahu values are also described. To emphasise the significance of this area to mana whenua, the concluding statement below is reproduced from the CVS; "Whakatipu-wai-Māori holds generations of Kāi Tahu histories, the knowledge of which holds the same value for Kāi Tahu today. Kāi Tahu taoka (treasures) cover the landscape; from the ancestral mauka (mountains), large flowing awa (rivers), tūpuna roto (great inland lakes), pounamu and ara tawhito (traditional travel routes/trails). These all make the area immensely significant to mana whenua."

[20] https://www.kahurumanu.co.nz/atlas

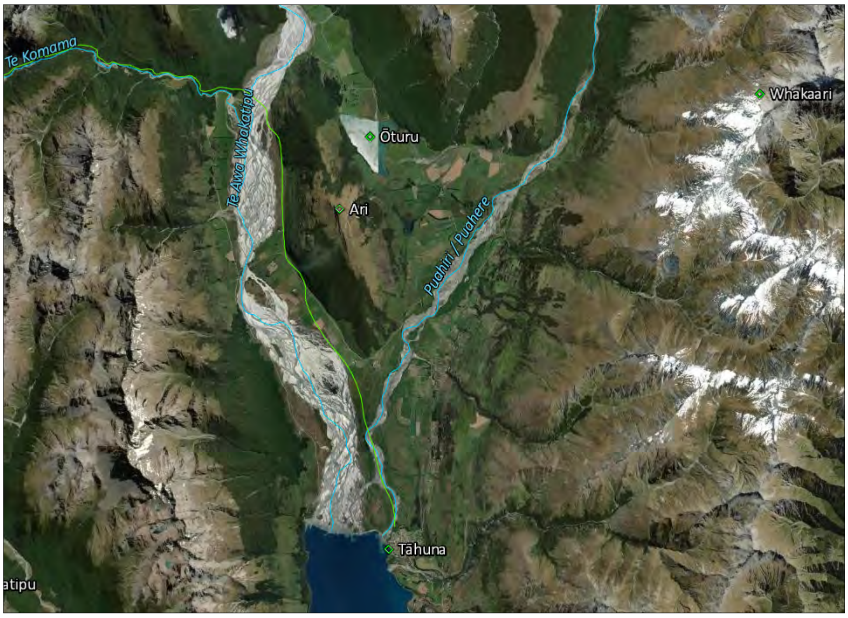


Figure 17: *Screenshot from the Ngāi Tahu Ka Huru Manu Atlas, showing traditional names for landscape features in the head of Whakatipu-wai-Māori. These include the main rivers; Puahiri (Rees River), Te Awa Whakatipu (Dart River) and Te Komana (Route Burn), the peaks and mountain ranges; Ari (Mount Alfred) and Whakaari (Richardson Mountains), and the lakes and shoreline features, Ōturu (Diamond Lake) and Tāhuna (the Glenorchy area).*

3.9. Support for future research

In addition to technical investigations proposed by ORC, we have also been approached by several research agencies to discuss possible support for proposed research projects which will advance knowledge of hazard events and assessment of geomorphic processes.

3.9.1. University of Canterbury – Bathymetric LiDAR evaluation.

An emerging technology for surveying of rivers and lakes is bathymetric LiDAR. This uses a shortwave (green) lidar sensor deployed from UAVs and helicopters. This new technology can be used to map the underwater bathymetry of shallow lakes and rivers, generating seamless 3D models of lakes and rivers, which would be a significant improvement in capturing and understanding riverbed bathymetry compared to cross section surveys or conventional LiDAR. ORC have indicated support for a proof-of-concept evaluation carried out by the University of Canterbury, and which will utilise the Rees River, Shotover Delta and Clutha River as Otago case study locations. If the suitability of these survey methods are demonstrated, they can potentially be more cost-effective, and provide a much richer dataset for monitoring of riverbed morphology than cross-section survey methods.

3.9.2. NIWA, Massey University, University of Otago.

PhD project: *Post-glacial geomorphic evolution of Lake Wakatipu basin and landslide-generated tsunami hazards*.

The research team have requested ORC support with operational costs for field investigations for a PhD research project commencing in 2021. The objectives of this PhD research include monitoring sediment transport and contemporary morphological changes on the delta, and mapping and evaluation of the potential for subaerial and lake-floor sources of slope instability, to support tsunami modelling. This project will build on and complement a previous PhD project supported by ORC (Michelle Wild, UC), benefits for ORC include gaining additional knowledge of lake tsunami hazards, which have not yet been assessed in any detail.

3.10. Flood Events and Response

There have been three significant flooding events in the head of Lake Wakatipu area over the last two years (Figures 18 and 19).

- **March 2019:** The Dart River reached its highest recorded flow since recording began in 1996 (1819 cumecs).
- **December 2019:** Lake Wakatipu reached a peak level of 311.375 masl (the 7th highest peak level since level recording commenced at Willow Place in 1962).
- **February 2020:** The Dart River reached its equal-highest recorded flow since recording began in 1996 (1822 cumecs), and Lake Wakatipu reached a level of 311.364 masl (the 8th highest peak level since level recording commenced at Willow Place in 1962).

