Safety and Resilience Committee
10 May 2023

Meeting will be held in the Council Chamber at Level 2, Philip Laing House
144 Rattray Street, Dunedin
ORC Official YouTube Livestream

Members:
Cr Gary Kelliher (Co-Chair)
Cr Alan Somerville (Co-Chair)
Cr Alexa Forbes
Cr Michael Laws
Cr Kevin Malcolm
Cr Lloyd McCall
Cr Tim Mepham
Cr Andrew Noone
Cr Gretchen Robertson
Cr Bryan Scott
Cr Elliot Weir
Cr Kate Wilson

Senior Officer: Pim Borren, Interim Chief Executive

Meeting Support: Liz Spector, Governance Support Officer

10 May 2023 02:00 PM

Agenda Topic **Page**

1. WELCOME

2. APOLOGIES

No apologies were submitted prior to publication of the agenda.

3. PUBLIC FORUM

Requests to speak should be made to the Governance Support team on 0800 474 082 or to governance@orc.govt.nz at least 24 hours prior to the meeting, however, this requirement may be waived by the Chairperson at the time of the meeting. No requests to speak were made prior to publication of the agenda.

4. CONFIRMATION OF AGENDA

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

5. DECLARATION OF INTERESTS

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

Otago Regional Council

Safety and Resilience Committee
MINUTES

Minutes of an ordinary meeting of the Safety and Resilience Committee held in the Council Chamber, Level 2 Philip Laing House, 144 Rattray Street, Dunedin on Thursday, 23 February 2023, commencing at 1:00 PM.

PRESENT

Cr Gary Kelliher (online)	*(Co-Chairperson)*
Cr Alan Somerville	*(Co-Chairperson)*
Cr Alexa Forbes	
Cr Kevin Malcolm	
Cr Lloyd McCall	
Cr Tim Mepham	
Cr Andrew Noone	
Cr Gretchen Robertson	
Cr Elliot Weir	
Cr Kate Wilson	

1. WELCOME

Co-Chairperson Alan Somerville welcomed Councillors, members of the public and staff to the meeting at 11:49 a.m. and led the meeting in a karakia. Staff present included Nick Donnelly (GM Corporate Services), Anita Dawe (GM Policy and Science), Richard Saunders (GM Communications), Liz Spector (Governance Support), Michelle Mifflin (Manager Engineering), Pam Wilson (Infrastructure Engineering Lead), Jean-Luc Payan (Manager Natural Hazards) and Glen Mitchell (Team Leader CDEM Group Office).

2. APOLOGIES

Resolution: Cr Weir Moved, Cr Forbes Seconded:
That the apologies for Cr Laws, Cr Scott be accepted. Cr McCall also indicated he would need to leave at 12:30p.m.
MOTION CARRIED

3. PUBLIC FORUM

There were no requests to speak during Public Forum.

4. CONFIRMATION OF AGENDA

The agenda was confirmed as published.

5. DECLARATION OF INTERESTS

No changes to the Councillor Register of Interests were advised.

6. MATTERS FOR CONSIDERATION

6.1. River Management Update

This report provided an update on the progress of recovery from the July/August 2022 floods and earlier floods and updated the Committee on river management operational progress of global consents, development of work programmes for 2022/23 and asset management plans for plantings alongside riverbanks. Michelle Mifflin (Manager Engineering), Pam Wilson (Team Leader Infrastructure Engineering) and Jean-Luc Payan (Manager Natural Hazards) were available to respond to questions.

Following Councillor questions and discussion of the report, it was moved:

Resolution SRC23-101: Cr Malcolm Moved, Cr Noone Seconded
That the Committee:

1) ***Notes*** *this summary.*
2) ***Notes*** *the progress that is being made with the reporting, planning and progression of the framework that supports river management activities.*
3) ***Notes*** *the update of the recovery resulting from the July/August 2022 floods and earlier floods*

MOTION CARRIED

Cr McCall left the meeting at 12:25 p.m.

6.2. Civil Defence Emergency Management (CDEM) quarterly update

This report was provided explain the CDEM framework and ORC's role and to provide a summary of CDEM group activity across the group's three areas of focus: Managing risk, Effective response to and Recovering from Emergencies, and Enabling, Empowering and Supporting Community Resilience. Glenn Mitchell (Team Leader Group Office CDEM) and Jean-Luc Payan (Manager Natural Hazards) were present to respond to questions about the report.

Following Councillor questions, the report was noted.

Resolution SRC23-102: Cr Wilson Moved, Cr Robertson Seconded
That the Committee:

1) ***Notes*** *this report.*
2) ***Notes*** *the updates in relation to the Alpine Fault Project (AF8), TRIFECTA, Catastrophic event planning (CAT Plan)*

MOTION CARRIED

7. CLOSURE

There was no further business and Co-Chair Somerville declared the meeting closed at 12:33 pm.

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Chairperson Date

7.1. Head of Lake Whakatipu floodplain and liquefaction hazard intervention assessments

Prepared for:	Safety and Resilience Comm
Report No.	OPS2256
Activity:	Governance Report
Author:	Jean-Luc Payan, Manager Natural Hazards; Tim van Woerden, Natural Hazards Analyst
Endorsed by:	Gavin Palmer, General Manager Operations
Date:	10 May 2023

PURPOSE

[1] To inform the Committee of the findings of assessments of potential hazard management approaches or interventions for liquefaction and floodplain hazards at the Dart-Rees floodplain and Glenorchy township, and to provide an update on other activities in the Otago Regional Council-led work programme to develop a natural hazards adaptation strategy for the area at the head of Lake Whakatipu.

EXECUTIVE SUMMARY

[2] The Otago Regional Council (ORC) led natural hazards adaptation programme for the area at the Head of Lake Whakatipu is now moving into the next phase of the adaptation (DAPP) approach "*What can we do about it?*"

[3] The reports presented in this paper are the first to assess potential hazard management approaches for liquefaction and floodplain hazards specific to the Glenorchy township and Dart-Rees floodplain area.

[4] These hazard management approach assessments were undertaken following the hazard assessments previously reported to Council which indicated a major earthquake[1] or flooding[2] event would have severe impacts in this area.

[5] The reports are intended to help ORC, QLDC, and the local community understand potential engineering approaches or interventions for managing the liquefaction and flooding hazards identified in Glenorchy and in the Dart-Rees floodplain area.

[6] The reports do not give recommendations for which hazard management interventions may be feasible or should be investigated further, but for each intervention considered, aims to outline the challenges and constraints as a starting point to inform continued discussions.

[7] ORC is using the Dynamic Adaptative Pathways Planning (DAPP) approach as a framework for development of a natural hazards adaptation strategy, with the first iteration of the strategy document expected to be completed by June 2024.

[1] Tonkin + Taylor Ltd, 2022. *Glenorchy Liquefaction Vulnerability Assessment*. Report prepared for Otago Regional Council.
[2] Land River Sea Consulting Ltd, 2022. *Dart-Rees flood hazard modelling*. Report prepared for Otago Regional Council.

[8] The strategy document will contain an overarching view of the context, principles and strategic elements, and be supported by a series of operative 'action plan' documents

[9] This paper outlines key activities in the proposed work programme to develop a natural hazards adaptation strategy.

[10] This paper also provides updates on other activities in this work programme, including current or planned natural hazard and risk assessments.

RECOMMENDATION

That the Safety and Resilience Comm*:*

1) ***Notes*** *this report.*
2) ***Notes*** *the report by Tonkin + Taylor Ltd;* Engineering approaches for managing liquefaction-related risk*, dated February 2023 and the report by Damwatch Engineering Ltd;* Dart-Rees floodplain adaptation – Report on 23-24 February workshop*, dated November 2022.*
3) ***Notes*** *the findings presented in these reports.*
4) ***Endorses*** *the use of the information presented in these reports to inform natural hazard management and adaptation decision-making for the Dart-Rees floodplain and Glenorchy.*
5) ***Notes*** *the proposed scope and intent of the Head of Lake Whakatipu natural hazards work programme.*

BACKGROUND

[11] The area at the head of Lake Whakatipu (*Whakatipu-Wai-Maori*) is exposed to multiple natural hazard risks, including those due to seismic events, flooding and slope-related processes.

[12] ORC, in collaboration with project partners, is leading a programme of work to develop a natural hazard adaptation strategy for the head of Lake Whakatipu area.

[13] The adaptation project approach and work activities previously completed are outlined in the papers presented to Council in May 2021,[3] and to the Data and information Committee in June 2022.[4]

[14] In June 2022, the Data and information Committee considered the paper, *Head of Lake Wakatipu flooding and liquefaction hazard investigations*, and made the following resolutions;

1) ***Notes*** *this report.*
2) ***Notes*** *the report by Tonkin + Taylor Ltd;* Glenorchy liquefaction vulnerability assessment*, dated May 2022 and the report by Land River Sea Consulting Ltd;* Dart-Rees flood hazard modelling*, dated May 2022.*
3) ***Notes*** *the findings presented in these reports.*
4) ***Endorses*** *the use of the information presented in these reports to inform adaptation decision-making for Glenorchy.*

[3] van Woerden T & Payan J, 2021. *Natural Hazards Adaptation in the Head of Lake Wakatipu*. ORC Report HAZ2105, Report to 27 May 2021 meeting of the Otago Regional Council.
[4] van Woerden T & Payan J, 2022. *Head of Lake Wakatipu flooding and liquefaction hazard investigations*. ORC Report HAZ2202, Report to 9 June 2022 meeting of the Otago Regional Council Data and Information Committee.

5) ***Notes*** *the Shepherd's Hut Creek debris flow event and the actions taken by ORC in response to that event.*

6) ***Notes*** *the establishment of the Queenstown-Lakes District Natural Hazards Steering Group which has further strengthened the working relationship between ORC and Queenstown Lakes District Council staff on the management of natural hazards.*

[15] In June 2022, technical reports were presented which outlined findings of assessments of liquefaction and flooding hazards.

[16] The liquefaction hazard assessment[5] showed that Glenorchy township is underlain by a thick sequence of sediments which are highly susceptible to liquefaction, and lakefront areas are also vulnerable to the impacts of lateral spreading.

[17] A liquefaction and lateral spreading vulnerability categorization was developed for the Glenorchy township study area using the criteria in the MfE/MBIE Guidance (Figures 1 and 2).[6]

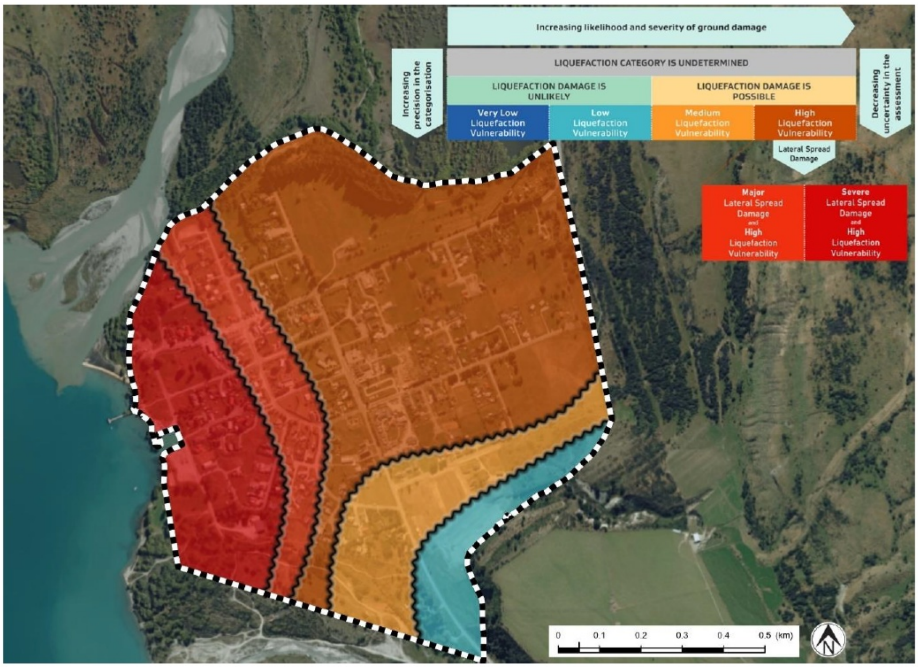

Figure 1: Liquefaction vulnerability categorisation for Glenorchy township,[7] this mapping follows the criteria shown in Figure 2. This vulnerability categorisation mapping can also be viewed within ORC's natural hazards portal (http://hazards.orc.govt.nz).

[5] Tonkin + Taylor Ltd, 2022. *Glenorchy Liquefaction Vulnerability Assessment*. Report prepared for Otago Regional Council.
[6] MBIE & MfE. (2017). *Planning and Engineering Guidance for Potentially Liquefaction-prone Land*. New Zealand Ministry of Business, Innovation and Employment, Building System Performance Branch.
[7] Appendix A of Tonkin + Taylor, 2022. *Glenorchy Liquefaction Vulnerability Assessment*.

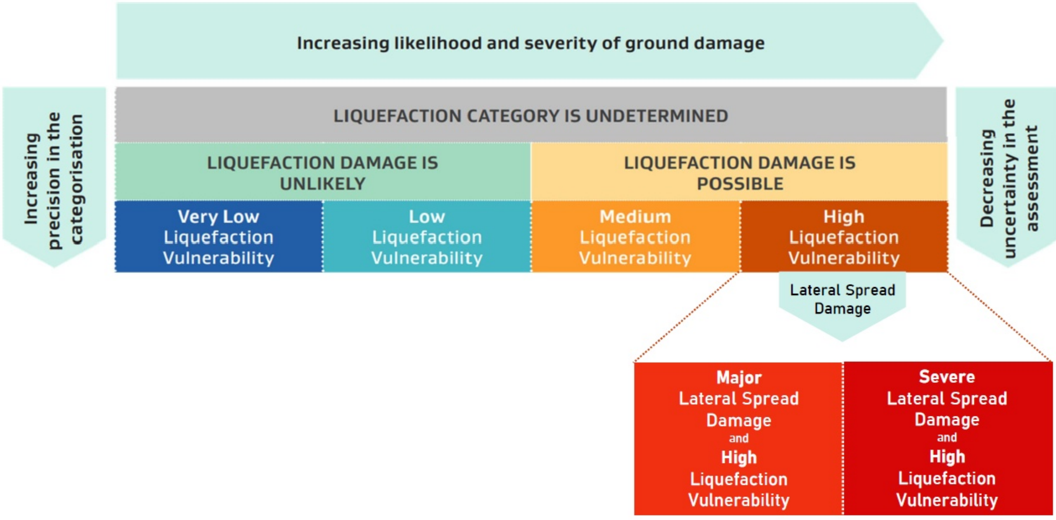

Figure 2: Liquefaction vulnerability criteria developed for the Glenorchy township study area. This follows the MfE/MBIE Guidance (2017), with the addition of categories for those areas with high vulnerability to both liquefaction and lateral spreading damages.

[18] The flooding hazard assessment[8] showed that large-magnitude flooding events on the Dart-Rees rivers could have widespread impacts across the floodplain. In the northern parts of Glenorchy township, floodwaters could inundate residential dwellings with floodwater depths in the range 0.5-2 metres and highest floodwater velocities in the range 0.5-2 m/s (Figure 3).

[19] Figure 3, and other flood modelling results reported, show the findings of specific scenarios for flooding derived only from the Dart and Rees Rivers and Lake Whakatipu. This does not represent the largest possible 'worst case' flooding event at Glenorchy, and also does not include other inflows from additional potential flooding sources such as the Buckler Burn, Bible Stream, or runoff from the hillslopes adjacent to the township.

[8] Land River Sea Consulting Ltd, 2022. *Dart-Rees flood hazard modelling*. Report prepared for Otago Regional Council.

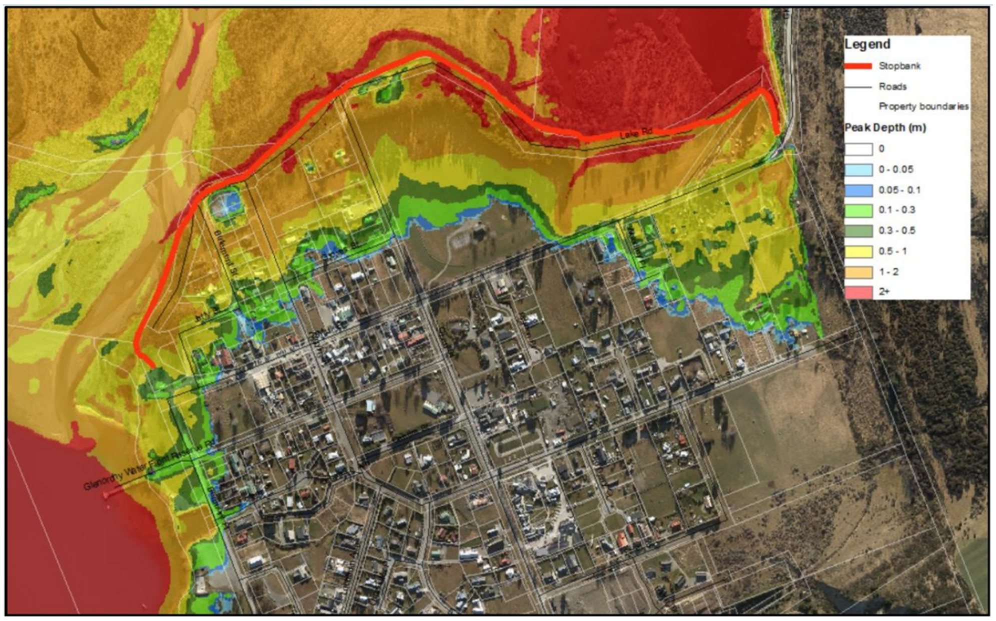

Figure 3: Model results for a Glenorchy flooding scenario with 100-year ARI river flows, and Lake Whakatipu at 10-year ARI levels. This scenario also includes the effects of climate change on river flows (RCP 8.5), and an avulsion of the Rees River channel eastwards towards the Glenorchy Lagoon. Colouring shows peak floodwater depths according to the included legend. Flood modelling results for a selection of modelled scenarios are also available for viewing within ORC's natural hazards portal (http://hazards.orc.govt.nz).

[20] The investigations presented in June 2022, and other previous natural hazard assessments, have focused largely on understanding the hazard characteristics. The new studies presented in this paper will contribute to the understanding of the potential approaches available for management of those hazards.

[21] The two reports presented here have considered the range of engineered approaches available as potential hazard management interventions for liquefaction or floodplain hazards.

[22] These new reports have not considered land-use planning approaches to management of natural hazard risks. These approaches will be within the scope of a future assessment.

[23] Figure 4 shows a conceptual overview of key activities in the head of Lake Whakatipu natural hazards adaptation work programme, with the programme currently essentially focussing on the third Phase, "*What can we do about it?*".

[24] The two studies reported in this paper are the first to investigate potential natural hazard management approaches/interventions as part of the work programme, these are highlighted in Figure 4.

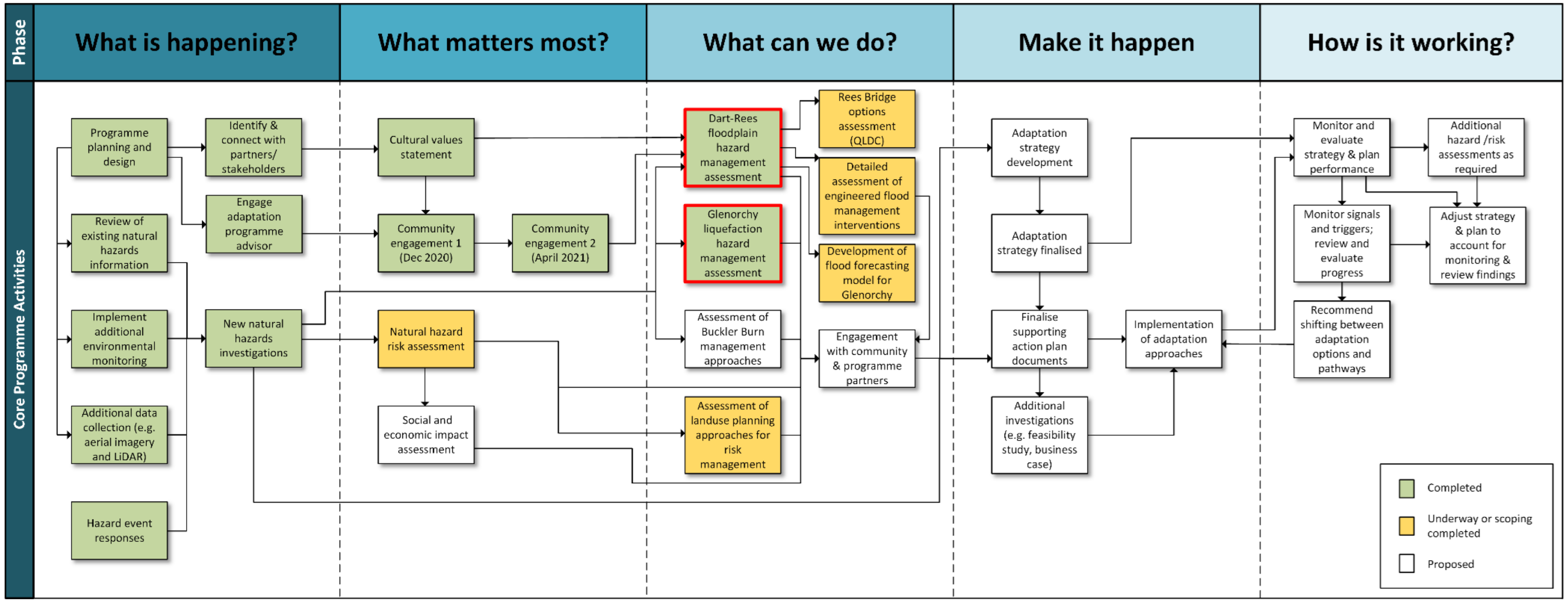

Figure 4: Head of Lake Whakatipu programme conceptual overview of key activities, the two studies reported in this paper are highlighted (red outline).

LIQUEFACTION HAZARD MANAGEMENT ASSESSMENT

[25] The report is titled *Engineering approaches for managing liquefaction-related risk* and is attached as Appendix 1.

[26] The report identifies a range of engineering mitigation techniques that could be considered for land, buildings and infrastructure, for the management of liquefaction and lateral spreading hazard at Glenorchy township. The techniques considered span from very robust options through to a "do nothing" option.

[27] The report then shows how these techniques could be applied across the township, and provides a preliminary high-level assessment of how effective these mitigation works could be in reducing damage, and an indicative relative cost comparison.

[28] The report notes that the more robust end of the range might be impractical or unaffordable, while the less robust end of the range might not satisfy Building Code or insurability requirements. However, for completeness, the report includes these options to provide context for discussion about the range of potential options that could be considered.

[29] Pre-emptive management of liquefaction and lateral spreading hazard through the use of engineered approaches is very challenging in locations of existing development.

[30] As an indication of the scale of work that would be required at the more robust end of the range, Options A to D presented in the T+T report include a strip of deep ground improvement constructed on public land running along the edge of the lake.[9]

[31] Based on the indicative relative cost estimates presented in the February 2023 T+T report, T+T advise that the construction cost for this edge-treatment work alone would likely be many tens of millions of dollars.

[32] In addition to this, many of the mitigation options include ground improvement across the wider township (under both public and private buildings and infrastructure), and there would also be additional coordination and enabling works costs associated with such a large programme of community-wide works. T+T advise that this could bring the overall cost into the hundreds of millions of dollars.

[33] Aside from cost, these engineered interventions considered also have other significant challenges associated with their implementation and effectiveness;

- These interventions do not provide a complete reduction in the natural hazard impacts. It is estimated that 25-30% of buildings and infrastructure in the lateral spreading hazard areas would suffer severe liquefaction damage in a large earthquake, even if comprehensive mitigation works were undertaken.
- These interventions involve the undertaking of large-scale engineering works and would likely be highly disruptive to the local community.
- Some of the area vulnerable to liquefaction and lateral spreading damage is also exposed to other types of natural hazard, such as flooding hazards from Lake Whakatipu, the Rees River or Buckler Burn. Consideration of any potential hazard management interventions for liquefaction and lateral spreading should be part of

[9] This ground improvement would need to be in the order of 15 – 20m deep, 30 – 40m wide, and approximately 1.5km in length (information provided by Mike Jacka, T+T).

an integrated response considering the full natural hazard risk profile, not just the seismic-induced hazards.

FLOODPLAIN HAZARD MITIGATION ASSESSMENT

[34] The report is titled *Dart-Rees floodplain adaptation – Report on 23-24 February workshop* and is attached as Appendix 2.

[35] This investigation was undertaken to identify the potential engineering or river management approaches available for management of flooding and floodplain hazards.

[36] The report assesses possible management interventions for three areas of interest where flooding or erosion may impact the community or infrastructure in the head of Lake Whakatipu area. These areas are;

- The lower Rees River and Glenorchy township.
- The Dart floodplain and Kinloch access.
- The Rees floodplain and the Rees bridge

[37] The report does not give recommendations for which hazard management interventions may be feasible or should be investigated further, but for each intervention considered aims to outline the benefits, challenges and constraints. This information is intended as a starting point to inform the development of the natural hazards adaptation strategy.

[38] For each area of interest, the report also outlines information gaps identified, and gives recommendations for monitoring and additional analysis to address those gaps.

[39] ORC and QLDC will consider the report's findings, including recommendations for monitoring and additional analysis, and discuss responsibilities for possible implementation of these tasks.

[40] Several new assessments for flooding or floodplain hazard management are currently in progress or being scoped, prompted by the findings of this report by Damwatch;

- An investigation of approaches to developing a flood forecasting model for Rees River flooding events at Glenorchy township (in progress).
- A technical study to investigate in more detail engineered interventions which may be able to provide a reduction in the flood hazard for the Glenorchy community (scoping).
- QLDC is currently undertaking a preliminary options assessment for management of the Rees River bridge. ORC is collaborating with and assisting QLDC to support their assessments.

NATURAL HAZARD RISKS

[41] One factor in assessing the need for a hazard management or adaptation response is the level of natural hazard risk present.

[42] A preliminary assessment of the natural hazard risk for Rees River flooding and liquefaction/lateral spreading at Glenorchy is shown in Table 1. This is a qualitative risk matrix assessment using the approach described in the proposed Otago Regional Policy Statement 2021 (Table 2).

[43] This preliminary risk assessment shows that individual risks for these hazards are relatively high, and for any area exposed to both liquefaction/lateral spreading and Rees River flooding, the risks considered together would also be cumulatively classed as 'significant'.

[44] A comprehensive natural hazard risk assessment is planned to be carried out for Glenorchy and Kinloch (see paragraphs 75-76). This will include a detailed assessment of all of the main natural hazard risks, including refinement of the preliminary assessments shown here.

Table 1: Preliminary risk classifications for Rees River flooding and liquefaction/lateral spreading at Glenorchy.

Likelihood	Consequence	Risk Class
Almost Certain / Likely **It has been estimated that the Rees-Glenorchy floodbank structure will not prevent flooding in the township for river flow events of a 5% AEP (20-year ARI) or greater. Moderate flooding events of 2-5% AEP (20-50 year ARI) classed as *Almost Certain*.** **Major flooding events with likelihood in the range 1-2% AEP (50-100 year ARI event) classed as *Likely*.** **This assessment is an estimate for the present-day flooding risk, however the likelihood and severity of flooding is expected to increase in future due to the effects of geomorphic and climatic factors.**	**Major** In a flooding event, estimated 21-50% of buildings within the flooded area have their functionality compromised, either as direct building damages through occurrence of a floodwater depth greater than floor level or indirectly through disruption to building access.	**SIGNIFICANT** (where likelihood is *Almost Certain*) **TOLERABLE** (where likelihood is *Likely*)

Likelihood	Consequence	Risk Class
Almost Certain **An Alpine Fault earthquake has been estimated to have an approximate conditional probability equivalent to a 30-year ARI event.**	**Catastrophic** Estimated to be a very high proportion (75-90%) of severe damages to buildings and infrastructure within the lateral spreading hazard areas, and also a high proportion (50%) of damage within the area classed as a high liquefaction susceptibility.	**SIGNIFICANT**

Table 2: The qualitative risk assessment matrix of the proposed Otago Regional Policy Statement 2021, showing preliminary assessment of the natural hazard risks for Rees River flooding and liquefaction/lateral spreading at Glenorchy.

[10] Assessments based on information reported by Land River Sea Consulting Ltd, 2022. *Dart-Rees flood hazard modelling.*
[11] Assessments based on information reported by Tonkin + Taylor, 2022. *Glenorchy Liquefaction Vulnerability Assessment*; and Tonkin + Taylor, 2023. *Engineering Approaches for Managing Liquefaction-Related Risk.*

Likelihood	**Consequences**				
	Insignificant	Minor	Moderate	Major	Catastrophic
Almost certain				Rees flooding	Liquefaction/ Lateral Spreading
Likely				Rees flooding	
Possible					
Unlikely					
Rare					
Green, Acceptable *Risk*: Yellow, Tolerable *Risk*: Red, Significant *Risk*					

DISCUSSION

[45] The ORC-led natural hazards adaptation programme for the area at the Head of Lake Whakatipu is now moving into the next phase of the adaptation (DAPP) approach "*What can we do about it?*"

[46] An Alpine Fault earthquake has a relatively high likelihood of occurring, estimated at 75% chance in the next 50 years. There is also a ~40-60% chance of a major (1-2% AEP)[12] flood in this 50-year period, and this flooding likelihood is expected to increase through time in response to geomorphic and climatic drivers.

[47] The relatively high likelihoods of these seismic and flooding natural hazard events illustrate the need for proactive hazard management and adaptation planning.

[48] This is a complex work programme considering multiple types of natural hazard with a high degree of uncertainty, where no single intervention will 'solve' the natural hazard challenges present.

[49] The management of these hazards may require use of a series of diverse approaches implemented progressively over time, referred to as 'pathways' in the adaptation planning approach. Natural hazard management or adaptation approaches could include;

- Continuation of the status quo; reactive small-scale actions to hazard impacts, but not taking any proactive action to address natural hazards and accepting that their impacts may increase in severity.
- Actions to anticipate hazard risk and reduce impacts of natural hazard events when they occur, such as civil defence planning, or property-scale interventions such as retrofitted modifications to increase the resilience of buildings to flooding or seismic damages.
- Engineered 'defence' interventions attempting to modify the characteristics of the hazard, such as flood protection structures or geotechnical ground improvement.
- Landuse planning approaches aiming to reduce the exposure of people and assets within harm's way in higher-risk areas.

[12] Annual Exceedance Probability, meaning there is a 1-2% chance in any given year of the event occurring.

[50] The two reports presented in this paper have focused on engineered approaches to hazard management, a next assessment step will be review of other types of approaches to natural hazard risk management such as land-use planning controls.

[51] No hazard management approaches or interventions considered have yet been selected or ruled out. All of these approaches are still 'on the table' and will be considered further in a collaborative decision-making process.

[52] The hazard management interventions assessed by the reports presented in this paper may be challenging to implement (economically, environmentally or socially). Any larger scale engineered approaches for hazard management would likely require a significant investment in further investigation and assessments prior to implementation. For example, these may require approval through a council long-term plan process, completion of feasibility studies or business cases, and a consenting process.

[53] Some smaller-scale hazard management actions may be able to be implemented in the shorter term and are currently being assessed further. For example, potential improvement to the flood forecasting and early-warning system for flooding at Glenorchy (paragraphs 72-74).

[54] Thorough consideration will be required to most effectively integrate development of management responses for both liquefaction and flooding hazards. These are distinct types of hazard events, and a specific hazard management approach may be required for each - the Adaptation Pathways (DAPP) approach is better-suited for flood-related hazards, whereas for geological hazards such as liquefaction a risk management approach may be more suitable. Although the management approaches may differ, the strategy will consider all natural hazards.

[55] Toka Tū Ake (EQC) provide natural disaster insurance for residential homes and land. ORC have approached Toka Tū Ake (EQC) to get their views on how they wish to be involved in, and engaged with, ORC's ongoing work programme in the head of Lake Whakatipu area.

[56] All technical reports, including the new report assessing management approaches for liquefaction hazards, have been provided to QLDC for their consideration.

CONSIDERATIONS

Strategic Framework and Policy Considerations

[57] The information presented and 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

[58] The programme is included in the ORC 2021-31 Long Term Plan with funding of $70,000 and $55,000 (excluding staff time) in the 2022/23 and 2023/24 financial years respectively.

Significance and Engagement Considerations

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

Legislative and Risk Considerations

[60] The information in this paper helps ORC, and the head of Lake Whakatipu community and stakeholders, to understand and manage the risks associated with flooding and liquefaction hazards.

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

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

[63] Key tasks to enable successful development and delivery of an effective adaptation strategy will include;

- To review and decide the most appropriate collaboration approach with QLDC. For example, if changing from the status-quo approach (an ORC-led work programme), this could include establishment of a joint governance structure, or initiation of a fully integrated joint work programme.[13]
- Development of a decision-making framework for development of a hazard management and adaptation strategy, including how best to incorporate input from all partners including community members, and allow effective consideration of all relevant factors (not just an economically-focussed cost-benefit framework). This could be a form of multi-criteria assessment approach.[14]

Climate Change Considerations

[64] The effects of climate change have been considered in flood hazard assessments for Dart and Rees Rivers, and Buckler Burn, and in the assessment of potential hazard management approaches for those hazards.

Communications Considerations

[65] ORC will continue to make all investigation findings available to the head of Lake Whakatipu community.

[66] ORC has continued to provide an update newsletter monthly (in general) to the head of Lake Whakatipu community. This newsletter was established in August 2020 and gives progress updates and an indication of upcoming project work. A link to sign up to receive this emailed newsletter, and copies of all previous newsletters are archived on the project webpage.[15]

[67] The assessment report for floodplain hazard management (by Damwatch) was made publicly available in December 2022, and the assessment report for liquefaction hazard management (by Tonkin + Taylor Ltd) is planned to be shared with the community prior to the May 2023 committee meeting.

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[13] Examples of similar collaboration options were considered by Council for ORC-DCC collaboration on the South Dunedin work programme, as outlined in paragraphs 21-23 of ORC Report P&S1885. (Hornblow S & Payan J, 2022. *ORC Role in South Dunedin/Harbourside Adaptation collaboration with DCC*. ORC Report P&S1885, Report to 1 December 2020 meeting of the Otago Regional Council Strategy and Planning Committee).

[14] Smith N et al, 2016. *Disaster risk management decision-making: review. Full cost accounting of disaster risk management decisions*. Resilient Organisations Research Report 2016/04.

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

[68] A series of engagement sessions are proposed as part of the adaptation strategy development process. Engagement input from the community, DOC and iwi will inform Steps 3-4 of the DAPP processes ("*What can we do about it?*, and "*Make it happen*").

NEXT STEPS – TECHNICAL ASSESSMENTS

[69] This section outlines tasks underway or planned for hazard and risk assessment, or assessment of potential hazards management interventions.

Buckler Burn flood hazard assessment

[70] A flood hazard and geomorphic assessment is in progress for the Buckler Burn and will be the first flood hazard assessment for this catchment to make use of detailed LiDAR topography and a 2-dimensional hydraulic modelling approach.

[71] This new flood hazard investigation for the Buckler Burn, together with the flood hazard study completed in 2022 for the Dart-Rees floodplain, will complete updated hazard assessments for the three main flooding sources which may impact Glenorchy; the Rees River, Lake Whakatipu, and the Buckler Burn.

Flood forecasting

[72] There are now approximately 16-30 months of monitoring data available from the three new environmental monitoring sites established by ORC in the Rees-Glenorchy area as part of the Head of Lake Whakatipu natural hazard adaptation programme.[16] These new datasets provide opportunity to investigate further developments of flood forecasting systems to improve the flood warning capability for Rees River flooding events at Glenorchy township.

[73] A current study is investigating potential approaches to forecasting water levels in the Glenorchy Lagoon and development of a flood forecasting approach for use by the ORC's 24/7 flood response team.

[74] This new forecasting approach would complement an existing ORC flood forecasting model which estimates high lake levels for Lake Whakatipu based on forecast or recorded rainfall totals.

Natural hazard risk assessment

[75] A risk assessment was specifically requested by community members and QLDC to better understand the natural hazard risk levels in the Glenorchy area relative to those in locations elsewhere in the country. The risk assessment will also provide supporting information for decision-making.

[76] A natural hazard risk assessment project has been scoped for the Glenorchy and Kinloch areas. The assessment scope includes assessment of natural hazard risks for the main natural hazard events which may impact on Glenorchy or Kinloch. This project is expected to commence by mid-2023.

NEXT STEPS – ADAPTATION PROGRAMME DEVELOPMENT

[16] These three new sites are measurement of; Rees River flows at Invincible (site established December 2021), Glenorchy Lagoon water level (site established October 2020), and Lake Wakatipu level at Glenorchy marina (site established January 2021).

[77] A programme objective has been previously stated in the May 2021 Council paper.[17] Additional programme objectives are now proposed to provide further detail of strategic and operational objectives, these are shown in Table 3.

Table 3: Head of Lake Whakatipu natural hazards programme strategic and operational objectives.

Strategic Objectives	**Vision: The head of Lake Whakatipu community has increased resilience* to natural hazard challenges**	
	Purpose: To enable preparation for, and proactive management of or adaptation to, natural hazards in the head of Lake Whakatipu area	
	Develop awareness and understanding of natural hazard risks for all, including community and councils.	Enable and empower the community and organisations to build their resilience to natural hazards.
	Ensure proactive, evidence-based, management of natural hazard risks.	Enable and support community ownership of process and outcomes.
Operational Objectives	**Develop 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**	
	Investigate and communicate natural hazard risks to inform proactive natural hazard risk management	Enable evidence-based and informed decision-making for current natural hazard risks, and to consider anticipated future changes to the natural hazard risks
	Consider all relevant factors in decision-making, including environmental, cultural, and community-related	Support development of a collaborative framework to include engagement with the head of Lake Whakatipu community and other partners and stakeholders
	Develop a strategy acceptable to community through transparent engagement process with the head of Lake Whakatipu community and other partners and stakeholders	Inform Council management activities and planning (including river management, environmental monitoring).
	Ensure alignment with Council strategies and policies	

*Where 'Resilience' is defined as "The ability to anticipate and resist the effects of a disruptive event, minimise adverse impacts, respond effectively post-event, maintain or recover functionality, and adapt in a way that allows for learning and thriving."

(Ministry of Civil Defence & Emergency Management, 2019. *National Disaster Resilience Strategy*. Published April 2019).

[78] Completion of an 'Adaptation Strategy' document is specified as a target measure in the 2021-2031 LTP.[18]

[79] It is proposed that the strategy document would be an overarching reference, similar in approach to those collaboratively developed by ORC such as the *Milton 2060*[19] project

[17] This was 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*."

[18] The 2021-31 LTP specifies a 2023/24 target of; '*The first Head of Lake Wakatipu natural hazards adaptation strategy completed by 30 June*'.

[19] ORC and CDC, 2012. *Milton 2060 – Flood Risk Management Strategy for Milton and the Tokomairiro Plain*.

(with CDC), and the *Learning to live with flooding*[20] strategy for the communities of Lakes Wanaka and Whakatipu (with QLDC).

[80] This strategy document is proposed to include overview of the strategy's context, principles and strategic elements, and be supported by a series of operative 'action plan' documents (Figure 5).

[81] These operative supporting documents could include;

- An adaptation pathways plan detailing which adaptation/hazard management approaches (e.g., physical interventions, planning controls, etc.) could progress to detailed analysis or business case and possible implementation. This can include concept pathways/sequences of interventions and details of triggers for implementation.
- A floodplain management plan supporting ORC's river management for floodplain gravel and vegetation.
- A monitoring plan for data collection, analysis and reporting of geomorphic changes to rivers and floodplains, and collection of flood event observations.
- A plan for regular strategy review and revision.

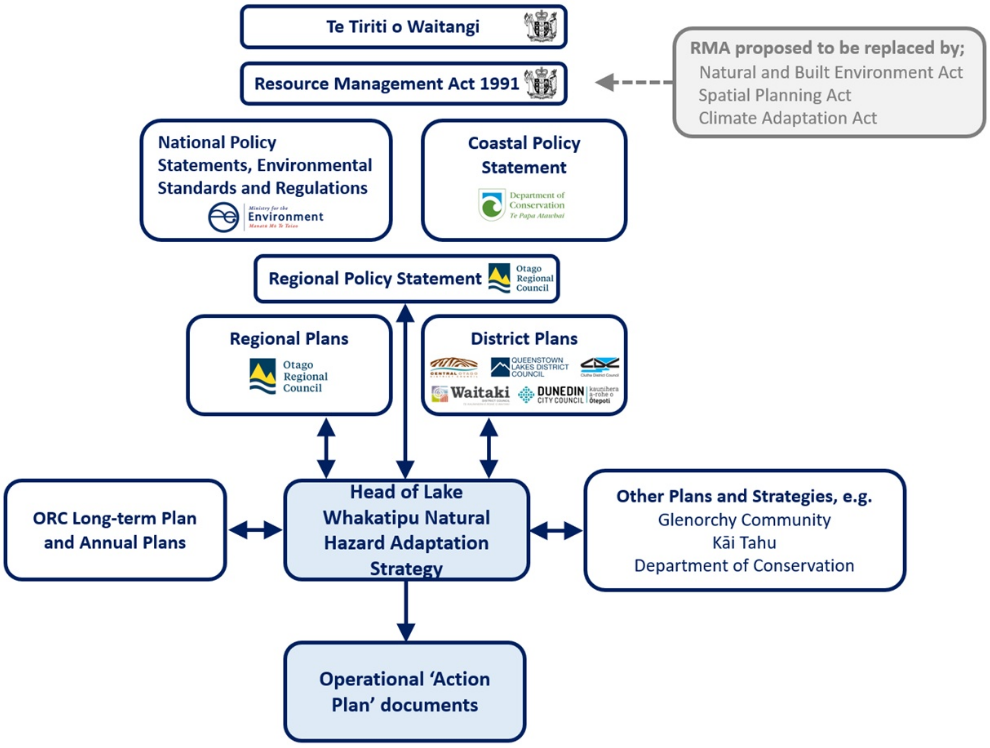

Figure 5: Hierarchy of policies and plans and relation with the Head of Lake Whakatipu Natural Hazard Adaptation Strategy and showing the relationship of the overarching strategy to supporting operational plans.

ATTACHMENTS

[20] ORC and QLDC, 2006. *Learning to Live with Flooding: A Flood Risk Management Strategy for the communities of Lakes Wakatipu and Wanaka*.

1. Damwatch Engineering Ltd 2022 Dart- Rees floodplain hazards adaptation workshop report [**7.1.1** - 137 pages]
2. Tonkin+ Taylor Ltd 2023 Engineering Options for Managing Liquefaction [**7.1.2** - 34 pages]

DAMWATCH
ENGINEERING BEYOND THE SURFACE

Dart-Rees Floodplain Adaptation - Report on 23-24 February 2022 Workshop

15 November 2022

Prepared for Otago Regional Council

Issue 3

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Executive Summary

Background

The floodplains and delta associated with the Dart and Rees Rivers at the head of Lake Wakatipu are subject to both flooding and erosion hazards which impact on the township of Glenorchy, and the wider communities of Kinloch and Greenstone through disruption of road access. The landscape scale geomorphic changes occurring in the area coupled with future climate change effects mean that these hazards are increasing over time.

The changing hazardscape is a strong influence on why and how the Otago Regional Council (ORC) and the Queenstown Lakes District Council (QLDC) are responding to these natural hazard issues. ORC are applying a Dynamic Adaptive Pathways Planning (DAPP) Approach as a framework for developing hazards adaptation pathways in this area. As part of the process of applying this approach, a floodplain adaptation workshop was held on 23-24 February 2022 which involved staff from both Councils as well as a small number of external technical experts. The workshop was intended to be a first-pass review of all possible flood mitigation and floodplain management options for the area, mainly focusing on engineering interventions (note though that this does not mean that non-engineering measures are not part of the DAPP Approach). The workshop also looked into the options put forward by the community at community workshops.

The floodplain adaptation workshop considered the flood and erosion hazard issues for three different locations as the issues are different for each location:

- Glenorchy and Lower Rees River floodplain – issue: flood hazard to residential and commercial activities;
- Kinloch Road - issue: flood hazard to access; and
- Rees Bridge and upstream right bank floodplain – Issue: flood hazard to access and to rural activities.

This report documents the proceedings and outcomes of the floodplain adaptation workshop. The conclusions presented below are outcomes from the workshop and should not be inferred to represent solely the views of the author of this report. The report is intended to inform further feedback from the community.

Glenorchy and Lower Rees River Floodplain

Due the perched nature of the Rees River, there are probably no viable long-term engineering / river management interventions to prevent flooding from the river at Glenorchy or the occurrence of an avulsion[1] event into the lagoon area. Therefore, the focus should be on preparing to manage the impacts of this inevitable event and / or mitigating those impacts or delaying the event occurrence.

In the immediate short term, this could involve:

- Flood warning improvements.
- Revision and communication of flood response procedures.
- Consideration of improvements to the existing stopbank (e.g. raising the crest profile, improving the structural quality and integrity).
- Investigation of vegetation planting on the left bank of the Rees River where flood breakouts into the lagoon area occur.

In medium or longer term, other strategies could be considered:

- Building-scale interventions (e.g. raising floor levels of existing buildings).
- Planning responses (e.g. preventing further intensification, setting a revised minimum floor level).
- Retreat of buildings in the highest-risk areas.

Planning for these possible medium or longer term strategies would need to start in the immediate short term.

It needs to be emphasised that any upgrade of the existing stopbank will be a short-term measure only. It should be communicated very clearly and carefully to the community that the purpose of the stopbank improvements is to reduce the current flooding threat to the town from the river.

ORC and QLDC will need to work together to:

- inform the community of new information on natural hazard risks;
- convey this information in an understandable way and why various flood mitigation interventions are not viable for the long-term;
- develop improved flood warning systems and updated flood response procedures;
- incorporate new flood hazard information into the planning framework; and

[1] *An avulsion is when a river channel switches location, often abruptly, along part of its course. Avulsions are characteristic of fluvial and deltaic environments, including alluvial fans and rivers with multiple channels.* *https://link.springer.com/referenceworkentry/10.1007/978-1-4020-4399-4_18#:~:text=An%20avulsion%20is%20when%20a,and%20rivers%20with%20multiple%20channels.*

- compile critical information to support the investigation, planning and implementation of any longer-term strategies.

Kinloch Road and Dart River Floodplain

The Kinloch Road is closed fairly frequently due to inundation by floodwaters from the Dart River overflowing the right bank and / or flood damage. The frequency of flood inundation has been increasing over time due to ongoing bed aggradation[2] and this trend is expected to continue in the future.

The road is also threatened by bank erosion on the right bank. The current westerly migration of the active channel belt along the right bank is expected to continue in the future due to the transverse slope across the riverbed. Since the 1960's, the long-term bank erosion rate has been > 10m/year in places and could be up to 50 m/year if a series of consecutive large flood events occurred.

The current reactive management approach of localised raising of the road formation and localised rock armouring of sections of the right bank are of limited benefit and not sustainable in the longer term. In the case of rock protection works, it is also expensive.

The development of any business case to improve the long-term reliability of access to Kinloch will not happen quickly due to competing higher priority works in the QLDC area. Therefore, there is a need to develop a plan for interim / emergency measures for implementation whenever road access is cut:

- An interim measure could be a temporary farm access track through Woodbine Station. This would require negotiations and an agreement with the landowner.
- An emergency access measure could be a barge / water taxi arrangement. However, this would still need to be supported by a business case.

The only longer-term solution to maintain road access to the Kinloch area which is viable would be relocation of the road onto the western hillslopes. However, this solution has several constraints such as legal and land ownership issues, and increased exposure to other hazards. It would also have high costs and a long lead time. Any permanent road relocation would need to be supported by a detailed business case by QLDC.

[2] Aggradation is a geomorphological term used to *describe the increase in land elevation, typically in a river system, due to the deposition of sediment. Aggradation occurs in areas in which the supply of sediment is greater than the amount of material that the system is able to transport. https://en.wikipedia.org/wiki/Aggradation#:~:text=Aggradation%20(or%20alluviation)%20is%20the,system%20is%20able%20to%20transport.*

Rees Bridge and Upstream Right Bank Floodplain

Widespread aggradation upstream of the Rees Bridge has not only reduced the bridge waterway capacity but created the potential for an avulsion event across the upstream right bank floodplain. Riverbed levels along the right bank are now approaching the crest of the primary stopbank in places and are higher than adjacent floodplain levels. This significantly reduces the level of service of the primary stopbank. The main impact of an avulsion event would be on road access to Paradise, Kinloch and the Routeburn Valley although it would also affect farmland and a Fish and Game Lodge near the confluence of Diamond Creek.

It is not feasible to control or prevent an avulsion event from the Rees River upstream of the bridge. However, work can be done now to manage the consequences of such an event. A better understanding of potential avulsion flow paths across the right bank floodplain needs to be obtained with the aid of 2D computational hydraulic modelling based on updated LiDAR topographic data. Planning controls need to be considered to ensure no future development occurs within these potential avulsion pathways.

One river management intervention worth exploring to lower the risk of an avulsion event on the right bank is to provide increased channel capacity with clearance of willows and other vegetation on the left bank which historically was part of the active riverbed.

Further investigation and monitoring of the Rees Bridge is required including:

- hydraulic modelling to determine a current water level / discharge rating relationship at the bridge and to understand flood patterns when the flood capacity of the bridge waterway is exceeded;
- establishing the current flood capacity of the bridge waterway and determining a critical point in terms of adequate flood capacity;
- assessing the scour risk to the bridge;
- assessing the structural stability of the bridge;
- monitoring of floodwater levels at bridge; and
- tracking shifts in the water level / discharge rating relationship at the bridge due to ongoing bed aggradation.

One urgent action than needs to be taken is to bolster the scour protection at the abutments of the existing bridge.

An emergency response plan also needs to be developed as an immediate priority to implement in case:

- the Rees Bridge is temporarily damaged; and / or
- a flood breakout and channel avulsion event occurs along the right bank upstream of the bridge.

A business case needs to be developed for the longer term by QLDC to consider longer-term options for the Rees Bridge. These options could include raising the existing bridge or constructing a new bridge. Maintaining access to Paradise, Kinloch and the Routeburn Valley during any construction works will be a significant consideration.

Table of Contents

1.0 Introduction

1.1 Background to Floodplain Adaptation Workshop

The Dart and Rees Rivers flow into Lake Wakatipu at the head of the lake (see Figure 1.1). The floodplains and combined delta associated with these rivers are subject to both flooding and erosion hazards which impact on the township of Glenorchy, and the wider communities of Kinloch and the Upper Rees Valley through disruption of road access.

The key flood related hazard issues affecting these locations are listed below:

- Glenorchy and Lower Rees River floodplain – flooding within parts of the Glenorchy township caused by high flows in the Rees River and / or high flood levels in Lake Wakatipu.
- Dart River floodplain and Kinloch / Greenstone Valley road access – flood inundation of floodplain causing road closures, and westwards migration of the active river channel belt towards the roadway causing bank erosion.
- Rees River Bridge – riverbed aggradation reducing the waterway flow capacity of the bridge and increasing the potential for bridge overtopping or outflanking which would also cause road closure.

There are also other associated natural hazard issues which are discussed later in this report.

In order to understand these natural hazard issues, it is necessary to consider the geomorphic processes at play in this floodplain and delta area. The environment is a dynamic, multi-hazard one characterised by actively aggrading riverbeds, actively migrating river channel belts and a prograding[3] delta shoreline. The landscape scale geomorphic changes occurring in the area coupled with future climate change effects mean that the flooding and erosion hazards are increasing over time.