Of these three flooding events, the February 2020 flooding event caused the most community concern, with flooding causing inundation and damages at several houses in Glenorchy township and precautionary evacuations of a number of others (Figures 20 and 21). Following this flooding event, ORC was contacted by several Glenorchy residents, the Glenorchy Community Association (GCA), and the Queenstown Lakes District Council (QLDC), requesting ORC to carry out an investigation of flooding causes and to provide assistance with development of flood management options.

ORC, QLDC and CDEM representatives attended a meeting of the GCA in early July 2020 to hear community input into potential flood management options, and to discuss the short-term flood response works proposed by ORC.[21] ORC have also commenced of a monthly community update to the GCA providing brief progress reports on completed and upcoming flood response and adaptation project activities.

This section provides a brief summary of the flooding event, and then lists the flood response actions carried out by ORC following this event.

On the afternoon of the 4th February 2020, floodwaters from the Rees River filled the Glenorchy Lagoon to the crest level of the adjacent Glenorchy floodbank and then overtopped to flow through the northwest margins of the township. Floodwaters filled much of the Glenorchy recreation ground

[21] Presentation slides from this meeting available at: https://www.orc.govt.nz/media/9410/orc-presentation-02-for-gca-july-2nd-2020.pdf

and golf course, before flowing along the northern/northwestern margin of the township to enter Lake Wakatipu near the lower end of Mull Street, with flooding of residential areas at the northern ends of Oban and Argyle Streets, and along much of Butement Street. Following the flood, inspections also noted increased erosion impacts to the section of the Glenorchy floodbank adjacent to the Rees River.

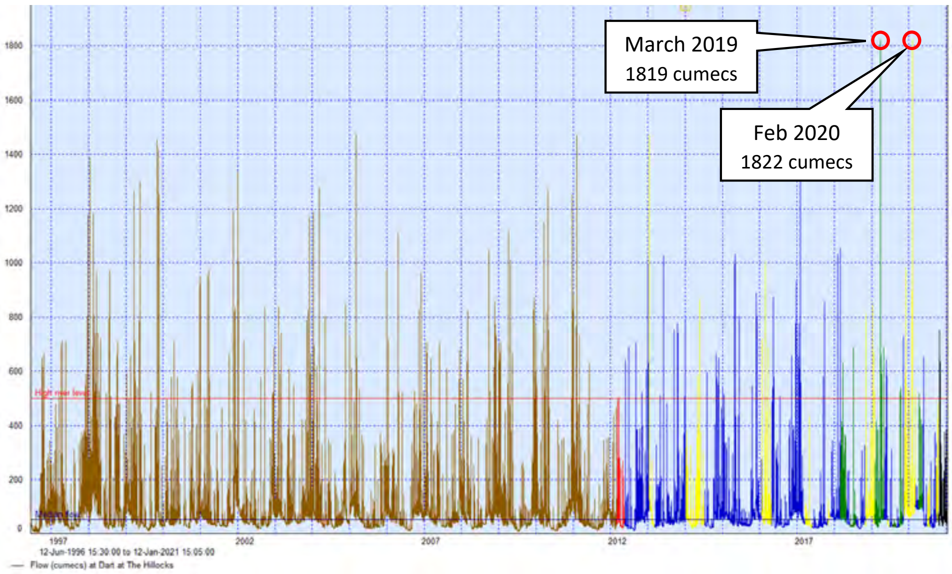


Figure 18: *The Dart River flow record 1996-2021. Prior to the high flows of March 2019 and February 2020, the four highest flows previously recorded were in the range of 1450-1480 cumecs (Nov 1999, March 2005, Feb 2011, Jan 2013).*

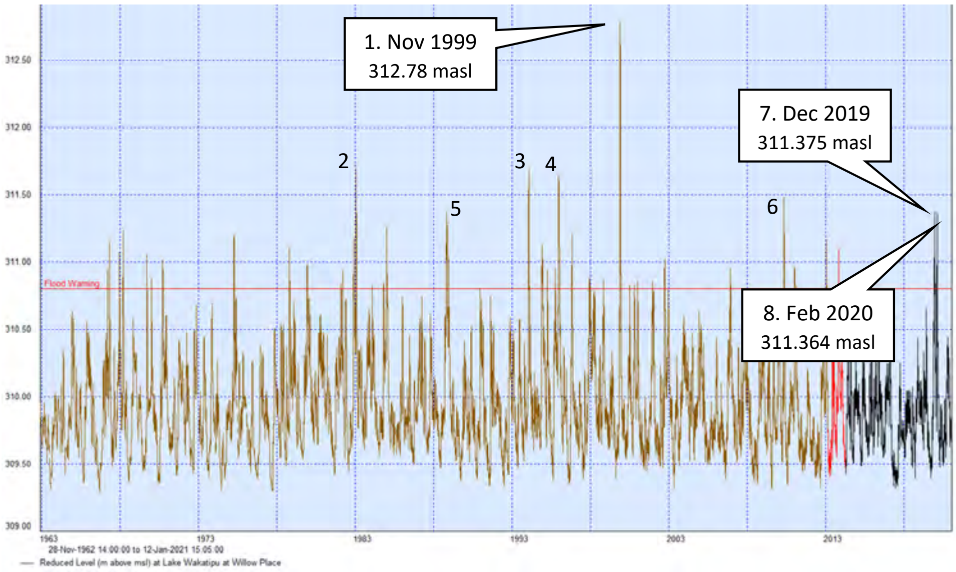


Figure 19: *Lake Wakatipu levels 1962-2021. The eight highest flood peaks are numbered, showing the December 2019 and February 2020 lake levels as being the 7th and 8th highest peaks respectively since 1962.*