The changing hazardscape affecting the Dart-Rees floodplain and delta area is a strong influence on why and how the Otago Regional Council (ORC) and the Queenstown Lakes District Council (QLDC) are responding to these natural hazard issues. ORC is applying a Dynamic Adaptive Pathways Planning (DAPP) Approach (described in Section 3) recommended by the Ministry for the Environment (MfE) as a framework for developing hazards adaptation pathways in this area (the Head of Lake Wakatipu Natural Hazards Adaptation Programme). As part of the process of applying this approach, a floodplain adaptation workshop was held on 23-24 February 2022 which involved staff from both Councils as well as a small number of external technical experts. The workshop was intended to be a first-pass review of all possible flood mitigation and floodplain management options, mainly focusing on engineering interventions (note though that this does not mean that non-engineering measures are not part of the DAPP Approach). The workshop also looked into the options put forward by the community at community workshops.

[3] The term progradation refers to the advance of a river delta further out into the receiving body of water (Lake Wakatipu in the case of the Dart Rees delta). This occurs when the volume of river-transported sediment exceeds the volume of sediment lost from the front face of the delta through subsidence, erosion and other processes.

This report documents the proceedings and outcomes of the floodplain adaptation workshop for transmission back to managers and decisionmakers in both Councils, and the local community. The report is intended to inform further feedback from the community.

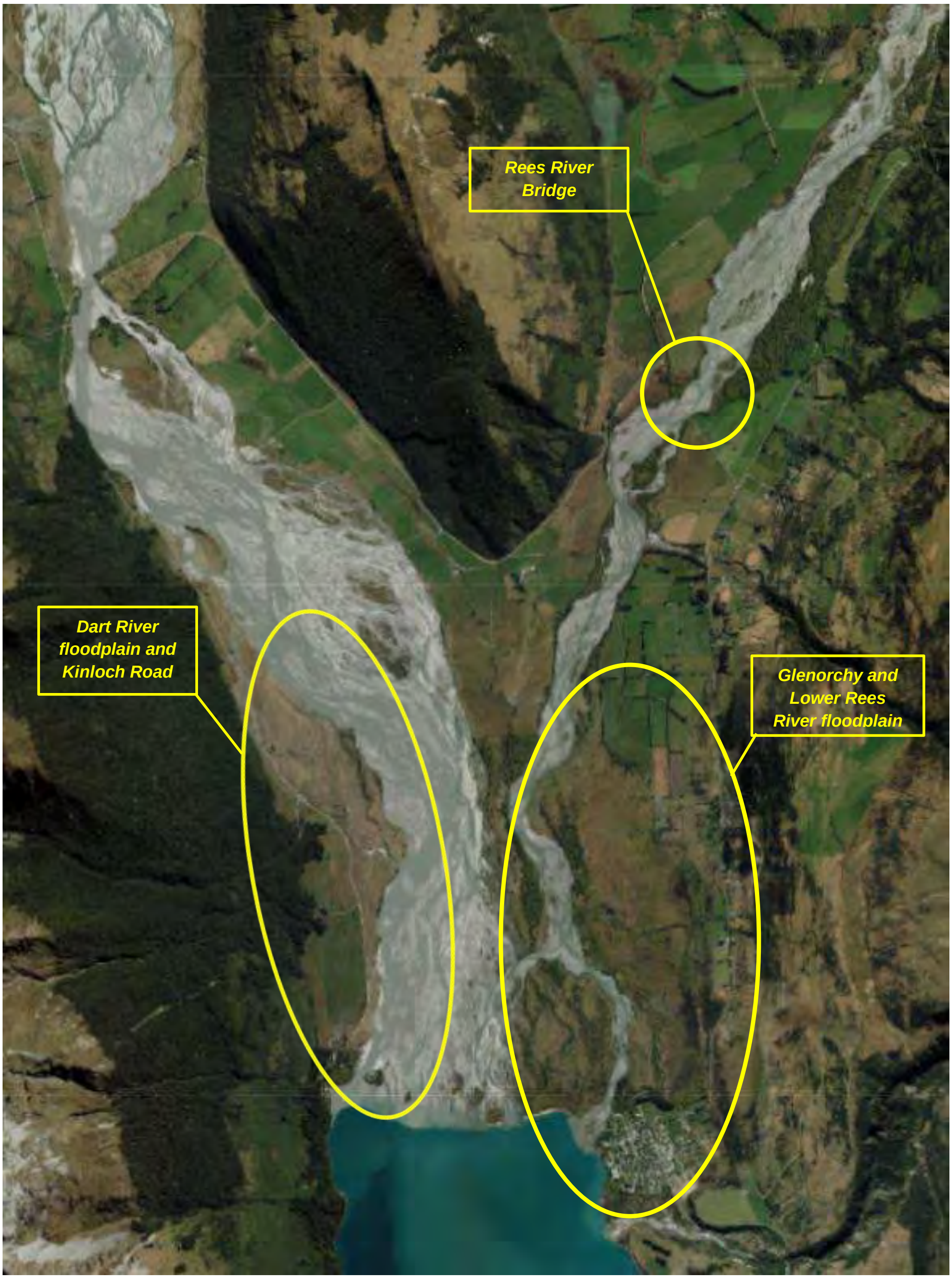

Figure 1.1: Overview of lower Dart-Rees floodplain and delta area showing key areas of interest (sourced from QLDC Spatial Data Hub)

1.2 Scope of Floodplain Adaptation Workshop and Key Questions

The broad scope of the floodplain adaptation workshop was:

- to help identify and understand which of the range of possible flood mitigation and floodplain management approaches may be feasible, environmentally acceptable and cost-effective, and;
- to identify and prioritise any next steps including filling information gaps and undertaking more detailed investigations.

The workshop posed some key questions to address:

- What does sustainable river and floodplain management look like for the Dart-Rees floodplain and delta area and what does it offer?
- What does sustainable flood protection look like and what level of protection is realistically achievable?
- What other complementary strategies are available and practical to implement in order to achieve natural hazard resilience (e.g. planning controls)?
- Can broad principles be defined for a river management strategy in this area, and what are those principles?

1.3 Project Objectives and Assessment Factors

The Head of Lake Wakatipu Natural Hazards Adaptation Programme has an objective of providing "*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'.*

In recognition of this, the following objectives were developed for the floodplain adaptation workshop:

a) An understanding of viable, sustainable river management approaches suitable for the floodplain / river environment of the Dart-Rees area.
b) An estimation of how long, or under what conditions these approaches might remain effective.
c) An understanding of key constraints and other factors affecting river management interventions (cost, environmental, cultural, feasibility, community acceptability etc.).
d) How these approaches might fit within the wider context of natural hazard management and adaptation (e.g. planning responses, potential retreat).
e) Specific review of risks and benefits of all options put forward by the community during engagement activities.

In assessing possible river management interventions, the following questions need to be considered:

- What are the interventions trying to achieve?
- What are the impacts?
- What are the risks?

- How much time will river management / engineered interventions provide?
- How viable are these river management / engineered interventions in the longer term given the environmental / hazard context (e.g. with continual riverbed aggradation, the geomorphic consequences of an Alpine Fault earthquake, and future climate change impacts on hydrology and flooding)?

In this context, for any river management intervention strategy to be successful:

- It must provide adequate flood protection benefits.
- The cost must be acceptable and justified.
- Adverse impacts on the environment are either avoided or minimised.
- The risks and benefits of alternative strategies / pathways must be satisfactorily communicated to other stakeholders.
- The strategy is supported and accepted by the wider community (e.g. local residents, Department of Conservation, Kāi Tahu).

1.4 Floodplain Adaptation Workshop Format and Programme

The floodplain adaptation workshop was originally planned as an in-person event but, due to the outbreak of the Omicron variant of Covid-19 in the community, it was shifted to an on-line event held over one and a half days. The workshop programme covered the following aspects:

- Setting the context and defining the problem
  - General overview of area
  - Community setting
  - QLDC and infrastructure overview
  - Overview of hazardscape for area
  - Summary of ORC's natural hazard adaptation programme
  - Geomorphic characteristics of area
  - Results of flood hazard assessment
- Describing the adaptation pathways approach, objectives and principles
  - General introduction to the approach
  - Summary of community engagement findings
  - Discussion of key questions to address
  - Discussion of objectives for adaptation
  - Discussion of principles for adaptation
  - Discussion of what a successful adaptation approach looks like
  - Discussion of assessment factors for judging success of interventions
- Considering the natural hazard challenges posed by each of the three focus areas (Rees River and Glenorchy, Dart River floodplain and Kinloch Road, and the Rees River Bridge and the upstream right bank floodplain)
  - Identification of specific threats and hazards
  - Identification of possible adaptation interventions
  - Evaluation of interventions (impacts, benefits, risks / consequences of failure, durability over time, long-term viability, regulatory / policy constraints)
  - Assessment of whether specific interventions satisfy objectives for adaptation
  - Assessment of whether specific interventions can be knitted together to provide a long-term adaptation pathway

1.5 Floodplain Adaptation Workshop Participants

The following participants were involved in the floodplain adaptation workshop:

Otago Regional Council
Dr Jean-Luc Payan (Workshop Facilitator) – Manager Natural Hazards
Tim van Woerden – Natural Hazards Analyst
Michelle Mifflin – Manager Engineering
Pam Wilson - Infrastructure Engineering Lead
Scott Liddell – River Engineer
Craig Hughes - Planning and Strategy Engineer

Queenstown Lakes District Council
Ben Greenwood - Roading Operations and Contracts Manager
Hugo De Cosse Brissac – Roading Engineer
Bill Nicoll - Resilience & Climate Action Manager
Mark Baker - Strategy & Asset Planning Manager
Alison Tomlinson - Transport Asset Manager

External Technical Experts
Professor James Brasington (Director, Waterways Centre for Freshwater Management New Zealand, University of Canterbury / Lincoln University)
Matt Gardner (Land River Sea Consulting)
Dr Grant Webby (Damwatch Engineering)

Observer
Jamie MacKenzie (University of Otago post-graduate student)

1.6 Structure of Report

The report on the floodplain adaptation workshop is structured as follows:

- Section 2 sets the scene and defines the problem.
- Section 3 outlines the adaptation pathways approach recommended by MfE.
- Section 4 considers potential flood mitigation and management approaches for the Rees River and Glenorchy.
- Section 5 considers potential flood related hazard mitigation and management approaches for the Kinloch Road and access to the Kinloch area.
- Section 6 considers potential flood related hazard mitigation and management approaches for the Rees Bridge and the upstream right bank floodplain.
- Section 7 presents a summary of the workshop outcomes and conclusions.
- Appendix A contains the workshop programme and briefing notes.
- Appendices B-E contain copies of presentations of background information contributed by different workshop participants.

2.0 Defining the Problem

2.1 Introduction

To provide some background context for the workshop participants, the floodplain adaptation workshop started with a series of presentations on different aspects by ORC and QLDC staff members and some of the external technical experts. This section provides a summary of the material presented. The slides used in each presentation are included in Appendices B-E.

2.2 Overview of Context

Figure 2.1 shows the environmental setting for the area with the floodplains for the Dart and Rees Rivers lying between the Humboldt Mountains to the west and the Richardson Mountains to the east. The Dart River Catchment extends back to the South Island Main Divide with the head of the catchment lying between the Main Divide and the head of the Rees River Catchment.

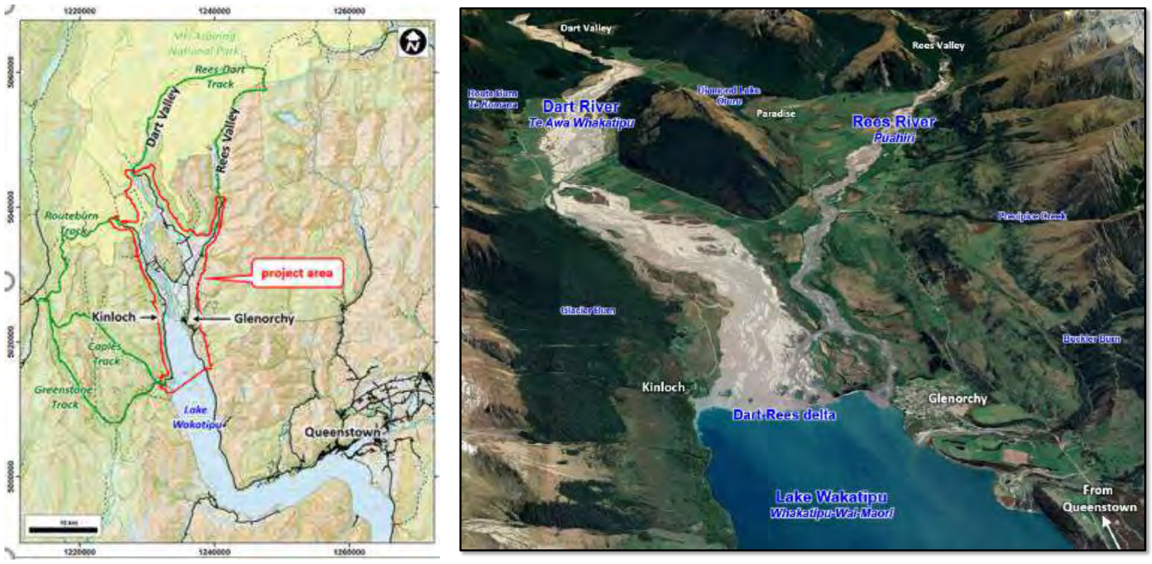

Figure 2.1: Overviews of head of Lake Wakatipu in relation to wider area

Glenorchy township is located at the head of Lake Wakatipu on the left bank floodplain of the Rees River and immediately adjacent to the shoreline delta of the Rees and Dart Rivers. The road north of Glenorchy provides access to the Dart and Rees Valleys, rural localities such as Paradise and Kinloch and the Routeburn, Caples and Greenstone Tracks. This access includes a single bridge across each river.

The area at the head of the lake is exposed to a complex range of hydrological, geomorphological and seismic related hazards. The communities in the area have been regularly impacted by natural hazard events since settlement began due to development in locations such as floodplains and alluvial fan surfaces which are prone to hazard impacts. In recent decades, these impacts have included flooding of low-lying parts of Glenorchy in November 1999 and February 2020, and frequent flooding and bank erosion affecting road access to Kinloch.

The area is also exposed to other lower-likelihood hazard sources which may have significant impacts on parts of the community. These hazard sources include debris flows, landslide dam-break induced floods, liquefaction or lateral spreading resulting from major earthquakes, and tsunamis triggered by sub-aerial or sub-aqueous landslides into Lake Wakatipu[4].

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. While the magnitude and timing of both types of change is uncertain, they are expected to cause increases in the severity and likelihood of natural hazard impacts[5]. This applies particularly to flooding and related hazards.

The braided channel belts, floodplains and delta of the Dart and Rees Rivers are undergoing continuous and irreversible geomorphic change over time[6]. This is evidenced by riverbed aggradation, lateral channel migration and delta advancement into the lake due to the ongoing natural process of sediment transport by water flows in these rivers.

These geomorphic changes are likely to cause an increase in the frequency and severity of future flooding impacts on the floodplains of the Dart and Rees Rivers.

2.3 Iwi Values

The area at the head of Lake Wakatipu holds significant cultural values for Kāi Tahu[7]:

> "*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*****."**Kāi Tahu are partners with ORC.

2.4 Community Setting and Values

The total community population in the area is currently about 500. The population is mainly centred around Glenorchy with other rural settlements at Kinloch, Paradise, Greenstone, the Rees Valley and Wyuna. The main business activities are tourism and farming. Pre-Covid, daily tourist visitors peaked at more than 1000.

The population has grown rapidly since the 1980s. From census data, the population in the wider Glenorchy area grew from 270 in 2001 to 390 in 2018. The population is projected to grow to 450[8] in 2048 while average daily tourist numbers are projected in increase from 1,000 to 1,420.

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[4] Tonkin and Taylor (2021a).
[5] NIWA (2019).
[6] Wild (2013); Brasington (2021).
[7] Aukaha (2021)
[8] QLDC staff have advised that revised modelling for projected population growth in Glenorchy is to be carried out in 2022. There are several scenarios where the population growth could spike (e.g. this could be triggered by construction of a reticulated wastewater system - QLDC is actively considering investing in a wastewater treatment plant for the town).

The community values highly the lifestyle and freedom associated with the unspoilt and spectacular environment of the area as set out in a 2001 community vision statement[9]:

> "*A vibrant community where lifestyle and freedom are highly valued together with the peaceful, unspoilt rural environment and the dynamic interaction of the spectacular landscape, heritage and wilderness".*

The area has significant conservation values with the Department of Conservation (DOC) being an important stakeholder. The area forms a Gateway to Mount Aspiring National Park and Te Wāhipounamu – South West New Zealand World Heritage Area. It also provides access to the Routeburn Track (a NZ Great Walk) and to the Greenstone-Caples and Dart-Rees Tracks, and incorporates extensive DOC-managed reserves and conservation areas. The area incorporates five regionally significant wetland areas including the DOC-administered Glenorchy Lagoon and Conservation Area.

2.5 Hazardscape Review

Figure 2.2 illustrates the wide range of potential natural hazard sources impacting the area at the head of Lake Wakatipu. As noted before, these natural hazard sources are non-static and continually adjusting in response to geomorphic (landscape) and climatic changes with an adverse trend. There is also a high potential for cascading hazard scenarios in the area (e.g. the geomorphic consequences of a major earthquake).

[9] Blakely Wallace Associates (2001).

Figure 2.2: Natural hazard sources impacting on area at head of Lake Wakatipu

The main flood related hazard issues for the four floodplain focus locations are:

a) Glenorchy township
  - Increasing flood hazard due to ongoing bed aggradation in Rees River
  - Increasing flood hazard due to breakout flows into Glenorchy Lagoon and the potential for permanent channel avulsion
  - Increasing flood hazard due to climate change impacts
  - Increasing erosion hazard to existing stopbank due to the combination of ongoing riverbed aggradation and climate change impacts

b) Kinloch road access
  - Increased flood hazard to road due to ongoing bed aggradation in Dart River
  - Increased erosion hazard due to ongoing lateral channel belt migration westwards and frequency of high-velocity flows adjacent to road
  - Increasing flood and erosion hazards due to climate change impacts

c) Rees Bridge
  - Reducing bridge waterway flood capacity due to the combination of ongoing riverbed aggradation and climate change impacts
  - Increasing potential for scour and erosion damage at bridge piers and abutments due to the combination of ongoing riverbed aggradation and climate change impacts (including potential for outflanking either of the bridge abutments)

- Increasing potential for structural damage to bridge from debris rafting and flood overtopping due to the combination of ongoing riverbed aggradation and climate change impacts

d) Right bank floodplain upstream of Rees Bridge
- Increasing flood hazard with potential for stopbank overtopping and permanent channel avulsion due to the combination of ongoing riverbed aggradation and climate change impacts
- Potential for cutting road access to Paradise and Kinloch
- Potential impact on adjacent farmland

Figures 2.3-2.5 illustrate these hazard issues.

Figure 2.3: Flooding in Glenorchy in November 1999 (a combination of lake and fluvial sourced flooding)

Figure 2.4: Flooding of Kinloch Road (in the foreground) in a minor flood event in 2019 - Dart River floodplain looking upstream

Figure 2.5: Erosion protection works adjacent to Kinloch Road with evidence of recent breakout flows across road in February 2022 (note level of riverbed adjacent to right bank floodplain)

Figure 2.6: Riverbed aggradation under Rees Bridge in February 2022 (viewed looking upstream)

2.6 QLDC Perspectives

Excluding outliers, the Kinloch Road is the most expensive road in QLDC's network in terms of the cost/km length for emergency works based on data from 2016 to the present time. Recent emergency works have included raising sections of the road to try and reduce the frequency of flood inundation[11] and protection of vulnerable sections of riverbank adjacent to the road with rock armouring.

QLDC's view is that the current reactive management approach is probably not sustainable in the longer term due to funding limitations, especially with the continuing westerly migration of the active channel belt in the Dart River towards the road and the ongoing trend of riverbed aggradation. However, there is an expectation that QLDC will continue to maintain access via this road.

In the short term, QLDC are managing the Kinloch Road using two funding streams:

- LTP funding of $220,000 every second year for Rees River Bridge resilience; and
- Emergency works – when unplanned works are required outside of gravel extraction opportunities such and bank armouring or raising the road level.

[11] The Kinloch Road currently gets flooded whenever flows in the Dart River reach a threshold of about 500 m^3/s (based on the Dart at Hillocks flow gauge) whereas previously this flow threshold was (anecdotally) much higher.

The purpose of the Rees River Bridge resilience funding is to reduce gravel aggradation under the bridge. Gravel is extracted and disposed of as economically as possible, and the opportunity has been taken to raise the level of the Kinloch Road with this material. However, the volume of material which can be removed for $110,000/year is very small compared to the total volume of gravel bed material transported by the Rees River each year.

QLDC's view is that it is inevitable that the Rees Bridge will need to be raised in the near future due to the current rate of riverbed aggradation. Five years ago a Moxy dump truck could be driven under the bridge but this is now no longer possible.

The 1.4 km long Glenorchy stopbank along the left side of Lagoon Creek and the Rees River was constructed in about 2000. It has been overtopped by floodwaters a few times in recent years including in the February 2020 flood event[12]. Following a survey of the stopbank crest, QLDC recently undertook some minor scale works which included:

- the supply and placement of 1,200 tonnes of rock to protect vulnerable sections of the stopbank along the Rees River:
- the repair of some over-steep sections of the stopbank; and
- localised and minor raising of a short section of the stopbank near the golf course where the crest was low.

In addition to these works, ORC recently completed fairly substantial works to clear willows from along the banks of Lagoon Creek in order to improve the discharge capacity of the creek and to lower water levels in the lagoon under flood conditions.

2.7 Geomorphic Characteristics and Trends

While not the most catastrophic threat, flooding from rivers poses the most frequent hazard to communities at the head of Lake Wakatipu. This hazard manifests itself in several forms:

- direct flood inundation
- fast flowing floodwaters
- entrained debris and sediment
- riverbank erosion

Fluvial related hazards are expected to increase in frequency and severity in the future. There are two main drivers for this trend. Increases in average temperature due to climate change are expected to produce a 20-40% increase in winter rainfall and more intense storms by 2090 with up to a 100% increase in the mean annual flood flow[13]. Continual riverbed aggradation will result in increased bed levels and ongoing lateral channel belt migration.

Due to their proximity to the South Island Main Divide (which is subject to continuing uplift of more than 5 mm/year), the Dart and Rees Catchments experience extreme rates of erosion. The glacial legacy of over-steep catchment slopes and orographic-induced precipitation of more than 5,000 mm/year are key factors in this. The resulting unstable landscape is dominated by retreating headwater glaciers and active landslides. Occasional mass movement events can give rise to the formation of landslide dam impounded lakes with the potential for a dam-break

[12] The February 2020 flood was estimated to have been about a 1 in 15 to 1 in 20 AEP event.
[13] NIWA (2019).

flood when these dams are overtopped. The unlimited supply of sediment in the Dart and Rees Catchments means that there is more sediment available than the capacity of the two rivers to transport the sediment downstream[14]. The average annual gravel bed material load of the Dart-Rees River System into Lake Wakatipu from 1966-2007 was estimated[15] to be 300,000 m^3.

The consequences of an over-supply of sediment to the river system are that:

- there is a continual trend of bed aggradation with bed levels in many areas approaching the levels of the adjacent floodplain;
- the width of the active belt of braided channels which characterises these rivers is continually changing over time, while the belt is also migrating laterally;
- deposited sediment is constantly being reworked as channel migration occurs and the width of the active channel belt changes;
- bank erosion occurs as a result of lateral channel migration; and
- the potential for channel avulsion across adjacent floodplains increases with active channel migration and the loss of freeboard along existing banks due to bed aggradation.

Figure 2.7(a) and (b), sourced from Professor Brasington's presentation in Appendix D, show bed level changes from detailed LiDAR topographic surveys over the lower part of the Dart-Rees River System between 2011 and 2019. The graduated blue shading on the aerial image in Figure 2.7(b) indicates sediment deposition (bed raising) while the graduated red shading indicates bed degradation (bed lowering). There are substantial areas of deposition across the Lower Dart active channel belt with significant erosion and bank retreat evident along the western edge adjacent to the Kinloch Road. The overall trend in average bed level change is shown in Figure 2.7(b) with a net increase in bed levels of up to 0.2 m over most of the 3.5 km distance upstream from the delta front.

Figure 2.8, also sourced from Professor Brasington's presentation in Appendix D, shows a similar image to Figure 2.7(b) of bed level changes over Lower Rees River between 2011 and 2019. Figure 2.8 indicates that there has been extensive sediment deposition across the riverbed over the 5 km distance upstream from the delta front. Mean bed levels increased in the order of 0.2-0.3 m over the 8-year period with the larger increases occurring upstream of where the river bifurcates and the righthand branch joins the Dart River. This mean bed level trend, if it continues, would translate to an increase in bed levels of 1.25-2 m over the next 50 years.

The increase in mean bed levels on the Lower Rees River imply a significant loss of flood capacity within the active channel belt and a loss of freeboard along the existing margins with the potential for the occurrence of channel avulsion events. This is illustrated by the photograph in Figure 2.9 which shows riverbed levels approaching adjacent floodplain levels and evidence of sediment deposition from recent flood breakout flows. The flood breakout flows would have flowed overland into the Glenorchy Lagoon.

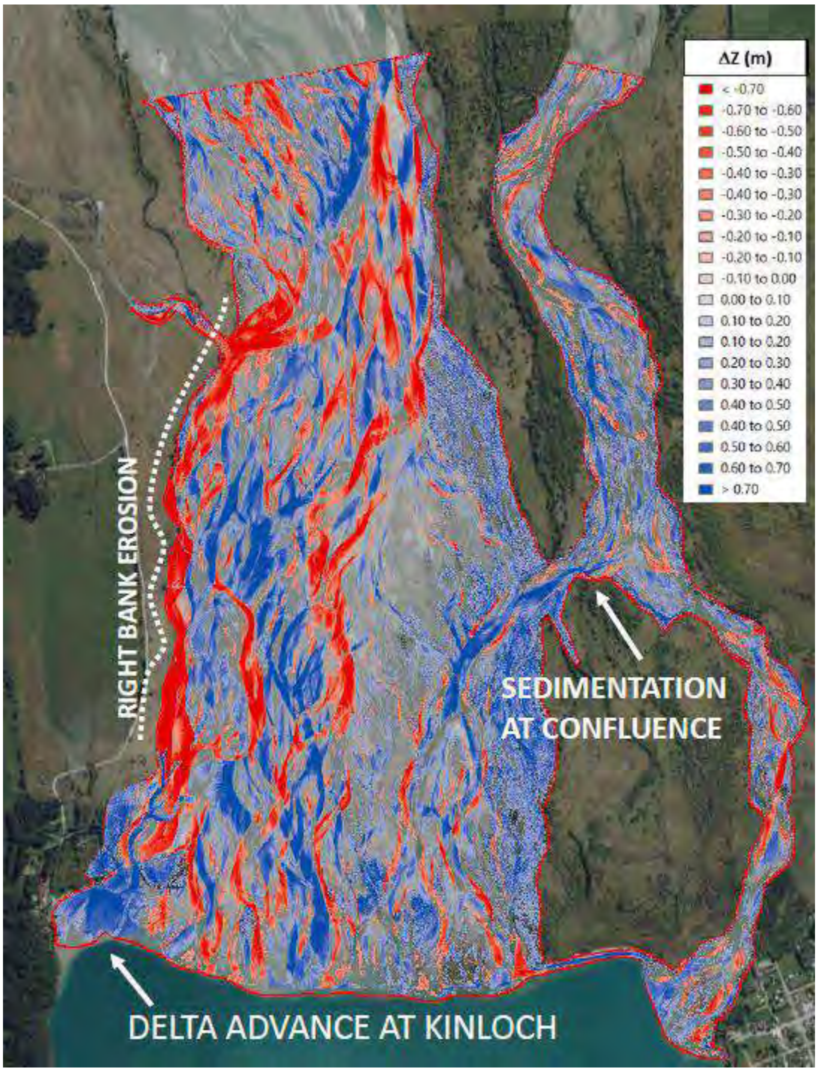
[14] The Slip Stream landslide in 2011 in the Upper Dart River Catchment had an estimated volume of 17.5 million m^3. Of this total volume, 7 million m^3 is estimated to remain in storage with about 10.5 million m^3 contributed to the sediment supply to the Dart River.
[15] Wild (2013).

A campaign of repeat high-resolution LiDAR surveys in 2009-2011 captured the evolution of a 3 km reach of the Rees River upstream of the Rees Bridge over an annual flood season. The following general observations can be made from the results of this campaign:

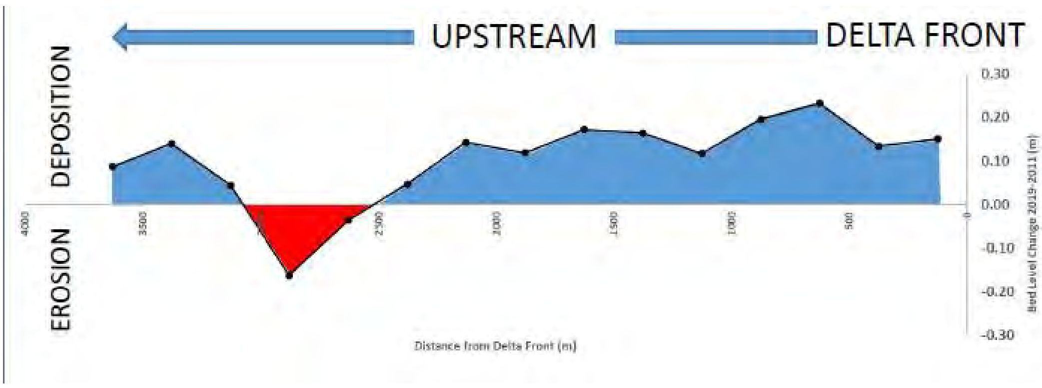
- Much of riverbed in this reach was disturbed in a single year with half of it experiencing repeated scour and fill cycles.
- Much of the riverbed in this reach was exposed to either scour or fill.
- Sediment mobilisation is episodic and related to flood events.
- The volume of sediment material mobilised in a flood is proportional to the power of that flood[16].

It should be noted that the average volume of bedload sediment material transported by flood activity in the Rees River in a single year significantly exceeds the volume of gravel material which QLDC is licensed to extract annually at the Rees Bridge.

[16] In this 2009-2011 campaign, a modest 350 m^3/s fresh in the Rees River was found to move about 30,000 m^3. This compares with the up to 20,000 m^3 volume of gravel bed material which QLDC is licensed to extract annually at the Rees Bridge to help improve the resilience of the bridge.



(a) Difference in LiDAR elevation models of riverbed between 2011 and 2019 (red indicates erosion, blue indicates aggradation)



(b) Average changes in bed level

Figure 2.7: Bed level change on Dart-Rees River System between 2011 and 2019

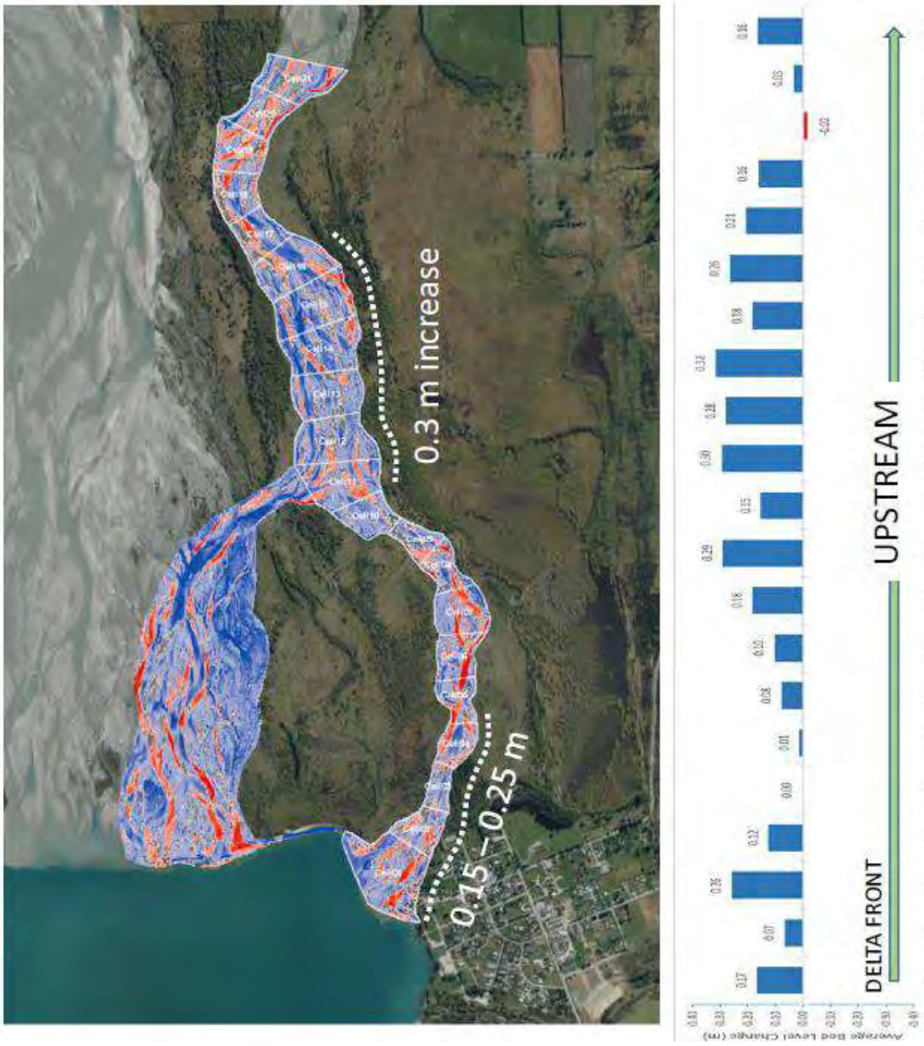


Figure 2.8: Average bed level change on Lower Rees River between 2011 and 2019 (red indicates erosion, blue indicates aggradation)

Figure 2.9: View looking downstream along the left bank of the Lower Rees River showing evidence of loss of freeboard and sediment deposition from recent flood breakout flows (photo taken on 9 February 2022 near start of bed level change map in Figure 2.8 – river flow ≈ 13 m^3/s at time of photograph)

The dynamic nature of the geomorphological behaviour of the Rees-Dart River System with an unlimited sediment supply, active expansion of the existing river corridor and sediment transport capacity limited by river flows giving rise to a continual bed aggradation trend has the following implications for existing flood hazards:

- Loss of level of service of existing stopbank protection at Glenorchy.
- Increased risk of backwater flooding along Lagoon Creek and overtopping of the stopbank at Glenorchy.
- Increased risk of severe breakout flooding and channel avulsion along the left bank of the Rees River into the Glenorchy Lagoon, along the right bank of the Rees River upstream of the Rees Bridge and along the right bank of the Dart River affecting the Kinloch Road.
- Increased risk of riparian erosion along the right bank of the Dart River affecting the Kinloch Road.
- Increased risk of abutment scour damage and structural damage due to overtopping of the Rees Bridge.

These increased risks relate to both severity and frequency.

Further information on the geomorphological characteristics and trends of the Dart-Rees River System is contained in Professor Brasington's presentation in Appendix D.

2.8 Flood Hazard Assessment

ORC recently commissioned Land River Sea Consulting to undertake a flood hazard assessment for the Dart-Rees River System using a two-dimensional (2D) computational hydraulic modelling approach. The 2D model developed for the assessment was based on a 2019 LiDAR topographic survey of the river system and covered the area shown in Figure 2.10 (reproduced from the Land River Sea Consulting report[17]). The model extended from the Rees River and Dart River Bridges down to Lake Wakatipu.

Figure 2.10: Extent of 2D computational hydraulic model of Dart-Rees River System used for flood hazard assessment

[17] Land River Sea (2022).

The model is a fixed-bed model based on the riverbed topography at the time of the 2019 LiDAR survey so that it is unable to account for scour and sediment deposition during the course of a flood which are known to occur and which will alter the riverbed bathymetry. In view of this limitation, the model predictions can only be used as an aid to understanding the inundation extent and flow depth and velocity patterns for a flood of given size. The model requires upstream boundary inputs of flood magnitudes in both the Dart and Rees Rivers, and a downstream boundary input of a fixed water level for Lake Wakatipu. The model also requires the frictional resistance of the ground surface to be defined for the riverbed area and for floodplain areas covered by different vegetation types.

The primary focus of the flood hazard assessment was on the Lower Rees River and Glenorchy area. The model was calibrated by adjusting the frictional resistance of the riverbed surface so that it correctly reproduced the flood inundation pattern in this area observed from aerial photographs of the February 2020 flood event.

Figure 2.11 (reproduced from the presentation in Appendix E) shows the flood extent estimated by the model for a 1% Annual Exceedance Probability (AEP) flood in the Dart-Rees River System with areas marked for different degrees of flood hazard depending on the magnitude of maximum flow depth and velocity. The flood hazard categories are based on those defined in Book 6 Flood Hydraulics of *Australian Rainfall and Runoff*[18] (ARR) for different degrees of hazard to people, vehicles and buildings (the hazard category definition diagram from ARR is reproduced in the presentation in Appendix E).

As noted in Section 2.4, the loss of freeboard due to widespread bed aggradation in the Lower Rees River increases the potential risk of flood breakout and channel avulsion along the left bank. Figure 2.12 (reproduced from the Land River Sea Consulting report[19]) shows one possible avulsion path towards Glenorchy Lagoon predicted by the 2D model. The flood inundation pattern and flow directions in Glenorchy resulting from this type of avulsion event for a 1% AEP flood adjusted for future climate change (and based on 2019 riverbed levels) is shown in Figure 2.13 (reproduced from the Land River Sea Consulting report[15]). This indicates the existing stopbank along Lagoon Creek and the Rees River would be overtopped with overtopping flow encroaching on the margins of the town and draining parallel to the stopbank down towards Lake Wakatipu. However, the topography of the alluvial fan surface underlaying Glenorchy prevents the floodwaters ponding in this low-lying area from flowing down the fan surface through the town directly to the lake. The stopbank overflow also spreads across the road providing access north to the Upper Rees Valley, the Routeburn Valley and Kinloch at the eastern end of the town and inundates a low-lying area there.

With floodwaters overtopping the existing stopbank at Glenorchy in this assumed flood scenario, there is also the potential for a stopbank breach to occur. In the event of this occurring, the additional floodwaters released through the breach would be contained by the natural topography of the alluvial fan surface as illustrated in Figure 2.13.

18 Ball *et al* (2019).
19 Land River Sea (2022).

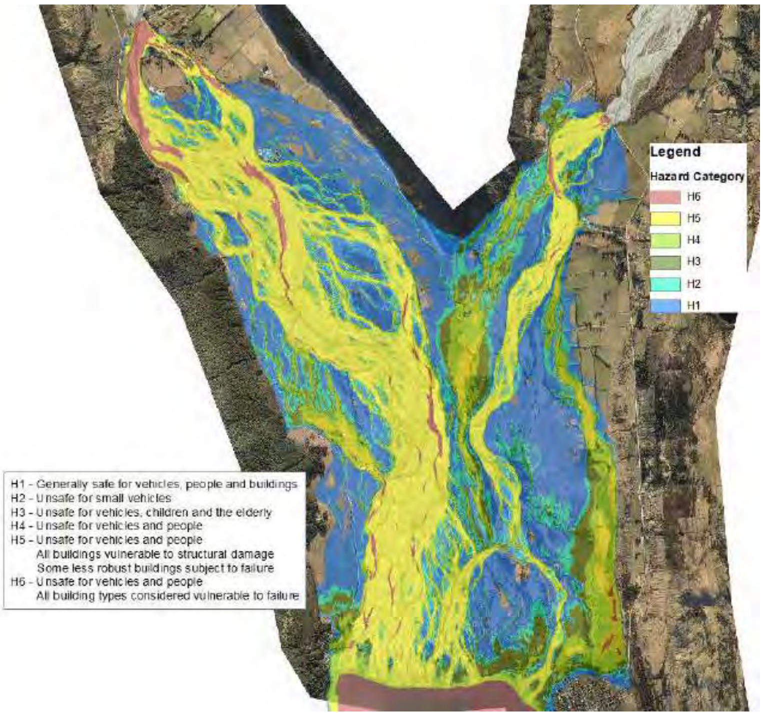


Figure 2.11: Estimated inundation extent and flood hazard categories of 1% AEP flood in Dart-Rees System

Figure 2.12: Possible channel avulsion path along left bank of Lower Rees River towards Glenorchy Lagoon

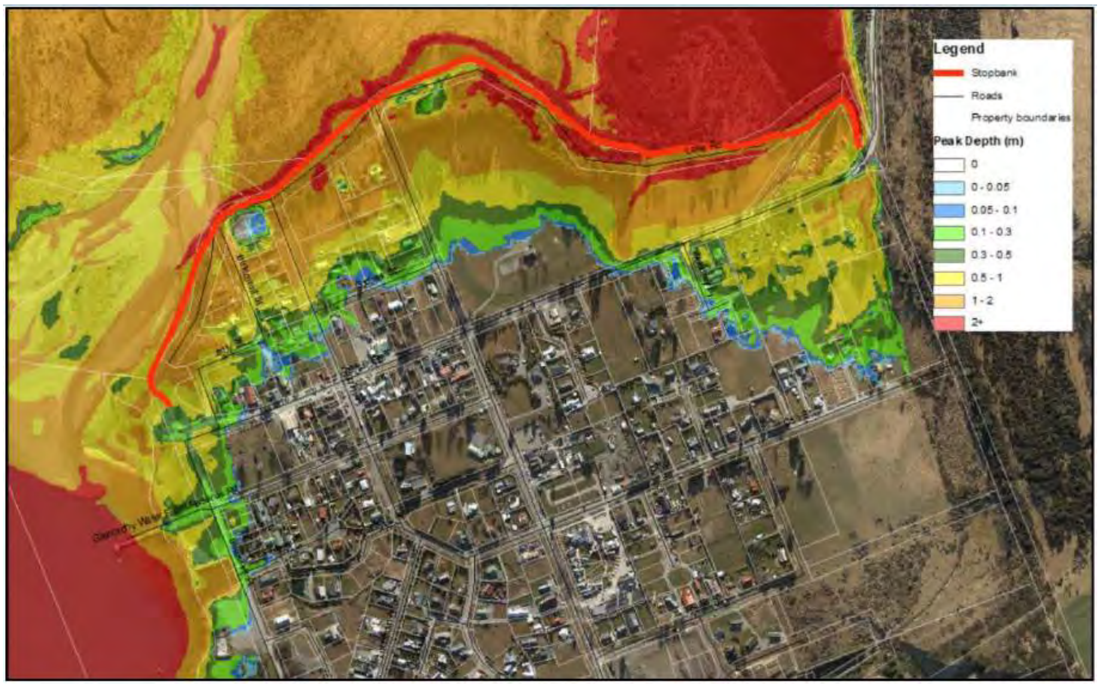


Figure 2.13: Flood inundation in Glenorchy for 1% AEP flood in Rees River adjusted for future climate change and 10% AEP lake level with flow avulsion occurring along left bank as shown in Figure 2.12

The flood inundation extents shown in Figures 2.11-2.13 reflect an assumed flood scenario for Glenorchy based on a moderately high level for Lake Wakatipu (i.e. fluvial sourced flooding from the Rees River dominates). As demonstrated by the November 1999 flood event (Figure 2.3), the potential exists for lake sourced flooding in combination with fluvial sourced flooding.

2.9 Summary of Natural Hazards Adaptation Programme

In view of the multi-hazard environment at the Head of Lake Wakatipu with the risks associated with those hazards being exacerbated over time by climate and geomorphic changes, ORC initiated an adaptation programme in July 2019 with an objective of providing "*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*".

It was proposed that the project would[20]:

- *Identify and evaluate potential natural hazard pathways based on the Adaptation Pathways approach recommended by MfE[21];*
- *take a more strategic and holistic approach than previous natural hazard studies;*
- *undertake a multi-hazard and climate change assessment for the area, including a review of potential hazard consequences, likelihoods and overall risks; and*

[20] ORC (2021)
[21] MfE (2017)

- *develop risk reduction / adaptation pathways over a longer-term timeframe of not less than 100 years.*

This would enable future planning to occur with more certainty in a context of ongoing change and increasing hazard risks.

The project is being led by ORC in partnership with QLDC, Kāi Tahu and other key stakeholders including the Department of Conservation (DOC) and local communities. Community engagement forms a key plank of the programme.

The programme is supported by several consultants providing specialist inputs.

3.0 Dynamic Adaptive Pathways Planning Approach

3.1 Introduction to Approach

An adaptation pathways approach to natural hazard management is a "*response strategy to anticipate and adjust to actual and expected changes in environmental conditions*". Adaptation involves "*iterative, continually evolving processes for managing change in complex systems*" (MfE, 2017). Effective adaptation means that (CCATWG, 2017) "*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, social and cultural systems to adapt*."

Figure 3.1 from MFE (2017) illustrates the ten-step decision cycle of the adaptation pathways approach based around five key questions. While the approach has been developed primarily for coastal settings where sea level rise due to climate change is a critical issue, the approach is also considered appropriate for application to the Head of Lake Wakatipu area because of the changing risk profile resulting from sediment aggradation, delta growth, and climate change.

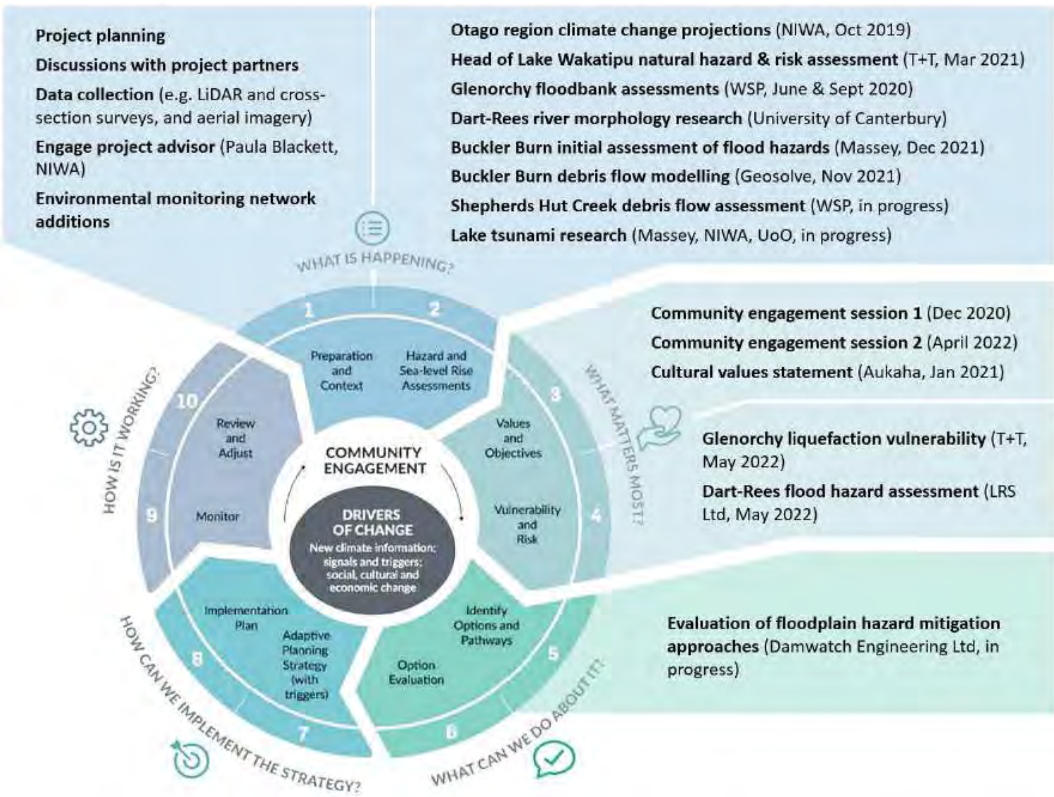


Figure 3.1: Summary of the 10-step adaptation pathways decision cycle framework (MfE, 2017) showing the main activities which have been completed for the Head of Lake Wakatipu Hazards Adaptation Project from ORC (2022)

Figure 3.2 from MfE (2017) shows an example of an adaptation pathways map. There may be a range of types of adaptation options which are available, each with advantages and disadvantages. Several alternative combinations of these options may be practical and feasible, over short-term (0-20 years), medium term (20-50 years) and long-term (50-100 years) timeframes. Aside from the 'status quo' option, there are four potential groupings of natural hazard mitigation options (MfE, 2017):

- accommodate
- protect
- retreat
- avoidance strategies

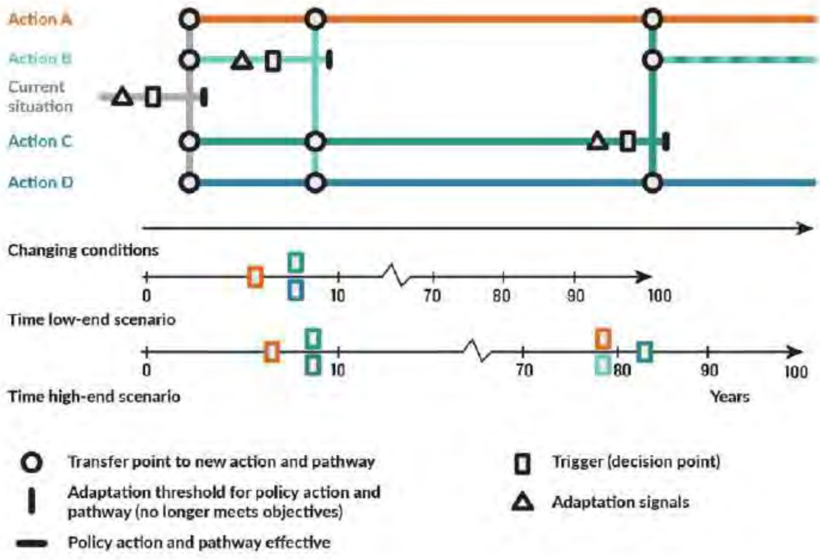


Figure 3.2: Example of an adaptation pathways map showing a series of possible adaptation options (A-D), each of which is assessed based on adaptation signals (MfE, 2017)

Adaptation pathways will evolve over time in response to changing conditions and, an effective adaptation strategy will incorporate key decision points based on triggers or thresholds.

3.2 Summary of Community Engagement Findings

ORC has embarked on a community engagement process with the support of a NIWA team to provide community input to an adaptation pathway development process, and to equip the community with the necessary knowledge to make informed decisions regarding adaptation approaches. The community engagement process is based around a series of four community engagement sessions with the titles:

a) What is happening now, and how does this affect you?

b) What could happen in the future, and what might we do?
c) How can we navigate the adaptation options?
d) 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. These sessions were designed to present and discuss the natural hazard issues affecting the Head of Lake Wakatipu area, and to promote conversations about possible adaptation approaches or interventions to manage or mitigate these hazards.

During these community engagement sessions, community members suggested several possible intervention options for consideration, including structural and river management measures (see Figure 3.3):

- raising or modifying the existing Rees-Glenorchy stopbank structure;
- gravel extraction;
- channel realignments, such as diversion of Rees River flows into the Dart River;
- river control structures or plantings (e.g. groynes to mitigate channel erosion);
- bunding or new stopbanks to reduce overland flood flows into the Glenorchy Lagoon; and
- willow management or channel modification of Lagoon Creek to enhance drainage ability from the lagoon.

Community concerns were also raised about the ongoing aggradation at the Rees River Bridge, and the consequential loss of waterway flow capacity at the bridge and increased vulnerability to overtopping and debris impacts.

Access to the Kinloch and Greenstone / Caples areas via the Kinloch Road is another matter of community concern in view of the frequency of flood inundation over the road (e.g. > 10 occasions in 2019-20) and the westerly migration of the active channel belt of the Dart River towards the road, and in several areas, hard against the road. A range of potential adaptation approaches has been put forward for consideration to maintain access to these areas (see Figure 3.4), based on advice from ORC technical staff and consultants but with some community input:

- status quo (i.e. reactive repair): localised erosion protection and road raising as required to manage highest priority erosion hotspots or flooding issues.
- local realignment: realignment of sections of road from areas threatened by erosion or most highly flood-prone (but still remaining on the floodplain.
- hard engineering: installation of larger-scale erosion or flood protection structures;
- redesign: relocation of erosion or flood-prone sections of road from the floodplain to adjacent hillslopes.
- alternative transport: use of alternative transport modes (e.g. boat access).

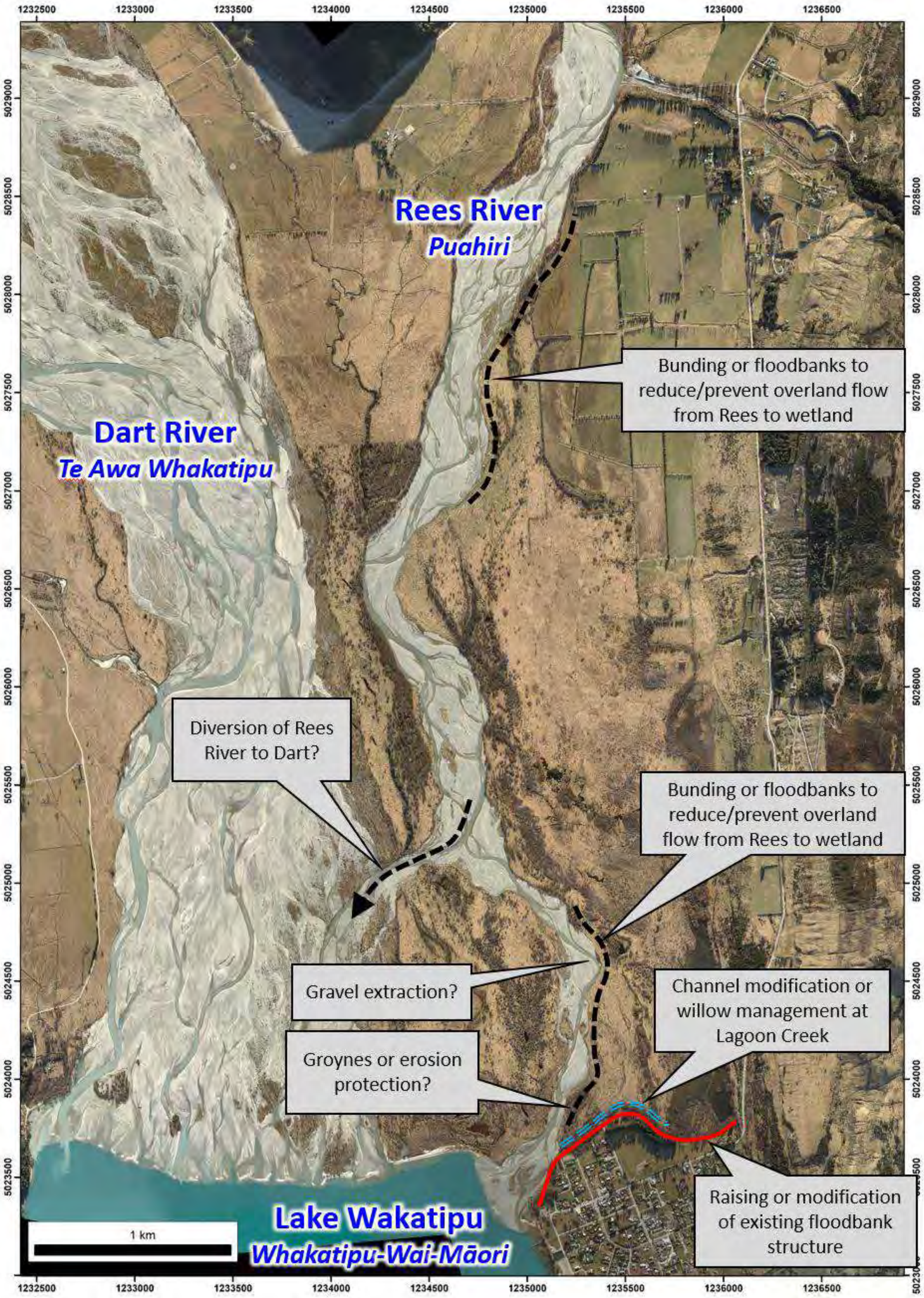


Figure 3.3: Overview of the lower Dart-Rees floodplain, showing range of potential flood mitigation options for the Rees River and Glenorchy township suggested by the local community

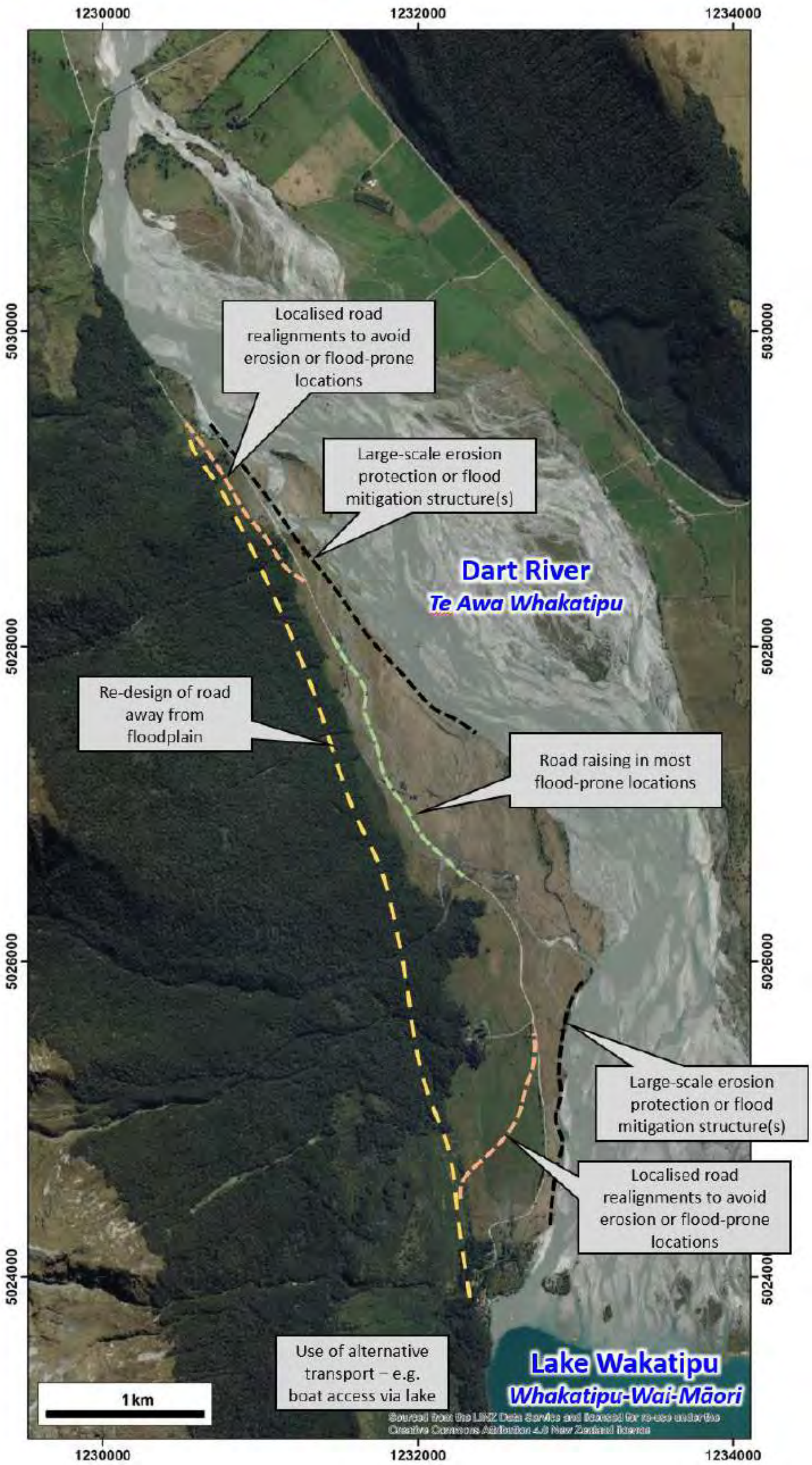


Figure 3.4: Overview of the lower Dart floodplain, showing the range of potential flood or erosion mitigation options which may be considered in order to maintain Kinloch access

3.3 Boundaries for Floodplain Adaptation Workshop

Forming an initial part of the process of applying this adaptation pathways approach, the floodplain adaptation workshop was primarily focussed on river management rather than about land-use planning controls and strategies. It also excluded responses to other hazards outside the Dart-Rees floodplain such those associated with the Buckler Burn alluvial fan or liquefaction.

3.4 Principles for Consideration in Development of Floodplain Adaptation Approach

The following principles were put forward to guide the development of adaptation pathways for the Dart-Rees floodplain area during the workshop. The principles can be grouped together under three main headings.

Natural System / Processes

- Recognition of the need to understand the underlying natural systems and processes.
- A long-term sustainable, integrated and strategic approach to floodplain risk. management, working with the natural river processes.
- Forms and levels of protection are appropriate and sympathetic to environmental amenity values.

Societal

- Widest possible benefits for community, works in with other community objectives.
- Affordable and acceptable to council, the community and direct beneficiaries.
- Sympathetic to environmental / cultural values.
- Community involvement and ownership

Political / economic

- A commitment by project partners (ORC, QLDC, DOC, Kāi Tahu) to work together.
- Adopting a precautionary approach.
- Ensuring adaptive management.
- Recognition and treatment of residual risk.
- Taking a low-regrets or even no-regrets approach to risk treatment/adaptation.
- Avoiding locking in options due to adaptation and development decisions that limit further adaptation in the future.

3.5 Workshop View of a Successful Adaptation Approach

The floodplain adaptation workshop considered that a successful floodplain adaptation approach in this context would be one:

- which has a long-term view of the situation (50+ years);
- which provides flood protection benefits;
- which has costs which are acceptable/justified;
- which considers the health of the environment and natural amenity values as key factors;

- In which the risk and benefits of alternative strategies/pathways are clearly communicated to other stakeholders;
- in which the approach is supported and acceptable to Kāi Tahu and the wider community (i.e. residents, DOC); and
- which Involves on-going monitoring of natural processes and tracking of adaptation performance.

3.6 Workshop View of Factors for Assessing Interventions

The floodplain adaptation workshop considered that the following questions need to be addressed in assessing proposed interventions as part of an adaptation approach and making a judgment on whether they are suitable and appropriate in this context:

- What are the interventions trying to achieve?
- What are the impacts?
- What are the benefits?
- What are the risks? What are the consequences of failure of specific interventions?
- How long will any river management/engineered interventions provide continued protection?
- How viable are these river management/engineered interventions in the longer-term - especially given the environmental/hazard context (e.g. ongoing riverbed aggradation, geomorphic consequences of an Alpine Fault earthquake, and climate change impacts on hydrology and flooding)?
- How are the interventions impacted by national, regional and district regulatory frameworks (e.g. National Policy Statement for Freshwater Management, the ORC Water Plan, the Resource Management Act, the District Plan etc.)?
- What on-going monitoring is required?
- What performance standards should be applied?
- What information gaps are there?

The above questions were considered during the workshop when each of the three main areas of concern on the Dart-Rees floodplain were considered. These areas are discussed in the next three section of this report.

4.0 Rees and Glenorchy Flooding

4.1 Specific Threats and Hazards

Due to the level of bed aggradation relative to the adjacent floodplain areas, the Rees River was described by Professor Brasington as "*a perched river and becoming more perched over time*" due to the unlimited supply of sediment material to feed it. This is illustrated in Figure 4.1 which shows a relative elevation model of the Dart-Rees valley floor computed by comparing valley floor levels to the average level of the adjacent riverbed. In terms of an adaptive pathways approach, the river has already reached a trigger point which largely prevents transitioning from one solution to another in such an approach.

The main hazard and threat issues for Glenorchy township were identified in Section 2.3 and Figure 2.2:

- Increasing flood hazard due to bed aggradation;
- Increasing flood hazard due to breakout flows into the Glenorchy Lagoon and the potential for permanent channel avulsion;
- Increasing flood hazard due to climate change impacts; and
- Increasing erosion hazard to existing stopbank due to the combination of ongoing riverbed aggradation and climate change impacts.

The first three flood hazards would be manifested in the occurrence of stopbank overtopping.

The erosion hazard to the stopbank could result in a stopbank breach which allow the release of floodwaters into parts of the town. A piping failure[22] of part of the existing stopbank under extreme flood conditions would also have the same effect.

As illustrated by Figure 2.13, flood inundation in Glenorchy by floodwaters originating from the Rees River (either through flood breakout into the Glenorchy Lagoon area and stopbank overtopping or a stopbank failure would mainly affect the margins of the township. However, flood inundation resulting from high lake levels in addition to fluvial sourced flooding could affect a larger part of the town (see Figure 2.3 showing the extent of flooding in the November 1999 flood event).

[22] Piping (also called "internal erosion") of an earth embankment structure takes place when water seeping through it carries soil particles away from the structure. If the seepage that discharges on the downstream side of the structure carries particles of soil (or sediment), an elongated cavity or "pipe" may be eroded backward (working upstream) toward the impounded 'reservoir' through the embankment body or foundation. When a backward-eroding pipe reaches the 'reservoir', an embankment breach can develop, forming a gap in the structure and releasing water from the 'reservoir'. Definition adapted from Unites State Association of State Dam Safety Officials, *Internal Erosion of Dams*, https://damsafety.org/dam-owners/internal-erosion-of-earth-dams.

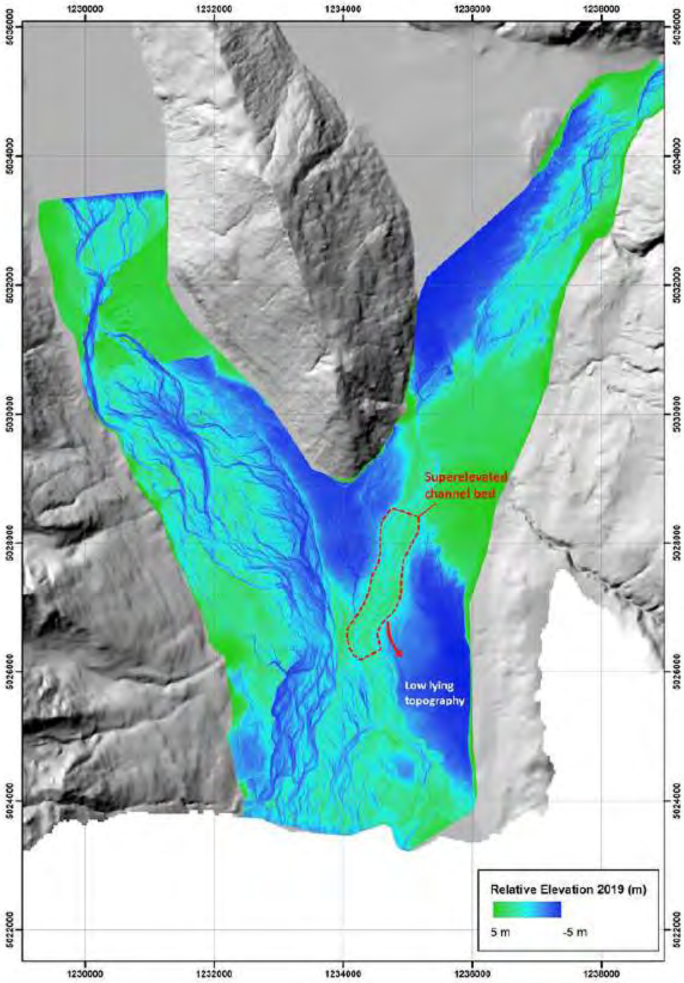


Figure 4.1: Relative elevation model of the valley floor for the Dart-Rees River System[23]

4.2 Evaluation of Community Suggestions for Intervention

Table 4.1 sets out the intervention suggestions put forward by the community for Glenorchy and provides comments on their suitability for inclusion in an adaptation pathways approach based on the information contained in Section 3.

Some of the suggested intervention options can be ruled out as ineffective or not viable. Other options are only of short-term or limited benefit and are discussed further in Section 4.3.

[23] The relative elevation model is computed by comparing valley floor elevations to average levels of the adjacent riverbed. The section of super-elevated riverbed which has been highlighted is the likely source for a potential flood breakout eastward into the lower-lying area of the wetland and Glenorchy Lagoon. The model is based on a LiDAR topographic dataset obtained in 2019.

Table 4.1: Evaluation of possible intervention options for Glenorchy suggested by community members during engagement events

Intervention	Comments	Key Challenges for Inclusion in Adaptation Pathways Approach
Raising or modifying existing stopbank structure	Intervention aims to increase level of service in short-term and provide greater scour and erosion security to existing barrier to keep floodwaters from Rees River out of Glenorchy Village. Practical short-term option but provides a false sense of long-term security and likely to result in an increased level of residual risk over time. Could be an interim measure and buy time to allow for a longer-term strategy or a strategy of raising floor levels (of existing houses) to be implemented along with new land-use planning controls.	The existing structure appears to have been constructed and maintained with a low level of engineering input (WSP, 2020a; WSP, 2020b; Tonkin and Taylor, 2021b). Any structural deficiencies will need to be remedied before the structure can be further modified. Ongoing bed aggradation will gradually reduce the level of service over time leading to an increasing fluvial hazard. Long-term bed aggradation would be exacerbated by the sediment input to the river system from a future Alpine Fault Mw 8 earthquake. Major investment in a stopbank structure makes it difficult to later retreat from the “protected” area.
Gravel extraction	Intervention would aim to lower bed levels in the Rees River in order to reduce flood levels.	Area of riverbed over which gravel extraction would be required is very extensive. Not a viable or sustainable intervention in view of the large volume of gravel material needing to be removed to lower bed levels and the large volume of sediment transported annually by the Rees River (300,000 m^3 per year from 1966-2007 into Lake Wakatipu (Wild, 2013)). Environmental impact of gravel extraction in a renowned wilderness area would be significant due to the widespread and continuous nature of the mining activity, and the problem of disposal of the extracted gravel material.
Channel realignments, such as diversion of Rees River flows into Dart River	Intervention would aim to try and divert a greater proportion of Rees River flows into the Dart River away from Glenorchy Village.	Approach would have limited effectiveness as the Rees overflow path to the Dart River is located downstream of the flow breakout points along the left bank of the Rees River. There is also no certainty over what proportion of the Rees River flow may be able to be diverted due to the braided nature of the river. Rees overflow path to the Dart River is highly dynamic and subject to continual rapid aggradation and there is no certainty that this intervention would remain permanently effective. This approach would need continuous active management to maintain some measure of diversion effectiveness (ORC currently actively monitor the overflow channel).

Intervention	Comments	Key Challenges for Inclusion in Adaptation Pathways Approach
River control structures or plantings (e.g. groynes to mitigate channel / stopbank erosion)	Intervention only aims to bolster the security of the existing stopbank by mitigating the erosion hazard to it. QLDC has recently applied some rock armouring to the most vulnerable part of the existing stopbank. Short stub groynes constructed of rock material are an alternative form of bank protection to a rock revetment type of protection (they push high flow velocities away from the bank being protected).	This intervention only provides increased erosion security to the existing stopbank, not enhanced protection from flood inundation. Other sections of the existing stopbank remain unprotected and vulnerable to attack by high flow velocities under flood conditions and as channel braids in the river shift over time. As with the existing stopbank, ongoing bed aggradation will eventually subsume groynes or other river control structures, thereby gradually reducing the level of service over time. Intervention does nothing to address the increasing flood hazard from the Rees River due to ongoing riverbed aggradation, flood breakout into the Glenorchy Lagoon and future climate change impacts.
Bunding or new structures to reduce overland flood flows into Glenorchy Lagoon	Intervention aims to block (or partially block) flood breakouts from Rees River into Glenorchy Lagoon. Glenorchy Lagoon is a Regionally Significant Wetland in the Regional Plan Water.	Blocking of flood breakouts along Rees River true left bank will cause the problem to be translocated to another point on the floodplain. This approach would require a very long structure or could be constructed as a series of partial barriers or baffles. Partial barriers/ baffles could well be washed away in an avulsion event. Intervention may provide short-term benefits for smaller floods but the level of service of any structure (or structures) would reduce over time due to ongoing bed aggradation and future climate change impacts. The Regional Plan Water has rules that limit changes affecting the functioning of a Regionally Significant Wetland. Intervention may alter wetland hydrology and therefore have potential adverse effects on lagoon ecology.
Willow management or channel modification of Lagoon Creek to enhance drainage ability from lagoon	Intervention aims to improve drainage capacity of Lagoon Creek.	This intervention would probably only have a very limited effect on lagoon flood levels. The volume of flow to be drained from the Glenorchy Lagoon in a flood breakout event is probably significantly greater than the existing discharge capacity of Lagoon Creek. Even if the discharge capacity of Lagoon Creek was doubled, this would probably only have a limited effect on flood levels in the Glenorchy Lagoon.

4.3 Evaluation of Other Possible Interventions

Table 4.2 sets out other possible intervention options for Glenorchy which were discussed during the floodplain adaptation workshop. As with the options set out in Table 4.1, comments are provided on their suitability and viability for inclusion in an adaptation pathways approach based on the information contained in Section 3.

During the workshop discussion, there were several comments made in relation to the consideration of other intervention options which are pertinent to record:

- If the benefits of any intervention are uncertain, and every large weather event is likely to “re-set” the system, then what level of cost for that intervention is acceptable needs to be carefully considered.
- There needs to be a balance between maintenance / tactical responses and major infrastructure investment for mitigating flood hazards.
- Both ORC and QLDC only have limited funds available for ongoing maintenance.
- The scope and scale of any planned river management works needs to be clearly set out in ORC’s Annual Plans and Long-Term Plan, as well as clearly communicated to the community.

Table 4.2: Evaluation of other possible intervention options and strategies for Glenorchy discussed during adaptation workshop

Intervention	Comments	Key Challenges for Inclusion in Adaptation Pathways Approach
"Status quo"	The approach could possibly be adopted in a very targeted way towards a smaller number of houses as opposed to the full community now that more is known about likely flood extents and depths.	This is a hazardous approach as it ignores the reality of a (negatively) changing hazardscape affecting Glenorchy. Following this approach would need to be an informed decision at both a community and political level.
Stopbank interventions		
Retaining existing stopbank without any upgrade	The existing stopbank with its current geometry is not fit for purpose and has no defined level of service.	. There is an existing threat to life and property from floodwaters conveyed by the Rees River, which is increasing over time. The changing threat has been identified and now needs to be remedied.
Removing existing stopbank	What if the existing stopbank was not present? Based on the February 2020 flood, there would be a similar flood inundation extent in Glenorchy to what occurred in that event.	Removal of an existing structure providing some level of protection, even if that level of protection is not defined, would be a hazardous approach. The flood inundation threat is known to be increasing. The rise in floodwaters in the absence of the existing stopbank would be much faster and flooding would occur more frequently.
Local scale interventions within town		
Bunding around houses	Intervention aims to keep floodwaters away from individual houses[24].	Intervention is only suitable for isolated houses where plenty of space is available. It could have an adverse effect by diverting floodwaters towards other properties. A bund traps water if it is overtopped by an over-design flood, leaving the "protected" house within a puddle and stranding residents. Any bund is also an access constraint to the "protected" house under normal (non-flood) conditions.
Raising floor levels of existing houses	Intervention aims to raise floor levels of habitable buildings within a flood prone area to achieve a minimum level of service[24].	While the approach is feasible, it is also costly for individual houses.

[24] Clause E1.3.2 of the *New Zealand Building Code Clause E1 Surface Water* sets out a minimum performance standard for buildings with respect to floods. "**E1.3.2** *Surface water*, resulting from an event having a 2% probability of occurring annually, shall not enter *buildings* (being limited to *housing, communal residential* and *communal non-residential buildings*" (MBIE, 2020). The Building Code only applies to new building work undertaken after 1991.

Intervention	Comments	Key Challenges for Inclusion in Adaptation Pathways Approach
	The approach is feasible as has been demonstrated in Christchurch where it has been applied in low-lying areas affected by the Canterbury earthquake sequence[25]. The approach could address both lake-sourced flooding and river-sourced flooding.	If a house gets surrounded by floodwaters, residents could get stranded without warning. If houses owners make a large investment in getting a house raised, then they will likely want to stay there for a long period of time to obtain the benefit of their investment. From the flood modelling carried out for a 1 in 100 AEP flood (historic climate) in the Rees River combined with a 1 in 10 AEP flood level in Lake Wakatipu (Land River Sea, 2022), flow velocities through the inundated part of the town would likely be in the order of 0.5-1 m/s (higher across roads) with flow depths of 0.5-2.0 m. These flow depths and velocities could be potentially hazardous to people and building foundations. It is important to note that, if an avulsion event occurs into the Glenorchy Lagoon and causes the stopbank to be overtopped, the floodwaters will be carrying a lot of sediment which creates an additional hazard to buildings and properties. Effectiveness of intervention diminishes over time due to the increasing flood inundation threat . Intervention does not address the impact on utility services and roads.
Other Interventions		
Raising section of Mull St / Glenorchy-Paradise Rd at east end of town	Intervention aims to block the spread of floodwaters from the Glenorchy Lagoon area southwards across Mull St / Glenorchy-Paradise Rd. Figure 2.13 shows flood inundation extending southwards across Mull St / Glenorchy-Paradise Rd and inundating several properties in a low-lying area to the south of the road.	Raising the road level would block the spread of floodwaters into this area but could potentially create a ponding area for localised rainfall events. The number of affected properties appears small so this strategy would likely only have limited benefit.
Installation of flap-gate on culvert under Mull Street / Glenorchy-Paradise Rd at east end of town	Inundation aims to prevent the backflow of floodwaters from the Glenorchy Lagoon area southwards under Mull St / Glenorchy-Paradise Rd. The existing culvert under Mull St / Glenorchy-Paradise Rd at the east end of the town would presently allow floodwaters ponding in the Glenorchy Lagoon to backflow	

[25] https://www.ccc.govt.nz/the-council/plans-strategies-policies-and-bylaws/policies/sustainability-policies/flooding-intervention-policy

Intervention	Comments	Key Challenges for Inclusion in Adaptation Pathways Approach
	up the creek draining Bible Terrace and inundate properties to the south of the road.	
Vegetation planting in flood breakout paths to Glenorchy Lagoon area	Intervention would aim to limit the volume of overland flow to Glenorchy Lagoon. Vegetation could be planted in overland flow areas along the left bank to encourage sediment deposition and build-up of ground levels. May be an opportunity to restore the original pre-development vegetation in this area.	The effectiveness of this intervention would be reduced over time with ongoing bed aggradation in the Rees River.
Other approaches		
Flood warnings – Glenorchy Lagoon	ORC have installed level monitoring in the Glenorchy Lagoon with two alarm levels set to provide timely warning of rising flood levels.	There is currently no redundancy in the water level sensors or the communication equipment. The monitoring system needs to be made more robust (note improvements are planned in the near future). A “rate of level rise” capability needs to be explored to assess whether the monitoring system would be effective at picking up potential avulsion events from the Rees River into the lagoon area.
Flood warnings – Rees River	ORC have established a new flow gauge in the Upper Rees Valley to provide timely warning of rising flood magnitudes in the Rees River. Alert levels have not yet been defined for this gauge but will be in the near future. Civil defence authorities have been made aware of the availability of this information. ORC operates an on-call 24/7 flood monitoring / response team for responding to flood emergencies and providing support to Civil Defence authorities.	

4.4 Information Gaps and Recommended Actions

A number of information gaps were identified during the floodplain adaptation workshop discussion which require specific actions to be taken. This are grouped below under different headings.

Flood Warning / Awareness

- The level of redundancy in water level gauges and communications equipment used for flood warning purposes needs to be checked (there is currently no redundancy with the water level sensor and communications equipment installed in the Glenorchy Lagoon). The reliability of these warning systems may need to be improved with additional system redundancy.
- The flood hazard extents for Glenorchy shown on the QLDC website reflect old data based on previous flood modelling and historical flood observations. QLDC and ORC need to work together to update the flood hazard extents based on the more recent modelling work carried out by Land River Sea Consulting for ORC.
- The Emergency Management Otago flood guide for Glenorchy is still in draft form and needs to be publicly released as an operative document. The guide can be updated as the adaptation plan is developed.

Flood Forecasting

- A flood frequency model using flow data from the Rees River gauge needs to be developed as soon as practicable, and updated periodically thereafter.
- Use flood modelling to establish an approximate threshold flow value for flood breakout along the left bank of the Rees River.
- Confirm the reliability of the flood warning system including telecommunication networks and backup communication systems[27].
- Monitor when future flood breakouts occur and relate the start of these breakout events to the flows measured by the upstream Rees River gauge.

Glenorchy Lagoon and Lagoon Creek

- Undertake a channel cross-section survey of Lagoon Creek
- Undertake a computational hydraulic modelling Investigation of the interaction of Lagoon Creek and the Rees River during high flow[28].
- Could obtain bathymetric survey data for Glenorchy Lagoon – this is probably not required though as Land River Sea Consulting's 2D computational hydraulic model of the Rees River and floodplain is not very sensitive to pre flood event lagoon levels.

Robustness and Reliability of 2D Model of Rees River and Floodplain

[27] There needs to be redundancy built into the monitoring and warning systems. This was highlighted in the July 2021 flood event in the Buller River where four flood gauges failed. Note ORC uses satellite communications for collecting flood data and not the cell phone network. It also uses two sensors per flow gauge so there some redundancy built into the monitoring equipment.
[28] A coupled 1D/2D model is recommended compared to discrete 1D and 2D models to ensure that the backwater influence from the Rees River at the Rees / Lagoon Creek confluence and flow transfer between the creek and the floodplain are correctly represented.

- Uncertainty of flood inflows measured by flow gauge – ensure an adequate number of flood gaugings is undertaken at the gauge site.
- Supplement this by undertaking flood gaugings at the Rees Bridge.
- Undertake regular LiDAR / TLS[29] surveys or satellite photo analyses of the riverbed to update the Digital Elevation Model incorporated in the 2D computational hydraulic model of the Rees River and floodplain (applying corrections to the DEM for below water parts of active channel braids).
- Obtain good aerial imagery of flood extents at the peak of future large flood events.
- Collect ground observations of future large flood events (debris marks, peak flood levels).
- After future large flood events, run model simulations of each flood event with an updated riverbed profile to check model accuracy with respect to flood extents.

Glenorchy Stopbank Level of Service and Improvements

- Establish what work needs to be carried out to remedy the structural deficiencies of the existing stopbank.
- Extract long-sections of flood levels along length of stopbank from 2D model simulations of different flood scenarios to compare to the existing stopbank crest profile. Establish the current level of service of the stopbank.
- "Glass-wall" the stopbank in the 2D model and run model simulations of different breakout flow volumes to provide a better understanding of the impact of different levels of flow avulsion along the left bank of the Rees River. Use the results of these model simulations to define a range of possible stopbank improvements.
- Investigate the impact of hypothetical stopbank breach scenarios with selected stopbank improvements.

Consequences of Constructing Bunds / Bands of Heavy Vegetation on Left Bank of Rees

- Develop a delta management plan setting out how the delta will be monitored and managed in the future, i.e. how sediment aggradation will be monitored, where vegetation will be actively planted and maintained, and where vegetation will be kept clear etc.
- As part of the development of the delta management plan, explore a range of possible options for constructing partial barriers or planting dense vegetation on the left bank floodplain of the Rees River to try and limit breakout flows into the Glenorchy Lagoon from the main river.
- Undertake additional 2D model simulations for the same flood scenario to assess the effectiveness of options to limit the volume of breakout flows in the lagoon.
- Assess the implications of these options for limiting breakout flows into the lagoon on the lagoon ecology.

Building Floor Levels in Glenorchy

- QLDC to review records and determine if they already have this data.
- If not, undertake a floor level survey of residential and commercial buildings in Glenorchy.

[29] Terrestrial Laser Scanning (TLS)

- Following the floor level survey, undertake a consequence assessment using the results of the 2D model simulations to determine the number of affected properties in Glenorchy for different flood scenarios, and the magnitude to which they are affected (i.e. flood inundation depth and flow velocity).

5.0 Kinloch Road

5.1 Specific Threats and Hazards

The main hazard and threat issues for the Kinloch Road were identified in Section 2.3:

- Continual bank erosion over significant lengths of the road;
- Inundation of the road by floodwaters from the Dart River which is increasing in frequency of occurrence.
- Localised flood and debris flow events; and
- Landslides on the valley side-slopes.

Figure 3.4 shows the threat locations along the road.

As illustrated in Figure 2.7(a), the active channel belt is slowly migrating westwards such that flood flows are constantly attacking the existing bank edge requiring it to be armoured in places (refer to Figure 2.5). The westerly migration of the active channel belt is due to the transverse slope of the riverbed with bed levels higher on the east side compared to the west side. This is illustrated by three cross-sections in Figure 5.1(b) sourced from recent LiDAR data which show cross-section profiles from south-west to north-east across the riverbed and the adjacent floodplains. Figure 5.1(a) shows the location of the cross-section profiles which are aligned to coincide with the currently affected sections of the road identified in Figure 3.4.

As noted in Section 2.3, the bank erosion hazard along the right bank of the Dart River adjacent to the Kinloch Road is exacerbated by the ongoing aggradation of the riverbed.

Two areas of rock armouring protection have been applied by QLDC along the bank edge in recent years (see Figure 3.4):

- One area at the north end where the road south to Kinloch first drops off the forested valley side-slopes onto the floodplain (this is downstream of where an old river training bank – now destroyed – was located); and
- Another area nearer the village and just upstream of where the road kicks back in towards the hillside.

Other sections of the road (as marked in Figure 3.4) have been locally raised above floodplain ground levels to reduce the risk of flood inundation.

5.2 Possible Interventions

Possible interventions are shown on Figure 3.4.

The localised bank protection works and localised road raising referred to in Section 5.1 are reactive measures. Due to the scale of the aggradation problem across the Dart-Rees River System, these localised interventions are going to only have a limited lifespan, and hence effectiveness, i.e. they will only be a temporary fix.

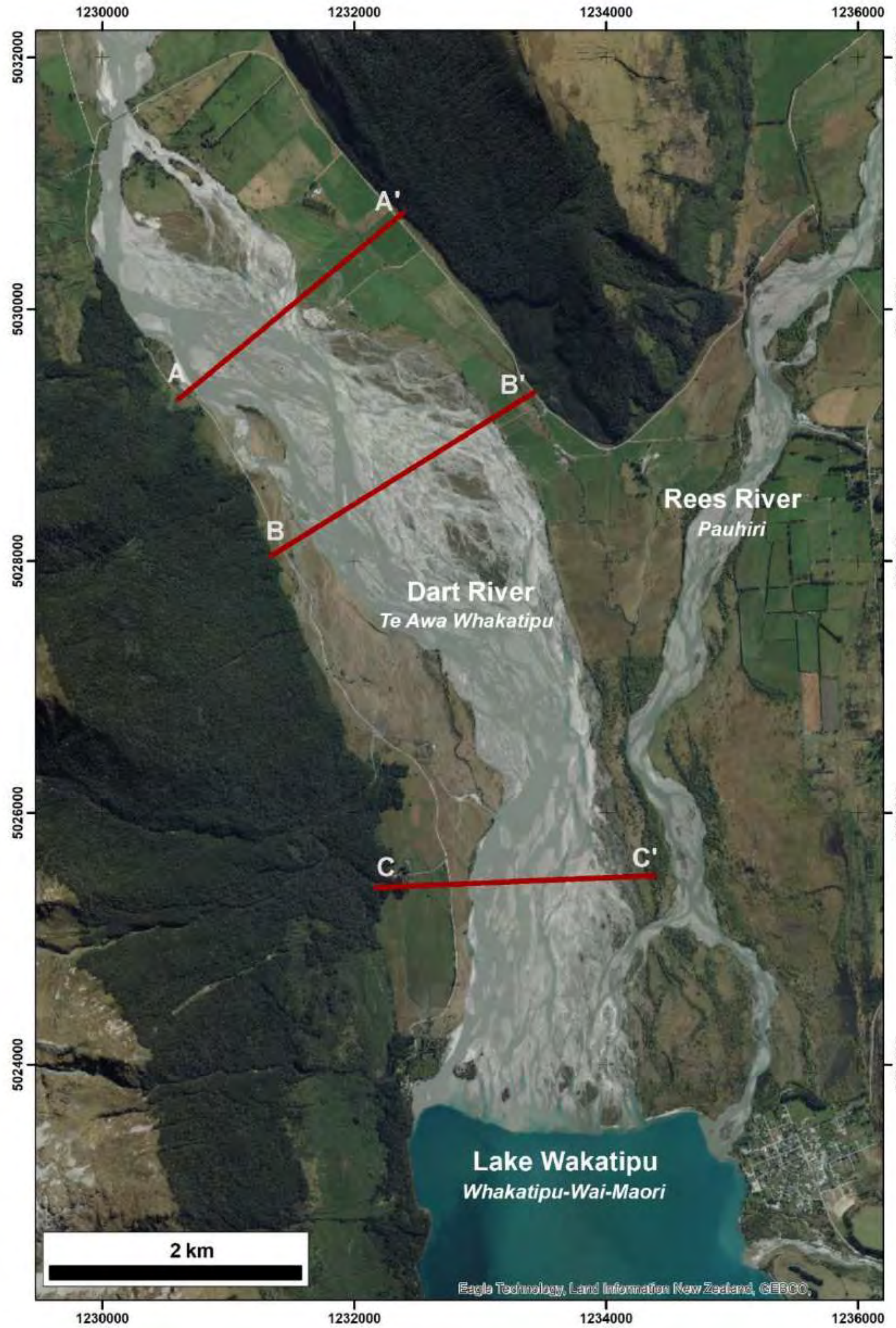


Figure 5.1(a): Location of selected Dart River cross-sections where flood flows are threatening the Kinloch Road

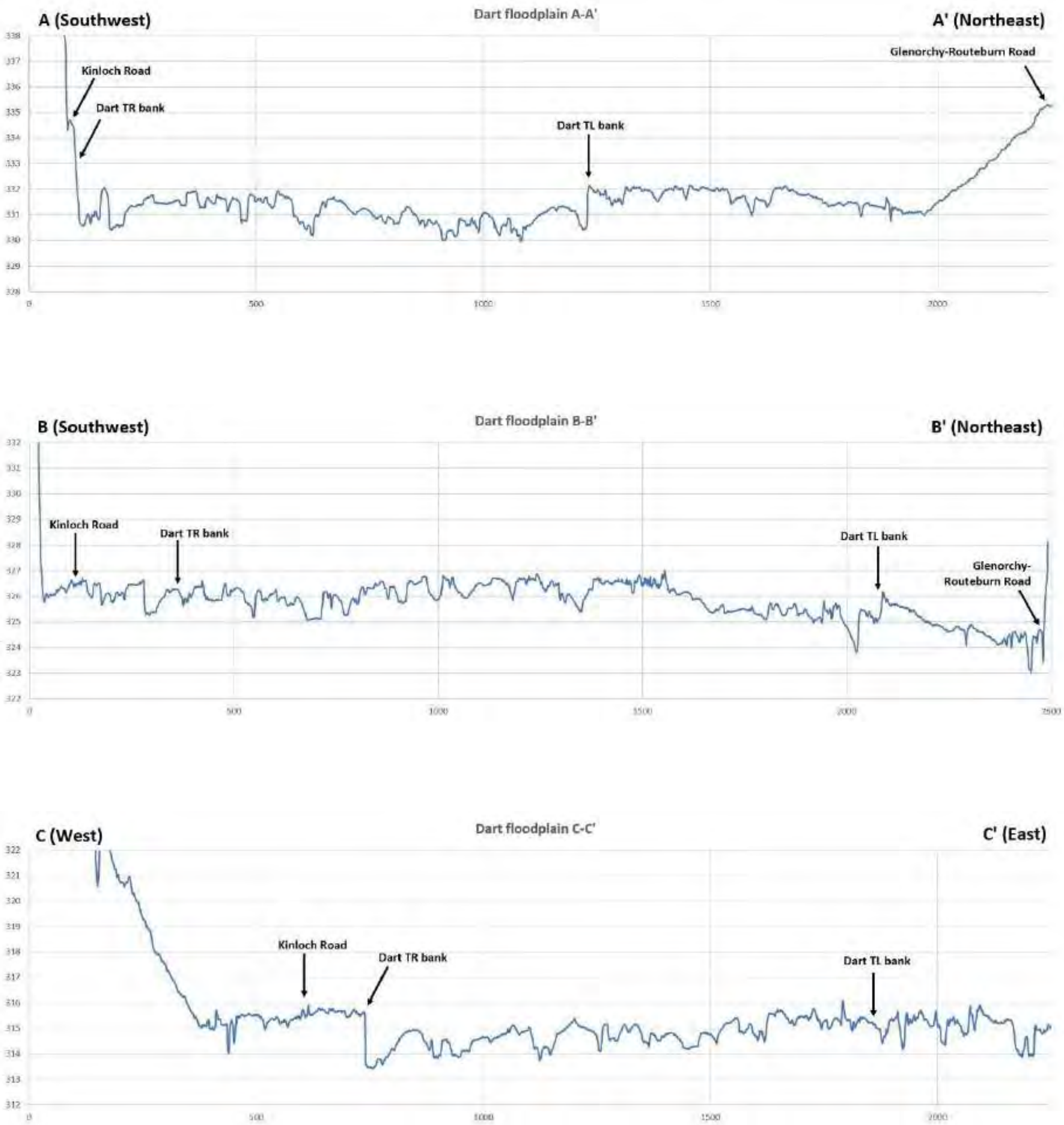


Figure 5.1(b): Profiles for selected Dart River cross-sections where flood flows are threatening the Kinloch Road

The rock that has been used for these works has been obtained from a mix of sources. Locally sourced material from the Glenorchy area has been used for ad-hoc and smaller scale repairs while the most recent works requiring a larger volume of rock have been sourced from the Queenstown area (Ben Greenwood, QLDC, pers. comm.). Rock material carted from Queenstown makes the cost of repair works quite expensive.

Another significant disadvantage of rock armouring of a bank in a braided river channel system is that the armouring tends to “suck in” braid channels and attract scour, requiring constant maintenance and often further extensions upstream and downstream beyond the original extent. Rock armouring of a bank can also be outflanked upstream and downstream.

The chance that the current east to west trajectory of the active channel belt in the Dart River will continue is very high. Rock armouring of the existing bank line may slow this trend down, but it is unlikely to have more than a 5-10 year lifespan. The next large flood could overwhelm the road.

Other intervention suggestions from the community included (see Figure 3.4):

- Large-scale erosion protection or flood mitigation structure(s);
- Re-design of the road away from the floodplain; and
- Use of alternative transport e.g. boat access across the lake.

These and other possible interventions are evaluated in Section 5.3.

5.3 Evaluation of Other Possible Interventions

Table 5.1 sets out other possible intervention options for the Kinloch Road which were discussed during the floodplain adaptation workshop. These options were evaluated for their suitability and viability. Table 5.1 also provides a summary of this evaluation with other relevant comments.

Table 5.1: Evaluation of other possible intervention options and strategies for Kinloch Road and access discussed during adaptation workshop

Intervention / Strategy	Comments	Key Challenges for Inclusion in Adaptation Pathways Approach
Large-scale erosion protection or flood mitigation structure(s)[30]	This intervention aims to arrest or slow the lateral migration of the active braid channel belt on the western side.	As noted in Section 5.2 with respect to more localised interventions of this nature, these types of structure would only have a limited lifespan due to ongoing riverbed aggradation. The approach would do nothing to address the existing flood inundation problem affecting the road which is likely to be experienced more frequently. This type of intervention is expensive. QLDC have spent $470,000 in the last five years on treating approximately 780 m of riverbank length to try and maintain access along the road. This amount is well in excess of QLDC's budget over five years for road maintenance activities and has had to be funded as emergency works.
Active river management to keep river away from road	This intervention would be aimed at separating the river from the road.	The highly dynamic nature of the braid channel pattern in the active channel belt with continual change and ongoing aggradation and channel migration makes this approach extremely challenging to implement. It would require large-scale and continuous channel modification works which would be environmentally damaging in a wilderness area. There is a high chance that such works would be ineffective in the short term due to the dynamic nature of the changing braid patterns across the riverbed. The approach would also very likely be unsustainable in the long-term due to the same dynamic behaviour of the riverbed (it is tantamount to 'fighting nature'). The cost would be very high, difficult to justify and very unlikely to be palatable to ORC, QLDC and ratepayers. The riverbed is already nearly at the level of the road in several areas and this approach does nothing to address the existing flood inundation problem.

[30] Note comparison of 1966 and 2019 right bank positions on the Dart River shows >500 m of westerly migration of the bank line in ~ 50 years. However, bank retreat is episodic and could be 20-30 m in a series of flood events, or up to 50 m in a year.

Intervention / Strategy	Comments	Key Challenges for Inclusion in Adaptation Pathways Approach
		This intervention would interfere with jetboating and other recreational activities on the Dart River. The ‘keep the river away from the road’ intervention would need to be fully explored in a business case developed by QLDC.
Temporary 4WD access through private land for use when existing road flooded	This strategy aims to provide an alternative temporary access route. It is an important temporary measure to investigate as a matter of urgency in order to maintain access to Kinloch most of the time and in case a section of the road nearer Kinloch is eroded away through riverbank retreat. Development of a 4WD access track could be implemented as a short-term solution in advance of the business case being drafted by QLDC for identifying a long-term solution.	The temporary access route may still not be fully passable under high flow conditions in the Dart River when the full width of the floodplain is inundated. This measure would require the cooperation of the owners of Woodbine Station (the station has recently changed ownership).
Permanent relocation of the road within the floodplain	This strategy aims to remove the road from exposure to existing flood inundation and riverbank erosion hazards. It could be a viable long-term option to maintain road access to Kinloch	This strategy would require initiating discussions with the new owners of Woodbine Station and establishing an agreement with them. Obtaining landowner agreement may take a long time and may not necessarily be achieved. This option would also need to be considered as part of a business case prepared by QLDC (the focus of the business case is not only physical access but also health and safety as people often ignore road closure signs and get stuck, requiring their rescue).
Permanent relocation of the road to the valley side-slopes	This strategy also aims to remove the road from exposure to existing flood inundation and riverbank erosion hazards. It could also be a viable long-term option to maintain road access to Kinloch. The Greenstone Road is an example of what this road could look like.	There may be legal issues with this strategy as large parts of the valley side-slopes are in the DOC estate. The environmental impact of this strategy would be more significant due to the need to clear a path through native vegetation to construct a new road. This option would lead to increased exposure to other hazards – landslides, debris flows, stream / alluvial fan flooding. This option would be more expensive than the ‘permanent road relocation within the floodplain’ option.
Alternatives to road access	This strategy would focus on other means of providing access to Kinloch (e.g. boat and air access).	The existing Kinloch Wharf is no longer accessible to boats due to progradation of the Dart-Rees sediment delta. There is currently no public transport funding available for a water taxi type service.

Intervention / Strategy	Comments	Key Challenges for Inclusion in Adaptation Pathways Approach
		Helicopter access is feasible but would be expensive and would require a permanent helipad at Kinloch. This option would need to be considered as part of a QLDC business case
Temporary access by boat across the lake as an emergency measure	This strategy would focus only on providing emergency access across the lake when the existing road became impassable due to flood inundation or damage. The local owner of Kinloch Lodge does operate a boat service for guests if the road is closed although this is problematic if the lodge guests have rental cars.	Delta progradation means the existing Kinloch Wharf is no longer serviceable for boat traffic. The provision of temporary access means could be required for extensive periods of time if the existing road is damaged or eroded away, or the lake remains high causing the road to stay inundated. This strategy is problematic if stranded visitors have cars (either private or rental) which they have to leave behind.

5.4 Information Gaps and Recommended Actions

The following information gaps and recommended actions were identified during the floodplain adaptation workshop discussion:

Topographic Data

- Undertake an inspection of historic aerial photographs and satellite imagery to determine detailed trends in bank line migration over time, and any hotspots[31].
- In the future, routinely obtain high-resolution satellite imagery to monitor future changes in bank lines over time.
- Obtain new LiDAR data and aerial imagery for the Lower Dart River[32].
- Analyse new LiDAR data to detect changes in bed levels and braid channel patterns.

Improved 2D Modelling

- Re-run 2D computational hydraulic model with new DEM incorporating braid channels based on 2022 LiDAR data.
- Use model simulation results to help develop possible alternative realignments of road on floodplain.
- Extract suitable information from model simulation results to support QLDC business case.

Previous Emergency Works

- Collate construction cost information on bank armouring and road raising carried out previously as emergency works to support QLDC business case.

Monitoring

- Develop a data collection plan for during and after significant flood events (Dart at the Hillocks hydrometric station flows > 1500 m^3/s).
- Obtain aerial imagery near peak of flood events.
- Fix debris marks at key locations and survey positions and levels.
- Carry out a post-event LiDAR survey of riverbed.

QLDC Business Case[33]

- Define the problem (refer Section 5.1).
- Establish who the stakeholders are.
- Identify the information needed to inform the business case.
- Start gathering the information needed to support the preparation of the business case.

[31] This work has partially been completed.
[32] Professor Brasington is planning on undertaking a repeat LiDAR survey covering this area in the 2022 calendar year.
[33] QLDC currently has a big backlog of business cases. Kinloch Road is not currently included in the QLDC Long-Term Plan. This does not preclude QLDC staff from starting work to clarify the scope of the business case and addressing data needs.

Emergency Response Plan

- Develop an immediate response plan[34] ready to implement in case the road is permanently closed before the business case is developed and considered. This includes developing a quick alternative access solution.

[34] Note that this is already in the process of being developed.

6.0 Rees Bridge and Upstream Right Bank Floodplain

6.1 Specific Threats and Hazards

The main threats to the Rees Bridge from ongoing riverbed aggradation and climate change effects were identified in Section 2.3. These include:

- Reducing bridge waterway flood capacity;
- Increasing potential for scour and erosion damage at the bridge piers and abutments; and
- Increasing potential for structural damage to the bridge from debris rafting and flood overtopping.

The bridge was originally constructed in 1958. It is currently inspected every 2 years. There was some concern about the bridge during the February 2020 flood when the freeboard under the bridge soffit was less than 0.5 m. As noted in Section 2.4, a Moxy dump truck could be driven under the bridge five years ago but this is now no longer possible due to the rise in riverbed levels from sediment aggradation.

During a site inspection prior to the floodplain adaptation workshop, it was observed that the bridge abutments appear to have no significant rock protection against scour. The left abutment is currently the most vulnerable (Figure 6.1) and there appears to be evidence of a slight amount of slumping of the approach embankment fill immediately adjacent to the structure (Figure 6.2). The right abutment appears less vulnerable with vegetation growing around and under the abutment (Figures 5.4 and 5.5). This suggests it is a long time since flood flows impinged directly on the right abutment. If flood flows are directed at an unprotected bridge abutment, there is potential for the fill in the approach embankment to be scoured out leaving the abutment undermined and flood flows outflanking the bridge structure. An immediate action should be to provide adequate rock protection to the bridge abutments, with the most urgent priority being the left abutment.

It was noted that a diffluence of braid channels exists upstream of the bridge where the main braid channel seems to pivot between left and right banks. In the 3 km long reach upstream of the bridge, there has been a mean aggradation height of about 0.3-0.35 m over the last 10 years. The highest aggradation rates in this reach are furthest upstream from the bridge. The amount of sediment deposition relative to the crest level of the existing right bank stopbank upstream of the bridge means that there exists the potential for a flood breakout onto the western floodplain. This would cause the roads to Paradise and Kinloch to be inundated. A permanent channel avulsion in this direction would sever these road connections.

Relatively small flood events in the Rees River based on measurements in the 2009-2011 field campaign (refer Section 2.5) can cause movement of 5,000-30,000 m^3 past the bridge in a single event. QLDC currently hold a resource consent to extract up to 20,000 m^3/year at the bridge but this is insignificant compared with the average volume of gravel bed material which is likely to be transported past the bridge annually. There is currently not much demand for the material and there is no desire on the part of QLDC to increase the annual take as there is no use for the material. It does not meet normal road construction specifications.