Figure 20: *Aerial image of Glenorchy township taken about 6.30pm 4th February 2020, taken prior to the maximum floodwater extent, but still showing significant inundation in the residential area of Glenorchy township. (photo from Luke Hunter, Donerite Contracting).*

Figure 21: *Example of flooding in Glenorchy in February 2020 flood event, this view is looking north along Butement Street (photo taken 04/02/2020 at about 6.30 pm, Michelle Morss, QLDC).*

The works undertaken by ORC in response to this flooding event are summarised below

- ORC natural hazards and engineering staff carried out site inspections and an initial review of the flooding event. The key factors are interpreted as; 1. the sustained, high flows in the Rees River, with overland flows eastwards into the wetland area, and 2. the backwater effects of elevated lake levels on flows in the lower Rees River, and on the drainage of the Glenorchy Lagoon.
- Cross section surveys were carried out in May 2020 for the lower Rees River to determine if riverbed aggradation was a factor in exacerbating flood impacts. These surveys showed little change at cross sections further upstream, but that mean bed levels at the Rees delta near the confluence with Lagoon Creek aggraded by 25-30 cm over the period August 2019 - May 2020.
- ORC engaged WSP[22] consultants to carry out assessments of Rees River erosion at the Glenorchy floodbank, evaluation of floodbank stability, and recommendations for erosion mitigation actions. The floodbank structure is owned by QLDC, and these consultant reports have been provided to QLDC to assist with their decisions regarding scope of possible floodbank repairs.

[22] Reports available at these links:
https://www.orc.govt.nz/media/9856/glenorchy-rees-floodbank-assessment_september-2020_ja.pdf
https://www.orc.govt.nz/media/9857/rees-river-erosion-and-floodbank-inspection_june-2020.pdf

- River management works undertaken in response were a realignment of the Rees River channel to assist with drainage into Lake Wakatipu during high river flows, and in collaboration with DOC, the clearance of thick willow growth alongside Lagoon Creek, which drains the Glenorchy Lagoon to the Rees River.
- Completion of the flood forecasting model referred to in Section 3.4.
- Implementation of the monitoring of Glenorchy Lagoon and Lake Wakatipu water levels referred to in Section 3.3.
- Emergency Management Otago have reviewed the community response plan for the Glenorchy area, this has been revised to clarify roles and responsibilities during flood response.

3.11. Response to Dart floodplain and Kinloch Road hazards issues.

The lower Dart floodplain floods and impacts sections of Kinloch Road at moderate flows, causing disruption of terrestrial access to Kinloch and Greenstone (e.g. Figure 5). Flooding impacts appear to have increased in frequency and severity in recent years, attributed to both aggradation of the riverbed levels, and the main Dart river channel being located nearer to the western side of the active riverbed and thus nearer to the roadway.

Riverbank erosion has also threatened the road at several locations, requiring mitigation works involving placement of rock armouring alongside localised sections of riverbanks. In 2019, ORC engaged WSP to carry out an assessment of localised erosion near the Turner Creek confluence. Several other locations of erosion have been managed by QLDC with placement of rock armouring. In late 2020, ORC provided a financial contribution to QLDC for bank protection works (Figure 23).

The westwards migration of the Dart River has brought the river's active channel near to the roadway in many locations, and is directly threatening the road margins in several sites (e.g. Figures 22 and 23). It is expected to become increasingly difficult to maintain road access using the current approach of reactive management to issues as they arise, and an assessment of longer-term adaptation options will be required. The river morphology research recently completed by James Brasington will be a valuable reference in these ongoing discussions regarding potential adaptation options for maintaining access to Kinloch in the longer-term.

Figure 22: *Aerial view (October 2020) of the Dart floodplain between Turner Creek and Kowhai Creek confluences (left). The red outline indicates the location of the right-hand photograph, taken February 2020, and showing erosion progressed very near to the Kinloch Road.*

Figure 23: *Aerial view (October 2020) of the Dart floodplain between the Dart Delta and Glacier Burn (left). The QLDC installed a section of rock armouring in this location in late 2020, with a financial contribution from ORC. The red outline indicates the location of the right-hand photograph, taken November 2020, and showing an area of active erosion which was rapidly progressing towards Kinloch Road.*

4. ADAPTATION PROJECT OVERVIEW

4.1. Background

This adaptation work was initiated as a two-year project commencing July 2019, with a project objective to "*provide a framework to actively manage risks associated with natural hazards for the resilience of the area located at the Head of Lake Wakatipu, including Glenorchy and Kinloch.*"

The objective of this project is to develop an adaptation strategy for the Head of the Lake Wakatipu communities. The project will identify and evaluate potential natural hazard adaptation pathways, and is intended to take a more strategic and holistic approach than previous natural hazard studies. This will be a multi-hazard and climate change assessment for the head of the lake, including review of potential hazard consequences, likelihoods and overall risks, and developing risk reduction/adaptation pathways over a longer-term timeframe over no less than 100 years[23]. This information will allow for planning with more certainty in the face of ongoing change and increasing hazard risks. The project area boundary was designed to include all significant residential and infrastructure locations (Figure 24).