Figure 6.1: View of left abutment of Rees Bridge on upstream side from bridge

Figure 6.2: View under left abutment of Rees Bridge from upstream side of road embankment showing small amount of slumping of approach embankment fill material

Figure 6.3: View of right abutment of Rees Bridge on upstream side from bridge

Figure 6.4: View under right abutment of Rees Bridge from downstream side of road embankment

The control of sediment aggradation at the bridge is therefore not a viable solution with the volume of aggradation vastly exceeding the extraction volume on an annual basis. It is noted that there are two other active consents for gravel extraction upstream of the bridge, but the volumes taken are also small.

The main stopbank on the right bank floodplain[35] of the Rees River upstream of the Rees Bridge runs along the existing bank line seen in the aerial image in Figure 6.5. It is about 4 km long (ORC, 1999) and protects agricultural land on the floodplain as well as the roads to Paradise, Kinloch and the Routeburn Valley (the junction of the road to Kinloch and the Routeburn Valley, and the road to Paradise can be seen just to the north of the Rees Bridge in Figure 6.5). There is also evidence of a low stopbank on the left bank floodplain[36] upstream and downstream of the Rees Bridge although this is largely obscured by willow trees.

An additional secondary stopbank (Figure 6.6), which extends upstream from the Rees Bridge running parallel with the Paradise Road, can also be seen in the aerial image in Figure 6.5. It appears that this may be designed to function as a guide-bank in the event of floodwaters breaking out across the floodplain on the right bank upstream of the bridge. The guide-bank would turn flood flows back towards the bridge and force them to flow through the bridge waterway. It is noted that old paleo-channels are evident on the floodplain between the primary and secondary stopbanks in Figure 6.5 so that this area was previously part of the riverbed at some time.

Riverbed levels upstream of the bridge are now 2-3 m higher than the western floodplain and almost up to crest of the primary stopbank in places. The threat of flood breakout and even a permanent channel avulsion along the right bank with river flows bypassing the bridge is therefore very real[37]. While this type of event would impact on farmland, the primary impact would be on road access to Paradise, Kinloch and the Routeburn Valley. It could also affect a Fish and Game Lodge near Diamond Creek (at the start of the Diamond Lake track). With floodplain levels significantly lower than current riverbed levels in this area, it could be very difficult to block off river flows that had formed an avulsion path through this area.

Further upstream (out of view at the top of the aerial image in Figure 6.5), ORC maintain some rock groyne structures along the right bank which attempt to force the active channel belt over towards the left bank. The head of one of these long groyne structures (Figure 6.7) has been damaged in the past by flood activity and ORC are currently stockpiling a supply of rock to enable the damaged section to be reinstated. These structures are located too far upstream to have any influence on the behaviour of the active channel belt nearer the bridge (which will be more affected by aggradation trends across the riverbed surface). They are also only likely to remain effective in the short-term due to the level of riverbed aggradation being experienced and their low degree of submergence before being overtopped.

The scale of riverbed aggradation upstream of the Rees Bridge is such that not much can be done to mitigate the risk of a flood breakout or channel avulsion event across the right bank floodplain. The existing primary stopbank could be raised but this would increase the residual risk over time (i.e. higher impacts would result when stopbank failure in the future inevitably

[35] The main right bank stopbank upstream of the Rees Bridge was constructed by ORC in 1984 together with willow plantings adjacent to the bank (ORC, 1999).
[36] The left bank stopbank upstream of the Rees Bridge was constructed by ORC in 1996 to reduce flood overflows in that area (ORC, 1999).
[37] The main right bank stopbank required frequent regular repairs and maintenance up to 1999, including a major breach which threatened the Glenorchy-Paradise Road in January 1994 (ORC, 1999).

occurred due to the combined effects of bed aggradation and climate change) and would only buy time. This underlines the importance of understanding the location of potential channel avulsion paths across the right bank floodplain and ensuring no development or intensification occurs within those pathways in the future.

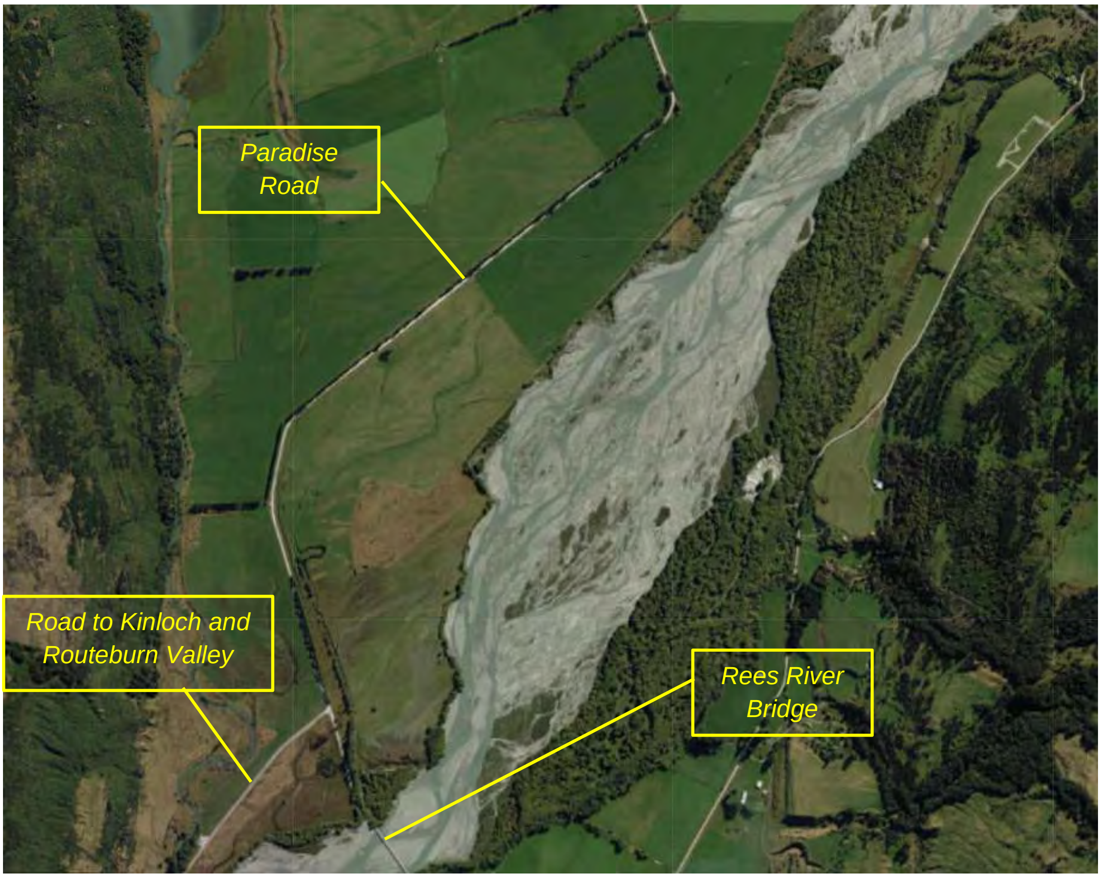


Figure 6.5: Overview of Rees River and floodplain upstream of Rees Bridge (sourced from QLDC Spatial Data Hub)

Figure 6.6: Secondary stopbank on right bank upstream of Rees Bridge which runs parallel with Paradise Road

Figure 6.7: Rock groyne structure on right bank of Rees River upstream of existing bridge (the head of the structure beyond the willow saplings in the right of the photo was damaged in a recent flood event)

It is not feasible in the long-term to either control or prevent channel avulsion from occurring somewhere across the right bank floodplain upstream of the Rees Bridge due to the unlimited supply of sediment material from the upstream catchment, the continual rapid rise in riverbed levels and the effects of future climate change. It is therefore important to be upfront in communications with local landowners and the community about:

- the threat posed by ongoing riverbed aggradation and the potential for channel avulsion to occur; and
- the increase in residual risk[38] that would result if the level of the existing primary stopbank was raised as a short-term response.

6.2 Evaluation of Possible Interventions

Figure 3.3 does not show any community suggestions for possible interventions at the Rees Bridge.

Table 6.1 sets out possible intervention options for the bridge which were considered during the floodplain adaptation workshop.

Ultimately, in view of the scale of riverbed aggradation, the bridge will need to be raised, or alternatively, replaced with a new structure. However, this is a medium to long-term solution and will require another business case to be developed by QLDC. In the interim, an ongoing programme of monitoring and investigations needs to be undertaken.

[38] Residual risk is the risk that remains after risk treatment or management has been applied to reduce the potential consequences of a hazard occurring (MfE, 2017).

Table 6.1: Evaluation of possible intervention options and strategies for Rees Bridge and upstream right bank floodplain discussed during adaptation workshop

Intervention / Strategy	Comments	Key Challenges for Inclusion in Adaptation Pathways Approach
Implement monitoring and investigations programme	Strategy aims to better quantify hazards (including changes over time), consequences and risks. Monitor riverbed aggradation over time (repeat LiDAR topographic surveys and data analysis). Use 2D computational hydraulic modelling to establish a water level / discharge rating curve at the bridge. Relate water level discharge rating data to flood frequencies. Evaluate scour risk to bridge. Evaluate structural stability of bridge including under surcharged and overtopping conditions during floods.	This strategy requires an ongoing investment in long-term active monitoring.
Install improved riprap protection of bridge abutments	Intervention aims to mitigate existing scour risk to bridge abutments. Immediate attention required as a matter of urgency (refer discussion in Section 6.1).	
Lengthen existing bridge	Strategy aims to relieve constriction of active channel belt and partially alleviate flood risk to the existing bridge. Current bridge is short relative to the width of the active channel belt upstream and downstream. Current channel belt constriction caused by bridge may accelerate gravel bed material movement past it, but may also exacerbate riverbed aggradation upstream (average bed level rise upstream was 0.3-0.35 m over 10 years to 2019). Lengthening existing bridge could assist in reducing flood levels for extreme events.	This strategy would need to consider the effects of flood breakout upstream of the bridge with flood flows bypassing the bridge. Consideration would need to be given to maintaining access across the Rees River while the bridge is being lengthened. This strategy would need to be included in QLDC's business case (noting that Waka Kotahi is a funding partner to QLDC).
Raise existing bridge	Strategy aims to alleviate current flood risk to the existing bridge. Strategy could be considered in conjunction with strategy of lengthening existing bridge. Raising the existing bridge would enable adequate freeboard to be established for design flood. Revised design flood magnitude would need to be quantified allowing for climate change effects.	The freeboard allowance for a raised bridge would need to accommodate future bed aggradation. This strategy would need to consider the effects of flood breakout upstream of the bridge with flood flows bypassing the bridge. Consideration would need to be given to maintaining access across the Rees River while the bridge is being raised.

Intervention / Strategy	Comments	Key Challenges for Inclusion in Adaptation Pathways Approach
		This strategy would need to be included in QLDC's business case (noting that Waka Kotahi is a funding partner to QLDC).
Construct new bridge	Strategy aims to alleviate current flood risk to the existing bridge and allow for futureproofing with respect to the appropriate design standards for flood magnitude and freeboard. Constructing a new bridge would enable the design flood standard with an allowance for ongoing bed aggradation and climate change effects to be achieved. Revised design flood magnitude would need to be quantified allowing for climate change effects. Consideration could also be given to making a new bridge longer than the existing to relieve the current constriction of active channel belt. Constructing a new bridge would allow the existing bridge to be used for maintaining access to Paradise, Kinloch and Routeburn Valley.	The freeboard allowance for a new bridge would need to accommodate future riverbed aggradation. This strategy would need to consider the effects of flood breakout upstream of the bridge with flood flows bypassing the bridge. Consideration could be given to a type of bridge construction that allows the bridge to be raised in the future (i.e. similar to the Waiho River Bridge at Franz Josef) to accommodate future riverbed aggradation. This strategy would need to be included in QLDC's business case (noting that Waka Kotahi is a funding partner to QLDC).
Emergency response planning	Strategy aims to have a response plan ready to implement in the event of damage to the existing bridge and / or a flood breakout / channel avulsion event on the right bank floodplain occurring before a permanent solution is implemented. Plans need to be developed for the occurrence of damage to the existing bridge and / or a flood breakout / channel avulsion event on the right bank floodplain upstream of the bridge.	
Planning controls for right bank floodplain upstream of bridge	Strategy aims to control any future development and intensification within any potential flood breakout pathways across the right bank to reduce the flood hazard to people and property.	There is a need to understand the location of potential flood breakout / channel avulsion pathways across the right bank floodplain. There is a need to compare the crest level profile along the length of the primary right bank stopbank[39] with adjacent riverbed levels. There is a need to establish a crest level profile along the length of the secondary stopbank /guide-bank running parallel with the Paradise Road.

[39] The crest level profile of the right bank stopbank was surveyed in 2020 by ORC.

Intervention / Strategy	Comments	Key Challenges for Inclusion in Adaptation Pathways Approach
		There is a need to implement planning controls to preclude further development and intensification within the area of potential flood breakout / channel avulsion pathways across the right bank floodplain.
Raise existing primary stopbank on right bank floodplain upstream of bridge	Strategy aims to improve the current level of protection against flood breakout on the right bank floodplain.	This strategy is a short-term solution only due to ongoing riverbed aggradation. It increases the residual risk to farmland and roads on right bank floodplain.
Raise existing secondary stopbank on right bank floodplain upstream of bridge	Strategy aims to improve the current level of protection against flood breakout on the right bank floodplain.	There is a need to understand the location of potential flood breakout / channel avulsion pathways across the right bank floodplain to know if this strategy would be effective, or more effective than raising level of existing primary stopbank This strategy may also only be a short-term solution due to ongoing riverbed aggradation.
Extend existing secondary stopbank on right bank floodplain further upstream	Strategy aims to improve the current level of protection against flood breakout on the right bank floodplain.	There is a need to understand the location of potential flood breakout / channel avulsion pathways across the right bank floodplain to know if this strategy would be effective, or more effective than raising level of existing primary stopbank This strategy may also only be a short-term solution due to ongoing riverbed aggradation.
Establishment of left bank flood breakout path upstream of bridge	Strategy aims to improve the current level of protection against flood breakout on the right bank floodplain with or without raising the primary or secondary stopbanks. Vegetated area on left side of Rees River upstream of bridge is lower-lying land and was previously active channel (i.e. 1966 aerial image shows this). Could remove vegetation to form a 250-300 m wide preferential breakout flow path over a 3 km distance upstream of bridge to ease pressure on right bank and reduce risk of channel avulsion occurring across right bank floodplain.	The likely effectiveness of this strategy is uncertain and needs to be investigated. Land ownership needs to be investigated. The existing Rees Bridge remains a pinch point for flood flows and this strategy does nothing to improve waterway capacity past the bridge.

6.3 Consideration of Other Monitoring and Investigation Techniques

In view of the uncertainty in the future behaviour and evolution of the Rees River upstream of the bridge, several other monitoring and investigation techniques to aid in improving the understanding of this were considered during the floodplain adaptation workshop.

One of the drawbacks of the existing 2D computational hydraulic model of Rees River is that it assumes a fixed bed based on the riverbed topography at the time of the LiDAR survey (i.e. it does not include a sediment transport component which allows for the morphology of the riverbed to change over time in response to flood activity). It is possible to develop 2D morphological models which track sediment movement and evolution of the bed morphology over time. These are good only for short-term forecasting of bed morphology change and require detailed knowledge of the prior bed topography. They diverge significantly from observed bed morphology changes over the long-term in actual case studies. Therefore, it is not considered that this technique would provide reliable or robust predictions of future riverbed evolution in this context.

Physical hydraulic modelling is another alternative technique. For the scale of the problem in this context, the size of the model would need to be very large which would make such a study very expensive. No hydraulics laboratory in New Zealand has the required capacity or the capability for a model of the size required. Even if it was practical to construct a large model, there are still likely to be scale effects (e.g. with correctly reproducing sediment transport rates). The recent physical hydraulic model projects (e.g. the Dart-Rees River System delta and the Shotover River delta) carried out in New Zealand used micro-scale models which had significant limitations to what they could represent.

Despite the limitations of 2D fixed bed computational hydraulic modelling, it is still the best approach available in conjunction with on-going observation and monitoring to assist with managing the flood hazard in the Upper Rees River. This type of model is a useful tool to help better understand what might happen in an avulsion event on the right bank floodplain upstream of the Rees Bridge as well as for visually communicating results to inform the community and decisionmakers.

One of the critical information needs to manage the flood risk associated with the Rees Bridge is to establish a water level / discharge rating relationship at the bridge site, and to monitor changes in this relationship over time in response to ongoing riverbed aggradation. The conventional approach to doing this would be to install a pressure transducer at the bridge to provide a continuous record of water levels over time and relate water level measurements to flow measurements at the upstream Rees at Invincible hydrometric station. However, there are practical difficulties with such an approach at this site as the main braid channel keeps flopping from side to side and there may be differences in water levels between braid channels. A more suitable approach would be to install a special camera system[40] at the bridge and use a Particle Image Velocimetry (PIV) technique to measure water levels and discharge at the bridge site.

[40] e.g. https://www.seba-hydrometrie.com/products.html?L=1&tx_sebaproducts_sebaproducts%5bproduct%5d=299&tx_sebaproducts_sebaproducts%5bprimarycategory%5d=3&tx_sebaproducts_sebaproducts%5bsecondarycategory%5d=&tx_sebaproducts_sebaproducts%5baction%5d=show&tx_sebaproducts_sebaproducts%5bcontroller%5d=Product&cHash=95452a37634fdd583904cc07ef1fd983

This technique is currently being used in NZ by Marlborough District Council and Horizons Regional Council.

6.4 Information Gaps and Recommended Actions

Riverbed Monitoring

- Undertake 2022 LiDAR topographic survey of riverbed and repeat surveys thereafter to monitor riverbed aggradation over time.
- Analyse LiDAR survey data to establish long-term bed aggradation trends (noting that there will be periods of slower and faster aggradation linked to flood activity and sediment pulses).
- Consider installation of a terrestrial laser scanner (TLS) on Mt Alfred to enable high frequency DEMs of the area to be obtained[41].

Existing Stopbank Crest Levels

- Use LiDAR data to establish a crest level profile for the primary right bank stopbank upstream of the Rees Bridge and compare this to adjacent riverbed levels.
- Use LiDAR data to establish a crest level profile for and the longitudinal extent of the secondary stopbank upstream of the Rees Bridge and parallel with the Paradise Road.

Computational Hydraulic Modelling

- Extend the existing 2D computational hydraulic model of Dart and Rees River System upstream to the Rees at Invincible hydrometric station with new 2022 LiDAR data.
- Carry out model simulations to establish a water level / discharge rating curve at the bridge.
- Use the model to identify flood breakout flow paths and potential avulsion pathways on the right bank floodplain upstream of the Rees Bridge.
- Use the model to investigate the establishment of preferential flood breakout flow path along the left side of the active riverbed upstream of bridge (refer further to “Upstream Floodplain Management Investigations” below).

Bridge Investigations

- Relate water level / discharge rating data at bridge to estimated flood frequencies.
- Establish current flood capacity of bridge waterway in terms of estimated flood frequencies and allowing for adequate freeboard allowance for bridge soffit.
- Determine the critical point in terms of acceptable capacity for the bridge waterway (a trigger to signal a required change in adaptation response).
- Assess the risk posed by pier and abutment scour to the bridge, including consideration of pressure scour when flood flows are surcharged on the bridge deck, or overtopping the bridge deck.

[41] TLS surveys are routinely used in the mining industry. A terrestrial laser scanner can scan over about a 6 km distance within the line of sight. The data captured could be analysed by contract or on an as required basis. Acquisition of such a scanner is currently the subject of a research proposal (Professor James Brasington, pers. comm.).

- Undertake a structural stability assessment of the bridge including for floods surcharging against bridge, and overtopping bridge.
- Determine design flood and freeboard values for either a raised bridge or a replacement bridge (design freeboard value needs to account for future riverbed aggradation).
- Consider how continued access to Paradise, Kinloch and Routeburn Roads can be maintained while the existing bridge is being raised (the existing bridge would provide this access if a new bridge is constructed).

QLDC Business Case

- Define the problem (refer to Section 6.1).
- Establish who the stakeholders are.
- Identify the information needed to inform the business case.
- Start gathering the information needed to support the preparation of the business case.

Emergency Response Plan

- Develop an immediate response plan ready to implement in case the bridge is temporarily damaged before the business case is developed and considered. This would need to consider a range of damage scenarios[42].
- Develop an immediate response plan ready to implement in case a flood breakout and channel avulsion event occurs along the right bank upstream of the bridge.

Upstream Floodplain Management Investigations

- Check land ownership details for vegetated land on left bank upstream of the Rees Bridge which was previously part of the active riverbed.
- Undertake 2D computational hydraulic modelling using the latest LiDAR data to investigate the viability of forming a controlled spillway / overland flow path across the left bank floodplain.
- Investigate removal of low vegetation over a 250-300 m wide strip to form a 3 km long controlled spillway / overland flow path across the left bank floodplain.
- Estimate costs of vegetation removal using information from similar previous work.
- Investigate revegetation of the right bank with willows as new edge protection.

Bridge Monitoring

- Use the extended 2D computational hydraulic model of the Rees River based on 2022 LiDAR data to estimate a water level / discharge rating relationship at the Rees Bridge.
- Consider installation of a PIV camera system at the Rees Bridge to help track changes in the water level / discharge rating relationship at the site over time and hence the change in flood risk.

[42] Typical damage scenarios would include scour of one of the abutments with flows partially outflanking the bridge, slumping of the bridge deck due to the occurrence of pier and / or pressure scour, lateral deformation and rotation of part of the bridge induced by flood surcharging and overtopping, and deposition of fine sediment and woody debris material on the bridge deck due to overtopping.

7.0 Summary and Conclusions

7.1 Introduction

The conclusions presented in this section are outcomes from the floodplain adaptation workshop and should not be inferred to represent solely the views of the author of this report.

7.2 Glenorchy and Lower Rees River Floodplain

Due the perched nature of the Rees River and trend of it becoming more perched over time, there are probably no viable options for engineering / river management to prevent flooding from the river at Glenorchy or the occurrence of an avulsion event into the lagoon area. Therefore, the focus should be on preparing to manage the impacts of this inevitable event and / or mitigating those impacts or delaying the event ocurrence.

In the immediate short term, this could involve:

- Flood warning improvements.
- Revision and communication of flood response procedures.
- Consideration of improvements to the existing stopbank (e.g. raising the crest profile, improving the structural quality and integrity).
- Investigation of vegetation planting on the left bank of the Rees River where flood breakouts into the lagoon area occur.

In the medium or longer term, other strategies could be considered:

- Building-scale interventions (e.g. raising floor levels of existing buildings).
- Planning responses (e.g. preventing further intensification, setting a revised minimum floor leve)l
- Retreat of buildings in the highest-risk areas.

Planning for these possible medium and longer term strategies would need to start in the immediate short term.

It needs to be emphasised that any upgrade of the existing stopbank will be a short-term measure only. It should be communicated very clearly and carefully to the community that the purpose of the stopbank improvements is to reduce the current flooding threat to the town from the river.

ORC and QLDC will need to work together to:

- inform the community of new information on natural hazard risks;
- convey this information in an understandable way and why some flood mitigation options are not viable;
- develop improved flood warning systems and updated flood response procedures;
- incorporate new flood hazard information into the planning framework; and
- compile critical information to support the investigation, planning and implementation of any longer-term options.

7.3 Kinloch Road and Dart River Floodplain

The Kinloch Road is closed relatively frequently due to inundation by floodwaters from the Dart River overflowing the right bank or flood damage. The frequency of flood inundation has been increasing over time due to ongoing bed aggradation and this trend is expected to continue in the future.

The road is also threatened by bank erosion on the right bank. The current westerly migration of the active channel belt along the right bank is expected to continue in the future due to the transverse slope across the riverbed. Since the 1960's, the long-term bank erosion rate has been > 10m/year in places and could be up to 50 m/year if a series of consecutive large flood events occurred.

The current reactive management approach for the road of localised raising of the road formation and localised rock armouring of sections of the right bank are of limited benefit and not sustainable in the longer term. In the case of rock protection works, it is also expensive.

The development of any business case for larger-scale interventions on the Kinloch Road will not happen quickly due to competing higher-priority works in the QLDC area.. Therefore, there is a need to develop a plan for interim / emergency measures for implementation whenever road access is cut:

- An interim measure could be a temporary farm access track through Woodbine Station. This would require negotiations and an agreement with the landowner. However, it needs to be pursued with some urgency.
- An emergency access measure could be a barge / water taxi arrangement. However, this would still need to be supported by a business case.

The only longer-term solutions to maintain road access which are viable would be either relocation of the road within the floodplain or relocation of the road onto the western hillslopes. The first relocation option would have significant land ownership issues. The second relocation option has several constraints such as legal and land ownership issues, and increased exposure to other hazards. It would also have higher costs and a longer lead time. Any permanent road relocation with either option would need to be supported by a detailed business case by QLDC.

7.4 Rees Bridge and Upstream Right bank Floodplain

Widespread aggradation upstream of the Rees Bridge has not only reduced the bridge waterway capacity but created the potential for an avulsion event across the upstream right bank floodplain. Riverbed levels along the right bank are now approaching the crest of the primary stopbank in places and are higher than adjacent floodplain levels. This significantly reduces the level of service of the primary stopbank. The main impact of an avulsion event would be on road access to Paradise, Kinloch and the Routeburn Valley although it would also affect farmland and a Fish and Game Lodge near the confluence of Diamond Creek.

It is not feasible to control or prevent an avulsion event from the Rees River upstream of the bridge. However, work can be done now to manage the consequences of such an event. A better understanding of potential avulsion flow paths across the right bank floodplain needs to be obtained with the aid of 2D computational hydraulic modelling based on updated LiDAR topographic data. Planning controls need to be considered to ensure no future development or intensification of development occurs within these potential avulsion pathways.

One river management intervention worth exploring to lower the risk of an avulsion event on the right bank is to provide increased channel capacity with clearance of willows and other vegetation on the left bank which historically was part of the active riverbed.

Further investigation and monitoring of the Rees Bridge is required including:

- hydraulic modelling to determine a current water level / discharge rating relationship at the bridge and to understand flood patterns when the flood capacity of the bridge waterway is exceeded;
- establishing the current flood capacity of the bridge waterway and determining a critical point in terms of adequate flood capacity;
- assessing the scour risk to the bridge;
- assessing the structural stability of the bridge;
- monitoring of floodwater levels at bridge; and
- tracking shifts in the water level / discharge rating relationship at the bridge due to ongoing bed aggradation.

One urgent action than needs to be taken is to bolster the scour protection at the abutments of the existing bridge.

An emergency response plan also needs to be developed as an immediate priority to implement in case:

- the Rees Bridge is temporarily damaged; and / or
- a flood breakout and channel avulsion event occurs along the right bank upstream of the bridge.

A business case needs to be developed for the longer term by QLDC to consider longer-term options for the Rees Bridge. These options could include raising the existing bridge or constructing a new bridge. Maintaining access to Paradise, Kinloch and the Routeburn Valley during any construction works will be a significant consideration.

8.0 References

Aukaha (2021). "Cultural Values Statement – Dart-Rees Natural Hazards Project".

Ball J, Babister M, Nathan R, Weeks W, Weinmann E, Retallick M, Testoni I, (Editors) (2019). *Australian Rainfall and Runoff: A Guide to Flood Estimation*. © Commonwealth of Australia (Geoscience Australia), 2019.

Blakely Wallace Associates (2001). "Glenorchy – Head of Lake Community Plan". Report prepared for the Community of Glenorchy, August 2001.

Brasington, J (2021). "Fluvial Hazards at the Top of the Lake – Living with Rivers on the Edge". Public presentation to the Glenorchy Community, 7 April 2021.

CCATWG (2017). "Climate Change Adaptation Working Group 2017". Stocktake report from the Climate Change Adaptation Working Group, Ministry for the Environment.

Land River Sea (2022). "Dart / Rees Rivers – Flood Hazard Modelling". Report prepared by Land River Sea Consulting for Otago Regional Council, June 2022.

MBIE (2020). *Acceptable Solution and Verification Methods: for New Zealand Building Code Clause E1 Surface Water* including Amendment 11. Ministry of Building, Innovation and Employment 5 November 2020, https://www.building.govt.nz/assets/Uploads/building-code-compliance/e-moisture/e1-surface-water/asvm/e1-surface-water-1st-edition-amendment11.pdf.

MfE (2017). *Coastal Hazards and Climate Change: Guidance for Local Government*. Ministry for the Environment, Pub. No. ME1341, Wellington, New Zealand.

NIWA (2019). "Climate Change Projections for the Otago Region". Report prepared for Otago Regional Council.

ORC (1999). "Queenstown-Lakes District Floodplain Report". Otago Regional Council Report, prepared by N Johnstone, Investigations Engineer, November 1999.

ORC (2021). "Natural Hazards Adaptation in the Head of Lake Wakatipu". Otago Regional Council Report No. HAZ2105, prepared for Council Meeting by T van Woerden and J-L Payan, 27 May 2021.

ORC (2022). "Head of Lake Wakatipu Flooding and Liquefaction Hazards Investigations". Otago Regional Council Report No. HAZ2202, prepared for Data and Information Committee Meeting by T van Woerden and J-L Payan, 9 June 2022.

Tonkin and Taylor (2021a). "Head of Lake Wakatipu Natural Hazards Assessment". Report prepared for Otago Regional Council., March 2021.

Tonkin and Taylor (2021b). "Rees-Glenorchy Floodbank Structure Failure Modes Assessment". Memorandum to Tim van Woerden, Otago Regional Council, 18 November 2021. Appendix D of Land River Sea (2022) report, "Dart / Rees Rivers – Flood Hazard Modelling".

Wild, M (2013). "Growth Dynamics of Braided Gravel-Bed River Deltas in New Zealand". PhD thesis, University of Canterbury.

WSP (2020a). “Glenorchy Floodbank Rees River”. Memorandum to Tim van Woerden, Otago Regional Council, 19 June 2020.

WSP (2020b). “Glenorch Rees Floodbank – Floodbank Assessment”. Report prepared for Otago Regional Council, Ref. 6-XO011.00, Final, September 2020.

Appendix A

Floodplain Adaptation Workshop Programme and Briefing Notes

Dart-Rees Floodplain Hazards Adaptation Workshop (Online, 23-24 February 2022)
Finalised Programme

Participants: ORC: Jean-Luc Payan, Tim van Woerden, Michelle Mifflin, Pam Wilson, Scott Liddell, Craig Hughes
QLDC: Ben Greenwood, Hugo De Cosse Brissac, Bill Nicoll, Mark Baker, Alison Tomlinson
James Brasington (University of Canterbury)
Matt Gardner (Land River Sea Consulting)
Grant Webby (Damwatch Engineering)
Jamie MacKenzie (University of Otago – observer only)

Day / Time	Session	Contributors
Day 1 - 23rd February 2022		
0830-0845	**Welcome and Introduction**	Jean-Luc to facilitate, all
0845-0945	**Context - Part 1 (defining the problem)** - Overview - Community setting - QLDC and infrastructure overview - Hazardscape review	Jean-Luc to facilitate Tim Tim QLDC Tim
0945-1000	*Break for morning tea*	
1000-1130	**Context – Part 2 (defining the problem)** - Summary of natural hazard adaptation project - Geomorphic characteristics - Flood hazard assessment	Jean-Luc to facilitate Jean-Luc James Matt
1130-1145	*Break*	
1145-1230	**Adaptation Pathways Approach / Objectives / Principles** - Introduction to approach - Community engagement findings summary - Discussion of key questions to address - Discussion of objectives for adaptation - Workshop boundaries (what is excluded from consideration) - Discussion of principles for adaptation - Discussion of what successful adaptation approach looks like - Discussion of assessment factors for interventions	Jean-Luc to facilitate Tim Tim Jean-Luc to facilitate, all
1230-1330	*Break for lunch*	
1330- 1530	**Natural Hazard Challenge - Rees River and Glenorchy flooding** - Summarise specific threats / hazards - What specific adaptation interventions are available? - Assess each intervention against list of evaluation factors (impacts, benefits, risks / consequences of failure, durability over time,	Jean-Luc to facilitate, all

	viability in longer term, regulatory / policy constraints) - Does intervention satisfy objectives for adaptation? - Can specific interventions be knitted together to provide a long-term adaptation pathway?	
1530-1545	*Break for afternoon tea*	
1545-1645	**Natural Hazard Challenge - Rees River and Glenorchy flooding** (continuation of previous session)	Jean-Luc to facilitate, all
1645-1730	**Wrap-up for Day 1** - Summarise key points & conclusions for Rees River and Glenorchy flooding - Programme for Day 2	Jean-Luc

Day 2 – 24th February 2022		
0830-0835	**Welcome to Day 2**	Jean-Luc
0835-1000	**Natural Hazard Challenge – Dart floodplain and Kinloch Road** - Summarise specific threats / hazards - What specific adaptation interventions are available? - Assess each intervention against list of evaluation factors (impacts, benefits, risks / consequences of failure, durability over time, viability in longer term, regulatory / policy constraints) - Does intervention satisfy objectives for adaptation? - Can specific interventions be knitted together to provide a long-term adaptation pathway?	Jean-Luc to facilitate, all
1000-1015	*Break for morning tea*	
1015-1115	**Natural Hazard Challenge – Rees Bridge and Rees true right floodplain** - Summarise specific threats / hazards - What specific adaptation interventions are available? - Assess each intervention against list of evaluation factors (impacts, benefits, risks / consequences of failure, durability over time, viability in longer term, regulatory / policy constraints) - Does intervention satisfy objectives for adaptation? - Can specific interventions be knitted together to provide a long-term adaptation pathway?	Jean-Luc to facilitate, all
1115-1230	**Workshop wrap-up** - Summarise key points & conclusions for Dart	Jean-Luc

	floodplain & Kinloch Road - Summarise key points & conclusions for Rees Bridge - Where to from here? - Next steps	
1230-1330	*End/Lunch*	
1330-1430	**Time for additional discussions if needed**	

ORC – Head of Lake Wakatipu natural hazards adaptation programme

Briefing notes for Dart-Rees floodplain hazards adaptation workshop

1. Introduction and background

The Dart-Rees floodplains and delta at the head of Lake Wakatipu are subject to both flooding and erosion hazards. These hazards impact on the township of Glenorchy, and the wider rural communities of Kinloch and Greenstone through disruption of road access. ORC is utilising the Dynamic Adaptive Planning Pathways approach recommended by MfE as a framework for hazards adaptation pathways activities in this project area.

The proposed adaptation workshop is intended to be a first-pass review of all possible flood mitigation and floodplain management options. This will help to identify and understand which of these approaches may be feasible, environmentally acceptable and cost-effective, and to prioritise and justify any next steps such as more detailed investigation.

2. Natural hazards challenges at the Dart-Rees

The key natural hazard issues relating to the Dart-Rees floodplains are noted in bullet points below, and summarised in section 4 below.

- Dart floodplain and Kinloch road access – flooding of floodplain causing road closures, and westwards erosion of active river channel towards roadway.
- Lower Rees floodplain and Glenorchy – flooding within Glenorchy township caused by high flows in the Rees River, and/or high levels in Lake Wakatipu
- Rees bridge – aggradation impacting on bridge capacity

A key factor in understanding those natural hazards issues are the geomorphic processes of this floodplain environment – this is a dynamic, multi-hazard environment, characterised by actively aggrading riverbeds and a prograding delta shoreline.

3. Project scope and objectives

Preliminary notes on the project direction are summarised below, showing our thoughts on the key questions, objectives and factors which will need to be considered.

Questions

- What does sustainable river management look like for the Dart-Rees and what does it offer?
- What does sustainable flood protection look like and what level of protection is realistically achievable?
- What other complementary strategies are available to achieve natural hazard resilience (e.g. planning controls)?
- Can we define principles for an ORC river management strategy in this location?

Project Objectives

a) An understanding of viable, sustainable river management approaches, suitable for the floodplain/river environment of the Dart-Rees area.
b) An estimation of how long, or under what conditions these approaches might remain effective.
c) An understanding of key constraints/factors for river management interventions (costs, environmental, cultural, feasibility, community acceptability etc).
d) How these approaches might fit within wider content of natural hazard management and adaptation (e.g. planning responses, potential retreat)
e) Specific review of risks/benefits of all options identified by the community during engagement activities.

Intervention assessment factors

- What is intervention trying to achieve?
- What are impacts?
- What are benefits?
- What are risks?
- How much time will river management/engineered interventions provide?
- How viable are these river management/engineered interventions in the longer-term? – especially given the environmental/hazard context (e.g. ongoing riverbed aggradation, geomorphic consequences of an Alpine Fault earthquake, and climate change impacts on hydrology and flooding).

Success factors

- Provides flood protection benefits
- Costs are acceptable/justified
- Health of the environment must be a key factor.
- Risk and benefits of alternative strategies/pathways communicated to other stakeholders
- Approaches are supported and acceptable to all of wider community (e.g. residents, DOC, Kai Tahu).

4. Natural hazards overview

Rees River and Glenorchy

Glenorchy township is located at the head of Lake Wakatipu, the lower-lying locations of the residential area are exposed to flooding and have been flooded on several occasions over the period of settlement, most recently in December 1999 (Figure 7) and February 2020 (Figure 2, 3). The township area has a complex hydrological setting, where flooding may be sourced from the Rees River, Lake Wakatipu, or Buckler Burn, (or a combination of these sources).

In this dynamic environmental setting, the flood hazard for the Rees River floodplain and Glenorchy township is continually being influenced and modified by changes to geomorphology[1] (e.g.

[1] Brasington, 2020, 2021

aggradation and erosion, delta progradation) and climate[2] (hydrological changes to rainfall and river flow variables).

An existing floodbank, owned and managed by QLDC, at the northern margin of Glenorchy township provides flood protection from low-moderate flood events. This structure may be overtopped by larger events, as occurred in February 2020. Initial assessments of bank erosion and floodbank stability by WSP[3] (2020a,b) have identified several issues of concern, and the highest priority of these are planned to be addressed by QLDC. ORC, on occasion, also carries out river management works in this area such as localised gravel extraction or channel realignments, but recognises these provide only limited and short-term benefits.

In December 2019 and April 2020, ORC has undertaken community engagement activities for natural hazards adaptation with the local community[4]. These have been designed to present and discuss the natural hazard issues of the area, and to initiate conversations regarding possible adaptation approaches or interventions to manage these hazards. For management or mitigation of flood hazards at Glenorchy, community members have raised a number of possible interventions for consideration, including structural or river management approaches such as (Figure 1);

- Raising or modifying the existing Rees-Glenorchy floodbank structure
- Gravel extraction (e.g. to reduce aggradation rates)
- Channel realignments, such as diversion of Rees River flows into the Dart River.
- River control structures or plantings (e.g. groynes to mitigate channel erosion).
- Bunding or new floodbanks to reduce overland floodwater flows from the Rees River to the Glenorchy lagoon.
- Willow management or modification of Lagoon Creek to enhance drainage ability from lagoon.

A distinct but related Rees River issue has been ongoing concerns regarding aggradation of the river bed at/near the road bridge structure. This would raise the flood stage at the bridge, reducing the bridge's hydraulic capacity and making it more vulnerable to floodwater or debris impacts.

Surveyed cross sections since the mid-1980's have indicated a mean aggradation trend in these reaches of the Rees, a finding which complements many anecdotal reports from the community. LiDAR differencing analysis (e.g. Figure 5) does not currently extend as far upstream as the Rees bridge, but analysis of a recently acquired new LiDAR survey (captured mid-August 2021) may help to understand these aggradation patterns with more resolution.

Dart River and Kinloch access

The terrestrial access to the Kinloch, Greenstone and Caples areas is by way of the Kinloch Road. Sections of this road are located on the Dart River floodplain, and access is typically disrupted through flooding on multiple occasions each year (e.g. >10 times in 2019-20), and has been closed for periods of up to about a week (Figures 9 and 10). 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

[2] NIWA, 2019
[3] WSP, 2020 a, b
[4] ORC, 2021

channel being located nearer to the western side of the active riverbed and thus nearer to the roadway.

The westwards migration of the Dart River over at least the last 50 years has brought the river's active channel near to the roadway in many locations (Figure 11), and is now directly threatening the road margins in several sites (e.g. Figure 12). It is expected to become increasingly difficult to maintain road access using the current approach of reactive management to localised issues as they arise – e.g. the installation of rock armouring for erosion control.

Based on discussions with the local community, and within the ORC hazards team and project consultants, a range of potential adaptation approaches have been identified to maintain access to these areas (Figure 8).

1. **Status quo (reactive repair):** Localised erosion protection and road raising etc as required to manage highest priority erosion hotspots or flooding issues.
2. **Local realignment:** Realignment of sections of road from areas threatened by erosion or most highly flood-prone (but still remaining on floodplain).
3. **Hard engineering:** Installation of larger-scale erosion or flood protection structures.
4. **Redesign:** Relocation of erosion or flood-prone sections of road from floodplain to adjacent hillslopes.
5. **Alternative transport:** Use of alternative transport modes (e.g. boat access).

Relevant technical reports[5]

Brasington J (2020) Statement of evidence of James Brasington on behalf of the Otago Regional Council, 1 December 2020. In the matter of an application for resource consent RM191318 by Blackthorn Lodge Glenorchy Ltd.

Brasington J (2021) Fluvial hazards at the top of the lake – living with rivers on the edge. Public presentation for the Glenorchy community, 7 April 2021.

GeoSolve, 2016. Flood Protection – Kinloch Road / Dart River. Prepared for Queenstown Lakes District Council, June 2016

ORC (2010) Natural hazards at Glenorchy. May 2010.

ORC (2020) Observations on February 2020 flood event. ORC file note dated February 2020

ORC (2021) Natural hazard adaptation in the head of Lake Wakatipu. Report to council, 27 May 2021

Tonkin + Taylor (2021) Head of Lake Wakatipu Natural Hazards Assessment. Prepared for Otago Regional Council, March 2021

WSP (2020a) Glenorchy Floodbank Rees River. Memo prepared for Otago Regional Council, June 2020.

WSP (2020b) Glenorchy Rees floodbank: floodbank assessment. Prepared for Otago Regional Council, September 2020.

[5] Most of these references are already available online via the ORC website, but any others can be provided as required.

Figures

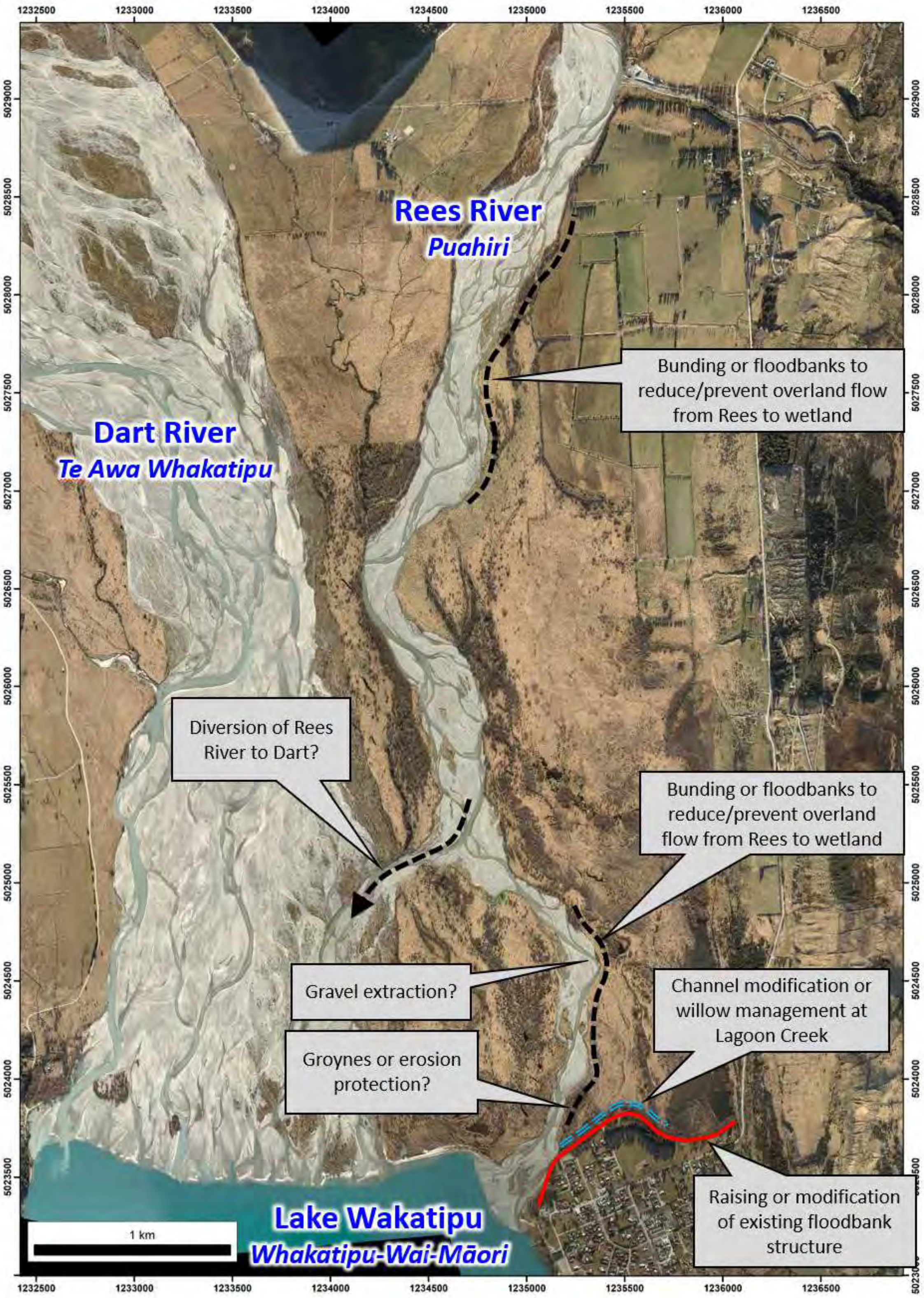
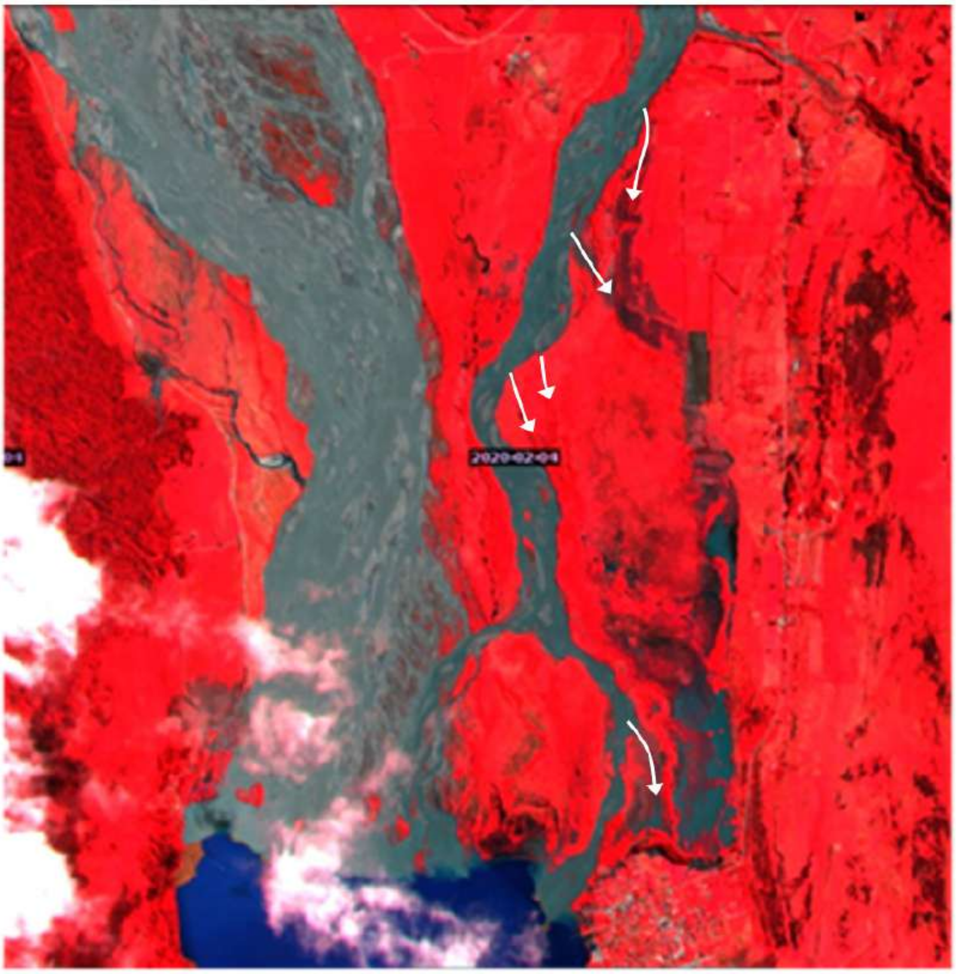


Figure 1: Overview of the lower Dart-Rees floodplain, showing the range of potential flood mitigation options for the Rees River and Glenorchy township suggested by the local community.

Figure 2: Flooding of the township in February 2020. In this event, 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 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.

The key factors in this flood event 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. (Photo credit: Luke Hunter)



4 FEBRUARY 2020

Figure 3: A false colour composite image captured shortly following the Glenorchy flood event of 4th February 2020. This shows surface water coloured grey, annotated to illustrate a series of overbank flood pathways (arrowed) eastwards from the main Rees channel.