The resulting adaptation strategy will be designed as a living document intended to evolve in response to new information on hazard and risks, and the needs of the community. This strategy will be a reference to enable informed decision-making regarding future planning and management of this area, supporting the investigation and implementation of natural hazard risk reduction measures. The strategy will be designed to guide implementation of adaptation measures and appropriate changes

[23] RPS policies 4.1.2, 4.1.6(c), 4.2.2

(including variations and reviews) to the planning framework (such as policy statement or regional or district plans) and to guide decision-making during consent application processes. The strategy will also be designed to guide decision-making around investment and renewal of community infrastructure and services (roading, transport, water supply reticulation, wastewater collection and disposal, stormwater collection and disposal) and other utilities (telecommunications, electricity), with links to lifelines planning.

This current project and community engagement will be only an initial phase of work towards implementation of adaptation pathways and initiatives. There will be further investment required with further investigations and community engagement expected during any implementation phase, for example, any planning response or large-scale infrastructure would require further investigations such as feasibility studies and cost-benefit analysis, and potentially also targeted hazard and risk assessment.

Since this project commencement in July 2019, the following project activities have been undertaken;

- Project planning to develop the scope and approach of the project.
- Establishment and development of partner and community relationships.
- Compilation and assessment of existing natural hazards datasets.
- Completion of technical assessments.
- Design of community engagement program, and completion of first two engagement session.

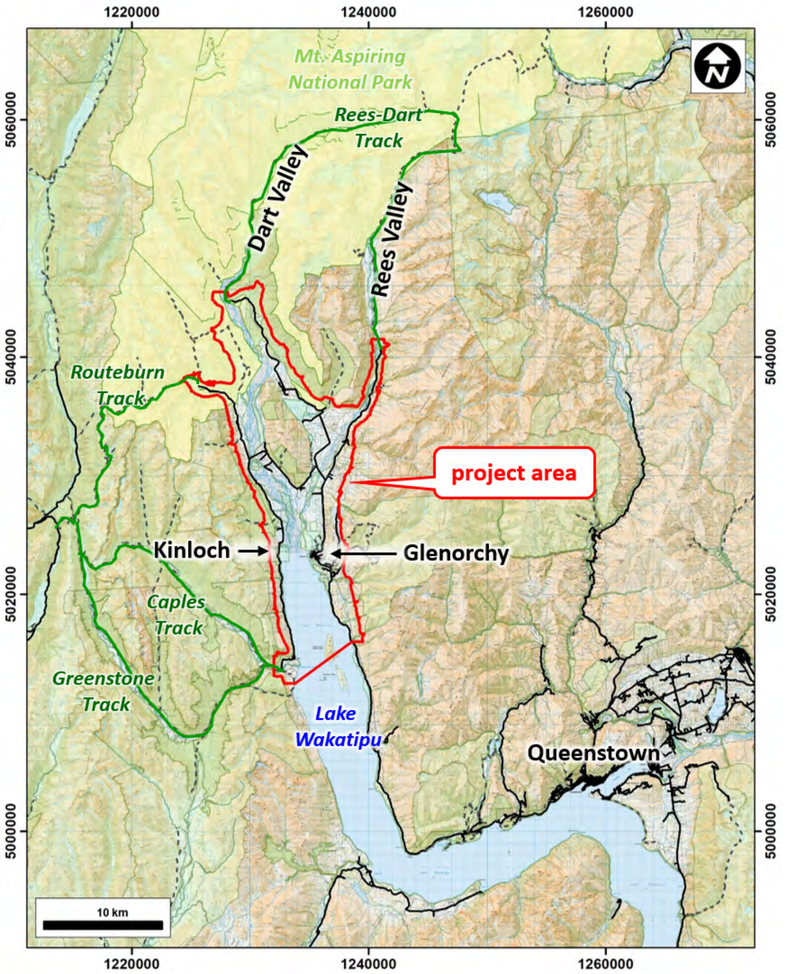


Figure 24: *Overview of the head of Lake Wakatipu, showing the proposed project area outlined in red, and the wider context in relation to Queenstown, Mount Aspiring National Park, and the main DOC walking tracks.*

4.2. Strategic Importance

This project aligns with ORC's stated community outcomes, for example; "Communities that are resilient in the face of natural hazards, climate change and other risks."

Both the regional and district councils have responsibility under the Resource Management Act (RMA) to control the use of land in order to manage natural hazard risks, implemented by means such as the Regional Policy Statement and District Plans. This project addresses the objectives and policies outlined in Chapter Four of ORC's 2019 Regional Policy Statement (RPS), which deals with "the response and ability to be resilient to resource limitations or constraints, shock events, system disruptions, natural hazards, and climate change". Specifically, this project is focused on the objectives below;

Objective 4.1: Risks that natural hazards pose to Otago's communities are minimised.