There have been several community suggestions for works (e.g. bunding/floodbanks) to reduce the impact of floodwaters taking these flow paths. (Image provided by James Brasington)

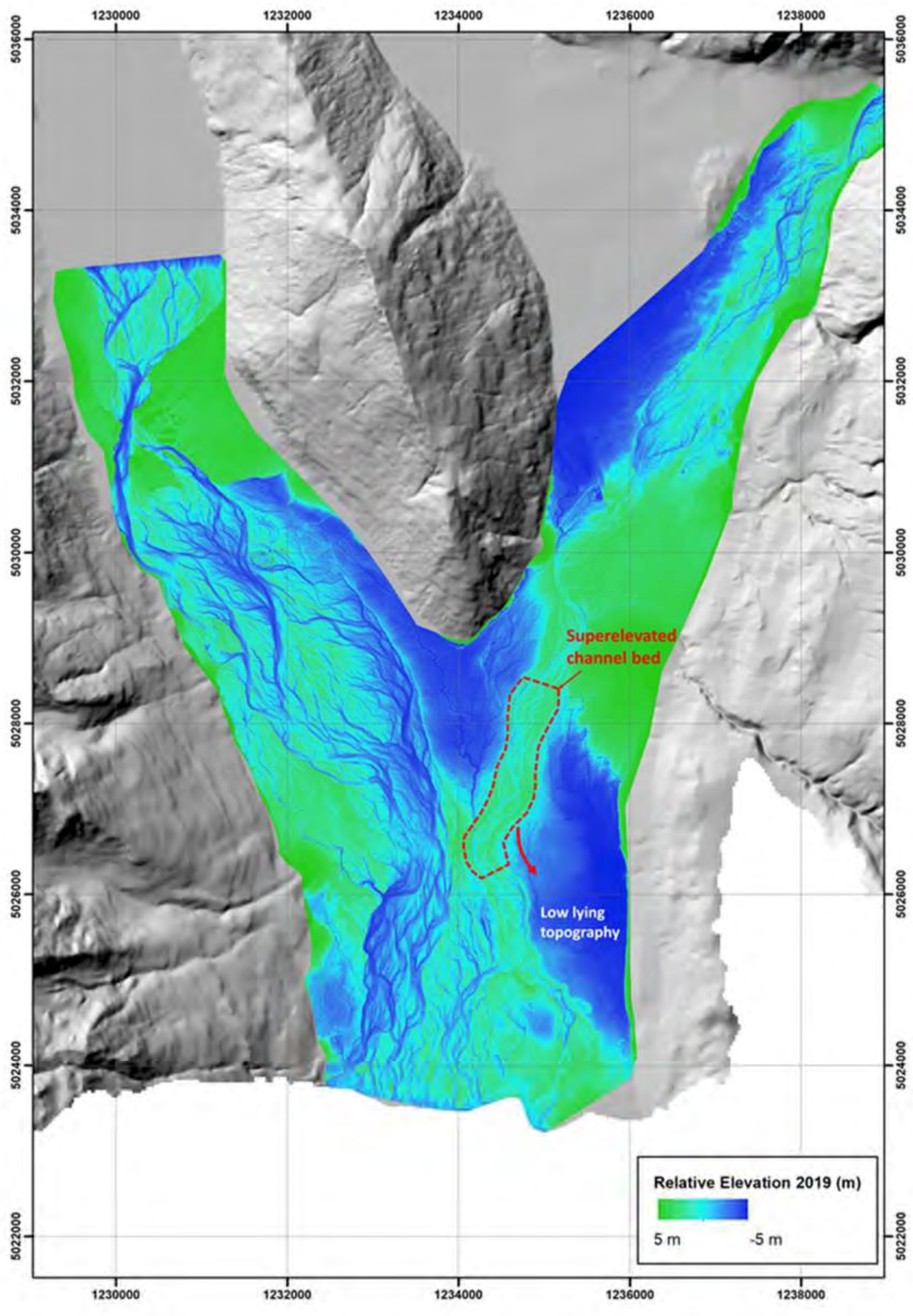


Figure 4: A relative elevation model of the Dart-Rees valley floor, comparing the valley floor elevations to the adjacent average level of the river bed. This clearly shows the section of Rees River superelevated above the valley floor, and posing a potential threat of an avulsion event. (Analysis and image by James Brasington)

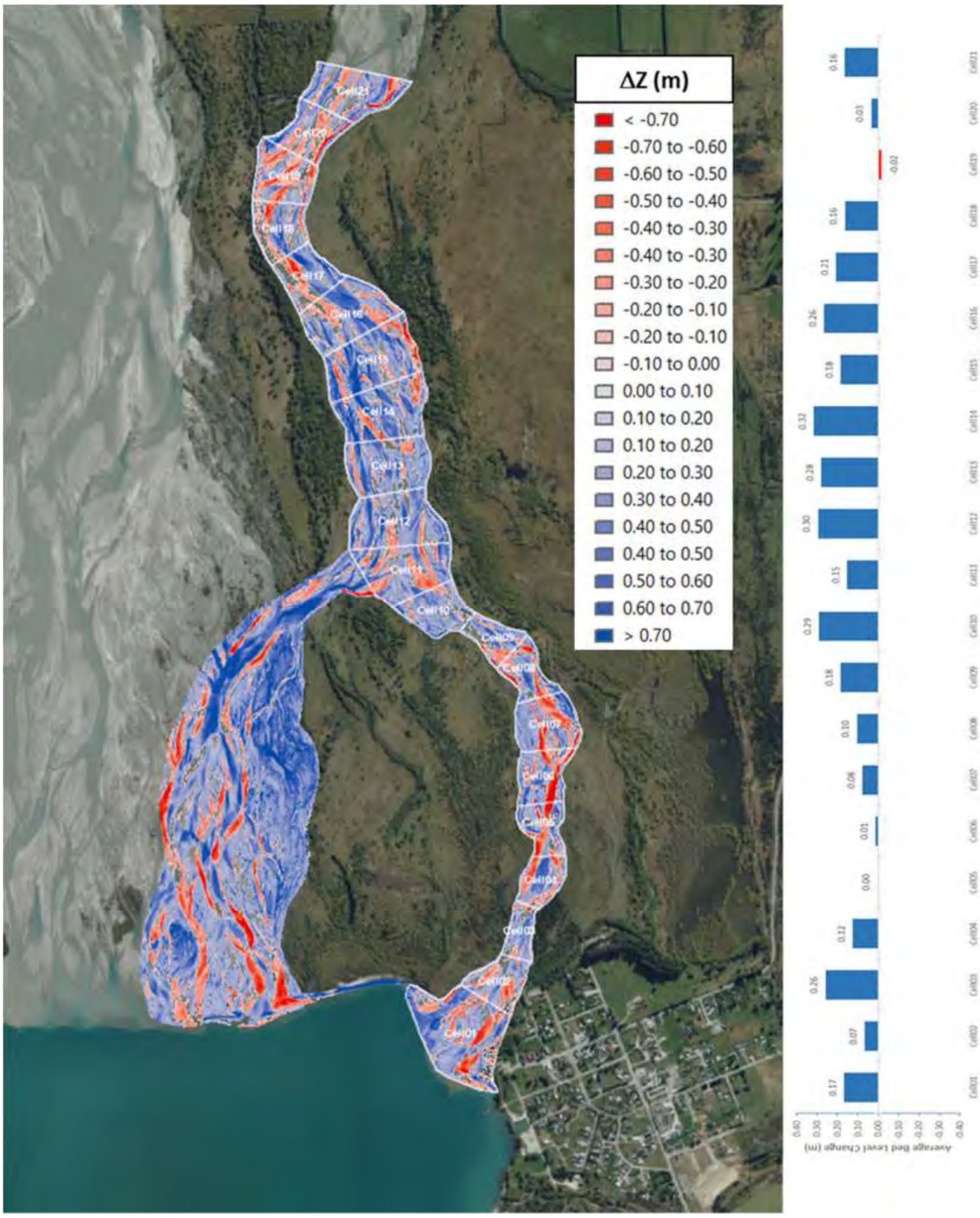


Figure 5: Map of bed level changes on the Rees River from 2011 and 2019. This shows a dominantly aggradational river system, with sedimentation (blue) outweighing erosion (red) for all reaches in the lower Rees. (Analysis and image by James Brasington)

Figure 6: Vertical aerial photograph of Glenorchy township during the January 1994 flood event.

Figure 7: Vertical aerial photograph of the lower Dart-Rees floodplain and delta, and Glenorchy township during the November 1999 flood event.

Figures: Dart floodplain and Kinloch access

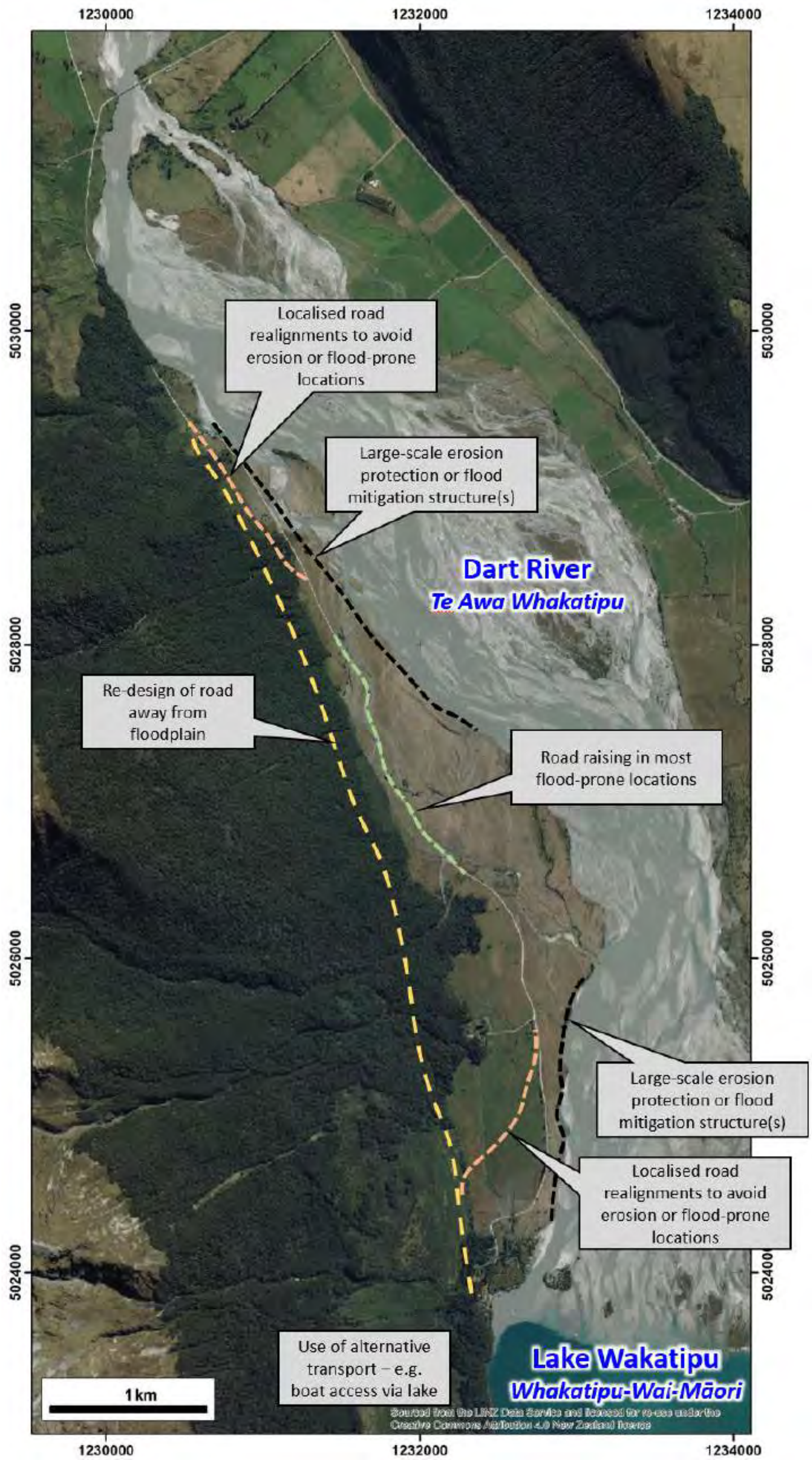


Figure 8: Overview of the lower Dart floodplain, showing the range of potential flood or erosion mitigation options which may be considered in order to maintain Kinloch access. These possible options based on suggestions provided by community.

Figure 9: 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.

Figure 10: Flooding of the lower Dart floodplain in the March 2019 flood event where the Dart River peaked at ~1800 cumecs. Upper photo shows the road near the delta closed due to the combination of river flooding and high lake levels. Lower photo is looking up-valley and shows flooding between Glacier Burn and Turner Creek.

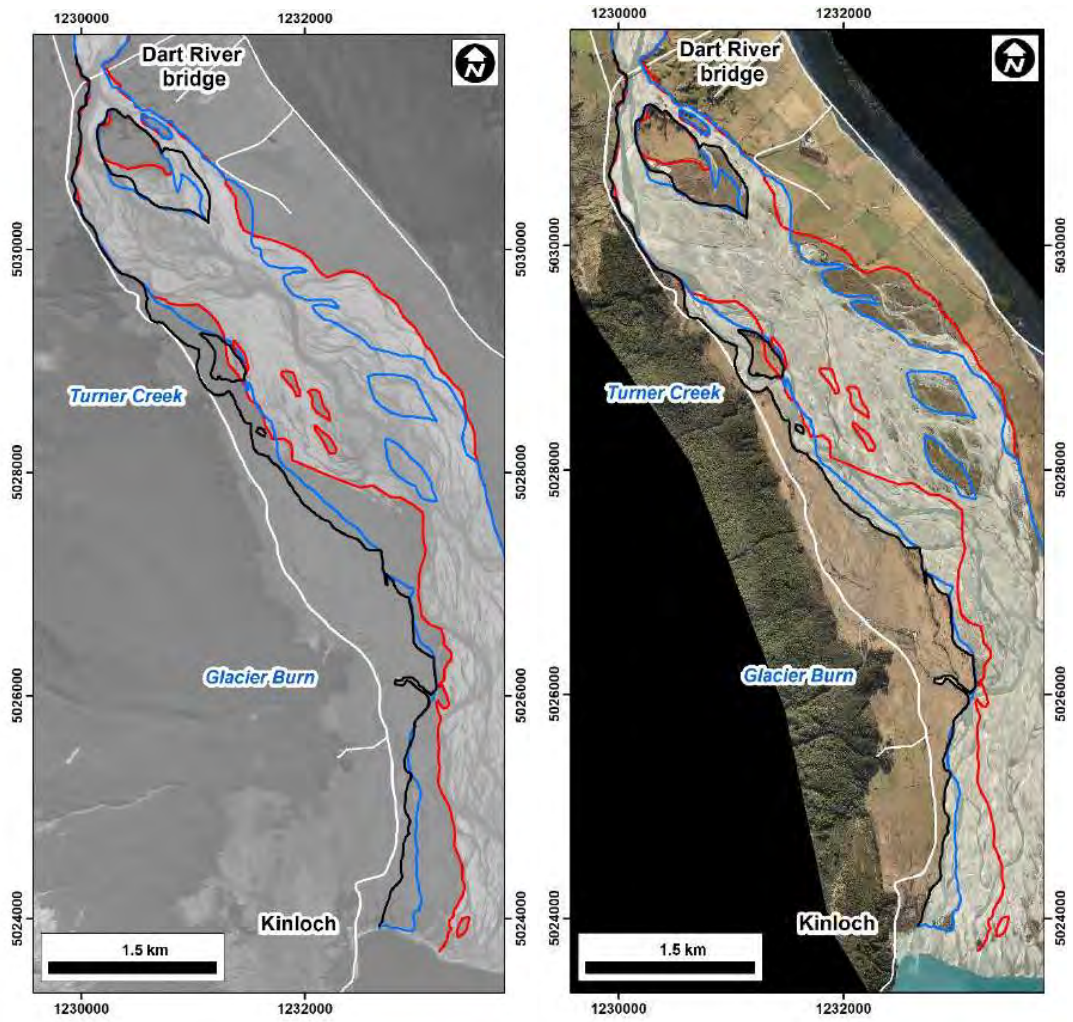


Figure 11: Comparison of aerial imagery for the lower Dart floodplain in 1966 (left) and 2019 (right). Annotation shows the river bank positions in 1966 (red), 2006 (blue) and 2019 (black), illustrating the dominant westwards migration of the active Dart River bed during this time period.

Figure 12: Aerial views (October 2020) of the Dart floodplain between Turner Creek and Kowhai Creek confluences (upper left) and between Glacier Burn and the Dart delta (lower left). Right-hand images show detail of erosion at these locations, taken February 2020 (upper right) and November 2020 (lower right).

Appendix B
ORC Presentation

10/02/2022

HEAD OF LAKE WAKATIPU NATURAL HAZARDS ADAPTATION

Floodplain hazard mitigation approaches workshop

23-24 February 2022

Otago Regional Council | QUEENSTOWN LAKES DISTRICT COUNCIL | UC University of Canterbury | LANDRIVERSEA CONSULTING | DAMWATCH ENGINEERING BEYOND THE SURFACE

1

WELCOME and INTRODUCTIONS

ORC Natural Hazards	Jean-Luc Payan (Facilitator) Tim van Woerden
ORC Engineering	Michelle Mifflin Pam Wilson Scott Liddell
QLDC	Ben Greenwood Hugo De Cosse Brissac Bill Nicoll Mark Baker Alison Tomlinson
Damwatch Engineering	Grant Webby
University of Canterbury	James Brasington
Land River Sea Consulting	Matt Gardner
University of Otago	Jamie MacKenzie (observer)

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2

WORKSHOP PROGRAMME

J-L to add simplified schedule here

- Tim – overview and community 10 min
- QLDC - 30 min
- Tim – hazardscape – 20 min
- James – 30 min plus questions
- Matt - 30 min plus questions
- Jean-Luc – Summary of HOTL Adaptation project - 15 min
- Tim – Adaptation pathways intro and community engagement – 10 min
- All – discussion on adaptation principles etc – 35 min

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3

ENVIRONMENTAL SETTING

4

1

10/02/2022

COMMUNITY SETTING

Total population of about 500

Centred on Glenorchy township, Also rural settlement – Kinloch, Paradise, Greenstone, Rees valley, Wyuna

Main businesses – tourism, farming

Peak of >1000 daily tourist visitors (pre-Covid).

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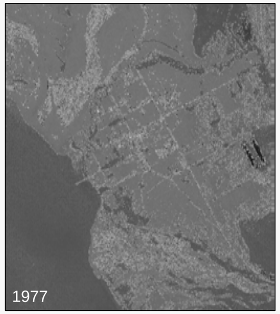
COMMUNITY SETTING

Rapid population growth since ~1980s

Resident population (census data for wider Glenorchy area)
2001: 270
2018: 450

Projected annual growth for Glenorchy township in residents, houses and visitors

	2018	2048
Residents	390	450
Total houses	230	250
Visitors (average day)	1,000	1,420



References:
NZ Census
Utility Ltd, 2018.

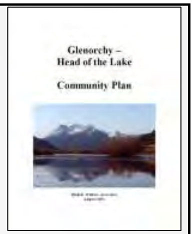
6

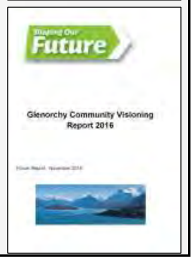
COMMUNITY SETTING

"A vibrant community where lifestyle and 'freedom' are highly valued together with the **peaceful, unspoilt rural environment** and the dynamic interaction of the **spectacular landscape, heritage and wilderness**."

Selected community vision and outcomes statements:

- The uniqueness of the area - the wilderness, scenery and quality of the landscape to be retained
- Activities to be low impact and 'fit' and respect the environment
- Flood management and repair to be visually acceptable as well as functional
- The community to be involved in decision making regarding development of the area





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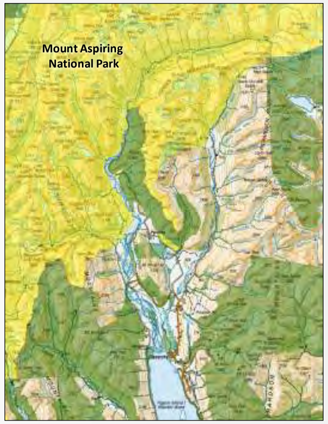
References:
Glenorchy – Head of the Lake community plan, 2001
Glenorchy community visioning report, 2016

7

8

CONSERVATION

- Gateway to Mount Aspiring National Park and Te Wāhipounamu – South West New Zealand World Heritage Area
- Access to Routeburn (a NZ Great Walk, ~15,000 walkers in 2018), and many others – Greenstone-Caples, Dart-Rees.
- Extensive areas of DOC-managed reserves/conservation areas
- 5x ORC 'regionally-significant' wetland areas
- DOC conservation area and significant wetland in lower Rees and Glenorchy Lagoon.
- ORC collaborated with DOC for willow clearance at lagoon in 2020
- ORC have been providing updates to DOC throughout this project



References:
DOC, 2011. Mount Aspiring National Park management plan.
DOC, 2016. Conservation Management Strategy - Otago.

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9

IWI VALUES

"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**."

Very high cultural values, to both Otago and Murihuku rūnaka.
- Widespread use and settlement
- Traditional travel routes
- Traditional resources (e.g. mahinga kai, pounamu)

Two sites designated as tōpuni (recognition of Kāi Tahu values on prominent landscape features):
- Pikirakatahi (Mount Earnslaw),
- Te Koroka (Dart/Slipstream)

- 3x high country stations returned to Ngai Tahu as part of treaty settlements (Elfin Bay, Greenstone, Routeburn).
- Several Ngai Tahu tourism businesses based in Glenorchy (Dart River Jet, kayak, horse riding, heli flights)

References:
Aukaha, 2021. Cultural values statement, Dart-Rees natural hazards project
Ngāi Tahu Ka Huru Manu Atlas (***kahuruumanu.co.nz/atlas***)
Te Rūnanga o Ngāi Tahu website (***ngaitahu.iwi.nz***)

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IWI VALUES

ORC have been providing updates to Iwi (Aukaha, Te Ao Marama) throughout this project

Aukaha has prepared a cultural values statement summarising Mana whenua associations and cultural values

Cultural values
- Mana
- Mauri
- Whakapapa
- Ki Uta ki Tai - 'from the Mountains to the Sea'
- Kaitiakitaka - 'guardianship', responsibility to provide an enhanced quality of life for future generations
- Manaakitaka
- Mahika kai
- Wai Māori and Wai Ora - protecting and enhancing the wellbeing of all bodies of water
- Maumaharataka
- Whakawhanaukataka

References:
Aukaha, 2021. Cultural values statement, Dart-Rees natural hazards project
Ngāi Tahu Ka Huru Manu Atlas (***kahuruumanu.co.nz/atlas***)
Te Rūnanga o Ngāi Tahu website (***ngaitahu.iwi.nz***)

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11

HAZARDSCAPE

Wide range of potential natural hazard impacts

High potential for cascading hazards scenarios

Dynamic/ non-static hazardscape;
- Geomorphic changes
- Climate change

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10/02/2022

HAZARDSCAPE
Glenorchy

Wide range of potential natural hazard impacts

High potential for cascading hazards scenarios

Dynamic/ non-static hazardscape;
- Geomorphic changes
- Climate change

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References:
ORC, 2010. Natural hazards at Glenorchy
T+T, 2021. Head of Lake Wakatipu natural hazards assessment

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HAZARDSCAPE
Cascading Hazards

Complex and inter-related hazards relationships,
- e.g. geomorphic consequences of a major earthquake

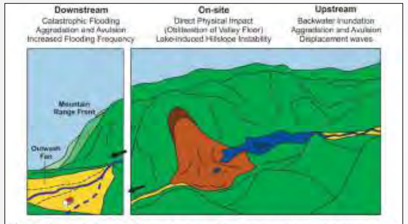
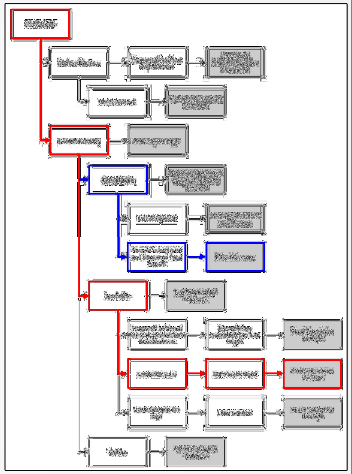


Figure 5.7: Sketch of geomorphic hazards which may result from formation and failure of a landslide dam in a mountain-foreland system (redrawn from Korup 2005a).



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References:
ORC, 2010. Natural hazards at Glenorchy
T+T, 2021. Head of Lake Wakatipu natural hazards assessment

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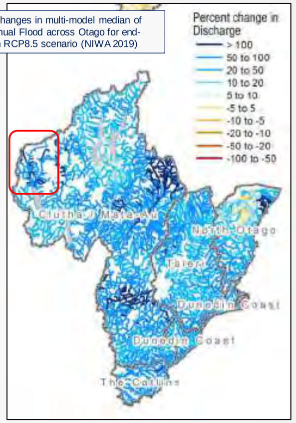
CLIMATE CHANGE

Projected increases in …
- Mean annual rainfall
- Extreme rare rainfall events
- Flood magnitudes
- Sediment transport (and aggradation rates?)
- Mean lake levels?

Dart River, 1% AEP flood
- Current climate: 2,420 cumecs peak flow
- RCP8.5 scenario: 2,900 cumecs peak flow (~20% increase)

Percent changes in multi-model median of Mean Annual Flood across Otago for end-century in RCP8.5 scenario (NIWA 2019)



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References:
NIWA, 2019. Climate change projections for the Otago Region
ORC (Mohssen), 2021. Analysis of Flood Hazards for Glenorchy

15

MAIN HAZARDS ISSUES FOR FLOODPLAN HAZARD MITIGATION

1. **Glenorchy township Rees River flooding hazard**
   - Increasing flooding hazard – aggradation relative to dwellings/floodbank
   - Avulsion hazard
   - Climate changes
2. **Kinloch access**
   - Increased flooding hazard to road with riverbed aggradation
   - Continued westwards erosion of Dart River
3. **Rees Bridge**
   - Rees aggradation at bridge reducing capacity?
4. **Rees true right floodplain upstream of bridge**
   - Increasing flooding hazard – aggradation relative to floodbank?
   - Road access to Paradise
   - Flood impact to farmland

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A LONG HISTORY OF FLOODING …

Notable flood events
- 1878 – Lake Wakatipu reached 312.6m
- 1924 & '25
- 1952 – original Rees bridge washed away
- 1978

FLOOD AT GLENORCHY, HEAD OF LAKE WAKATIPU

Otago Witness, Issue 3650, 26 February 1924, p37

"***The Rees and Dart Rivers have joined forces and become one raging torrent***" (1952)

"The Dart and Rees … having converged some miles up at the foot of Mount Alfred. As far as the eye can reach this part of the country is one sheet of water" (1924)

References:
ORC, 1993. Known floods of Queenstown Lakes District
ORC, 1999. Queenstown Lakes District floodplain report

17

January 1994 - the 'Race Day Flood'

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18

November 1999

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References:
ORC-QLDC, 2006. Learning to live with flooding – a flood risk management strategy for the communities of Lakes Wakatipu and Wanaka

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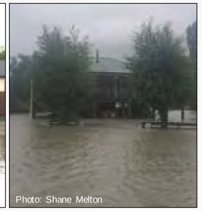
February 2020



References:
ORC file note, 2020. Notes on February 2020 flooding in Glenorchy

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10/02/2022

Dart floodplain 2019-2022

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REES RIVER FLOOD DEFENCES

Rees-Glenorchy floodbank

- Constructed in 2000, length of ~1400m
- Several assessments of structure stability in 2020-2021
- 2021 floodbank repairs near creek confluence (update from QLDC?)

Rees floodbank (true right, u/s of bridge)

- Constructed in 1984, length of ~4km

References:
WSP, 2020. Glenorchy floodbank Rees River. Memo July 2020.
WSP, 2020. Glenorchy-Rees Floodbank assessment. September 2020
T+T, 2021. Rees-Glenorchy floodbank structure failure modes assessment.

22

RIVER MANAGEMENT ACTIVITIES

By ORC & QLDC

- Gravel extraction
- Channel realignments
- Groyne construction
- Rock armouring
- Floodbanking/bunding
- Debris fencing
- Willow planting
- Willow removal

23

REES BRIDGE

Concerns by QLDC and community members that continued aggradation will threaten flow capacity at bridge

But potential hazard not well known;

- What is flow capacity of bridge?
- No regular monitoring of river bed levels at bridge?
- Not yet any modelling of how aggradation might impact flow capacity?

QLDC hold consent[1] for gravel extraction at bridge

- Usually extracting 10-20k m^3 annually)

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1. Consent RM20.205

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REES FLOODBANK

Concerns by residents that continued aggradation will reduce floodbank protection levels
- Potential for increased flood impacts to road and farmland

But potential hazard not well known;
- What is LOS of floodbank?
- Not yet any modelling of how aggradation might impact flow capacity?

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26

HEAD OF THE LAKE NATURAL HAZARDS ADAPTATION

Using the Adaptation Pathways approach to create a natural hazards adaptation strategy for the area

Aiming to develop a process for decision-making regarding the natural hazard threats in this area, in collaboration with project partners, and the local community

Key project steps to date:
- Project planning
- Develop project partner relationships
- Technical hazards investigations
- Community relationships and initial engagement sessions

Next project steps:
- Assessment of potential adaptation approaches and interventions
- Continued community engagement
- Development of initial adaptation pathways and draft adaptation strategy

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References:
ORC, 2021. Natural hazards adaptation in the head of Lake Wakatipu.

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ADAPTATION PROJECT
Project timelines

Project planning
- Planning, data and information compilation, natural hazards investigations

2019/20

Additional natural hazards investigations

Natural hazard risk assessments
Late 2020

Engagement sessions 1 & 2
Late 2020 – early 2021

Review possible adaptation options
2022

Engagement sessions 3 & 4
2022

Implementation planning
- Further investigation of preferred options (feasibility, cost-benefit etc)
- Additional hazard/risk assessments

2022 - …?

Implementation and review
- (e.g. engineering or planning responses)
- Reviews of strategy

ongoing…

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10/02/2022

HEAD OF THE LAKE NATURAL HAZARDS ADAPTATION

- Substantial revision of Dart-Rees and Glenorchy natural hazards information in progress (2021-2022);
  - **Dart-Rees River morphology and geomorphic change assessments**
  - **Flood frequency analysis** (Dart & Rees Rivers, Lake Wakatipu)
  - **Hydraulic modelling and flood hazard assessment** (Dart-Rees, Glenorchy)
  - **Liquefaction and lateral spreading susceptibility investigation** (Glenorchy township)
  - **Buckler Burn alluvial fan hazards**
  - **Lake tsunami** (ORC support for PhD research project)

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COMMUNITY ENGAGEMENT

Four-stage engagement process

✓ 1. What is happening now, and how does this affect you? (December 2020)

✓ 2. What could happen in the future, and what might we do? (April 2021)

3. How can we navigate the adaptation options?
4. What do the adaptation pathways look like, and what happens now?

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James, Matt intro content here

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THE ADAPTATION PATHWAYS APPROACH

Adaptation: "a response strategy to anticipate and adjust to actual and expected changes in environmental conditions"

Adaptation could entail …
- tweaks and small changes to existing practices systems (i.e., incremental adaptation)
- fundamental changes and re-design (i.e., transformational adaptation)

Sequencing adaptations over time is a concept known as **adaptation pathways**
- a conceptual and analytical framework for enabling adaptation planning and decision-making in response to long-term change

References:
Ministry for the Environment, 2017). Coastal Hazards and Climate Change: Guidance for local government.

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10/02/2022

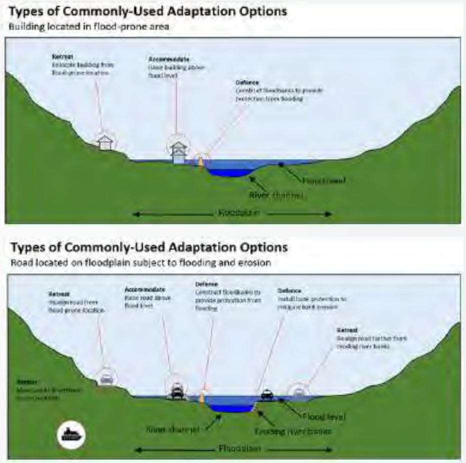
NATURAL HAZARDS ADAPTATION APPROACHES

Four groupings of natural hazard adaptation options

- Accommodate, Protect, Retreat, or Avoidance strategies
- But 'do nothing' is also an option (no systematic or proactive adaptation planning).

Combinations of these options will be required

- short term, medium term, and longer term



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ADAPTATION PATHWAYS
Signals, Triggers and Thresholds

Under what conditions does the action or option in the plan (or for the existing situation) no longer meet objectives?

Adaptation Threshold: the point at which a range of evolving conditions would become unacceptable and objectives or levels of service are no longer met (or "***what people do not want to happe***n")

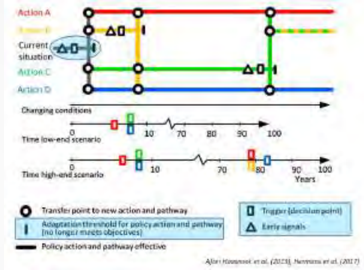
e.g. Catastrophic/repeated flooding of Glenorchy houses, sudden/complete loss of access to Kinloch?

Triggers: a decision point, when implementation of an alternative plan or pathway is required to avoid the impacts of reaching an Adaptation Threshold.

e.g. Near-miss flood events, frequency/severity of access disruptions, $ value of repair works, distress/uncertainty for residents?

Signals: indicators providing early indication of need to start re-engaging and reviewing the adaptive plan.

e.g. Channel migration/locations, aggradation and mean bed levels



References:
Ministry for the Environment, 2017). Coastal Hazards and Climate Change: Guidance for local government.

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Signal → Trigger → Threshold
Change

Threshold is loss of access to Kinloch (or only ad-hoc informal access possible – private boats etc)

Possible **signals/triggers** for change

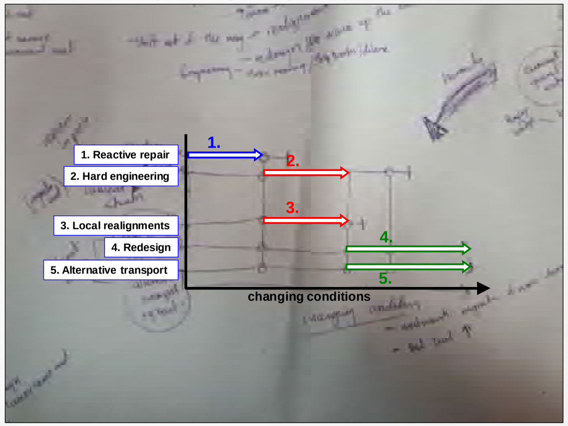
- Frequency of road closures
- $ value of repair works
- Distance of active channel from road

X-axis is **changing conditions** (not time)

e.g. for Kinloch access could be

- Westwards migration of river channel
- Bed level rise

Conceptual Adaptation pathways: Kinloch access



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ADAPTATION
Examples of Adaptation Triggers

Hazards	Riverbank erodes to within X m of house(s), or other infrastructure	After X floods overtop flood protection or land use assets	The 20-year Mean Annual Flood reaches X m^3/s
Risk	Event causing >$XM damage (or insured losses)	The next catastrophic flood (define risk/impact, extent)	Levels of service for a utility or infrastructure dip below a minimum agreed level (or for X times)
Social	Measure of concern/ anxiety or wellbeing	Tolerance measure, e.g., sense of community is threatened; people start moving out or cannot move because cannot afford to	Specific societal objective is no longer met
Financial/ Economic	Insurance withdrawn or no new build insurance	Maintenance costs exceed $X pa for protection works	Bank mortgages difficult to secure
Cultural	Taonga or sites (e.g., urupa) begin to be inundated or are regularly inundated	Access to mahinga kai limited or lost	
Environmental	X% loss of wetlands/ marshes/bird numbers/ riparian habitat		
Governance/ institutional	Central government adaptation law changes	Reduction in LoS, e.g., flood control, wastewater, water supply	

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10/02/2022

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COMMUNITY ENGAGEMENT
Rees River and Glenorchy flood hazards

Potential river management or engineered interventions suggested by community members

- Raise buildings or raise land levels in the town
- Control willows at lagoon
- Gravel extraction, river channel realignments, divert Rees
- Raise the Glenorchy floodbank
- Erosion control (groynes, willow/flax plantings)
- Prevent river flows towards lagoon from lower Rees (bunding/floodbanking)

- Raise the Rees bridge, or extract gravel from underneath bridge

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References:
NIWA, 2021. Thematic analysis of notes from 8th April 2021 Glenorchy community engagement event

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References:
NIWA, 2021. Thematic analysis of notes from 8th April 2021 Glenorchy community engagement event

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COMMUNITY ENGAGEMENT
Dart floodplain and Kinloch access

Potential river management or engineered interventions suggested by community & in ORC discussions

- Status quo ('reactive repair')
- Hard engineering structures
- Local road realignments
- Redesign (relocation from floodplain to hillslopes?)
- Alternative transport (boat access)

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KEY QUESTIONS FOR ADAPTATION AT THE DART-REES FLOODPLAIN

- What does sustainable river management look like for the Dart-Rees floodplain and what does it offer?
- What does sustainable flood protection look like and what level of protection is realistically achievable?
- What other complementary strategies are available to achieve natural hazard resilience (e.g. planning controls)?
- Can we define principles for an ORC river management strategy in this location?

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OBJECTIVES FOR ADAPTATION AT THE DART-REES

- An understanding of viable, sustainable river management approaches, suitable for the floodplain/river environment of the Dart-Rees area.
- An estimation of how long, or under what conditions these approaches might remain effective.
- An understanding of key constraints/factors for river management interventions (costs, environmental, cultural, feasibility, community acceptability etc).
- How these approaches might fit within wider content of natural hazard management and adaptation (e.g. planning responses, potential retreat)
- Specific review of risks/benefits of all options identified by the community during engagement activities.

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PRINCIPLES FOR ADAPTATION

Natural system/processes
- Recognition of the need to understand the underlying natural systems and processes
- A long-term sustainable, integrated and strategic approach to floodplain risk management, working with the natural river processes
- Appropriate forms and levels of protection, and are sympathetic to environmental amenity values

Societal
- Widest possible benefits for community, works in with other community objectives
- Affordable and acceptable to council, the community and direct beneficiaries, also environmental/cultural factors
- Community involvement and ownership

Political/economic
- A commitment by project partners (ORC, QLDC, DOC, Iwi) to work together
- Adopting a precautionary approach;
- Ensuring adaptive management;
- Recognition and treatment of residual risk
- Taking a low-regrets or even no-regrets approach to risk treatment/adaptation;
- Avoiding locking in options due to adaptation and development decisions that limit further adaptation in the future;

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WHAT DO SUCCESSFUL ADAPTATION APPROACHES LOOK LIKE?

- Has a long-term view (50-100 years)
- Provides flood protection benefits
- Costs are acceptable/justified
- Health of the environment and natural amenity values must be key factors.
- Risk and benefits of alternative strategies/pathways communicated to other stakeholders
- Approaches are supported and acceptable to all of wider community (e.g. residents, DOC, Kai Tahu).
- Involves on-going monitoring of natural processes and tracking of geomorphic changes and adaptation performance

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WHAT INTERVENTION ASSESSMENT FACTORS NEED TO BE CONSIDERED?

- What is intervention trying to achieve?
- What are impacts?
- What are benefits?
- What are risks?
- What are consequences of failure of specific interventions? (e.g. reducing level of protection through time – due to aggradation?)
- How long will river management/engineered interventions provide continued protection?
- How viable are these river management/engineered interventions in the longer-term? – especially given the environmental/hazard context (e.g. ongoing riverbed aggradation, geomorphic consequences of an Alpine Fault earthquake, and climate change impacts on hydrology and flooding).
- Regulatory frameworks (Freshwater NPS, ORC Water Plan, RMA, district Plan etc).
- What on-going monitoring is required?
- What performance standards should be applied? (what performance do community consider is acceptable?)

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CONSERVATION

References:
DOC online maps: www.doc.govt.nz/map/index.html

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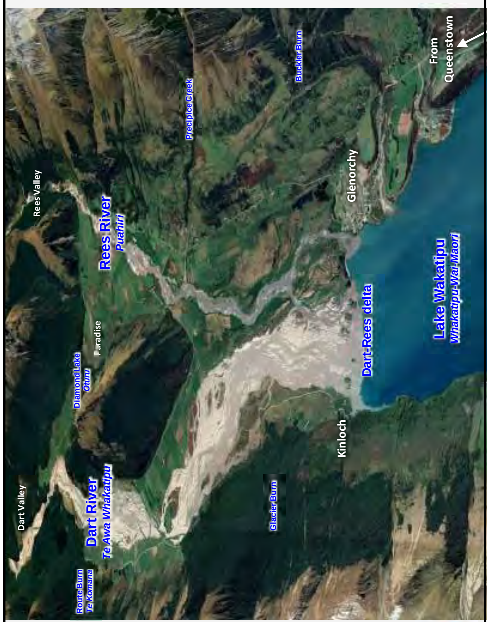

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Appendix C

QLDC Presentation on Kinloch Road

12/05/2022

Kinloch Road

Impact on operations and ongoing repair costs due to flooding

QUEENSTOWN LAKES DISTRICT COUNCIL

1

Context

- Dart River has been changing course over the past several years and in places flows very close to Kinloch Road
- Kinloch Road is closed relatively frequently due to surface water covering the road or flood damage

QUEENSTOWN LAKES DISTRICT COUNCIL

2


Photo during flood 25/10/20


Photo 1 week before flood


Post flood armouring

QUEENSTOWN LAKES DISTRICT COUNCIL

3

Operations approach

- Once a rainfall event which is forecast for >30mm in 24 hours begins, **monitoring** is undertaken every 4 hours between 8am-6pm in keeping with winter maintenance LoS
- If the road formation is not visible or un-trafficable the road will be **closed**
- The road will be **opened** once the road formation is clearly defined and other safety hazards (eg culverts, surface shape) are assessed and repaired
- Downer provide **communications** updates to the QLDC Comms address

QUEENSTOWN LAKES DISTRICT COUNCIL

4

1

12/05/2022

Maintenance approach

- In the short term we are managing Kinloch Road under the following two approaches

1) LTP funding of $220,000 every 2nd year for Rees River Bridge Resilience

For the 21-24 LTP, funding is in 21/22 and 23/24. The purpose of this activity is to reduce gravel aggregation under the bridge. Gravel is extracted and disposed of, ideally as economically as possible. We have been taking the opportunity to raise Kinloch Road with this gravel. Although a lesser quantum of gravel can be extracted for the budget due to a longer haul distance, there are overall synergies to Council as if this was not done, the road raising with an alternative gravel source would hit emergency works budgets. In reality the quantities of gravel we can remove for $110,000/year regardless of the disposal approach is insignificant compared to the volume of gravel that comes down the river. Ie bridge raising is likely to be inevitable in the near future. This approach only works for planned works ie securing resource for gravel extraction, notifications, season.

2) Emergency works – when unplanned works are required outside of gravel extraction opportunities such as armouring or emergency road raising

5

Maintenance cost

- Context of Kinloch Road cost for emergency works Oct 2016 - now
- Excluding outliers it is Council's most expensive road /km for emergency works
- The below data does not factor in the Gravel extraction budgets, and $130k worth of Fulton Hogan work done in 2019 (this would make Kinloch Rd the most expensive despite its length)

TOP 10 ROADS BY TOTAL COST

Sum of sum_cost

Road	Total
GLENORCHY-QUEENSTOWN ROAD	$1,779,379.67
CROWN RANGE ROAD	$445,131.30
SKIPPERS ROAD	$437,471.73
KINLOCH ROAD	$359,792.68
CARDRONA VALLEY ROAD	$258,349.98
GLENORCHY-PARADISE ROAD	$164,282.23
THE MALL	$107,472.79
VON ROAD	$97,854.20
REES VALLEY ROAD	$92,035.55
WANAKA-MOUNT ASPIRING ROAD	$82,443.36
Grand Total	$3,824,213.47

TOP 10 ROADS BY COST PER KM

Sum of cost_pkm

Road	Total
THE MALL	$716,485.27
JOCK BOYD PLACE	$220,513.73
TOBINS TRACK(CROWN TERRACE END)	$138,345.63
KINLOCH ROAD	$40,918.08
GLENORCHY-QUEENSTOWN ROAD	$40,478.17
RIVERSIDE ROAD	$34,744.91
BENMORE PLACE	$34,565.52
SOHO STREET	$28,065.91
MONLEY LANE	$27,403.06
SKIPPERS ROAD	$26,781.25
Grand Total	$1,308,301.54

6

Strategic approach

- We are hoping to have more idea of "where to from here" for Kinloch Rd following this workshop.. ☺

7

Glenorchy Floodbank repairs

- Floodbank of Rees River has overtopped a few times in the recent past
- A piece of "do-minimum" works was complete by QLDC, informed by a WSP report

- This work involved:
- 1200T (about $100k supply and haul) of rock was carted to Glenorchy last year
- We had a delay approx. 6mo while WSP / ORC worked out some issues with the consent
- Works completed (about $100k more) to place the rock, repair over steepened areas and raise a small area of the stop bank near the golf course

- In addition, last year? ORC completed fairly significant works to clear the river bed of willows and this appears to have helped reduce risk by lowering the water level in the lagoon

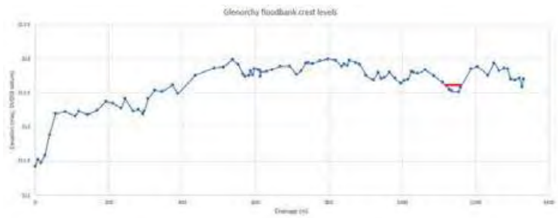
8

2

12/05/2022

Historic survey of floodbank

- Red line = recently completed raising (indicative)



QUEENSTOWN LAKES DISTRICT COUNCIL

9

QUEENSTOWN LAKES DISTRICT COUNCIL

10

3

Appendix D

Presentation by Professor James Brasington (Waterways Centre for Freshwater Management)

FLUVIAL HAZARDS AT THE TOP OF THE LAKE

LIVING WITH RIVERS ON THE EDGE

PROFESSOR JAMES BRASINGTON
Waterways Centre for Freshwater Management

Waterways

UC Lincoln University

FAR FROM EQUILIBRIUM

DRIVER 1: CLIMATE CHANGE

0.5-1.5 °C by 2040; 0.5-3.5 °C by 2090
20-40% increase in winter rainfall and intense storms
Up to 100% increase in mean annual flood flow

DRIVER 2: RIVER BED AGGRADATION

Build up of riverine sediment
Reduces the cross-sectional area
Reduces the gradient of the river

→ **REDUCED FLOOD CAPACITY**

REES-DART DELTA, DECEMBER 2009

FLUVIAL HAZARDS

If not the most catastrophic threat … rivers pose the **most frequent hazard** to the lakeside communities

Risks to **life, property and critical infrastructure**

- Direct inundation and swift water hazards
- Entrained debris and sediment
- Bank and stream erosion

Unlike other natural hazards … at Glenorchy we expect **fluvial hazards to increase in frequency and severity in the coming decades**

FEBRUARY 4TH 2020; c/o LUKE HUNTER

SEDIMENT: unlimited

Globally extreme rates of erosion

- **Glacial legacy > oversteepened slopes**
- **Continuing uplift > 5 mm / year**
- **Orographic precipitation > 5000 mm / year**

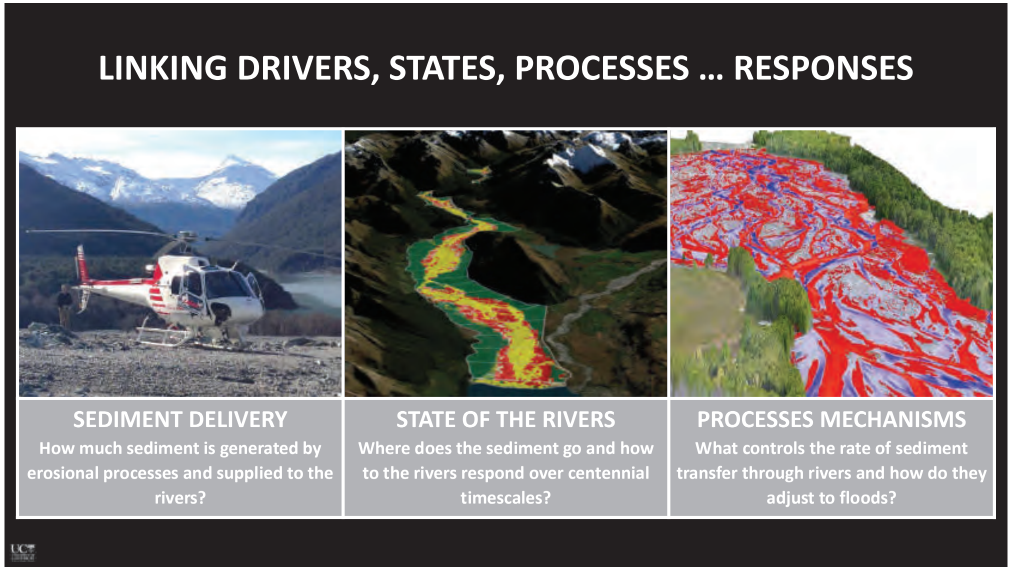
Unstable 'paraglacial' landscape

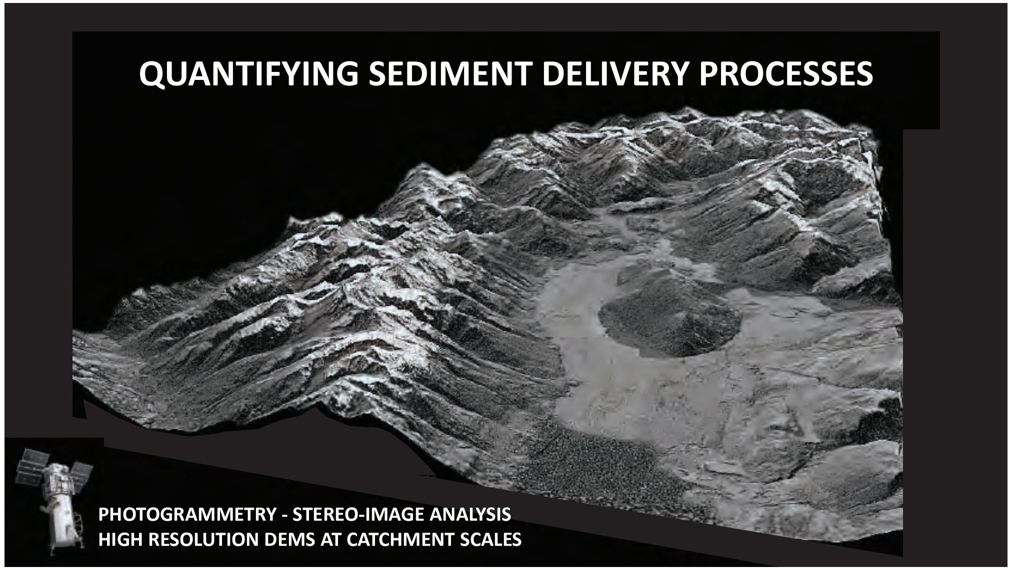
- **Catchment dominated by active landslides**
- **Retreating headwater glaciers**

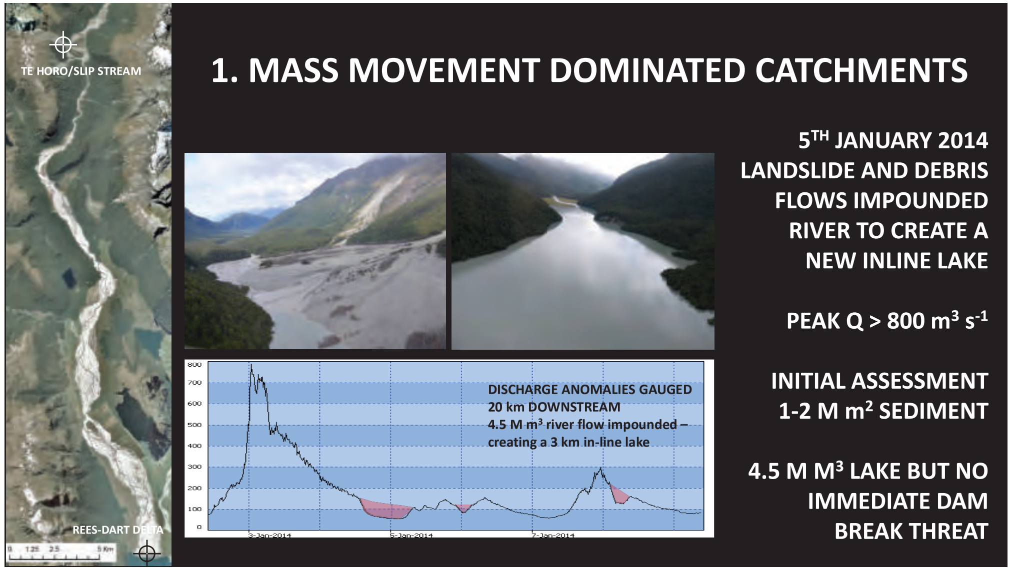
'*Unlimited*' sediment availability

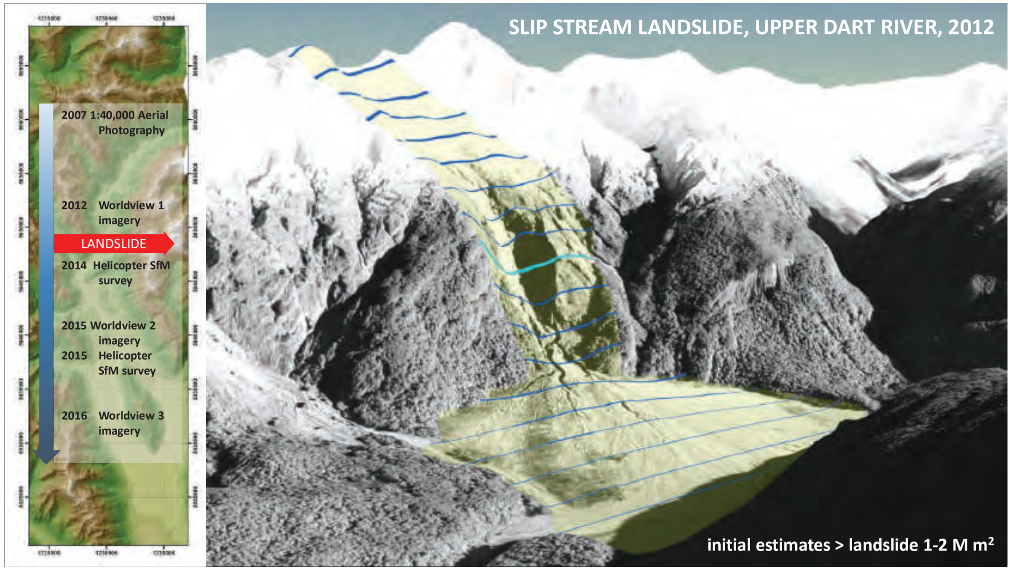
- **More sediment available than the capacity of the rivers to transport it downstream**
- ***Transport limited* catchment system**

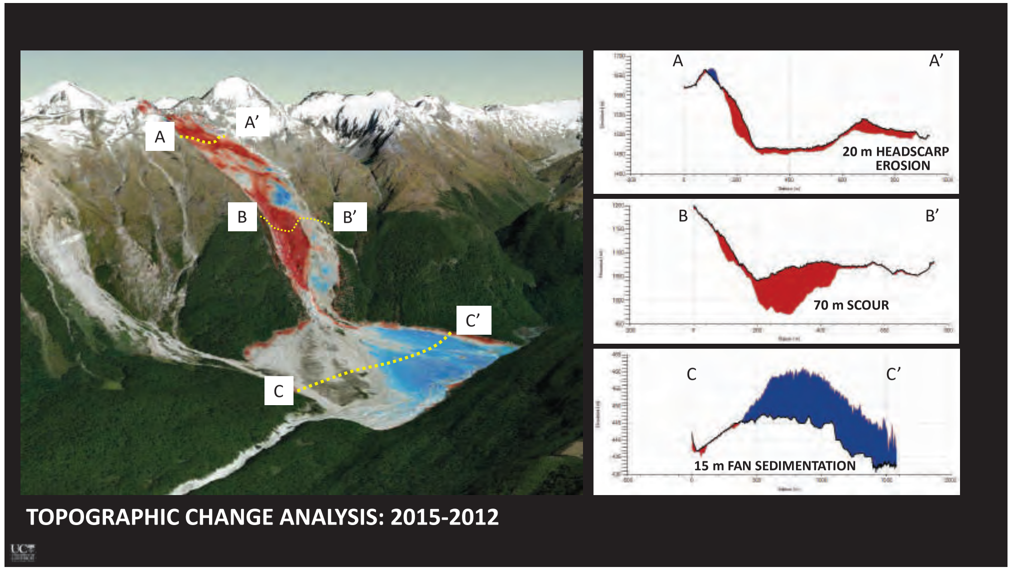
TE HORO | SLIP STREAM, MAY 2014

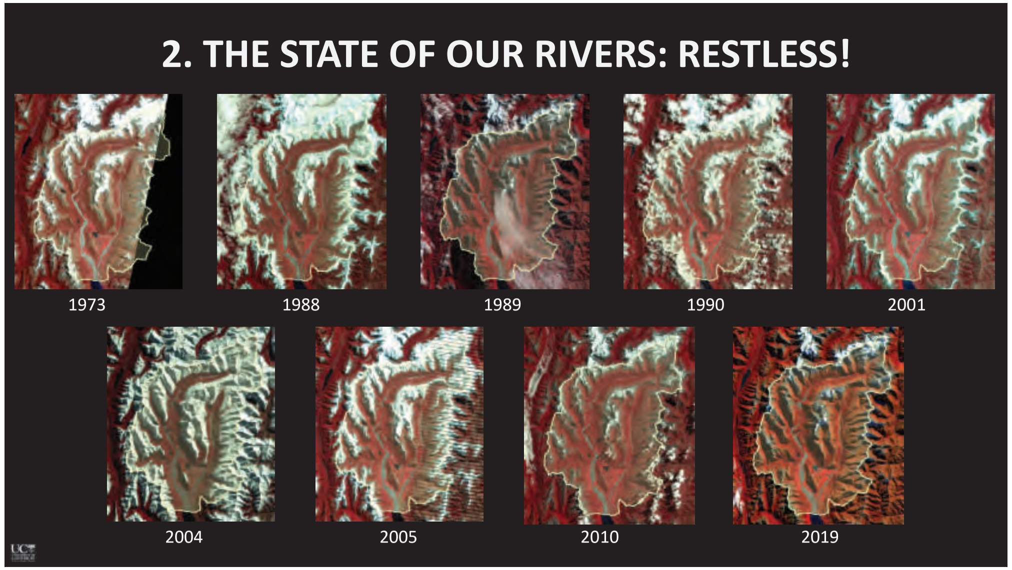

LINKING DRIVERS, STATES, PROCESSES … RESPONSES
SEDIMENT DELIVERY
How much sediment is generated by erosional processes and supplied to the rivers?
STATE OF THE RIVERS
Where does the sediment go and how to the rivers respond over centennial timescales?
PROCESSES MECHANISMS
What controls the rate of sediment transfer through rivers and how do they adjust to floods?