Objective 4.2: Otago's communities are prepared for and able to adapt to the effects of climate change.

The Queenstown Lakes District addresses natural hazards in Chapter 28 of the Proposed District Plan (PDP, June 2019), which contains the following natural hazards objectives;

1. The risk to people and the built environment posed by natural hazards is managed to a level tolerable to the community.
2. Development on land subject to natural hazards only occurs where the risks to the community and the built environment are appropriately managed.
3. The community's awareness and understanding of the natural hazard risk in the District is continually enhanced.

ORC has carried out several natural hazard risk management projects in recent decades, in collaboration with Otago territorial authorities. For example, the *Milton 2060*[24] project (with CDC), and the *Learning to live with flooding*[25] strategy for the communities of Lakes Wanaka and Wakatipu (with QLDC). This head of Lake Wakatipu adaptation project is another example of a collaborative natural hazards project involving both ORC and a territorial authority, but in this case is also a pilot study for ORC's implementation of the 'Adaptation pathways' approach to natural hazard risks. The natural hazards of this study area also have greater number and complexity, and as a multi-hazard project, this contrasts with most previous projects which focused largely only on a single hazard type (e.g. flooding).

This adaptation approach, and learnings from this project will be able to be applied to ORC's other current or proposed natural hazards project where an adaptation approach will be required (e.g. South Dunedin, Clutha Delta).

4.3. Project Relationships

The project to develop the adaptation strategy is being led by the Otago Regional Council (ORC), in partnership with Queenstown Lakes District Council (QLDC), Department of Conservation (DOC), Aukaha and Te Ao Marama representing Ngai Tahu, working together with the local community.

In addition, we have several consultants providing specialist inputs and advice for the project. These are:

- Paula Blackett from NIWA is providing expertise in implementing the adaptation pathways approach to natural hazards and risks.
- Professor James Brasington from Canterbury University is providing technical expertise in river morphology and floodplain hazards.
- A Tonkin + Taylor hazards team led by Nick Rogers and Tom Bassett have completed natural hazard risk assessments and provided technical advice.

[24] https://www.orc.govt.nz/media/3796/milton-2060-strategy.pdf
[25] https://www.orc.govt.nz/media/2970/queenstown-lakes-flood-management-strategy-with-appendix-c-maps.pdf

- Aukaha and Te Ao Marama are representing local iwi, Ngāi Tahu, and will provide cultural direction and understanding to ensure an appropriate cultural values statement is developed for the strategy.

ORC has developed a good working relationship with community members and organisations through the adaptation project and flood response activities carried out over 2019-2020.

- ORC have presented at three meetings of the Glenorchy Community Association (GCA) to provide updates on completed and planned activities (October 2019, July 2020, December 2020).
- ORC has been providing project updates emailed monthly (since August 2020) to the GCA, providing a summary of completed and planned flood response and adaptation project activities and events. In addition, the ORC hazards team has prepared responses to a number of community members who contacted ORC directly with concerns following the February 2020 flood event.
- ORC has established a project webpage which provides a summary of project information including copies of presentations and community updates[26],
- The first drop-in session held as part of adaptation engagement in December 2020 was attended by 30-40 community members, summarised in Section 4.5.1.
- The second sessions of adaptation engagement activities were held in April 2021; a public talk outlining river and flooding hazards research attended by ~40 community members, and a drop-in session to discuss possible adaptation options attended by ~25 community members.
- A posted letter outlining the project details in planned to be distributed in late May 2021, to ensure all residents and landowners in the head of Lake Wakatipu area are aware of this adaptation project and the objectives and further details for this work.

The establishment of these working relationships between project partners, the community of the head of Lake Wakatipu area, and engagement of consultant expertise is a key step in establishing a strong team and relationships which will enable successful adaptation outcomes.

[26] https://www.orc.govt.nz/managing-our-environment/natural-hazards/head-of-lake-wakatipu

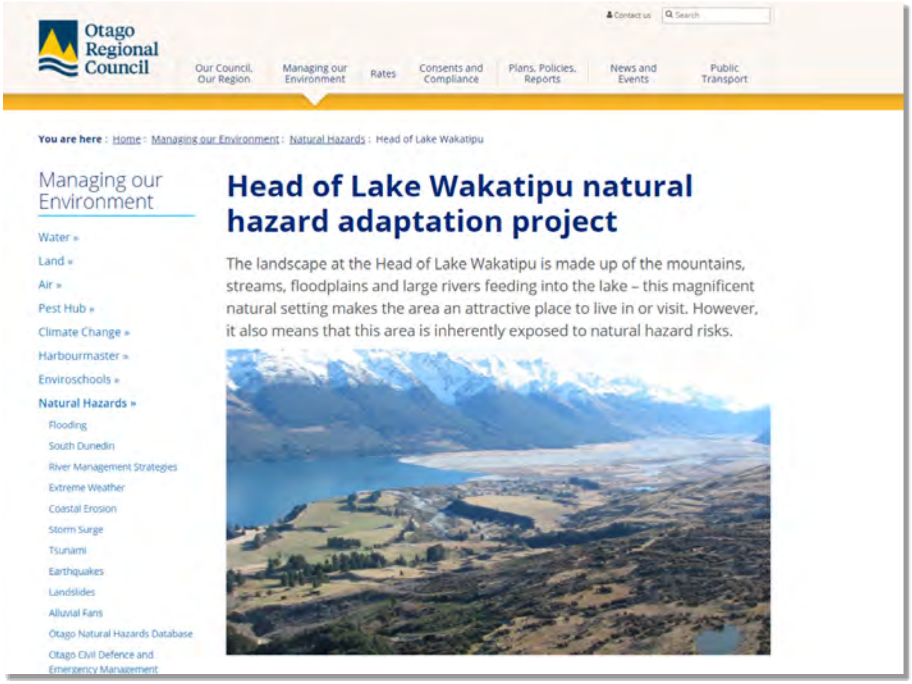


Figure 25: *Example of ORC's webpage for this adaptation project, which provides public access to project presentations, poster materials and other project updates.*

4.4. The 'Adaptation Pathways' approach

The project plan is structured around an 'adaptive pathways' approach to natural hazard assessment, where adaption is an "iterative, continually evolving processes for managing change in complex systems" (MfE 2017). Effective adaptation has been defined[27] as meaning that "*current and future communities are able to reduce the risks from natural hazard and climate change impacts over the medium and long term by:*

- *reducing the exposure and vulnerability of our natural, built, economic, social and cultural systems*
- *maintaining or improving the capacity of our natural, built, economic and social and cultural systems to adapt."*

The adaptive pathways approach is structured as a ten-step decision cycle formed around five key questions, as outlined in the Ministry for the Environment coastal hazards and climate change guidance (Figure 7). Although the head of the Lake Wakatipu project area is not a coastal setting, the escalating natural hazard risks due to delta growth and climate change are appropriate for application

[27] Climate Change Adaptation Technical Working Group, 2017. *Stocktake Report from the Climate Change Adaptation Technical Working Group.*

of this approach, which is designed to allow for flexible and adaptive decisions, and for planning under conditions of uncertainty regarding the rate, timeframes and magnitude of future changes.

This approach (Figure 26) comprises a values, hazard and risk assessment component (Steps 1-4), followed by development and implementation of an adaptation strategy (Steps 5-8), and later by a monitoring and review phase (Steps 9-10). Project planning for the Head of Lake Wakatipu covers the first eight steps of this adaptive pathways approach, and at the end of the project is intended to have reached a point where an adaptive pathways strategy has been developed, and any more detailed investigation or feasibility studies for preferred options can be commenced.

A range of types of adaptation options may be available, with these each having their own advantages and disadvantages. In practice a combination of these measures will be required, over timeframes in the short term (0 – 20 years), medium term (20 – 50 years) and long term (50 – 100 years). Besides the 'status quo' option, there are four potential groupings of natural hazard adaptation options[28];

- Accommodate
- Protect
- Retreat
- Avoidance strategies

Pathways will develop over time in response to changing conditions, and an effective adaptation strategy will incorporate decision points based on triggers or thresholds. For example, if conditions change and a current action is no longer effective at meeting objectives, then this may be a trigger for implementation of an alternative action or strategy pathway.

[28] Ministry for the Environment, 2017. *Coastal Hazards and Climate Change, guidance for local government*.

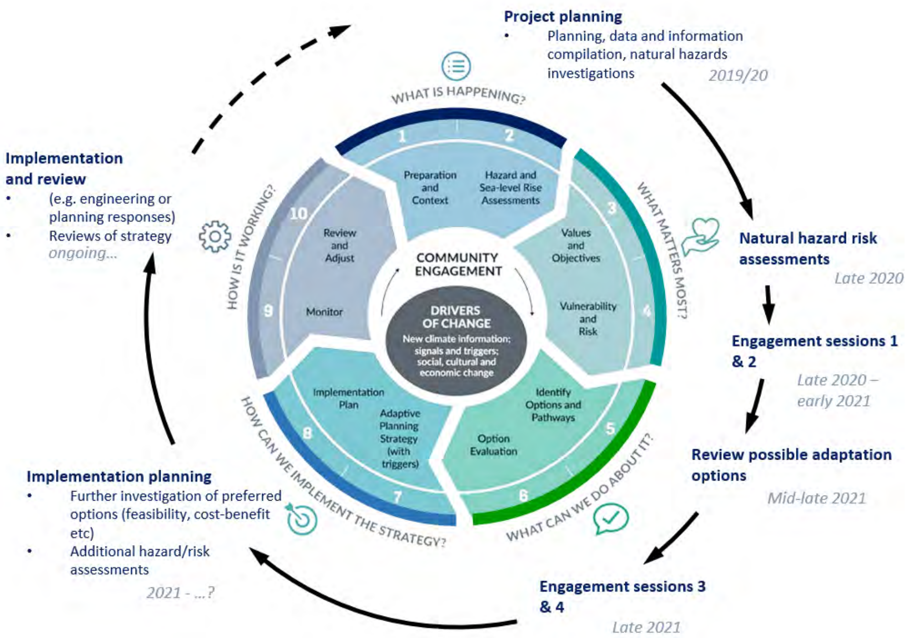


Figure 26: *Summary of the 10-step adaptation pathways decision cycle framework (MfE 2017), and showing the proposed timeframes for the key activities in this project. We have recently completed the second of the community engagement sessions, and are now moving into the phase of reviewing possible adaptation options.*