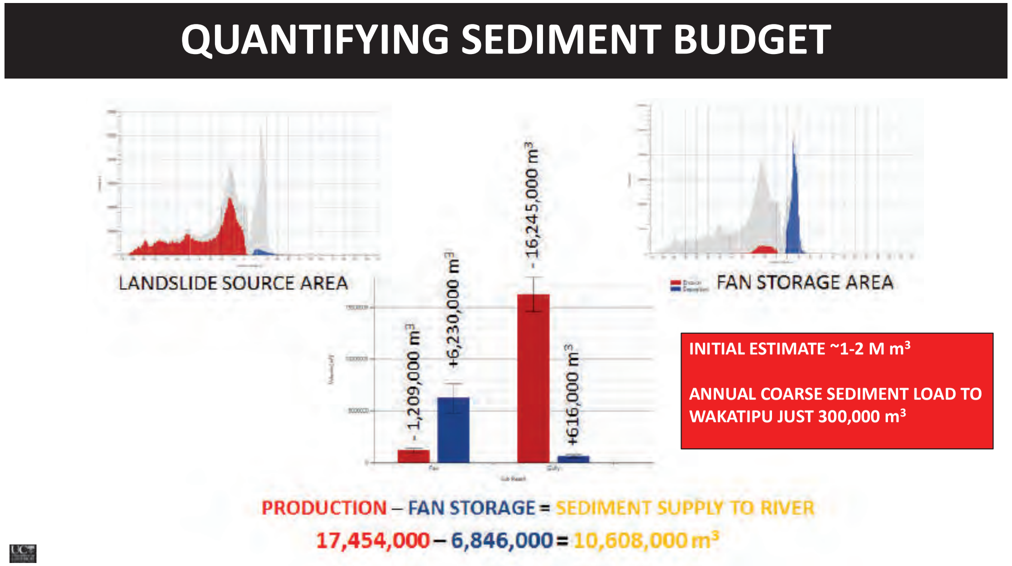

QUANTIFYING SEDIMENT DELIVERY PROCESSES
PHOTOGRAMMETRY - STEREO-IMAGE ANALYSIS
HIGH RESOLUTION DEMS AT CATCHMENT SCALES

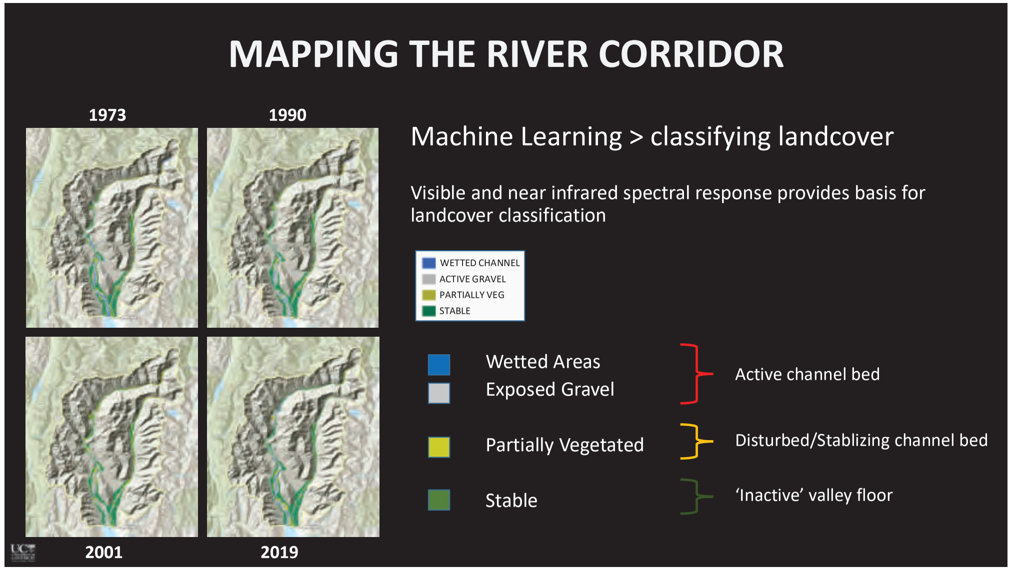

1. MASS MOVEMENT DOMINATED CATCHMENTS
TE HORO/SLIP STREAM
REES-DART DELTA
5TH JANUARY 2014
LANDSLIDE AND DEBRIS FLOWS IMPOUNDED RIVER TO CREATE A NEW INLINE LAKE
PEAK Q > 800 m3 s-1
INITIAL ASSESSMENT
1-2 M m2 SEDIMENT
4.5 M M3 LAKE BUT NO IMMEDIATE DAM BREAK THREAT
DISCHARGE ANOMALIES GAUGED
20 km DOWNSTREAM
4.5 M m3 river flow impounded – creating a 3 km in-line lake

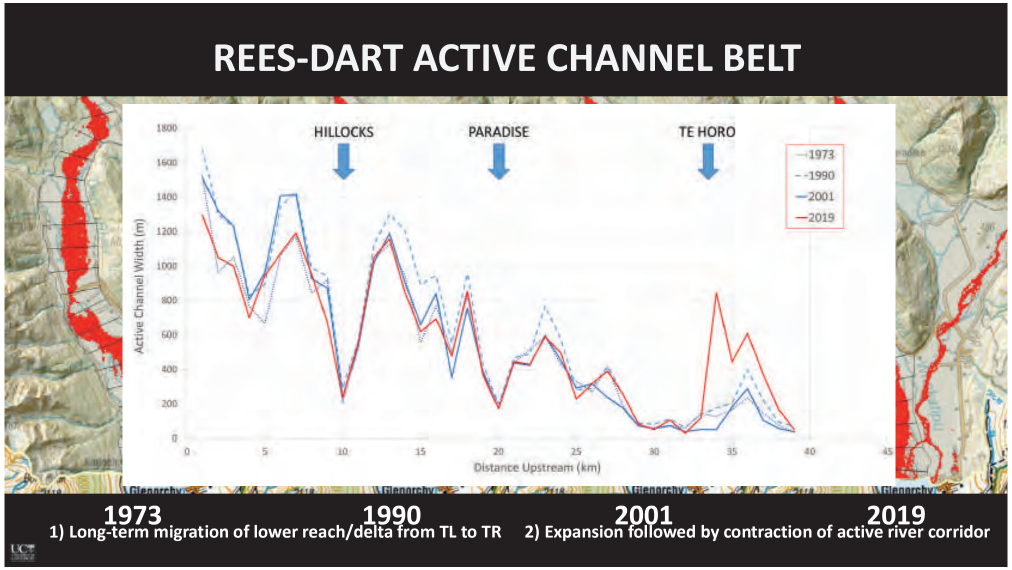

SLIP STREAM LANDSLIDE, UPPER DART RIVER, 2012
2007 1:40,000 Aerial Photography
2012 Worldview 1 imagery
LANDSLIDE
2014 Helicopter SfM survey
2015 Worldview 2 imagery
2015 Helicopter SfM survey
2016 Worldview 3 imagery
initial estimates > landslide 1-2 M m2

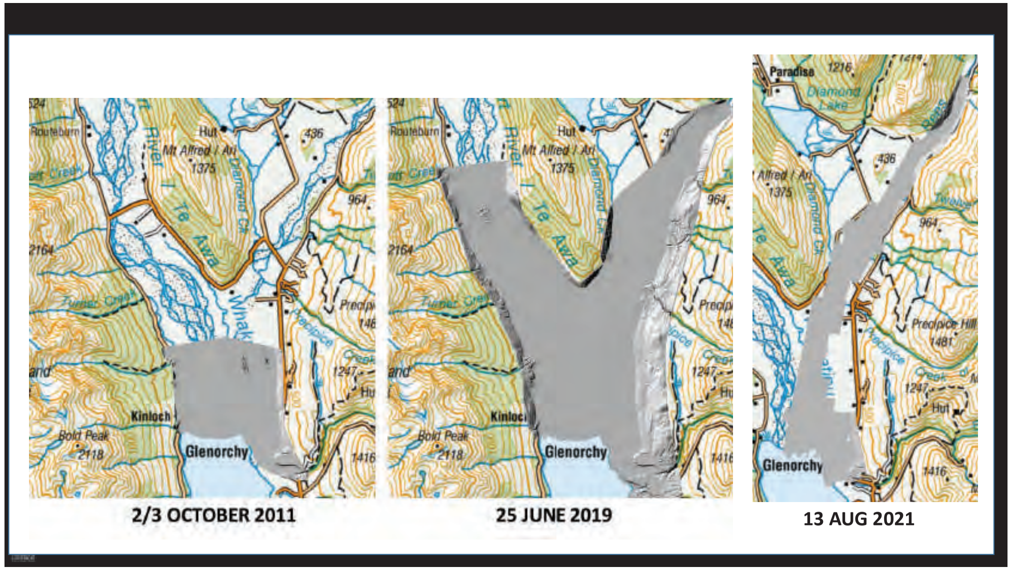

A
A′
B
B′
C
C′
20 m HEADSCARP EROSION
70 m SCOUR
15 m FAN SEDIMENTATION
TOPOGRAPHIC CHANGE ANALYSIS: 2015-2012

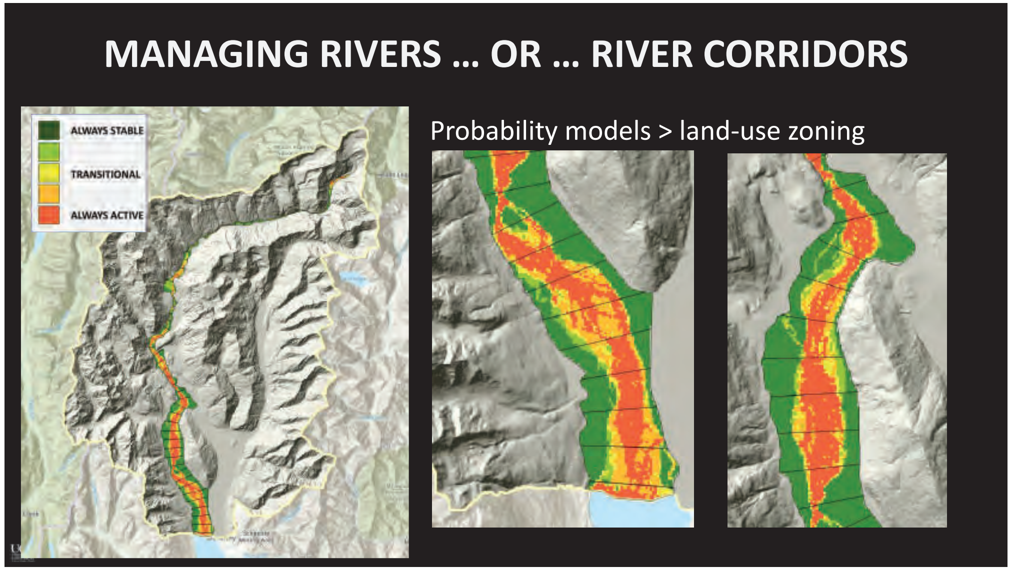

2. THE STATE OF OUR RIVERS: RESTLESS!
1973
1988
1989
1990
2001
2004
2005
2010
2019

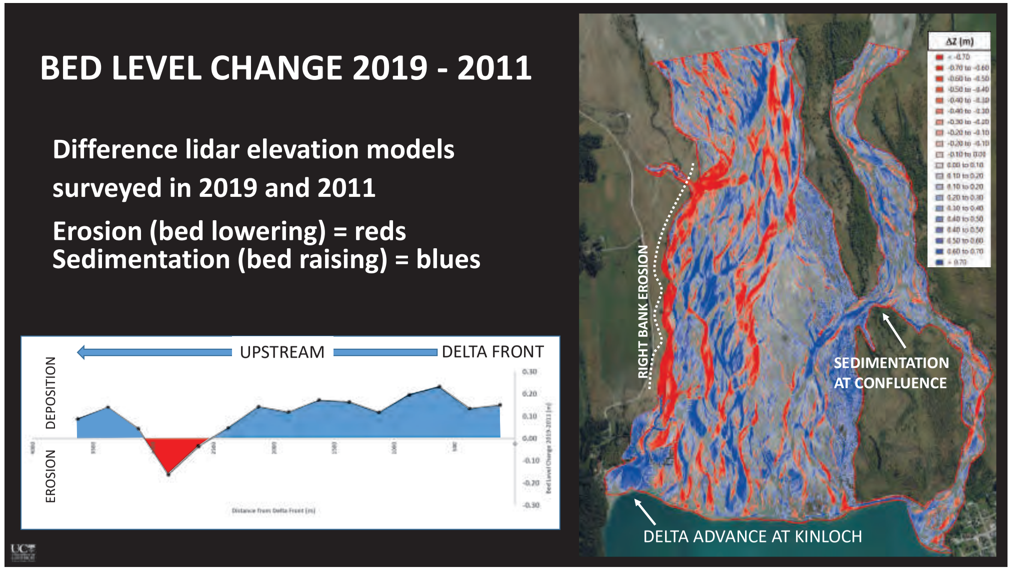

QUANTIFYING SEDIMENT BUDGET
LANDSLIDE SOURCE AREA
FAN STORAGE AREA
- 1,209,000 m³
+6,230,000 m³
- 16,245,000 m³
+616,000 m³
INITIAL ESTIMATE ~1-2 M m³
ANNUAL COARSE SEDIMENT LOAD TO WAKATIPU JUST 300,000 m³
PRODUCTION – FAN STORAGE = SEDIMENT SUPPLY TO RIVER
17,454,000 – 6,846,000 = 10,608,000 m³


MAPPING THE RIVER CORRIDOR
1973
1990
2001
2019
Machine Learning > classifying landcover
Visible and near infrared spectral response provides basis for landcover classification
WETTED CHANNEL
ACTIVE GRAVEL
PARTIALLY VEG
STABLE
Wetted Areas
Exposed Gravel
Partially Vegetated
Stable
Active channel bed
Disturbed/Stablizing channel bed
'Inactive' valley floor


REES-DART ACTIVE CHANNEL BELT
HILLOCKS
PARADISE
TE HORO
1973
1990
2001
2019
Active Channel Width (m)
Distance Upstream (km)
1973
1990
2001
2019
1) Long-term migration of lower reach/delta from TL to TR
2) Expansion followed by contraction of active river corridor


Glenorchy
Kinloch
2/3 OCTOBER 2011
25 JUNE 2019
13 AUG 2021


MANAGING RIVERS … OR … RIVER CORRIDORS
ALWAYS STABLE
TRANSITIONAL
ALWAYS ACTIVE
Probability models > land-use zoning


BED LEVEL CHANGE 2019 - 2011
Difference lidar elevation models
surveyed in 2019 and 2011
Erosion (bed lowering) = reds
Sedimentation (bed raising) = blues
UPSTREAM
DELTA FRONT
DEPOSITION
EROSION
RIGHT BANK EROSION
SEDIMENTATION
AT CONFLUENCE
DELTA ADVANCE AT KINLOCH

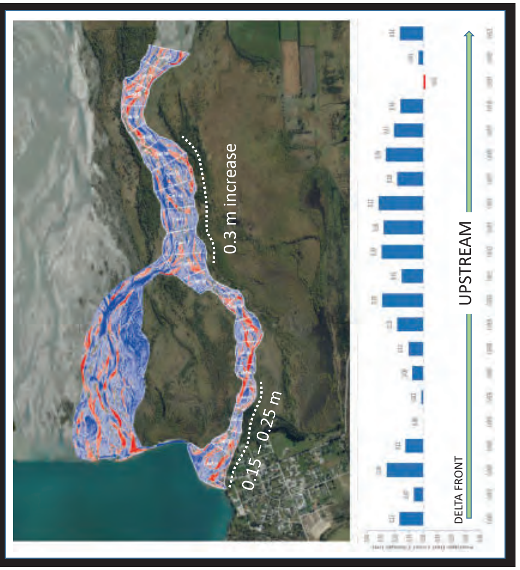
LOWER REES RIVER

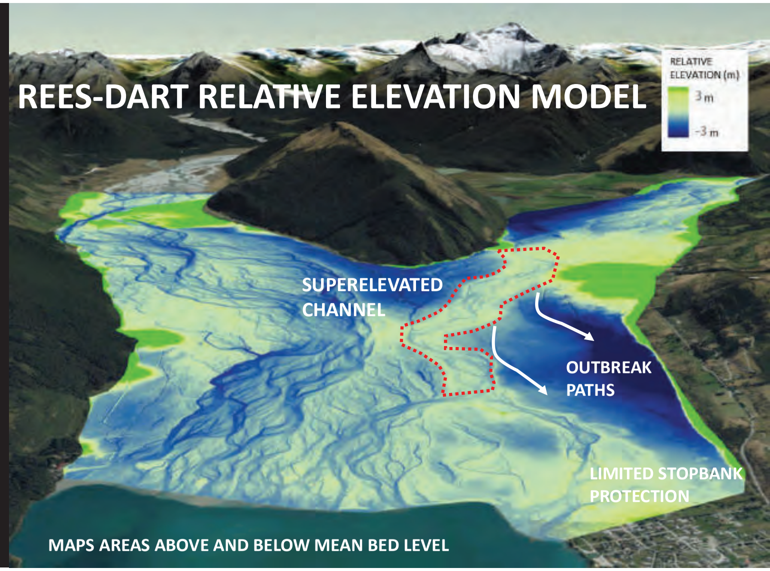
Bed level change averaged over 250 m sections (cells)

Significant and extensive sedimentation throughout lower 5 km

- 0.2 – 0.32 m increase in mean bed level in just 8 years
- > 1.25 – 2 m increase over 50 years

SIGNIFICANT LOSS OF FLOOD CAPACITY





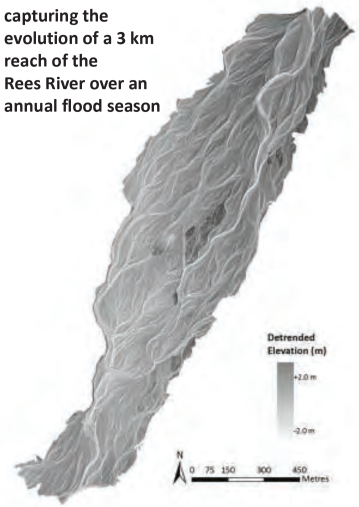
JUNE 2020

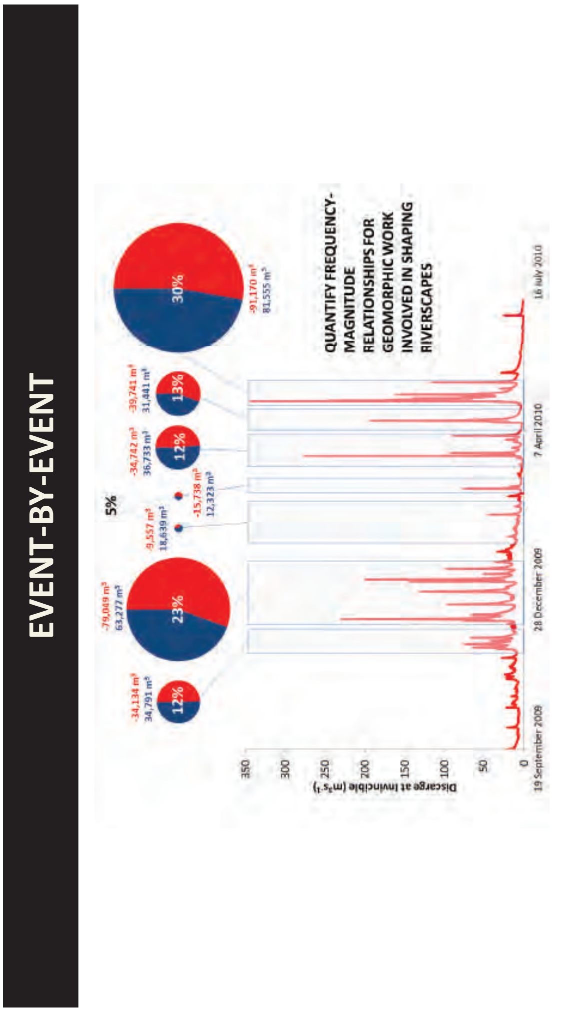
Significant loss of 'freeboard' evident along reaches of the lower Rees River

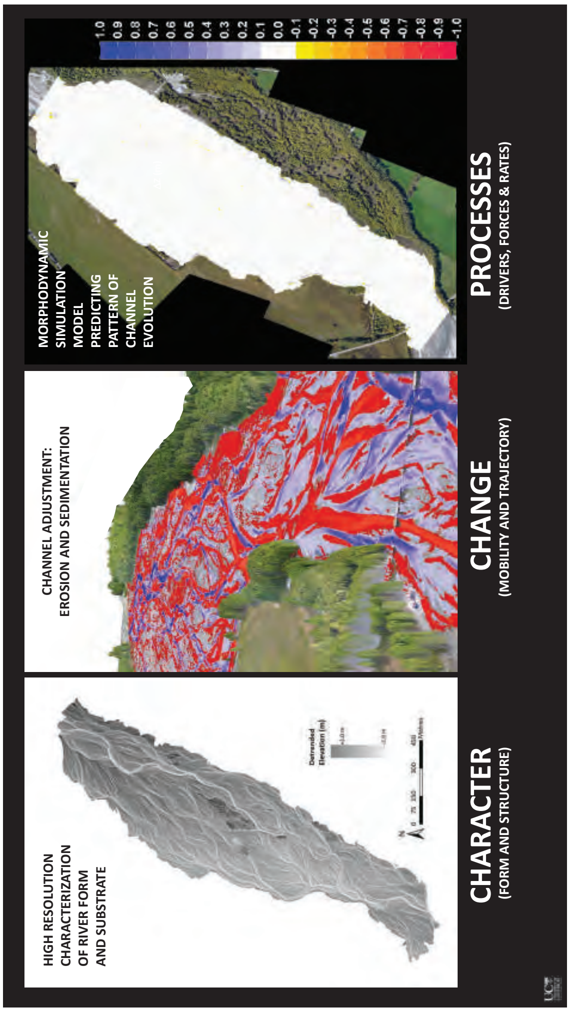
3. FORMATIVE PROCESSES

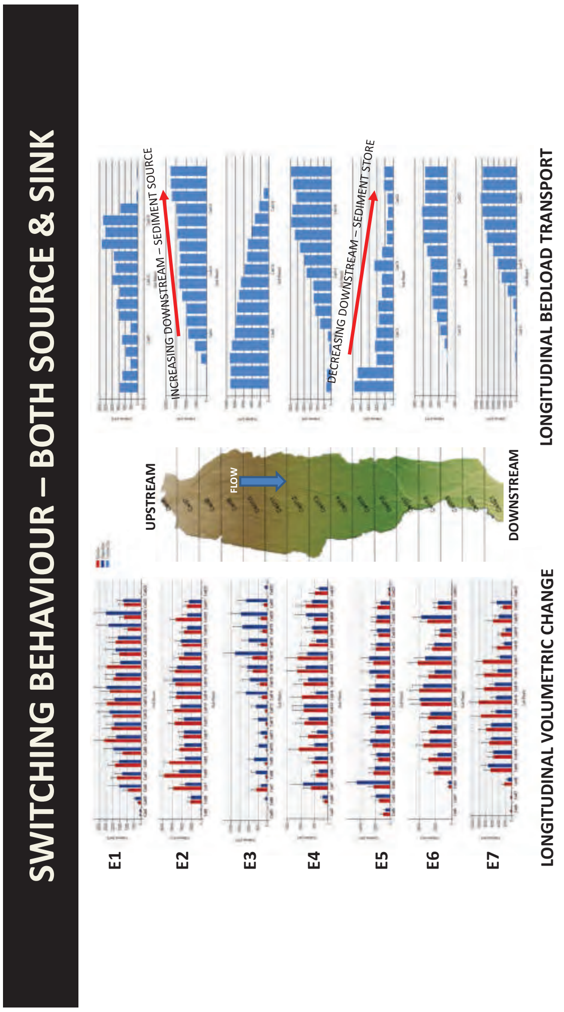
AMPHIBIOUS MOBILE TLS: REESCAN PROJECT 2009-2011

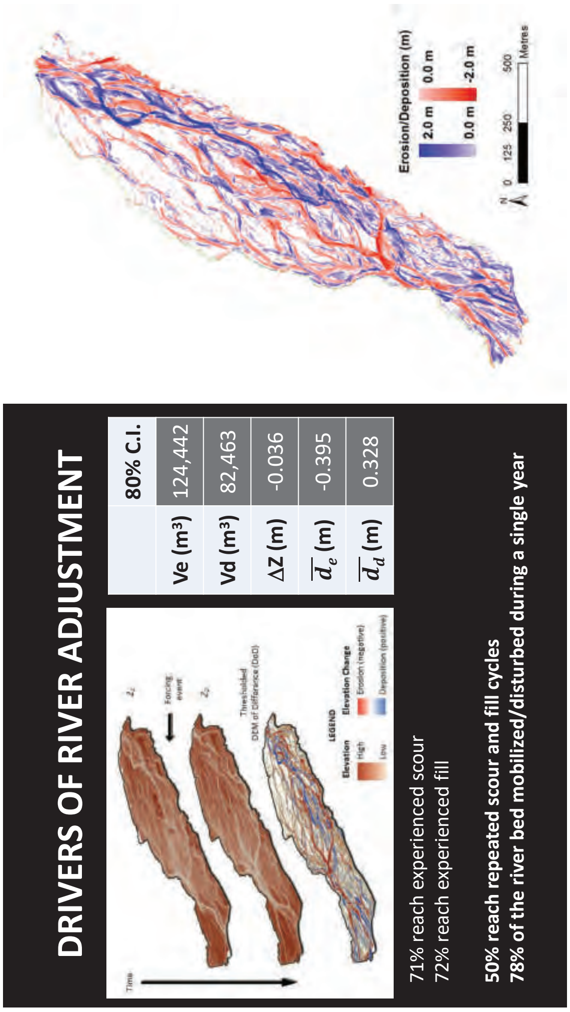
0.25 m DEMs capturing the evolution of a 3 km reach of the Rees River over an annual flood season

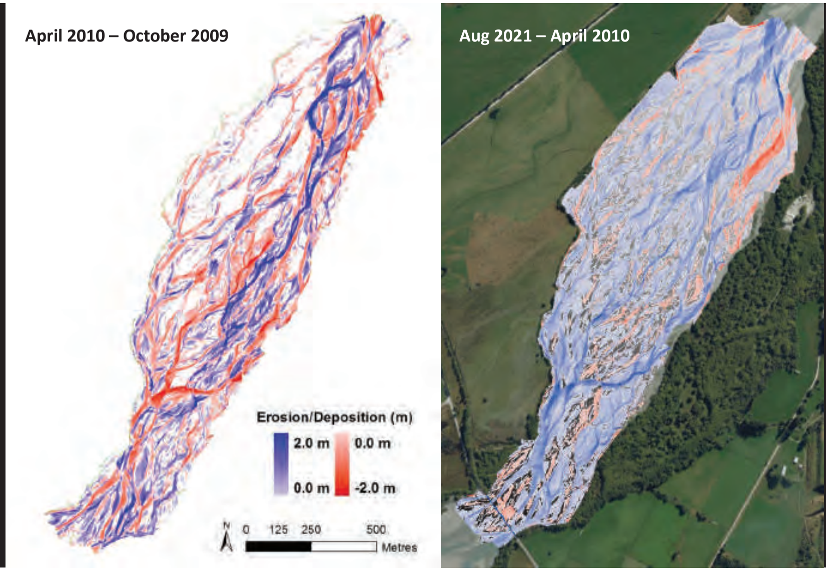



EVENT-BY-EVENT
QUANTIFY FREQUENCY-MAGNITUDE RELATIONSHIPS FOR GEOMORPHIC WORK INVOLVED IN SHAPING RIVERSCAPES
12%
23%
5%
12%
13%
30%
-34,134 m³
34,791 m³
-79,049 m³
63,277 m³
-9,557 m³
18,639 m³
-15,738 m³
12,323 m³
-34,742 m³
36,733 m³
-39,741 m³
31,441 m³
-91,170 m³
81,555 m³
Discarge at Invincible (m³s⁻¹)
19 September 2009
28 December 2009
7 April 2010
16 July 2010


HIGH RESOLUTION CHARACTERIZATION OF RIVER FORM AND SUBSTRATE
CHANNEL ADJUSTMENT: EROSION AND SEDIMENTATION
MORPHODYNAMIC SIMULATION MODEL PREDICTING PATTERN OF CHANNEL EVOLUTION
CHARACTER
(FORM AND STRUCTURE)
CHANGE
(MOBILITY AND TRAJECTORY)
PROCESSES
(DRIVERS, FORCES & RATES)


SWITCHING BEHAVIOUR – BOTH SOURCE & SINK
E1
E2
E3
E4
E5
E6
E7
UPSTREAM
FLOW
DOWNSTREAM
INCREASING DOWNSTREAM – SEDIMENT SOURCE
DECREASING DOWNSTREAM – SEDIMENT STORE
LONGITUDINAL VOLUMETRIC CHANGE
LONGITUDINAL BEDLOAD TRANSPORT

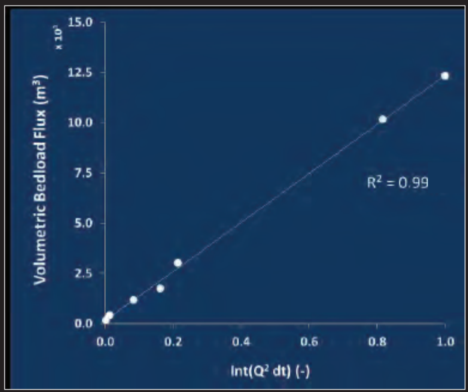

DRIVERS OF RIVER ADJUSTMENT
80% C.I.
Ve (m³) 124,442
Vd (m³) 82,463
ΔZ (m) -0.036
$\overline{d_e}$ (m) -0.395
$\overline{d_d}$ (m) 0.328
71% reach experienced scour
72% reach experienced fill
50% reach repeated scour and fill cycles
78% of the river bed mobilized/disturbed during a single year
Erosion/Deposition (m)
2.0 m
0.0 m
-2.0 m



LESSONS FROM THE LANDSCAPE

1. SEDIMENT SUPPLY IS HIGH; DYNAMIC > PULSES DUE TO EXTREME EVENTS
   - Should expect variability over time, which will affect rates of downstream channel stability
2. MAKE SPACE FOR RIVERS – TREAT THE VALLEY FLOOR AND RIVER AS A CONTINUUM
   - Should expect the active river corridor to expand/contract/migrate over decadal timescales
3. SEDIMENT TRANSFER IS 'TRANSPORT LIMITED'
   - Should expect increases in storm frequency and severity to directly impact sediment transfer through the river system

CONTROLS ON SEDIMENT TRANSPORT



Rate of sediment transport increases predictability with the intensity of the driving flood

Sediment is essentially is unlimited … so …

Rate of transport is directly proportional to the power of floods

> Increases in flood frequency will lead to a direct increase in the rate of sediment transport

INCREASING FLUVIAL HAZARD?

1. RIPARIAN EROSION

Migration of the channel belt over time > periodic pressure on managed margins

Increasing sediment delivery > higher rates of anabranch migration > increased rate of lateral migration of channel belt

> KINLOCH ROAD

INCREASING FLUVIAL HAZARD?

2. LOSS OF SERVICE OF EXISTING STOPBANK PROTECTION

Elevated bed level > higher flood stages
> Increased pressure on outer bends
> Increased hydrostatic pressure

> overtopping
> Piping under earthen stopbanks > catastrophic breach

INCREASING FLUVIAL HAZARD?

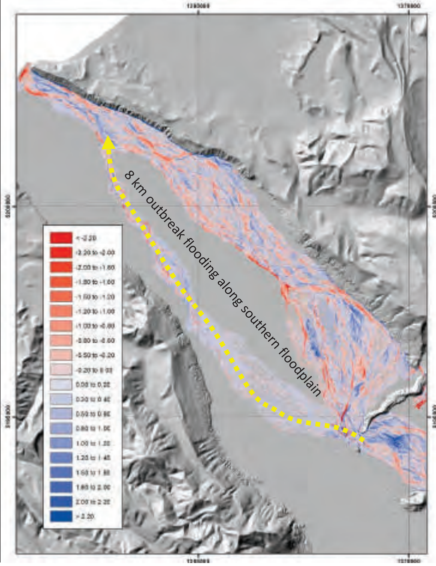
4. ELEVATED RISK OF SEVERE OUTBREAK FLOODING

Loss of freeboard upstream

Rerouting of flood flows along steeper path across the floodplain > avulsion

Catastrophic – erosional – flooding with the potential to overwhelm stopbanks

Swift water flooding through township



INCREASING FLUVIAL HAZARD?

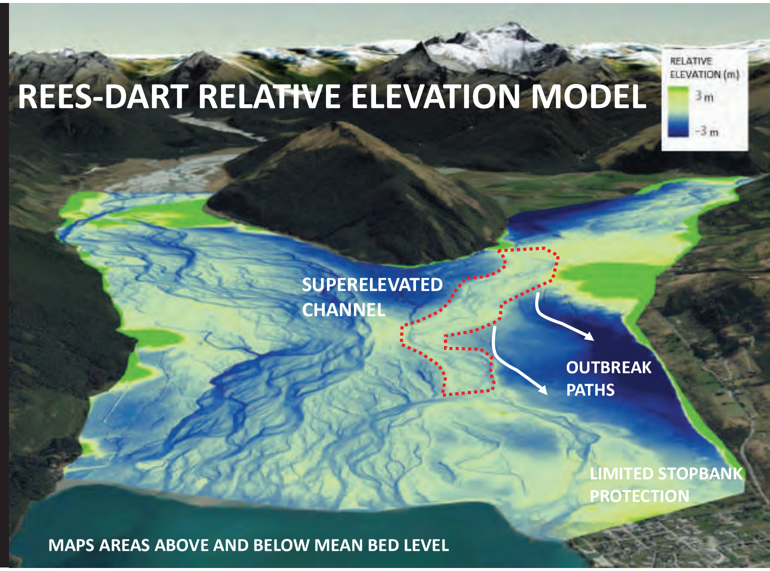
3. BACKWATER FLOODING ALONG LAGOON CREEK > OVERTOPPING OF STOPBANK

Bed aggradation > reduced cross-sectional area and reduced channel gradient

Reduces Rees mainstem flood capacity > blocks and then reverses flow along floodplain channels (Lagoon Creek)

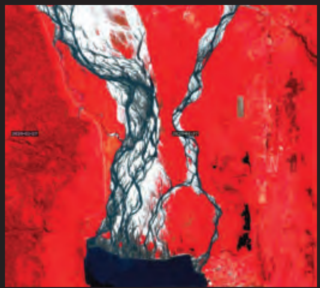
Overtopping of stopbank at low points

BACKWATER FLOODING



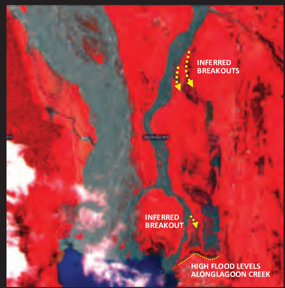
INCIPIENT AVULSION

BEFORE FLOOD



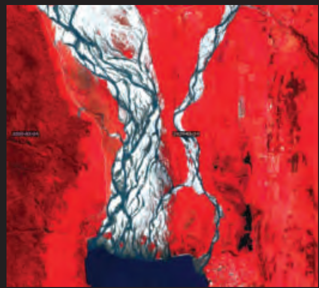
27 JANUARY 2020

FLOOD RECESSION



5 FEBRUARY 2020 (11:21 AM)

POST FLOOD



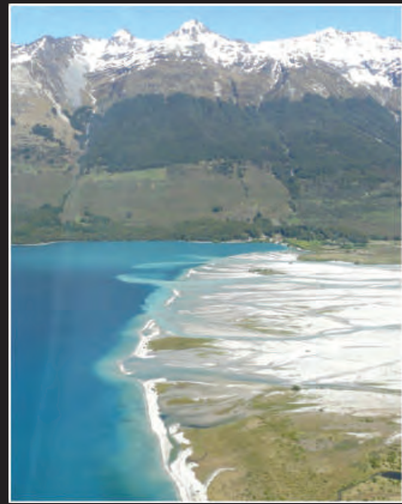
24 FEBRUARY 2020

CONCLUSIONS

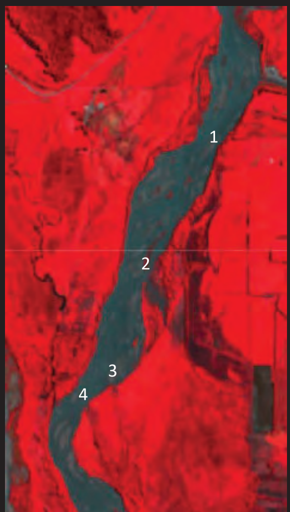
Fluvial hazards pose significant and increasing challenge for the local community into the future

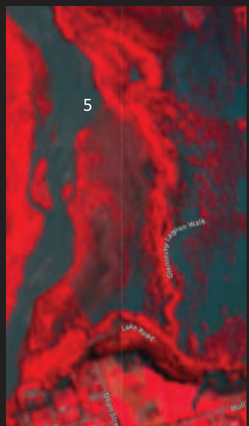
Hazard set to increase due to both climate change and long-term geomorphic evolution

Some hazards that will become increasingly hard to mitigate



FEB 2020: MULTIPLE BREACHES





Appendix E

Presentation by Matt Gardner (Land River Sea Consulting)

12/05/2022

Rees / Dart Modelling

2021 Study

LANDRIVERSEA CONSULTING

1

Model Extent

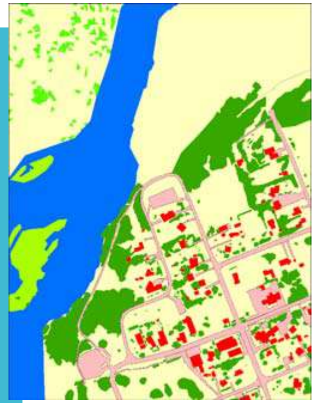
2

Model Setup

- Based on 2019 LiDAR DEM flow by LandPro
- Fixed bed model – so doesn't account for scour and aggradation – these effects need to be manually accounted for
- Main input is flow and downstream boundary level (ie Lake Level)
- Flow inputs developed by Magdy (ORC) – complex hydrology due to lack of gauging information
- Model can output – Water Level – Depth – Velocity – Shear Stress – Hazard etc to help better understand dynamic nature of the hazard
- Model is only a tool to help understand the real world – must always be interpreted in light of limitations.

3

Vegetation etc represented through roughness



4

Bathymetry

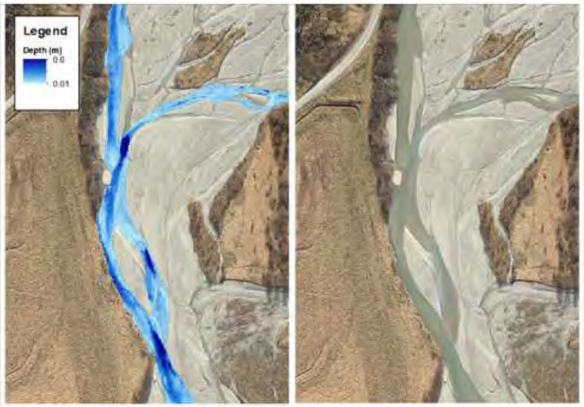


Figure 1 - Visualisation of DEM of Depth

Figure 2 - Aerial Image used for generating DEM of Depth

5

Calibration – Feb 2020 event

Model is primarily calibrated for Glenorchy flooding – not Kinloch etc – however flood extent covers full area

6

Animation (Glenorchy)

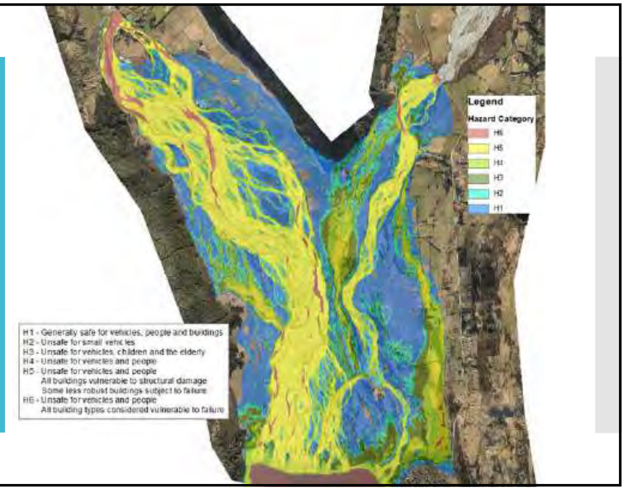
7

Animation (Full Extent)

8

12/05/2022

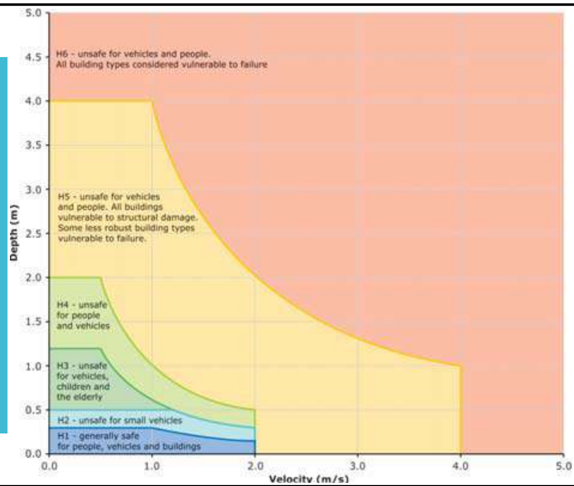
100 year ARI (1%AEP) Estimated Extent / Hazard Map



9

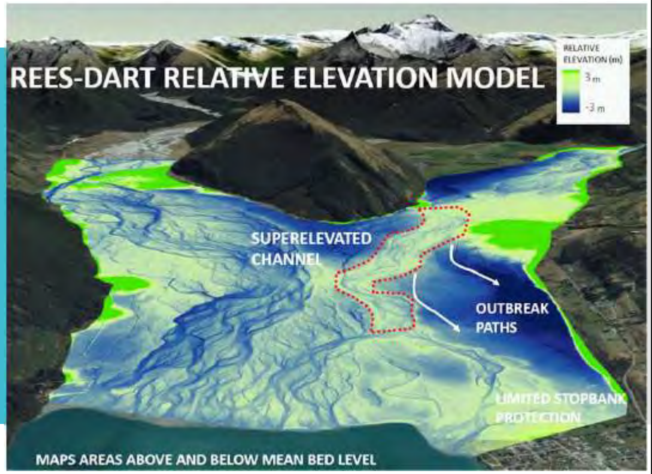
HAZARD MAP

Function of D x V



10

Modelled Avulsions / Outbreaks



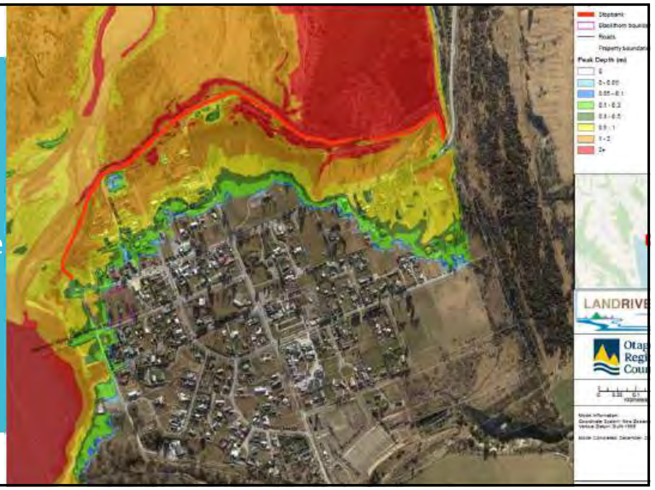
11

Avulsion path

12

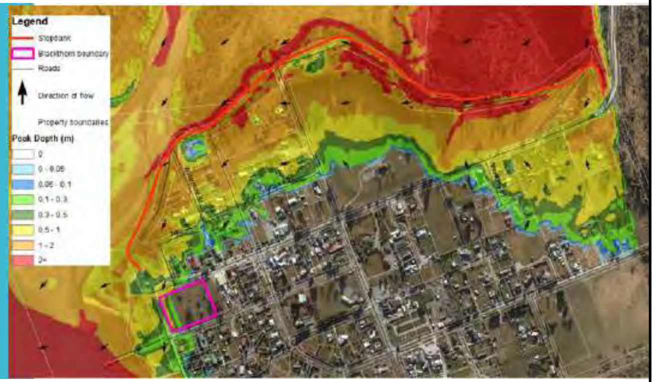
12/05/2022

100yrARI Future Climate Avulsion



13

Direction of flow



14

15

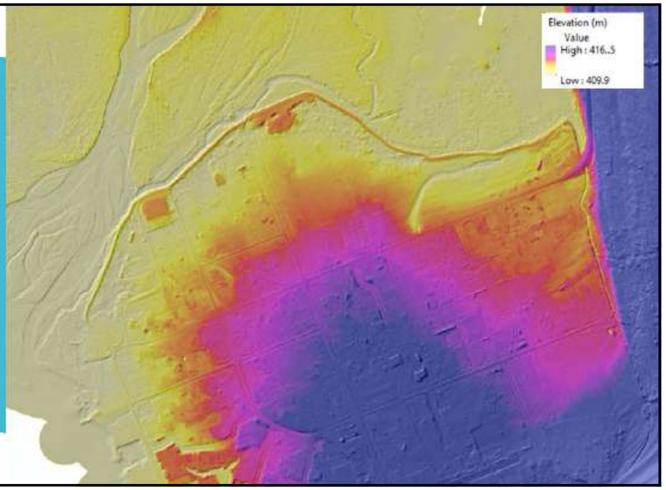
Sensitivity

- Roughness
- Water Levels in Lagoon (limited difference for event of size of Feb 2020 event)
- Main cause of excess water heading towards Glenorchy is likely due to diversion of flows from upstream, rather than lagoon capacity

16

12/05/2022

Natural topography controls the flow



17

Road access issues - Dart

18

Road access issues - Rees

19

Climate Change

- Only impact on peak flow has been considered
- Impact on lake levels has not been investigated..in reality very complex as climate change likely to impact on entire long term climate cycle as well as intensity and duration of storms
- Cliamte change will have significant impact on geomorphology impacting volume of material entering the river
- This may effect level of both Dart and Rees as well as bed levels of river such as Kawarau which control the outflows from the lake and hence act as a control on lake levels.

20

12/05/2022

Thoughts on management

- Every action has a reaction
- Models can be used to help assess wider impact on catchment
- Stopbanks can limit flood extent, but at the same time will impact on gravel transport – as well as channel more water downstream
- Models are a tool, but need expertise to interpret, especially in active gravel braided systems such as this one
- We can model removing gravel etc – however need to

21

REPORT

Tonkin+Taylor

Head of Lake Wakatipu Natural Hazards Adaption

Engineering Approaches for Managing Liquefaction-Related Risk

Prepared for
Otago Regional Council

Prepared by
Tonkin & Taylor Ltd

Date
February 2023

Job Number
1017916 v1

Together we create and sustain a better world
www.tonkintaylor.co.nz

Table of contents

Cover photo credit: Vladka Kennett, CC BY-SA 3.0.

1 What is this report about?

Otago Regional Council (ORC) has engaged Tonkin & Taylor Ltd. (T+T) to provide engineering advice regarding the susceptibility of the Glenorchy area to liquefaction and lateral spreading hazards.