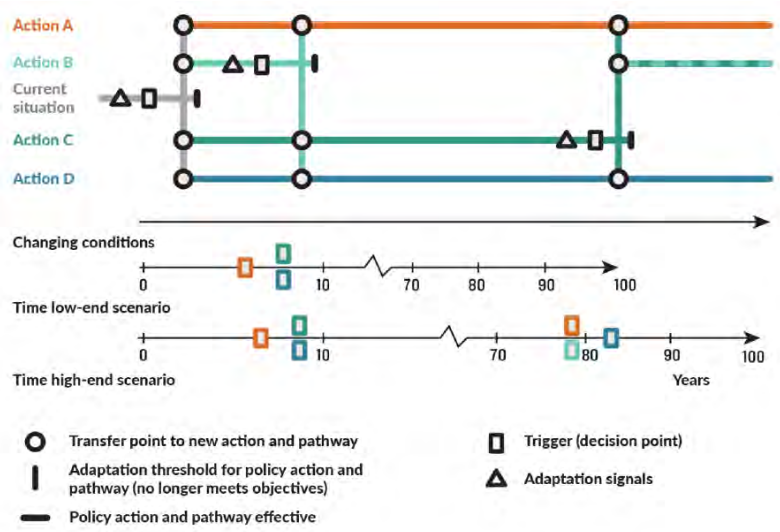


Figure 27: *Example of an adaptive pathways map (MfE coastal hazards guidance). This shows a series of possible adaptation options (A-D), each of which is assessed based on adaptation signals,*

before reaching a 'trigger' decision point where it may be decided the current options are no longer effective and a change to an alternative option is required.

4.5. Community engagement for natural hazards adaptation

ORC has engaged a NIWA team led by Dr Paula Blackett to assist with the design and development of the community engagement and adaptation pathways development phase of this project. Dr Blackett is an environmental social scientist with extensive experience in the theoretical development of adaptation pathways, participatory processes and community engagement, and the practical application of adaptation pathways in New Zealand. For a complex adaptation project of this nature, it will be critical to achieve community buy-in through a collaborative decision-making process incorporating all stakeholder's views, and NIWA's expertise will be valuable in successful development of this process.

The objectives of this engagement process are to enable and facilitate community involvement, provide opportunities for the community to contribute to this adaptation process, and to equip the community with knowledge to make informed decisions regarding adaptation approaches. The proposed engagement process is based around a series of four community engagement sessions, titled;

1. What is happening now, and how does this affect you?
2. What could happen in the future, and what might we do?
3. How can we navigate the adaptation options?
4. What do the adaptation pathways look like, and what happens now?

The first and second of these engagement sessions were held in December 2020 and April 2021. The design and content for these sessions were developed collaboratively with NIWA, ORC, QLDC, and consultant input, and are summarised in Sections 4.5.1 and 4.5.2.

The design and format of the next phases of community engagement will be developed in the coming months based on review of the feedback received to date. The next engagement steps are expected to be different than the drop-in type format utilised for the first and second community events, and may involve a more targeted approach, or alternative methods of eliciting further community feedback. One possible option which may be utilised is the 'Serious Games'[29] concept designed by NIWA for facilitating discussion of natural hazards adaptation and the constraints in implementation of adaptation pathways.

4.5.1. Summary of December 4th 2020 community engagement event

The first of four community engagement sessions planned as part of the natural hazards adaptation project was held in Glenorchy on 4th December 2020, with ORC and T+T representatives also attending

[29] https://niwa.co.nz/natural-hazards/our-services/serious-games-as-a-tool-to-engage-people]

the previous evening's GCA meeting to provide an overview of the session to these community leaders.

This session was titled: *What is happening now, and how does this affect you?* The purpose of this session was to set the scene for later adaptation meetings through discussing and providing information on the range of natural hazard events the community is exposed to, and how these events and landscape changes have impacted the community in the past. This event was attended by representatives from the ORC natural hazards and engineering teams, QLDC planning and infrastructure teams, Civil Defence, councillors from both ORC and QLDC, Tonkin and Taylor natural hazards experts, and a NIWA team who assisted with recording of conversations and later data analysis.

For ORC this session was an opportunity to build community buy-in and awareness of this adaptation project, and to ensure community views and local hazards knowledge are taken into account. For the 30-40 local community members who attended, the key benefit of this session was enabling the ability to be heard and part of the process. The community was able to discuss natural hazards issues with experts, ensure their concerns are recorded, and to provide information on their views and experiences.

The event was structured as a drop-in session, with informal discussions loosely guided by the following questions.

Hazard experience and impacts:

- *What do you value most in the natural environment of this area?*
- *What hazards have you experienced while you have lived there?*
- *What changes in the local environment have you noticed?*
- *What happened, and what effect did it have on you (your daily activities) and the community?*
- *How long did it take for you to be able to return to your normal daily activities?*
- *What other things (items objects, places etc) that are important to you were affected during these events?*
- *What are you concerned about in the future? Are there any local hazards that worry you? Why is that?*

Tolerance of hazards:

- *What would be too much for you to remain living here? (too much risk etc)*
- *Do you think any of these hazards might cause you to move?*
- *Which ones and what might be too much to cope with?*

Community feedback was overall positive, with attendee's evaluation responses reporting they found the session to be a great opportunity to ask questions and get answers to things that were important to them. Selected community feedback includes; "an informative and receptive discussion", "excellent commitment to educated decision making", "excellent information good to see you in the community", and "very approachable and informative".

An important learning from the session was the high level of awareness among the attendees regarding the dynamic nature of the environment, the natural hazards challenges facing this community, and the risks associated with the ongoing changes to the river and delta systems.

Figure 28: *Glenorchy hall during the December 2020 community engagement session.*

Figure 29: *Posters used in community engagement as an introduction to the natural hazards and changing environment of the project area, setting the scene for more in-depth discussions of these hazards events.*

Figure 30: *Through these adaptation sessions we have gained valuable natural hazard information from resident's observations and anecdotes, for example about changes to the river systems through time.*

4.5.2. Summary of April 7th – 8th 2021 community engagement events

The first of the adaptation events held in April 2021 was a public talk by Professor James Brasington (University of Canterbury) outlining his research on the Dart and Rees river systems.[30] James has had extensive research involvement in the project area for >10 years, and provided a summary of river processes, drivers of change, expected future behaviour, and implications for future hazards. This talk was well-attended by the local community (about 40 attendees).

This talk was an opportunity to provide the community with access to an independent expert view of the area's natural hazard challenges, presenting the high-quality technical information supporting ORC's knowledge of these hazards, and to demonstrate the scientific basis justifying the need for adaptation.

[30] Presentation slides: https://www.orc.govt.nz/media/9816/james-brasington-presentation_-fluvial-hazards-at-the-top-of-the-lake_20210407.pdf
Audio recording: https://www.youtube.com/watch?v=wMWeIhp6GOI

Figure 31: *James Brasington giving a public talk on the 7th April, to provide an overview for the community on his research on the Dart and Rees braided river systems, and the implications for the future flood hazards. These presentation slides and an audio recording are available online via our project webpage.*

The second adaptation engagement event was held as a drop-in session on the 8th April 2021, the session being titled: *What could happen in the future, and what might we do?* The purpose of this session was to further discuss with the community the natural hazards challenges facing this area in the future, and to initiate discussions about what adaptation to those challenges could look like. As for the December 2020 event, this session was attended by representatives from the ORC natural hazards and engineering teams, QLDC planning and infrastructure teams, Civil Defence, councillors from both ORC and QLDC, natural hazards experts from Tonkin + Taylor and Canterbury University. A NIWA team assisted with recording of conversations and are carrying out compilation and analysis of these records.

The event was structured as a drop-in session, with discussions guided by the following questions.

Are there any of these impacts that you are particularly concerned about? What and where?

How do you think we might adapt to these changes?

- *What the option is, where it is and how it might work*
- *Who might benefit from the option?*
- *How long would it last short, medium or long term?*
- *Would it create any problems (other impacts) or provide any opportunities*
- *Under what conditions would option no longer be effective (when might it fail?)*
- *Could any of these be sequenced overtime- (e.g. first we do this then we do this …)*

- *What shouldn't we do and why?*

What are the most important factors we need to consider to choose between the various options ?

How will we know that we have been successful adaptation in adapting?

Figure 32: *Photo from the community engagement event held in the Glenorchy hall on 8th April.*

Figure 33: *Photo from the community engagement event held in the Glenorchy hall on 8th April.*

4.6. Next steps for supporting investigations

The immediate next steps following on from the recent community engagement events are the compilation and analysis of feedback from community, and then to also discuss and gather further input on these issues from our project partners.

Our next project steps will also include evaluation of the need for additional technical studies, and to commence scoping and scheduling for these investigations, with the aim of commencing the highest priority of the these within the current financial year. Additional technical work will be required both to further understand the natural hazard risks in more detail, and as initial assessments of potential adaptation options.

Additional natural hazard and risk studies may include the following;

- Climate change modelling to better understand the effects of climate change on the flood hydrology of the Dart and Rees rivers, and on Lake Wakatipu.
- Hydraulic modelling to better understand the extents and severity of the future flooding risks in the Glenorchy area, taking into account both geomorphic and climate changes.
- Further investigations of natural hazard risks facing Glenorchy, which could include further investigation of alluvial fan (debris flow, dambreak flood), liquefaction and lateral spreading, and lake tsunami. The potential hazard extents, consequences and likelihoods of these risks are still uncertain, and may need to be known with more confidence to be used as inputs to adaptation decision-making.

There will also be new studies required as supporting information to help evaluate adaptation options suggested. For example, these may include assessment of river management or engineered options which may be able to modify the Glenorchy flood hazard, or review of feasibility and costings of options for maintaining access to Kinloch.