The first stage of this assessment was to undertake ground investigations and analysis to help understand the current susceptibility of the land. The results were presented in the T+T report "Glenorchy Liquefaction Vulnerability Assessment" (v1, issued May 2022), including the liquefaction vulnerability map shown in Figure 1.1 below. The assessment concluded that significant damage due to liquefaction and lateral spreading could be expected at a "50 to 100 year" level of earthquake shaking (a 40 – 60% chance of occurring over the next 50 years). The key areas identified are:

- Areas where both liquefaction and lateral spreading damage could occur. This area is subdivided into Major and Severe lateral spreading.
- Areas where only liquefaction damage is expected. This area is subdivided into Medium and High liquefaction vulnerability.

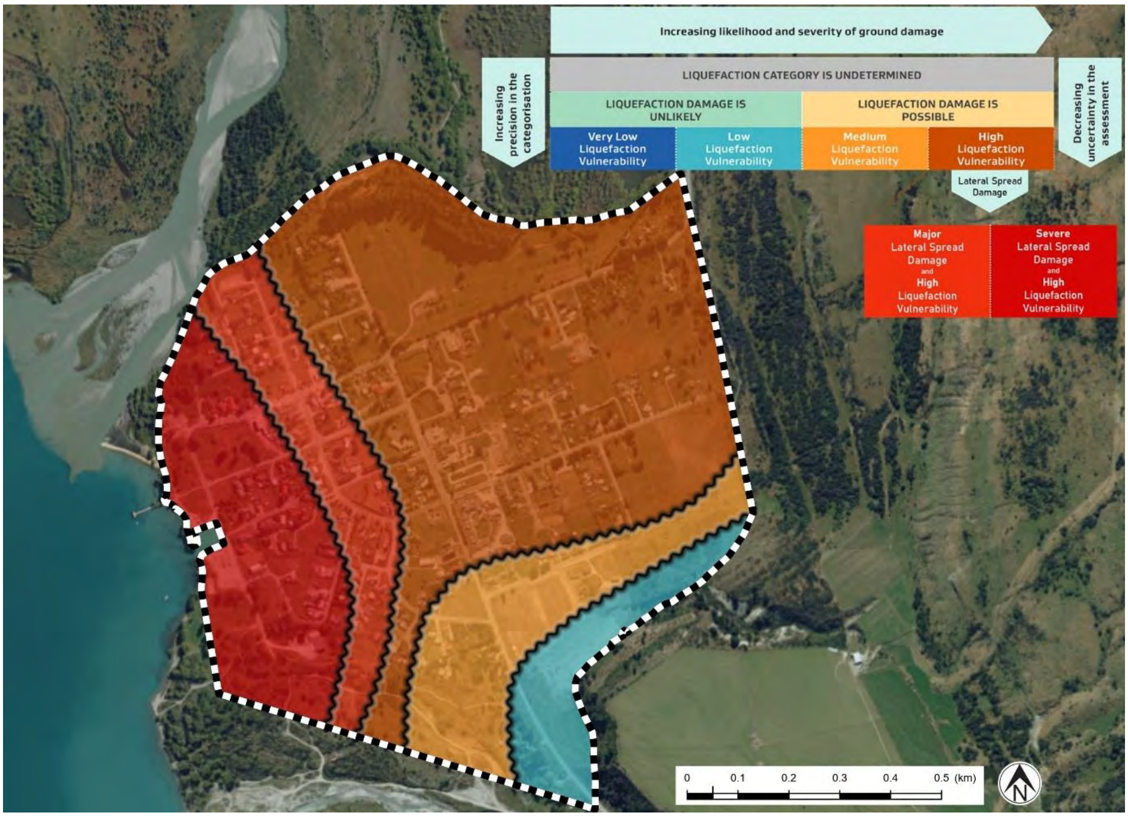


Figure 1.1: The liquefaction vulnerability map from the T+T May 2022 report. Note that boundaries between the various categories are not precise, so more or less damage could occur on either side of the boundaries.

This current report presents the second stage of the liquefaction assessment – aiming to help ORC and the local community understand potential engineering approaches for managing the liquefaction and lateral spreading hazards. Other non-engineering approaches also exist (e.g. land use planning and emergency preparedness), however ORC will be considering these separately so they are not covered here. This report identifies a range of mitigation techniques that could be considered for land, buildings and infrastructure, and how these techniques could be applied across the Glenorchy township. It then provides a preliminary high-level assessment of how effective these mitigation works could be in reducing damage, and an indicative relative cost comparison.

2 What damage could be caused by liquefaction?

Liquefaction is a natural process where earthquake shaking increases the water pressure in the ground in some types of soil, resulting in temporary loss of soil strength. The following three key elements are all required for liquefaction to occur:

- Sufficient ground shaking (a combination of the duration and intensity of shaking).
- A loose to medium-dense soil (typically sands and silts, or in some cases gravel).
- That these soils are saturated (i.e., below the groundwater table).

The severity of the liquefaction hazard therefore depends on the strength and duration of earthquake shaking, the thickness, depth, density and type of soils and the depth of the groundwater table.

Liquefaction can cause significant damage to land, buildings and infrastructure. It can cause highly variable settlement of the ground due to ejection of liquefied soil and consolidation of loose ground. It can also trigger lateral spreading, which is where the ground cracks and drops sideways towards a "free face" such as a river, lake or terrace edge. Lateral spreading is often the cause of the most severe liquefaction-related damage to land, buildings and infrastructure, particularly in areas closest to the free face.

Some of the effects of liquefaction and lateral spreading are illustrated in Figure 2.1, Figure 2.2 and Figure 2.3 below, with examples from the 2010 – 2011 Canterbury Earthquakes and the 2016 Kaikoura Earthquake.

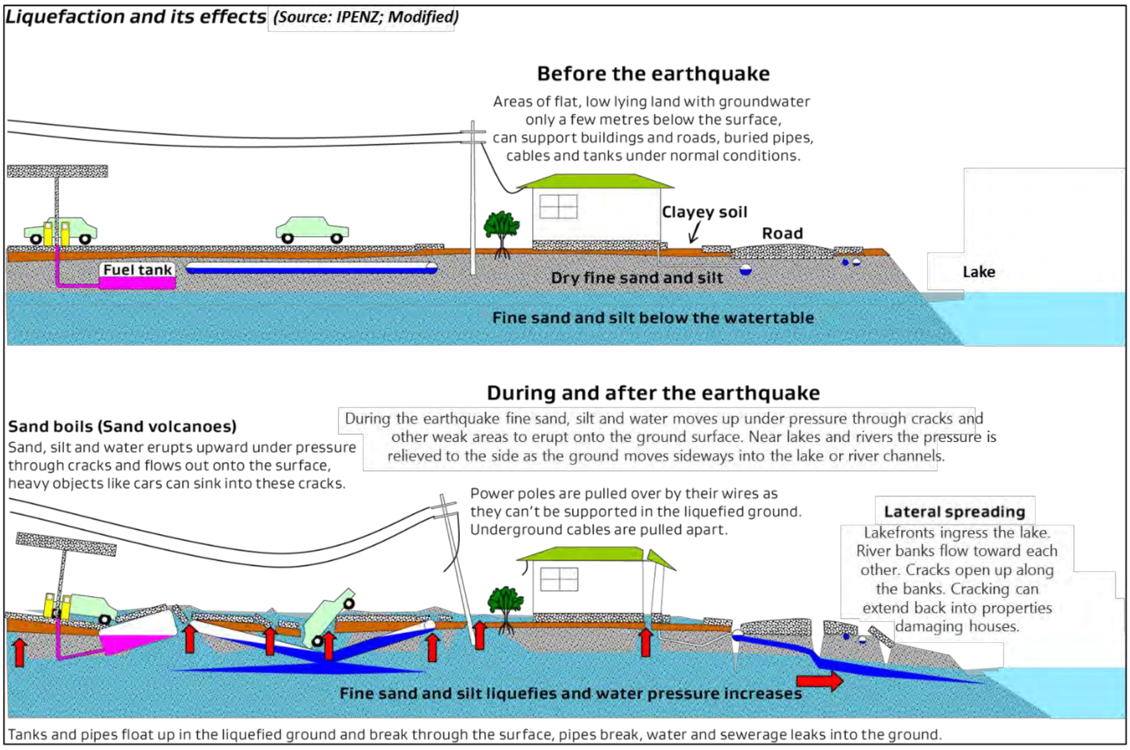


Figure 2.1: Visual schematic of the consequences of liquefaction.

Liquefied sand ejected from underneath a house.

Liquefied sand on the street, with piles of sand shovelled out from under and around houses.

Foundation and brickwork damage.

Liquefied sand that has broken through the floor slab and filled up inside the house.

Power transformer that has sunk into the liquefied ground.

Stormwater manholes that have floated up out of the liquefied ground.

Figure 2.2: Example photographs of the types of damage to land, buildings and infrastructure that could be expected in a large earthquake in the parts of Glenorchy categorised as Medium and High liquefaction vulnerability (without lateral spread).

Lateral spreading pulled this foundation beam out from underneath the house.

A 1m wide ground crack ran through the middle of this house, pulling the garage walls apart.

The cracks running under this house caused the front part to pull away and drop 0.5m.

Lateral spreading buckled this bridge and damaged the approaches, cutting the main trunk water supply and fibre optic cable running across the bridge.

Lateral spreading caused a series of 0.5m cracks and drops in this road.

Liquefaction and lateral spreading pushed these power poles over, and flooded the streets.

Figure 2.3: Example photographs of the types of damage to land, buildings and infrastructure that could be expected in a large earthquake in the parts of Glenorchy categorised as Major and Severe lateral spreading. For these examples the free face was about 4m high. In Glenorchy the free face is much higher (about 25m below lake level), so lateral spreading could be more severe and extend further inland.

3 How much risk is tolerable?

Before discussing potential options for managing liquefaction hazard, it is useful to ask the question "how much risk is tolerable". This helps to set a benchmark level of performance that the various different options can be compared against.

When it comes to natural hazards risk management and adaptation planning, there are no fixed rules about exactly how much risk is tolerable. Rather than being a purely technical engineering or legal question, this becomes a balance between costs and benefits, recognising that communities have many other objectives in addition to managing natural hazards. Finding the balance that best suits a particular situation requires a collaborative approach including the community, stakeholders, technical experts and decision-makers. To help with these discussions, Table 3.1 includes various factors that may be relevant when deciding how much liquefaction-related risk is tolerable.

Table 3.1: Relevant factors when deciding how much risk is tolerable

Factor	Comments
Life safety during an earthquake	Lateral spreading damage to buildings is the main life safety concern related to liquefaction. While there were no deaths caused by lateral spreading in the 2010 – 2011 Canterbury Earthquakes, this was more a matter of good luck rather than good design – if the shaking had been stronger or longer then building collapse could have occurred.
Habitability in the days and weeks after an earthquake	If buildings are severely damaged, it may not be possible to use them after the earthquake so people would need alternative accommodation. Damage to electricity, water supply, stormwater and sewer networks would also impact on habitability, potentially for many months (or longer) after the earthquake. These issues could be worsened if earthquake damage cuts off the only road in and out of the town.
Long term recovery after an earthquake	While it is the most severe damage which often attracts most attention immediately after an earthquake, a more significant issue for long term recovery can sometimes be the minor and moderate damage (as it can be much more extensive). While it may be possible to continue living with this damage until it is eventually repaired, there can be far-reaching economic, social and environmental consequences.
Other hazards	Some locations may also be exposed to other hazards (e.g. flood) and cascading hazards (e.g. liquefaction settlement leaves building more flood-prone).
Building Act	All building work must comply with the Building Code regardless of whether a building consent is required, and irrespective of whether it is to construct a new building or to repair or alter an existing building. In the case of alterations or repairs it is only the new work that must comply with the current Building Code. If existing parts of the building do not comply, then the main requirement (with some exceptions) is that the alterations or repairs do not result in the building complying with the Building Code to a lesser extent than before. The Building Act requires councils to refuse building consent if the land is likely to be subject to natural hazards, unless adequate steps are taken to protect against the hazard. However, the Act provides a specific list of hazards that this applies to, and it is unclear whether this includes earthquakes and liquefaction. Nonetheless, it is useful to note that the test of whether a hazard is considered "likely" has been defined as a "100 year" event (which has a 40% chance of occurring over the next 50 years).

Table 3.1 (continued): Relevant factors when deciding how much risk is tolerable

Factor	Comments
Building Code minimum requirements	For most "normal" buildings (and other structures) the Building Code mandates minimum acceptable performance for two earthquake scenarios: The Serviceability Limit State (SLS) is assessed for "25 year" earthquake shaking levels (a 90% chance of occurring over the next 50 years). The building should suffer little or no structural damage and remain accessible and safe to occupy. There may be minor damage to building fabric that is readily repairable. The Ultimate Limit State (ULS) is assessed for "500 year" earthquake shaking levels (a 10% chance of occurring over the next 50 years). The building is expected to suffer moderate to significant structural damage (which might not be repairable), but not to collapse.
Resource Management Act (RMA)	The RMA identifies management of significant risks from natural hazards as a matter of national importance, which means it needs to be considered at all levels of planning and decision-making. The RMA also gives councils power to refuse or place conditions on subdivision consents where there is a significant natural hazard risk.
Insurance and mortgages	Insurers each make their own decisions about natural disaster risk, often balancing many different factors. The availability and cost of insurance is subject to these decisions. In New Zealand there is an increasing trend of insurers moving toward more "risk-based" pricing where specific attributes (such as location and presence of hazards) are taken into account in both deciding whether to offer cover, and in determining the cost of providing that cover. Following the Christchurch earthquakes, most insurers adopted an approach where new dwellings would be provided insurance cover on the basis that compliance with the Resource Management Act and Building Act/Code largely provided mitigation of the hazards potentially affecting the dwelling. In general, insurers were more concerned with existing dwellings on land that was revealed to be both liquefaction and flood prone, as there was little opportunity to mitigate the hazards for existing buildings. In the past banks have typically provided mortgage lending as long as insurance was in place, however in future banks may also undertake their own independent assessment of natural hazard risk before offering lending.
Chance of an earthquake occurring	The T+T May 2022 liquefaction assessment report concluded that significant damage due to liquefaction and lateral spreading could be expected at a "50 to 100 year" level of earthquake shaking (a 40 – 60% chance of occurring over the next 50 years). The Alpine Fault is particularly relevant, as it passes relatively close to Glenorchy (55km at its nearest point). There is a 75% chance of a large earthquake occurring on the Alpine Fault within the next 50 years. It is likely that a large Alpine Fault earthquake would cause significant liquefaction and lateral spreading damage in Glenorchy, however there is some uncertainty in the severity and extent of damage that could occur.
Type of land use activity	There are many different ways that land can be used, such as for housing, commercial activity, infrastructure, recreation, environmental purposes etc. Because each of these different land uses has different consequences if damaged in an earthquake, they each have different risk profiles. This means that a particular degree of liquefaction-induced damage might be tolerable for some types of land uses but not for others.

4 What can be done to manage the risk?

There is a wide range of possible approaches for managing the risks from natural hazards, as illustrated in Figure 4.1 below. It is not necessary to select just a single approach, in fact it is often best to combine multiple approaches to find the best balance for the particular situation faced by each individual community.

This report discusses only engineering approaches for managing liquefaction-related risk, as ORC will be considering other types of approaches and other hazards separately. The primary focus of this report is on mitigation which reduces the potential impact of liquefaction. This can be achieved by reducing how often damage occurs (so a larger earthquake is needed to trigger damage), by decreasing the severity of that damage when it occurs and making it easier to repair afterwards. However, this report also provides information about the potential impacts after mitigation is undertaken (or with no mitigation), to help ORC and the community make informed decisions about what residual risks[1] it might be appropriate to accept.

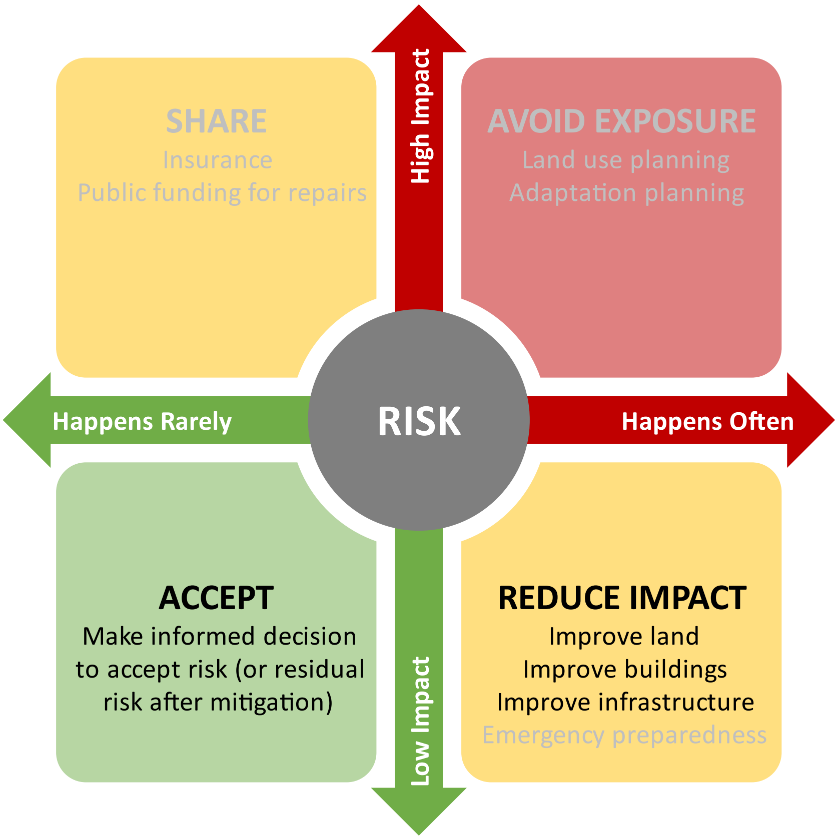


Figure 4.1: Example aproaches for managing the risks from natural hazards, depending on the frequency of the event and severity of the impacts. This report focusses only on engineering approaches only (black text above). Other approaches also exist (grey text above), however Otago Regional Council will be considering these separately.

[1] "Residual risk" is the risk that remains even after all adopted risk management measures are implemented. It is usually not practical or affordable to completely eliminate all risks. One of the goals of risk management is to find the point where the residual risk is reduced to a level which is acceptable, or the point of "diminishing returns" where further investment in risk management measures does not give a worthwhile reduction in the overall level of residual risk.

5 What engineering mitigation techniques are available?

There are various mitigation techniques available for protecting land, buildings and infrastructure from the effects of liquefaction. The techniques considered for this assessment are summarised in Table 5.1, Table 5.2 and Table 5.3 table below. The options are listed in order from the most robust (and also the most expensive, disruptive and time-consuming) at the top, through to the least robust (and least expensive, disruptive and time-consuming) at the bottom.

We have considered a wide range of options, spanning from very robust options through to a "do nothing" option. At the more robust end of the range, there could be many cases where undertaking the work would be impractical or unaffordable. At the less robust end of the range, there could be many cases where new buildings might not meet minimum the Building Code requirements for building consent, or where it may become more difficult to obtain insurance because of the high residual risk. However, rather than pre-judge any outcomes and rule out any options immediately we have included them in this report to provide context for discussion about a wide range of approaches that exist.

In New Zealand it is rare for ground improvement for mitigation of liquefaction hazards (as presented in Table 5.1 below) to be undertaken at a township or suburb scale, however over the past two decades there have been some examples of large-scale ground improvement (tens of hectares in area) as part of new subdivision construction.

Similarly, while residential buildings in New Zealand have historically not been designed to accommodate the effects of liquefaction, this is now becoming standard practice where liquefaction-prone soils are present. The MBIE Canterbury rebuild guidance[2] provides a range of foundation concepts which offer improved robustness and ability to tolerate the effects of liquefaction, as summarised in Table 5.2 below. While initially intended for the Canterbury rebuild, it has proven to be useful more widely across the country to help guide resilient foundation design. These foundations are grouped into three "Technical Categories" (TC's) depending on the potential consequences of liquefaction and the level of geotechnical investigation and specific engineering design required:

TC1: Future land damage from liquefaction is unlikely, and ground settlements from liquefaction effects are expected to be within normally accepted tolerances. Shallow geotechnical investigations are required, and if a 'good ground' test is met then conventional NZS 3604 foundations (simple concrete slabs or suspended timber floors) can be used.

TC2: Liquefaction damage is possible in future large earthquakes. Shallow geotechnical investigations are required and if this proves that the ground has sufficient strength then "off the shelf" suspended timber floor or enhanced slab foundation options can be used.

TC3: Liquefaction damage is possible in future large earthquakes. Deep geotechnical investigation (or assessment of existing information) and depending on the geotechnical assessment, might require specific engineering design for foundations.

2 https://www.building.govt.nz/building-code-compliance/canterbury-rebuild/repairing-and-rebuilding-houses-affected-by-the-canterbury-earthquakes/

Table 5.1: Liquefaction mitigation techniques for reducing damage to land

Mitigation works	Description
15 – 20m deep by 30 – 40m wide perimeter treatment ground improvement alongside lake	A long vibrating probe is used to compact the ground and inject gravel to form columns about 1m in diameter, in a grid pattern at about 2m spacings. This strip of very deep improvement along the lake edge acts like an "underground dam" of solid ground which helps to hold back the liquefied ground and reduce lateral spreading ground displacements. Perimeter treatment can help reduce the lateral spreading hazard for areas further inland (but the inland ground could still experience settlement damage if the underlying ground liquefies).
12m deep ground improvement, all land	Ground compaction and gravel columns as above, covering all land in an area (e.g. under buildings, roads and the land in between). Only 12m deep so there is still potential for the ground deeper than this to liquefy. This means that liquefaction settlement and lateral spreading could still occur, but the magnitude of displacement should be less.
12m deep ground improvement, land under buildings & infrastructure only	Ground compaction and gravel columns as above, but only covering land under buildings & infrastructure (no improvement of land in between). This will form individual "islands" of ground improvement which can help to reduce settlement and lateral spreading (but less effective at controlling lateral spreading that the options above).
12m deep ground improvement, land around buildings & infrastructure where accessible	This ground improvement approach could be considered where there are existing buildings & infrastructure, to avoid the need relocate them to improve underneath. The main benefit of this is reducing lateral spreading by improving a block of surrounding ground. Significant ground settlement could still occur due to liquefaction of the unimproved ground beneath.
4m deep ground improvement, land under buildings & infrastructure only	There are various shallow ground improvement methods which could be used to compact the upper 4m of the soil profile, including gravel columns (as above), dynamic compaction (a crane drops a weight on the ground) and impact compaction (a square roller or hammer hits the ground). This will have little effect on lateral spreading displacements, but can help reduce the severity of differential ground settlement due to liquefaction and ejected soil. Therefore this option is more applicable in areas further inland where less lateral spreading is expected, or in conjunction with perimeter treatment to reduce lateral spreading displacements.
1.2m deep geogrid-reinforced crushed gravel raft, under buildings & infrastructure only	This method provides a stiff platform of well compacted and reinforced gravel beneath buildings & infrastructure. The main benefit of this is to help reduce the severity of differential ground settlement due to liquefaction and ejected soil. The geogrid can help reduce the magnitude of lateral ground stretching to some degree (encouraging cracks to instead form on either side), but is less effective than deep ground improvement for controlling lateral spread. Therefore this option is more applicable further inland where less lateral spread is expected, or in conjunction with perimeter treatment which reduces lateral spreading.
No improvement	Ground remains in its current state within an area. However, in some mitigation scenarios ground improvement in a neighbouring area may help to provide some reduction in lateral spreading ground displacement, so we have made allowance for this in our damage estimates where appropriate.
NOTE: The details quoted in this table (such as depth and extent of treatment) are intended to be indicative only, to provide a general picture of the relative scale of the various options. Actual details would need to be determined as part of the design process, to meet agreed target performance requirements.	

Table 5.2: Liquefaction mitigation techniques for reducing damage to buildings

Mitigation works	Description
New TC3 surface structure foundations	The MBIE Canterbury rebuild guidance provides five concepts for raised platform foundations designed to accommodate significant ground settlement and lateral spreading while limiting deformation of the overlying structure. Settlement and damage is still expected to occur, but the aim is for this to be readily repairable. Existing buildings would need to be temporarily lifted, and possibly relocated, for the new foundation to be constructed underneath. This foundation type also has the added benefit of raising floor levels higher above flood levels.
New TC2 waffle slab foundation or enhanced lightweight platform on timber piles	The MBIE Canterbury rebuild guidance provides numerous TC2-type foundation options, however the most commonly adopted are waffle slab foundations (for concrete slabs) and enhanced lightweight platforms (for timber floors). Existing buildings would need to be temporarily lifted, and possibly relocated, for the new foundation to be constructed underneath. Enhanced lightweight platforms also have the added benefit of raising floor levels higher above flood levels.
Retrofit to strengthen existing foundations and buildings	While the primary focus of the MBIE Canterbury rebuild guidance is on robust design of new buildings and repair of damaged buildings, some of the same concepts could be applied for proactive retrofit strengthening of existing buildings. This would avoid the need to lift/relocate existing buildings, but might not provide the same performance as a new TC2 or TC3 foundation. For timber floor foundations this could include subfloor sheet bracing, bolt-spliced bearers, and enhanced connections between piles and bearers. Retrofit strengthening may be more difficult for concrete slab foundations, but could include internal and perimeter tie beams and edge stiffening. There may also be opportunities to enhance the superstructure, such as sheet claddings/linings, lightweight roof/cladding, stiffening walls, and enhanced connections between walls and roof framing.
No improvement	Foundation and building remain in their current state.
NOTE: The foundation concepts in this table are for simple lightweight timber-frame buildings (such as typical houses, or small commercial buildings of similar construction). It might be possible to apply similar concepts to other types of building, but this would need specific engineering assessment. For all buildings, actual details would need to be determined as part design, to meet Building Code performance requirements for building consent.	

Table 5.3: Liquefaction mitigation techniques for reducing damage to infrastructure

Mitigation works	Description
New infrastructure with resilient detailing	New infrastructure should incorporate resilient detailing to better accommodate displacement. This includes avoiding higher hazard areas, providing redundancy within a system, adopting appropriate technology (e.g. pressure sewer), careful selection of pipe/cable materials, robust/flexible connections, utilising details that resist uplift, and granular/cemented trench backfill.
Retrofit to strengthen existing infrastructure	For existing infrastructure, opportunities to enhance the entire network can be more limited (short of complete replacement). However, detailed assessment of the system may identify critical "weak links" where targeted upgrades can improve the overall resilience of the wider network.
No improvement	Infrastructure remains in its current state.

6 How could these mitigation techniques be applied across Glenorchy?

Two of the important factors when deciding what type of mitigation (if any) is undertaken at particular locations across the town are:

- The current vulnerability of the ground to liquefaction and lateral spreading at the location. This is shown on the map in Figure 1.1.
- Whether there are existing buildings and infrastructure at the location, or whether new development is proposed.

Table 6.1 and Table 6.2 below summarise a range of potential layouts for how liquefaction mitigation could be undertaken across Glenorchy. The options are listed in order from the most robust (and also the most expensive and disruptive) at the top, through to the least robust (and least expensive and disruptive) at the bottom. The options towards the top of the table might prove to be impractical or unaffordable, while the options towards the bottom of the list might not meet building consent requirements or be difficult to obtain insurance for. However, rather than rule any options out immediately we have included them in this report to provide context for discussion.

At this stage it is uncertain whether it would be feasible to undertake ground improvement underneath existing buildings and infrastructure, and this may vary depending on the specific details of each situation. Therefore our assessment has considered both potential outcomes to help understand the implications either way:

- For Table 6.1, we have assumed that it would be feasible to undertake ground improvement beneath existing buildings and infrastructure (Options A1 to C1). This would help to provide protection against both liquefaction settlement and lateral spreading. Existing buildings would need to be temporarily lifted, and probably relocated, for the ground improvement to be constructed underneath. For some types of existing infrastructure it may be possible to undertake ground improvement on either side to protect the infrastructure. For other types of existing infrastructure it may be more practical to install new robust infrastructure after the ground improvement, rather than attempting to improve underneath the existing.
- For Table 6.2, we have assumed that it would not be feasible to undertake ground improvement beneath existing buildings and infrastructure (Options A2 to C2). For these options, we have instead assumed ground improvement is undertaken in the clear space around buildings and infrastructure. This would help to provide some degree of protection against lateral spreading, but not liquefaction settlement.

Further consideration of these options is provided in Appendix A, including the degree to which they might reduce the liquefaction hazard and the level of damage.

Table 6.1: Mitigation options - ground improvement under existing buildings & infrastructure

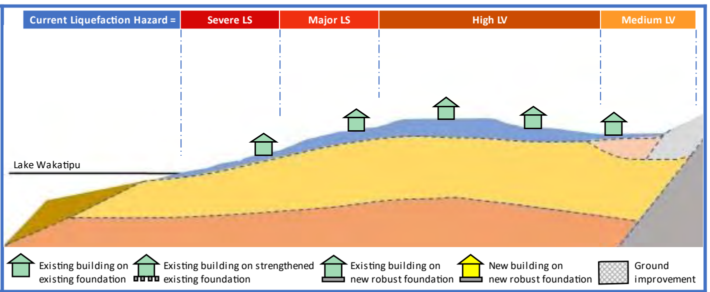
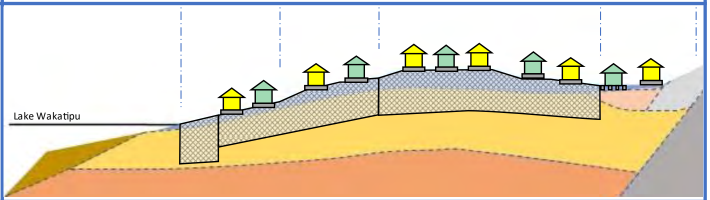
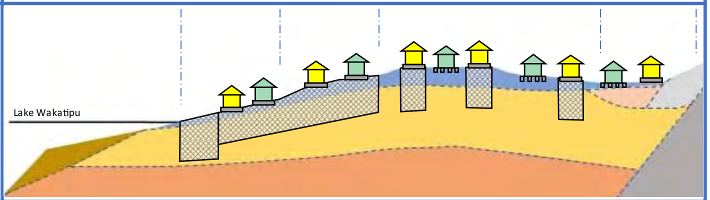
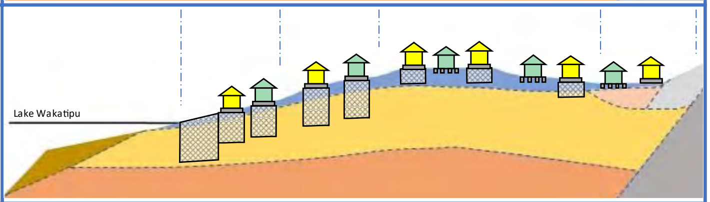
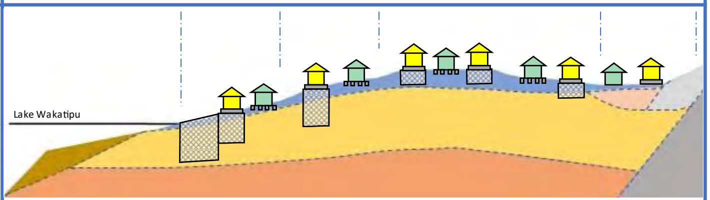
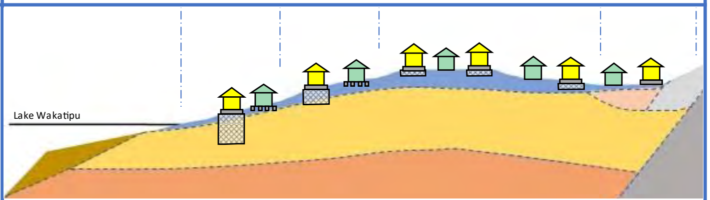
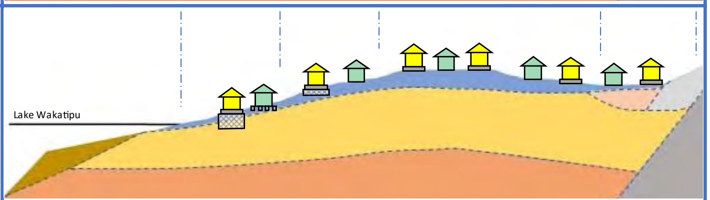
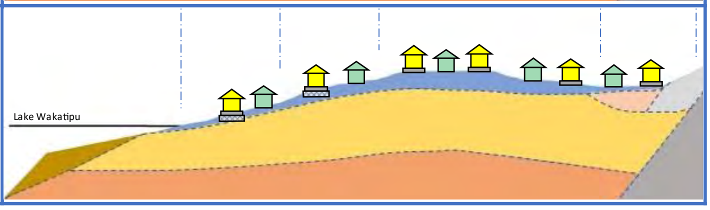
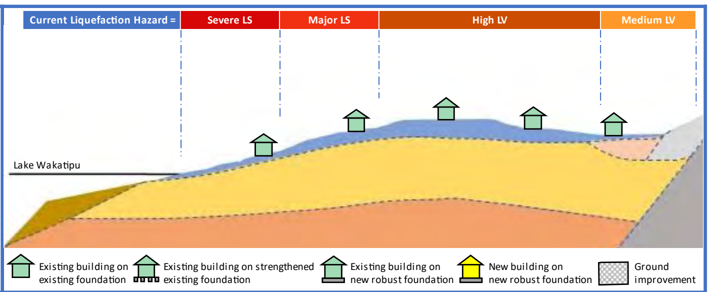
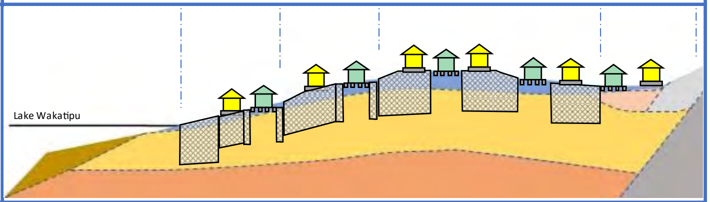
Current situation	
Option A1 Perimeter treatment beside lake. Deep ground improvement and robust foundations & infrastructure for all of lateral spread and High LV area. Elsewhere, robust new buildings and infrastructure, and retrofit strengthening for existing.	
Option B1 Perimeter treatment beside lake. Deep ground improvement and robust foundations & infrastructure for all of lateral spread area, and under new robust buildings and infrastructure for High LV area. Elsewhere, robust new buildings and infrastructure, and retrofit strengthening for existing.	
Option C1 Perimeter treatment beside lake. In lateral spread area deep ground improvement under robust buildings & infrastructure. In High LV area shallow ground improvement under robust new buildings & infrastructure. Elsewhere, robust new buildings & infrastructure, and retrofit strengthening for existing.	
Option D1 Perimeter treatment beside lake. In lateral spread area deep ground improvement under robust new buildings & infrastructure. In High LV area shallow ground improvement under robust new buildings & infrastructure. Elsewhere, robust new buildings & infrastructure, and retrofit strengthening for existing (except Medium LV).	
Option E In Severe LS area deep ground improvement under new robust buildings & infrastructure, reducing to shallow improvement for Major LS area. In High LV area gravel rafts under robust new buildings & infrastructure. Elsewhere, robust new buildings & infrastructure. Retrofit strengthen existing buildings & infrastructure in lateral spread area.	
Option F In Severe LS area shallow ground improvement under new robust buildings & infrastructure, reducing to gravel rafts for Major LS area. Elsewhere, robust new buildings & infrastructure. Retrofit strengthening for existing buildings & infrastructure in Severe LS area.	
Option G In lateral spread area gravel rafts under robust new buildings & infrastructure. Elsewhere, robust new buildings & infrastructure. No retrofit strengthening for existing buildings & infrastructure.	

Table 6.2: Mitigation options - no ground improvement under existing buildings & infrastructure

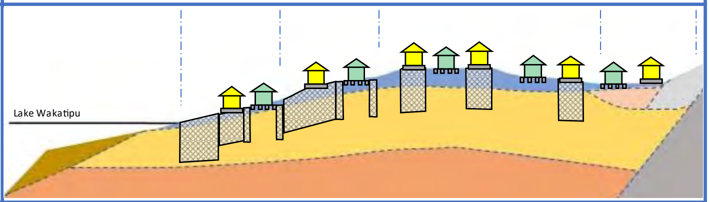
Current situation



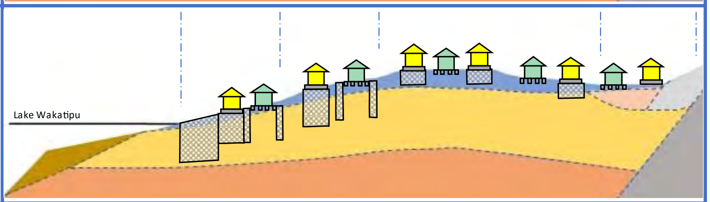
Option A2
Perimeter treatment beside lake. Deep ground improvement and robust foundations & infrastructure for all accessible parts of lateral spread and High LV area. Elsewhere, robust new buildings and infrastructure, and retrofit strengthening for existing.



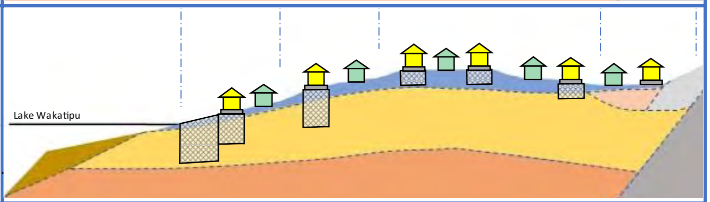
Option B2
Perimeter treatment beside lake. Deep ground improvement and robust foundations & infrastructure for all accessible parts of lateral spread area, and under new robust buildings and infrastructure for High LV area. Elsewhere, robust new buildings and infrastructure, and retrofit strengthening for existing.



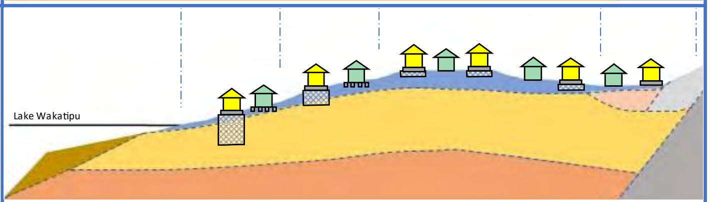
Option C2
Perimeter treatment beside lake. In lateral spread area deep ground improvement under new robust buildings & infrastructure, or around existing where accessible. In High LV area shallow ground improvement under robust new buildings & infrastructure. Elsewhere, robust new buildings & infrastructure, and retrofit strengthen existing.



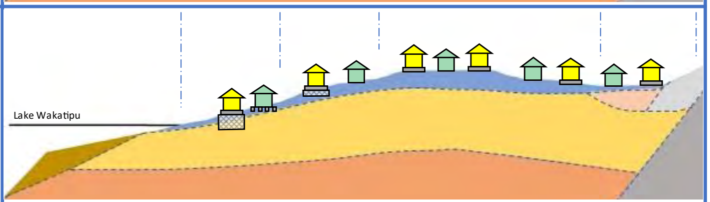
Option D2
Perimeter treatment beside lake. In lateral spread area deep ground improvement under robust new buildings & infrastructure. In High LV area shallow ground improvement under robust new buildings & infrastructure. Elsewhere, robust new buildings & infrastructure. No retrofit strengthening of existing buildings & infrastructure.



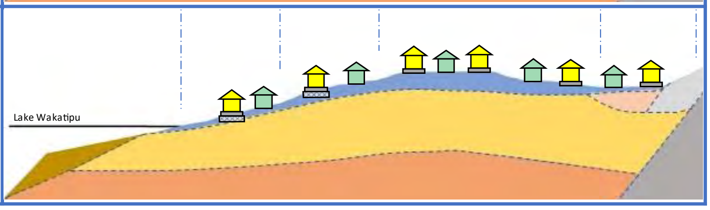
Option E
In Severe LS area deep ground improvement under new robust buildings & infrastructure, reducing to shallow improvement for Major LS area. In High LV area gravel rafts under robust new buildings & infrastructure. Elsewhere, robust new buildings & infrastructure. Retrofit strengthen existing buildings & infrastructure in lateral spread area.



Option F
In Severe LS area shallow ground improvement under new robust buildings & infrastructure, reducing to gravel rafts for Major LS area. Elsewhere, robust new buildings & infrastructure. Retrofit strengthening for existing buildings & infrastructure in Severe LS area.



Option G
In lateral spread area gravel rafts under robust new buildings & infrastructure. Elsewhere, robust new buildings & infrastructure. No retrofit strengthening for existing buildings & infrastructure.



7 How well do these mitigation options work?

The very thick deposits of liquefiable soil under Glenorchy, and the very high free face at the lake edge, mean that it will be challenging to improve the performance of the land in an earthquake. Even with very extensive ground improvement to reduce the liquefaction and lateral spreading hazard, it is unlikely that the hazard could be eliminated. This means that it is important to understand the level of "residual risk" that would remain even after mitigation works were undertaken.

An understanding of residual risk can help to guide discussion about mitigation options, and comparison against other non-engineering risk management approaches (e.g. land use planning and emergency preparedness). This can be useful to help to find the point of "diminishing returns" where the additional benefits of undertaking more robust mitigation do not justify the additional costs. This should consider not just financial benefits, but also social and environmental measures.

Table 7.1 below provides a general picture of the residual liquefaction hazard that would remain after each mitigation option was implemented. Table 7.2 presents a similar summary, looking at the approximate proportion of buildings and infrastructure expected to experience severe liquefaction-induced damage for each option[3]. As explained above, even for the most robust mitigation options listed, there remains significant liquefaction hazard and potential for damage.

When considering the cost and benefits of mitigation works, it can be useful to ask the question "who benefits from the mitigation work?", which runs in parallel with a similar question of "who bears the costs?". For mitigation options which include deep ground improvement over a large area, there can be benefits for other properties further inland if these works help to reduce the severity of lateral spreading towards the lake. Similarly, ground improvement which helps to protect infrastructure at locations of highest hazard or "weak links" can have benefits to many users across the wider network.

[3] This damage analysis is based on generalised damage trends observed from the 2010-2011 Canterbury Earthquakes. The analysis uses damage data for ground conditions and types of buildings which are generally similar to those in Glenorchy, but it is not based on a specific analysis of the individual buildings in Glenorchy. For this analysis, severe damage to buildings and infrastructure is taken to mean that it would likely be impractical or uneconomic to repair. There will also be additional buildings and infrastructure which are damaged, but not as severely. As the proportion of severe damage increases, the general scale and nature of this other damage will also worsen.

Table 7.1: Indicative liquefaction hazard, after mitigation works are undertaken

	EXISTING DEVELOPMENT				NEW DEVELOPMENT			
Current liquefaction hazard:	Severe LS	Major LS	High LV	Medium LV	Severe LS	Major LS	High LV	Medium LV
Option A1	High LV	High LV	Medium LV	Medium LV	High LV	High LV	Medium LV	Medium LV
Option B1	High LV	High LV	High LV	Medium LV	High LV	High LV	Medium LV	Medium LV
Option C1	High LV	High LV	High LV	Medium LV	High LV	High LV	Medium LV	Medium LV
Option D1	Severe LS	Major LS	High LV	Medium LV	High LV	High LV	Medium LV	Medium LV
Option E	Severe LS	Major LS	High LV	Medium LV	Major LS	Major LS	High LV	Medium LV
Option F	Severe LS	Major LS	High LV	Medium LV	Severe LS	Major LS	High LV	Medium LV
Option G	Severe LS	Major LS	High LV	Medium LV	Severe LS	Major LS	High LV	Medium LV
Option A2	Major LS	High LV	High LV	Medium LV	High LV	High LV	Medium LV	Medium LV
Option B2	Major LS	High LV	High LV	Medium LV	High LV	High LV	Medium LV	Medium LV
Option C2	Major LS	High LV	High LV	Medium LV	High LV	High LV	Medium LV	Medium LV
Option D2	Severe LS	Major LS	High LV	Medium LV	High LV	High LV	Medium LV	Medium LV

Table 7.2: Indicative proportion of buildings & infrastructure with severe liquefaction damage in a large earthquake, after mitigation works are undertaken

	EXISTING DEVELOPMENT				NEW DEVELOPMENT			
Current liquefaction hazard:	Severe LS	Major LS	High LV	Medium LV	Severe LS	Major LS	High LV	Medium LV
Expected damage for current ground conditions:	90%	75%	50%	25%	-	-	-	-
Option A1	30%	25%	15%	15%	25%	20%	10%	10%
Option B1	30%	25%	40%	15%	25%	20%	15%	10%
Option C1	35%	30%	40%	15%	30%	25%	20%	10%
Option D1	55%	50%	40%	25%	35%	30%	20%	10%
Option E	75%	65%	50%	25%	40%	40%	25%	10%
Option F	80%	75%	50%	25%	50%	50%	30%	10%
Option G	90%	75%	50%	25%	60%	50%	30%	10%
Option A2	45%	40%	40%	15%	30%	25%	10%	10%
Option B2	45%	40%	40%	15%	30%	25%	15%	10%
Option C2	45%	40%	40%	15%	30%	25%	20%	10%
Option D2	65%	60%	50%	25%	35%	30%	20%	10%

NOTE: These table are intended to be indicative only, to provide a general picture of the relative effectiveness of the various options. Actual performance in an earthquake is expected to be variable, with some locations experiencing more damage than listed above, and some locations experiencing less.

8 How much do these mitigation options cost?

As this is an initial concept report only, we have not undertaken any analysis or design for the various mitigation options presented. However, we have developed assumed mitigation concepts based on our experience assessing area-wide remediation options for the "Red Zone" following the Canterbury Earthquakes. Similarly, we have not undertaken project-specific cost estimation, instead relying on indicative cost information from ground improvement trials undertaken by the Earthquake Commission following the Canterbury Earthquakes. Based on these preliminary assumptions, we have prepared, in relative terms, an approximate comparison of potential estimates for the various mitigation options, as summarised in Table 8.1.

When considering the cost and benefits of mitigation works, it can be useful to ask the questions "when are the costs incurred?" and "when are the benefits received". One of the challenging aspects of liquefaction mitigation works is that there can be a significant up-front cost to undertake the work, but most of the benefit is not received until some uncertain time in the future when an earthquake occurs. This means that a very long-term view is required when evaluating options for managing liquefaction-related risk. It also means that the engineering analysis and design needs to strike a careful balance to avoid being overly pessimistic or optimistic. There can be significant current-day costs for construction if the mitigation design is more robust than is actually needed, but also significant future costs from damage if the mitigation design is not robust enough.

The same as when assessing benefits, the viability assessment should consider not just financial costs, but also social and environmental measures, and the opportunity cost of investing in mitigation works instead of other things. Given the current economic environment, careful consideration of cost inflation would also be prudent.

Table 8.1: Indicative relative comparison of estimates for mitigation works

		EXISTING DEVELOPMENT				NEW DEVELOPMENT			
Current liquefaction hazard:		Severe LS	Major LS	High LV	Medium LV	Severe LS	Major LS	High LV	Medium LV
MITIGATION WORKS									
LAND	15 – 20m deep by 30 – 40m wide perimeter treatment ground improvement alongside lake	$$$$	$$$$	N/A	N/A	$$$$	$$$$	N/A	N/A
LAND	12m deep ground improvement, all land	$$$$$	$$$$$	$$$$$	N/A	$$$$$	$$$$$	$$$$$	N/A
LAND	12m deep ground improvement, land under buildings & infrastructure only	$$$$	$$$$	$$$$	N/A	$$$$	$$$$	$$$$	N/A
LAND	12m deep ground improvement, land around buildings & infrastructure where accessible	$$$$	$$$$	N/A	N/A	N/A	N/A	N/A	N/A
LAND	4m deep ground improvement, land under buildings & infrastructure only	$$$	$$$	$$$	N/A	$$$	$$$	$$$	N/A
LAND	1.2m deep geogrid-reinforced crushed gravel raft, under buildings & infrastructure only	$$$	$$$	$$$	N/A	$$$	$$$	$$$	N/A
LAND	No land improvement	-	-	-	-	-	-	-	-
BUILDINGS	New TC3 surface structure foundations	$$$$	$$$$	$$$$	N/A	$$$	$$$	$$$	N/A
BUILDINGS	New TC2 waffle slab foundation or enhanced lightweight platform on timber piles	N/A	N/A	N/A	$$$	N/A	N/A	N/A	$
BUILDINGS	Retrofit to strengthen existing foundations and buildings	$$	$$	$	$	N/A	N/A	N/A	N/A
BUILDINGS	No foundation or building improvement	-	-	-	-	-	-	-	-
INFRASTRUCTURE	New infrastructure with resilient detailing	$	$	$	$	$	$	$	$
INFRASTRUCTURE	Retrofit to strengthen existing infrastructure	$	$	$	$	N/A	N/A	N/A	N/A
INFRASTRUCTURE	No infrastructure improvement	-	-	-	-	-	-	-	-

INDICATIVE RELATIVE COST SCALE

-	No mitigation works, so no construction cost
$	Estimate in the order of $25,000
$$	Estimate in the order of $50,000
$$$	Estimate in the order of $100,000
$$$$	Estimate in the order of $200,000
$$$$$	Estimate more than $300,000
N/A	Mitigation option is not applicable for this scenario

Notes:
1) These indicative estimates are based on the results of the EQC residential ground improvement trials and ground improvement pilot projects undertaken in 2015, uplifted by 50% for construction cost inflation between 2015 and 2022.
2) All estimates are per property, assuming an average building footprint of 150m^2 on a lot size of 800m^2.
3) For perimeter treatment & infrastructure, the total estimate for mitigation is divided between the properties which benefit.
4) For existing development, TC2 and TC3 foundation estimates include the foundation construction as well as the enabling and reinstatement works required (e.g. lifting the existing building, repairing damage and reinstating services). These estimates relate to the direct construction work only, and do not include indirect costs such as overall community-wide programme management or temporary accommodation.
5) For new development, TC2 and TC3 foundation estimates are calculated as the additional over and above a NZS3604 foundation (the standard foundation typically used for ground that is not liquefaction-prone).
6) Infrastructure mitigation works relate to underground services only. Estimates are calculated as the additional over and above standard infrastructure construction on ground that is not liquefaction-prone.
7) The estimates presented in this report are indicative only, to illustrate the potential order of magnitude and relativity between options. These estimates are based on assumed concepts – no analysis or design has been undertaken. Consequently, a significant margin of uncertainty exists on the estimates. If decision-making is found to be sensitive to these estimates, then we recommend further, more location-specific engineering design and construction cost advice is sought.

9 Applicability

This report has been prepared for the exclusive use of our client Otago Regional Council, with respect to the particular brief given to us and it may not be relied upon in other contexts or for any other purpose, or by any person other than our client, without our prior written agreement.

The cost estimates presented in this report are indicative only, to illustrate the potential order of magnitude and relativity between options. These estimates are based on assumed concepts – no analysis or design has been undertaken. In particular, we have not made any attempt to allow for the potential impact of COVID-19 in this estimate. Also, supply chain disruptions are currently having quickly-changing effects on construction costs and schedules. Consequently, a significant margin of uncertainty exists on the estimates. If decision-making is found to be sensitive to these estimates, then we recommend further, more location-specific engineering design and construction cost advice is sought.

Tonkin & Taylor Ltd
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Document control

Title: Head of Lake Wakatipu Natural Hazards Adaption – Engineering Approaches for Managing Liquefaction-Related Risk					
Date	**Version**	**Description**	**Prepared by:**	**Reviewed by:**	**Authorised by:**
8-Feb-2023	1	Client issue	M. Jacka	S. van Ballegooy	T. Morris

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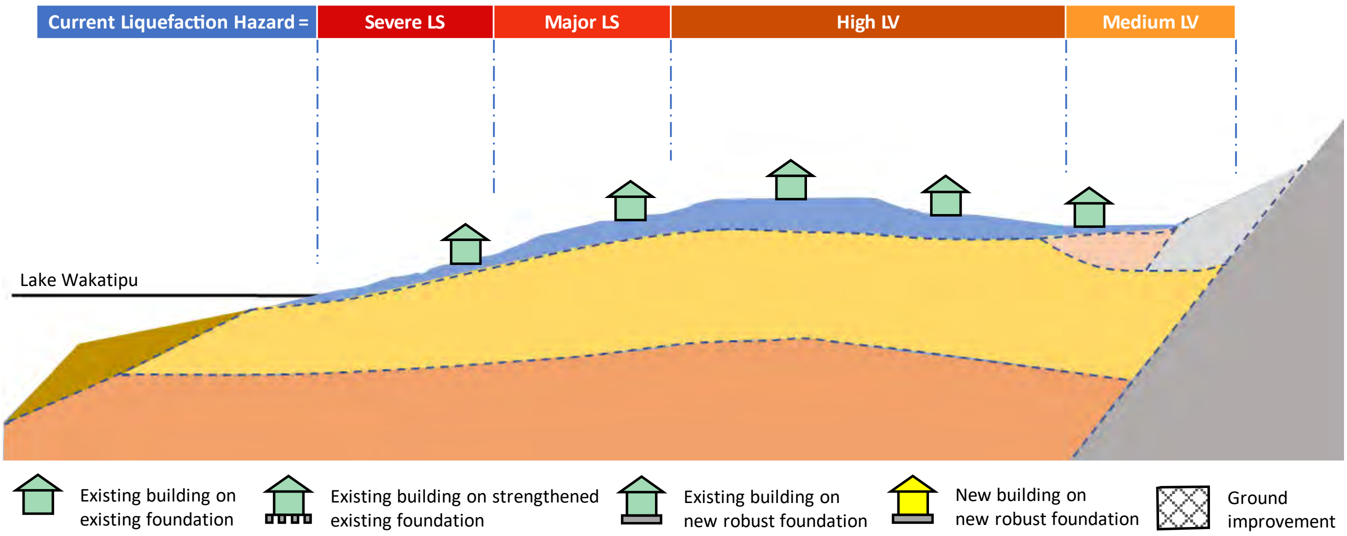
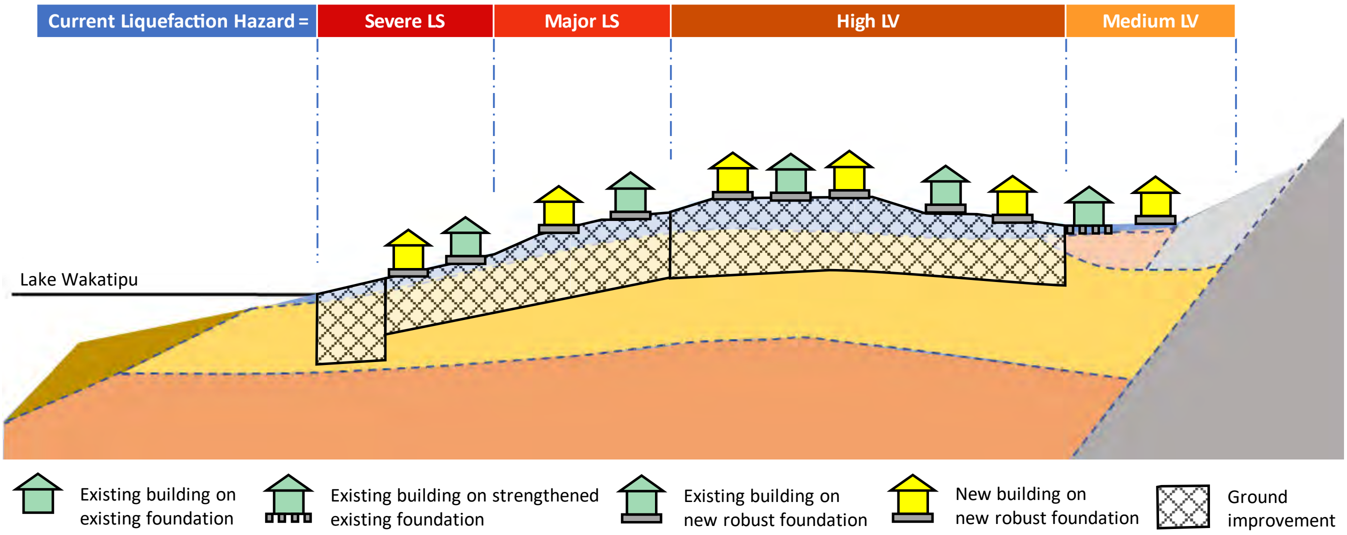
Appendix A Mitigation concept layouts

Existing situation



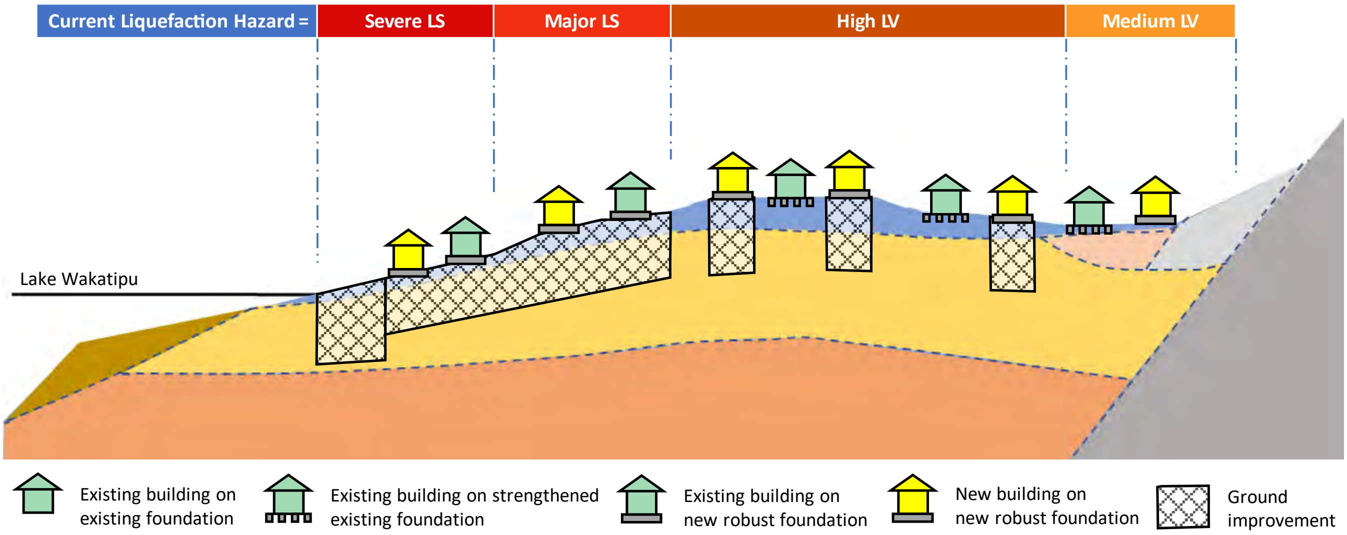
		EXISTING DEVELOPMENT				NEW DEVELOPMENT			
Current liquefaction hazard:		Severe LS	Major LS	High LV	Medium LV	-	-	-	-
Post-mitigation liquefaction hazard:		-	-	-	-	-	-	-	-
Current % of buildings & infrastructure with severe liquefaction damage in a major earthquake:		90%	75%	50%	25%	-	-	-	-
Post-mitigation % of buildings & infrastructure with severe liquefaction damage in a major earthquake:		-	-	-	-	-	-	-	-
MITIGATION WORKS									
LAND	15 – 20m deep by 30 – 40m wide perimeter treatment ground improvement alongside lake								
	12m deep ground improvement, all land								
	12m deep ground improvement, land under buildings & infrastructure only								
	12m deep ground improvement, land around buildings & infrastructure where accessible								
	4m deep ground improvement, land under buildings & infrastructure only								
	1.2m deep geogrid-reinforced crushed gravel raft, under buildings & infrastructure only								
	No land improvement	X	X	X	X				
BUILDINGS	New TC3 surface structure foundations								
	New TC2 waffle slab foundation or enhanced lightweight platform on timber piles								
	Retrofit to strengthen existing foundations and buildings								
	No foundation or building improvement	X	X	X	X				
INFRASTRUCTURE	New infrastructure with resilient detailing								
	Retrofit to strengthen existing infrastructure								
	No infrastructure improvement	X	X	X	X				

Option A1



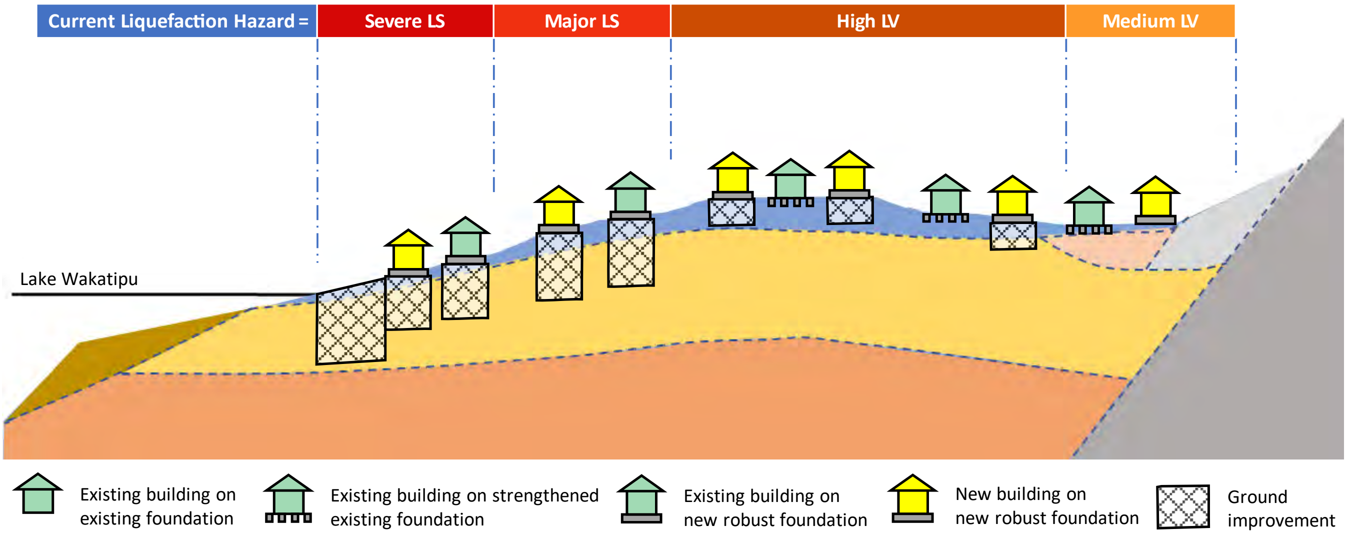
		EXISTING DEVELOPMENT				NEW DEVELOPMENT			
Current liquefaction hazard:		Severe LS	Major LS	High LV	Medium LV	Severe LS	Major LS	High LV	Medium LV
Post-mitigation liquefaction hazard:		High LV	High LV	Medium LV	Medium LV	High LV	High LV	Medium LV	Medium LV
Current % of buildings & infrastructure with severe liquefaction damage in a major earthquake:		90%	75%	50%	25%	-	-	-	-
Post-mitigation % of buildings & infrastructure with severe liquefaction damage in a major earthquake:		30%	25%	15%	15%	25%	20%	10%	10%
MITIGATION WORKS									
LAND	15 – 20m deep by 30 – 40m wide perimeter treatment ground improvement alongside lake	X				X			
	12m deep ground improvement, all land	X	X	X		X	X	X	
	12m deep ground improvement, land under buildings & infrastructure only								
	12m deep ground improvement, land around buildings & infrastructure where accessible								
	4m deep ground improvement, land under buildings & infrastructure only								
	1.2m deep geogrid-reinforced crushed gravel raft, under buildings & infrastructure only								
	No land improvement				X				X
BUILDINGS	New TC3 surface structure foundations	X	X			X	X		
	New TC2 waffle slab foundation or enhanced lightweight platform on timber piles			X				X	X
	Retrofit to strengthen existing foundations and buildings				X				
	No foundation or building improvement								
INFRASTRUCTURE	New infrastructure with resilient detailing	X	X	X		X	X	X	X
	Retrofit to strengthen existing infrastructure				X				
	No infrastructure improvement								

Option B1



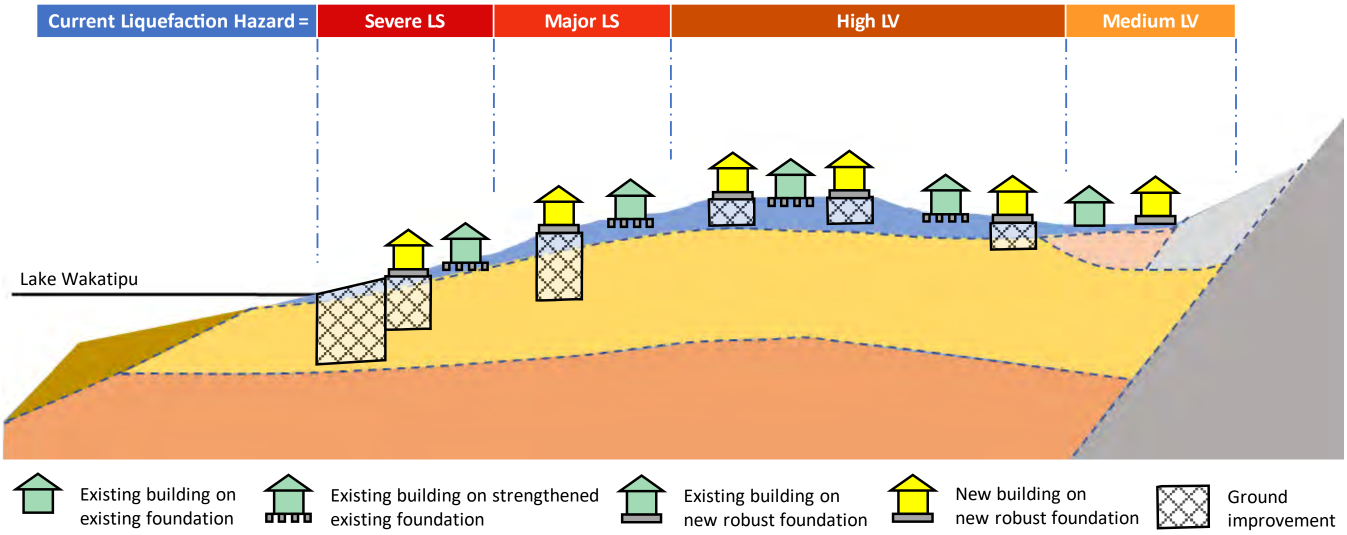
		EXISTING DEVELOPMENT				NEW DEVELOPMENT			
Current liquefaction hazard:		Severe LS	Major LS	High LV	Medium LV	Severe LS	Major LS	High LV	Medium LV
Post-mitigation liquefaction hazard:		High LV	High LV	High LV	Medium LV	High LV	High LV	Medium LV	Medium LV
Current % of buildings & infrastructure with severe liquefaction damage in a major earthquake:		90%	75%	50%	25%	-	-	-	-
Post-mitigation % of buildings & infrastructure with severe liquefaction damage in a major earthquake:		30%	25%	40%	15%	25%	20%	15%	10%
MITIGATION WORKS									
LAND	15 – 20m deep by 30 – 40m wide perimeter treatment ground improvement alongside lake	X				X			
LAND	12m deep ground improvement, all land	X	X			X	X		
LAND	12m deep ground improvement, land under buildings & infrastructure only							X	
LAND	12m deep ground improvement, land around buildings & infrastructure where accessible								
LAND	4m deep ground improvement, land under buildings & infrastructure only								
LAND	1.2m deep geogrid-reinforced crushed gravel raft, under buildings & infrastructure only								
LAND	No land improvement			X	X				X
BUILDINGS	New TC3 surface structure foundations	X	X			X	X		
BUILDINGS	New TC2 waffle slab foundation or enhanced lightweight platform on timber piles							X	X
BUILDINGS	Retrofit to strengthen existing foundations and buildings			X	X				
BUILDINGS	No foundation or building improvement								
INFRASTRUCTURE	New infrastructure with resilient detailing	X	X			X	X	X	X
INFRASTRUCTURE	Retrofit to strengthen existing infrastructure			X	X				
INFRASTRUCTURE	No infrastructure improvement								

Option C1



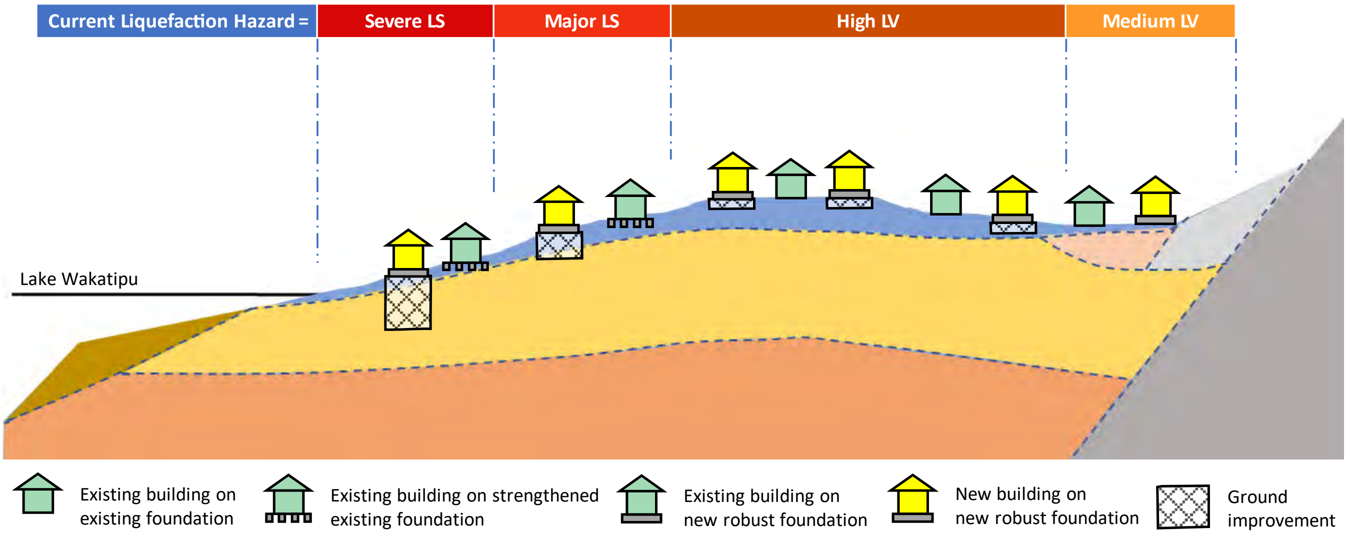
		EXISTING DEVELOPMENT				NEW DEVELOPMENT			
Current liquefaction hazard:		Severe LS	Major LS	High LV	Medium LV	Severe LS	Major LS	High LV	Medium LV
Post-mitigation liquefaction hazard:		High LV	High LV	High LV	Medium LV	High LV	High LV	Medium LV	Medium LV
Current % of buildings & infrastructure with severe liquefaction damage in a major earthquake:		90%	75%	50%	25%	-	-	-	-
Post-mitigation % of buildings & infrastructure with severe liquefaction damage in a major earthquake:		35%	30%	40%	15%	30%	25%	20%	10%
MITIGATION WORKS									
LAND	15 – 20m deep by 30 – 40m wide perimeter treatment ground improvement alongside lake	X				X			
LAND	12m deep ground improvement, all land								
LAND	12m deep ground improvement, land under buildings & infrastructure only	X	X			X	X		
LAND	12m deep ground improvement, land around buildings & infrastructure where accessible								
LAND	4m deep ground improvement, land under buildings & infrastructure only							X	
LAND	1.2m deep geogrid-reinforced crushed gravel raft, under buildings & infrastructure only								
LAND	No land improvement			X	X				X
BUILDINGS	New TC3 surface structure foundations	X	X			X	X		
BUILDINGS	New TC2 waffle slab foundation or enhanced lightweight platform on timber piles							X	X
BUILDINGS	Retrofit to strengthen existing foundations and buildings			X	X				
BUILDINGS	No foundation or building improvement								
INFRASTRUCTURE	New infrastructure with resilient detailing	X	X			X	X	X	X
INFRASTRUCTURE	Retrofit to strengthen existing infrastructure			X	X				
INFRASTRUCTURE	No infrastructure improvement								

Option D1



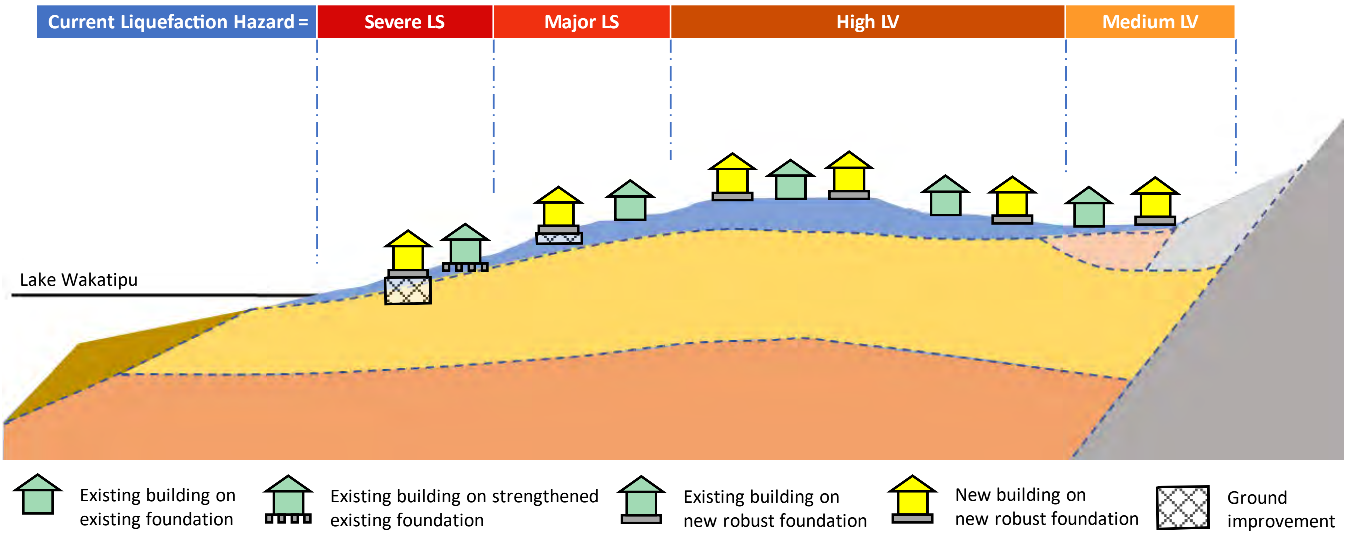
		EXISTING DEVELOPMENT				NEW DEVELOPMENT			
	Current liquefaction hazard:	Severe LS	Major LS	High LV	Medium LV	Severe LS	Major LS	High LV	Medium LV
	Post-mitigation liquefaction hazard:	Severe LS	Major LS	High LV	Medium LV	High LV	High LV	Medium LV	Medium LV
	Current % of buildings & infrastructure with severe liquefaction damage in a major earthquake:	90%	75%	50%	25%	-	-	-	-
	Post-mitigation % of buildings & infrastructure with severe liquefaction damage in a major earthquake:	55%	50%	40%	25%	35%	30%	20%	10%
MITIGATION WORKS									
LAND	15 – 20m deep by 30 – 40m wide perimeter treatment ground improvement alongside lake	X				X			
LAND	12m deep ground improvement, all land								
LAND	12m deep ground improvement, land under buildings & infrastructure only					X	X		
LAND	12m deep ground improvement, land around buildings & infrastructure where accessible								
LAND	4m deep ground improvement, land under buildings & infrastructure only							X	
LAND	1.2m deep geogrid-reinforced crushed gravel raft, under buildings & infrastructure only								
LAND	No land improvement	X	X	X	X				X
BUILDINGS	New TC3 surface structure foundations					X	X		
BUILDINGS	New TC2 waffle slab foundation or enhanced lightweight platform on timber piles							X	X
BUILDINGS	Retrofit to strengthen existing foundations and buildings	X	X	X					
BUILDINGS	No foundation or building improvement				X				
INFRASTRUCTURE	New infrastructure with resilient detailing					X	X	X	X
INFRASTRUCTURE	Retrofit to strengthen existing infrastructure	X	X	X					
INFRASTRUCTURE	No infrastructure improvement				X				

Option E



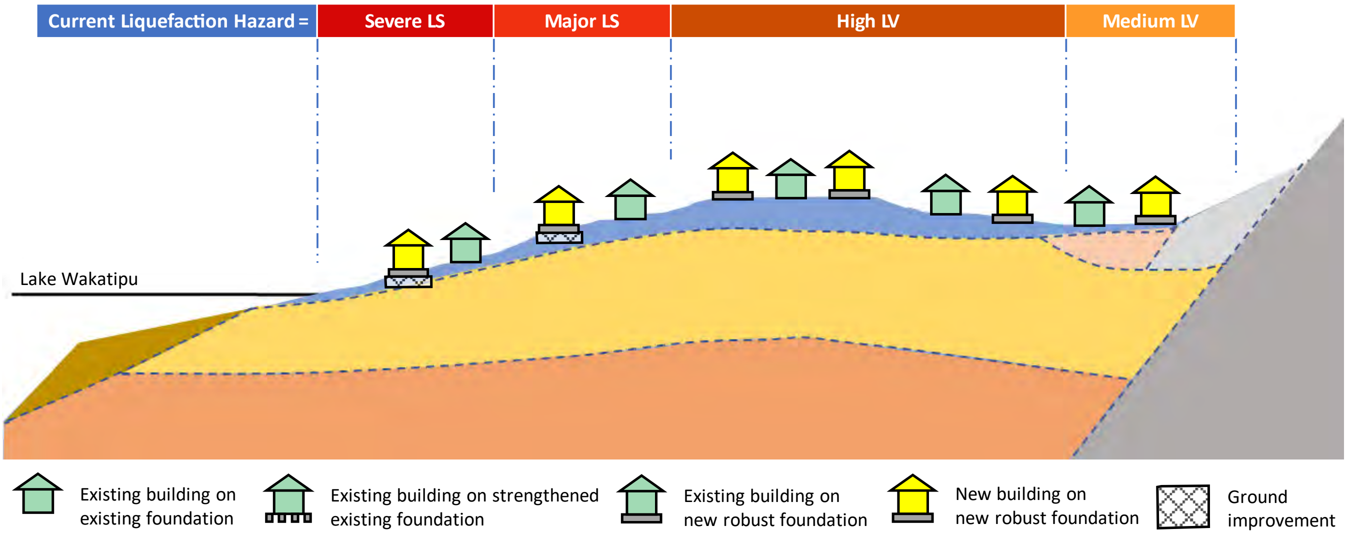
		EXISTING DEVELOPMENT				NEW DEVELOPMENT			
Current liquefaction hazard:		Severe LS	Major LS	High LV	Medium LV	Severe LS	Major LS	High LV	Medium LV
Post-mitigation liquefaction hazard:		Severe LS	Major LS	High LV	Medium LV	Major LS	Major LS	High LV	Medium LV
Current % of buildings & infrastructure with severe liquefaction damage in a major earthquake:		90%	75%	50%	25%	-	-	-	-
Post-mitigation % of buildings & infrastructure with severe liquefaction damage in a major earthquake:		75%	65%	50%	25%	40%	40%	25%	10%
MITIGATION WORKS									
LAND	15 – 20m deep by 30 – 40m wide perimeter treatment ground improvement alongside lake								
	12m deep ground improvement, all land								
	12m deep ground improvement, land under buildings & infrastructure only					X			
	12m deep ground improvement, land around buildings & infrastructure where accessible								
	4m deep ground improvement, land under buildings & infrastructure only						X		
	1.2m deep geogrid-reinforced crushed gravel raft, under buildings & infrastructure only							X	
	No land improvement	X	X	X	X				X
BUILDINGS	New TC3 surface structure foundations					X	X	X	
	New TC2 waffle slab foundation or enhanced lightweight platform on timber piles								X
	Retrofit to strengthen existing foundations and buildings	X	X						
	No foundation or building improvement			X	X				
INFRASTRUCTURE	New infrastructure with resilient detailing					X	X	X	X
	Retrofit to strengthen existing infrastructure	X	X						
	No infrastructure improvement			X	X				

Option F



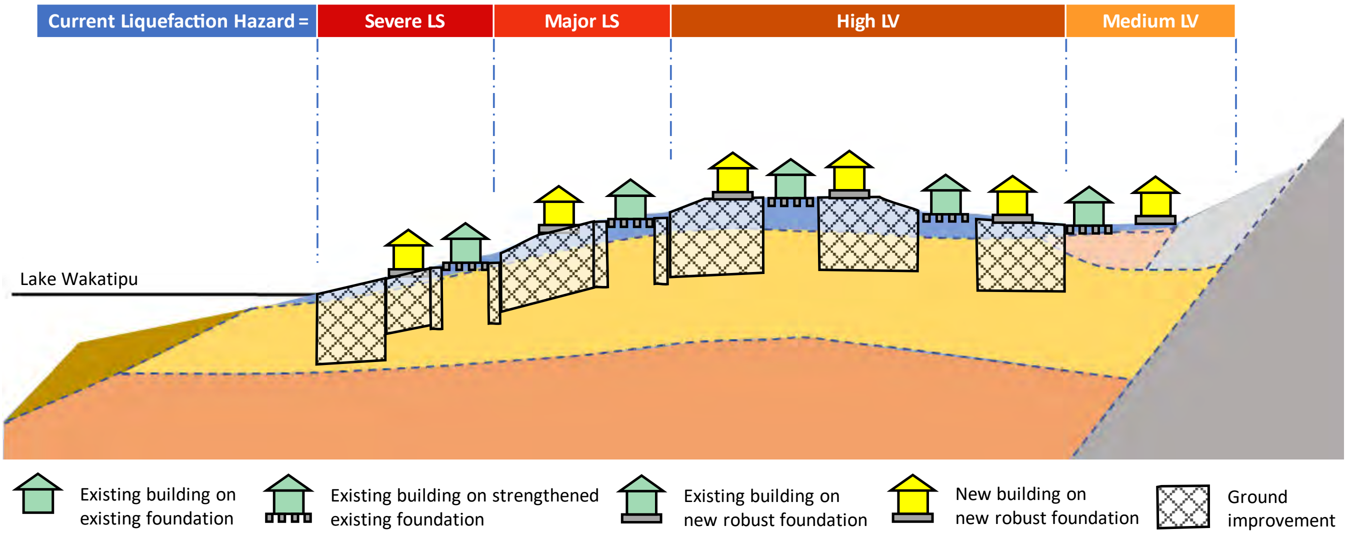
		EXISTING DEVELOPMENT				NEW DEVELOPMENT			
Current liquefaction hazard:		Severe LS	Major LS	High LV	Medium LV	Severe LS	Major LS	High LV	Medium LV
Post-mitigation liquefaction hazard:		Severe LS	Major LS	High LV	Medium LV	Severe LS	Major LS	High LV	Medium LV
Current % of buildings & infrastructure with severe liquefaction damage in a major earthquake:		90%	75%	50%	25%	-	-	-	-
Post-mitigation % of buildings & infrastructure with severe liquefaction damage in a major earthquake:		80%	75%	50%	25%	50%	50%	30%	10%
MITIGATION WORKS									
LAND	15 – 20m deep by 30 – 40m wide perimeter treatment ground improvement alongside lake								
LAND	12m deep ground improvement, all land								
LAND	12m deep ground improvement, land under buildings & infrastructure only								
LAND	12m deep ground improvement, land around buildings & infrastructure where accessible								
LAND	4m deep ground improvement, land under buildings & infrastructure only					X			
LAND	1.2m deep geogrid-reinforced crushed gravel raft, under buildings & infrastructure only						X		
LAND	No land improvement	X	X	X	X			X	X
BUILDINGS	New TC3 surface structure foundations					X	X	X	
BUILDINGS	New TC2 waffle slab foundation or enhanced lightweight platform on timber piles								X
BUILDINGS	Retrofit to strengthen existing foundations and buildings	X							
BUILDINGS	No foundation or building improvement		X	X	X				
INFRASTRUCTURE	New infrastructure with resilient detailing					X	X	X	X
INFRASTRUCTURE	Retrofit to strengthen existing infrastructure	X							
INFRASTRUCTURE	No infrastructure improvement		X	X	X				

Option G



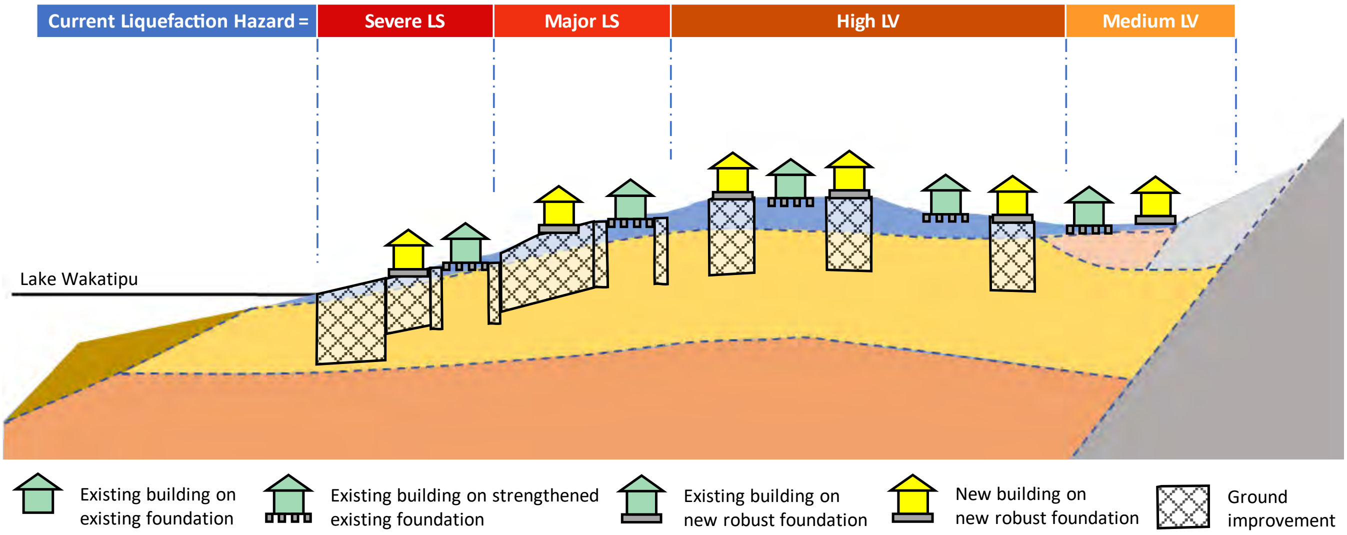
		EXISTING DEVELOPMENT				NEW DEVELOPMENT			
Current liquefaction hazard:		Severe LS	Major LS	High LV	Medium LV	Severe LS	Major LS	High LV	Medium LV
Post-mitigation liquefaction hazard:		Severe LS	Major LS	High LV	Medium LV	Severe LS	Major LS	High LV	Medium LV
Current % of buildings & infrastructure with severe liquefaction damage in a major earthquake:		90%	75%	50%	25%	-	-	-	-
Post-mitigation % of buildings & infrastructure with severe liquefaction damage in a major earthquake:		90%	75%	50%	25%	60%	50%	30%	10%
MITIGATION WORKS									
LAND	15 – 20m deep by 30 – 40m wide perimeter treatment ground improvement alongside lake								
	12m deep ground improvement, all land								
	12m deep ground improvement, land under buildings & infrastructure only								
	12m deep ground improvement, land around buildings & infrastructure where accessible								
	4m deep ground improvement, land under buildings & infrastructure only								
	1.2m deep geogrid-reinforced crushed gravel raft, under buildings & infrastructure only					X	X		
	No land improvement	X	X	X	X			X	X
BUILDINGS	New TC3 surface structure foundations					X	X	X	
	New TC2 waffle slab foundation or enhanced lightweight platform on timber piles								X
	Retrofit to strengthen existing foundations and buildings								
	No foundation or building improvement	X	X	X	X				
INFRASTRUCTURE	New infrastructure with resilient detailing					X	X	X	X
	Retrofit to strengthen existing infrastructure								
	No infrastructure improvement	X	X	X	X				

Option A2



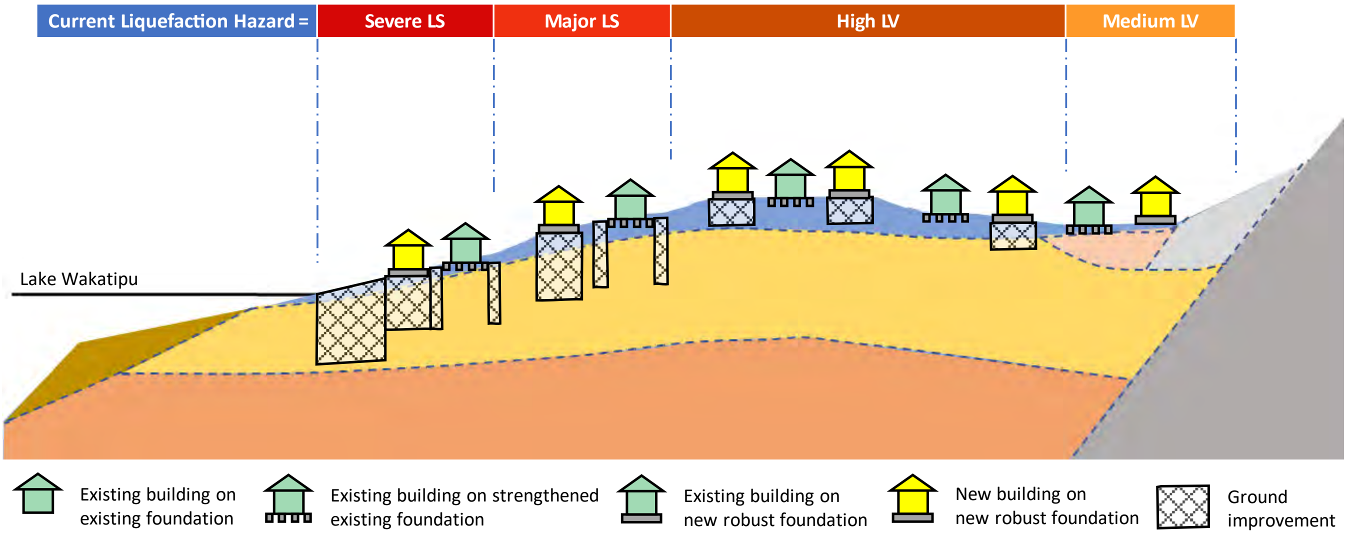
		EXISTING DEVELOPMENT				NEW DEVELOPMENT			
Current liquefaction hazard:		Severe LS	Major LS	High LV	Medium LV	Severe LS	Major LS	High LV	Medium LV
Post-mitigation liquefaction hazard:		Major LS	High LV	High LV	Medium LV	High LV	High LV	Medium LV	Medium LV
Current % of buildings & infrastructure with severe liquefaction damage in a major earthquake:		90%	75%	50%	25%	-	-	-	-
Post-mitigation % of buildings & infrastructure with severe liquefaction damage in a major earthquake:		45%	40%	40%	15%	30%	25%	10%	10%
MITIGATION WORKS									
LAND	15 – 20m deep by 30 – 40m wide perimeter treatment ground improvement alongside lake	X				X			
LAND	12m deep ground improvement, all land					X	X	X	
LAND	12m deep ground improvement, land under buildings & infrastructure only								
LAND	12m deep ground improvement, land around buildings & infrastructure where accessible	X	X						
LAND	4m deep ground improvement, land under buildings & infrastructure only								
LAND	1.2m deep geogrid-reinforced crushed gravel raft, under buildings & infrastructure only								
LAND	No land improvement			X	X				X
BUILDINGS	New TC3 surface structure foundations					X	X		
BUILDINGS	New TC2 waffle slab foundation or enhanced lightweight platform on timber piles							X	X
BUILDINGS	Retrofit to strengthen existing foundations and buildings	X	X	X	X				
BUILDINGS	No foundation or building improvement								
INFRASTRUCTURE	New infrastructure with resilient detailing					X	X	X	X
INFRASTRUCTURE	Retrofit to strengthen existing infrastructure	X	X	X	X				
INFRASTRUCTURE	No infrastructure improvement								

Option B2



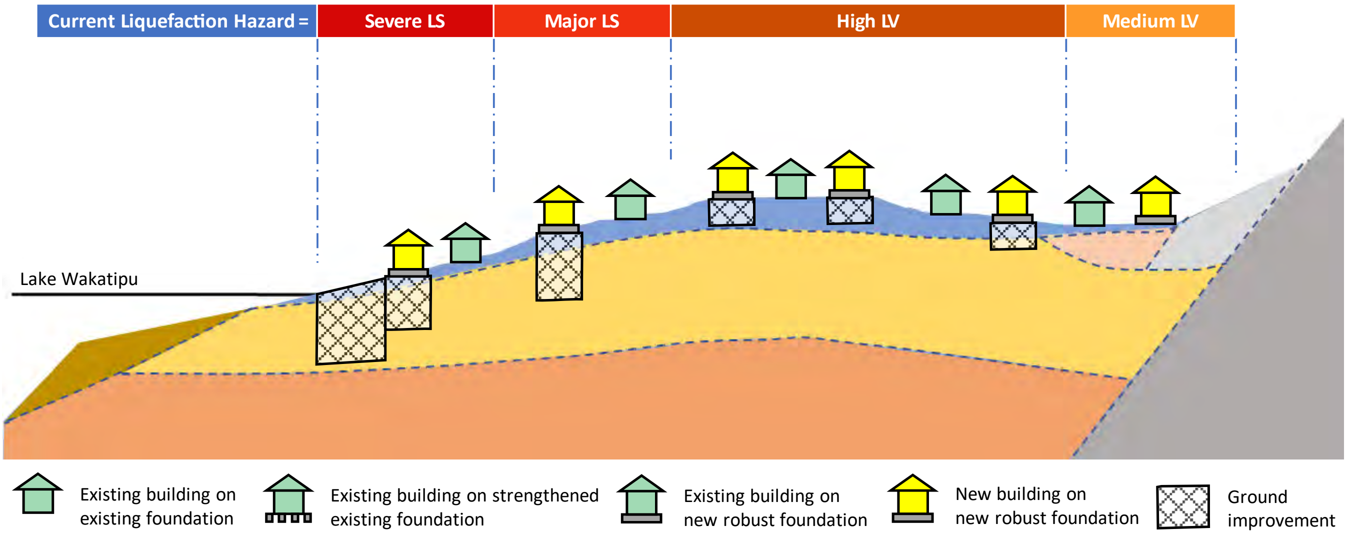
		EXISTING DEVELOPMENT				NEW DEVELOPMENT			
Current liquefaction hazard:		Severe LS	Major LS	High LV	Medium LV	Severe LS	Major LS	High LV	Medium LV
Post-mitigation liquefaction hazard:		Major LS	High LV	High LV	Medium LV	High LV	High LV	Medium LV	Medium LV
Current % of buildings & infrastructure with severe liquefaction damage in a major earthquake:		90%	75%	50%	25%	-	-	-	-
Post-mitigation % of buildings & infrastructure with severe liquefaction damage in a major earthquake:		45%	40%	40%	15%	30%	25%	15%	10%
MITIGATION WORKS									
LAND	15 – 20m deep by 30 – 40m wide perimeter treatment ground improvement alongside lake	X				X			
LAND	12m deep ground improvement, all land					X	X		
LAND	12m deep ground improvement, land under buildings & infrastructure only							X	
LAND	12m deep ground improvement, land around buildings & infrastructure where accessible	X	X						
LAND	4m deep ground improvement, land under buildings & infrastructure only								
LAND	1.2m deep geogrid-reinforced crushed gravel raft, under buildings & infrastructure only								
LAND	No land improvement			X	X				X
BUILDINGS	New TC3 surface structure foundations					X	X		
BUILDINGS	New TC2 waffle slab foundation or enhanced lightweight platform on timber piles							X	X
BUILDINGS	Retrofit to strengthen existing foundations and buildings	X	X	X	X				
BUILDINGS	No foundation or building improvement								
INFRASTRUCTURE	New infrastructure with resilient detailing					X	X	X	X
INFRASTRUCTURE	Retrofit to strengthen existing infrastructure	X	X	X	X				
INFRASTRUCTURE	No infrastructure improvement								

Option C2



		EXISTING DEVELOPMENT				NEW DEVELOPMENT			
Current liquefaction hazard:		Severe LS	Major LS	High LV	Medium LV	Severe LS	Major LS	High LV	Medium LV
Post-mitigation liquefaction hazard:		Major LS	High LV	High LV	Medium LV	High LV	High LV	Medium LV	Medium LV
Current % of buildings & infrastructure with severe liquefaction damage in a major earthquake:		90%	75%	50%	25%	-	-	-	-
Post-mitigation % of buildings & infrastructure with severe liquefaction damage in a major earthquake:		45%	40%	40%	15%	30%	25%	20%	10%
MITIGATION WORKS									
LAND	15 – 20m deep by 30 – 40m wide perimeter treatment ground improvement alongside lake	X				X			
LAND	12m deep ground improvement, all land								
LAND	12m deep ground improvement, land under buildings & infrastructure only					X	X		
LAND	12m deep ground improvement, land around buildings & infrastructure where accessible	X	X						
LAND	4m deep ground improvement, land under buildings & infrastructure only							X	
LAND	1.2m deep geogrid-reinforced crushed gravel raft, under buildings & infrastructure only								
LAND	No land improvement			X	X				X
BUILDINGS	New TC3 surface structure foundations					X	X		
BUILDINGS	New TC2 waffle slab foundation or enhanced lightweight platform on timber piles							X	X
BUILDINGS	Retrofit to strengthen existing foundations and buildings	X	X	X	X				
BUILDINGS	No foundation or building improvement								
INFRASTRUCTURE	New infrastructure with resilient detailing					X	X	X	X
INFRASTRUCTURE	Retrofit to strengthen existing infrastructure	X	X	X	X				
INFRASTRUCTURE	No infrastructure improvement								

Option D2



		EXISTING DEVELOPMENT				NEW DEVELOPMENT			
Current liquefaction hazard:		Severe LS	Major LS	High LV	Medium LV	Severe LS	Major LS	High LV	Medium LV
Post-mitigation liquefaction hazard:		Severe LS	Major LS	High LV	Medium LV	High LV	High LV	Medium LV	Medium LV
Current % of buildings & infrastructure with severe liquefaction damage in a major earthquake:		90%	75%	50%	25%	-	-	-	-
Post-mitigation % of buildings & infrastructure with severe liquefaction damage in a major earthquake:		65%	60%	50%	25%	35%	30%	20%	10%
MITIGATION WORKS									
LAND	15 – 20m deep by 30 – 40m wide perimeter treatment ground improvement alongside lake	X				X			
LAND	12m deep ground improvement, all land								
LAND	12m deep ground improvement, land under buildings & infrastructure only					X	X		
LAND	12m deep ground improvement, land around buildings & infrastructure where accessible								
LAND	4m deep ground improvement, land under buildings & infrastructure only							X	
LAND	1.2m deep geogrid-reinforced crushed gravel raft, under buildings & infrastructure only								
LAND	No land improvement	X	X	X	X				X
BUILDINGS	New TC3 surface structure foundations					X	X		
BUILDINGS	New TC2 waffle slab foundation or enhanced lightweight platform on timber piles							X	X
BUILDINGS	Retrofit to strengthen existing foundations and buildings								
BUILDINGS	No foundation or building improvement	X	X	X	X				
INFRASTRUCTURE	New infrastructure with resilient detailing					X	X	X	X
INFRASTRUCTURE	Retrofit to strengthen existing infrastructure								
INFRASTRUCTURE	No infrastructure improvement	X	X	X	X				

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7.2. Otago Region Natural Hazards Risk Assessment

Prepared for: Safety and Resilience Comm

Report No. OPS2305

Activity: Governance Report

Author: Jean-Luc Payan, Manager Natural Hazards; Andrew Welsh, Spatial Analyst

Endorsed by: Gavin Palmer, General Manager Operations

Date: 10 May 2023

PURPOSE

[1] To inform the Committee of the work programme to undertake a natural hazards risk assessment for the Otago region, and development of a prioritisation approach to inform ORC's natural hazard risk management/adaptation planning and implementation.

EXECUTIVE SUMMARY

[2] ORC is undertaking a natural hazard risk assessment work programme, designed as a review and high-level assessment of natural hazard risks for the full Otago region.

[3] The purpose of the natural hazards risk assessment is to work towards a comprehensive, regional-scale, spatial understanding of Otago's natural hazards and risks.

[4] Completion of the risk assessment will enable a consistent assessment and prioritisation of risk management or adaptation responses between areas across the region.

[5] A prioritisation approach is being developed, which is designed to identify the areas of highest natural hazard risks, and assist with planning for natural hazards risk management or adaptation responses

RECOMMENDATION

That the Safety and Resilience Committee:

1) ***Notes*** *this report.*
2) ***Notes*** *the Otago Regional Council natural hazards risk assessment work programme.*

BACKGROUND

[6] The Otago region is exposed to a wide variety of natural hazards that impact on people, property, infrastructure and the wider environment. The natural hazards threats range from coastal erosion and flooding in lowland coastal areas to alluvial fan deposition, landslide, rock fall, and seismic hazards elsewhere in the region.

[7] In order to understand the exposure of the Otago region to natural hazard impacts, ORC has previously completed extensive natural hazard mapping and hazard assessments. This work has informed compilation of regional or district-scale datasets providing an overview of the extents and characteristics of natural hazards.

[8] ORC's natural hazards mapping is publicly available on the ORC Natural Hazards Portal,[1] which also includes supporting information such as technical reports and photographs.

[9] An important next step following natural hazard identification and characterisation, is an assessment of the natural hazard risks and their spatial distribution.

[10] There has not yet been any systematic review or assessment of the natural hazard risks across the Otago region as a whole, although there have been localised natural hazard risk assessments undertaken for specific locations.[2]

[11] The Otago Climate Change Risk Assessment (OCCRA)[3] developed a regional dataset of climate change related risks and opportunities and provides a broad understanding of how these may change over time.

[12] This paper provides an overview of the current natural hazard risk assessment work programme, which is designed as a review and high-level assessment of natural hazard risks for the full Otago region, incorporating the effects of future climate change, for the main potential natural hazards which may potentially impact these areas. The paper also provides an update on development of a prioritisation approach and proposed next steps.

[13] This work programme supports the ORC community outcome "*Communities that are resilient in the face of natural hazards & climate change and other risks*."

[14] The proposed natural hazard risk assessment programme is listed in the 2021-2031 ORC Long-term Plan (LTP) as work to "*Develop comprehensive risk mapping of natural hazards across Otago*" and specifies the performance measure: "*Complete regional natural hazards risk assessment (NHRA) and develop a regional approach for prioritising adaptation to inform adaptation planning and implementation.*"

[15] This risk assessment is included in the ORC 2021-2031 LTP as a ten-year programme. The first three years (to the end of the 2023-24 financial year) have a target of completing natural hazard risk assessment and definition of a regional risk prioritisation approach (Table 1). The remainder of the LTP timeframe is specified for further development of a regional approach for natural hazards risk adaptation.

Table 1: Performance measures and targets for the natural hazards risk assessment program, from the 2021-31 Long Term Plan.

PERFORMANCE MEASURES	BASELINE RESULTS	2021/22 TARGET	2022/23 TARGET	2023/24 TARGET	2024-31 TARGET
Complete regional natural hazards risks assessment (NHRA) and develop a regional approach for prioritising adaptation* to inform adaptation planning and implementation	*New measure*	Commence natural hazard risk assessment and investigation of prioritisation approach	Report to Council on progress of natural hazard risk assessment and prioritisation approach	Complete natural hazard risk assessment and define a regional approach for prioritising adaptation	Develop a regional prioritisation plan for natural hazard risks adaptation

[1] http://hazards.orc.govt.nz

[2] For example, assessment of debris flow risks at Roxburgh (for ORC), and for debris flows and rockfall risks at Gorge Road, Queenstown (for QLDC).

[3] Gore E & Payan J, 2021. *Otago Climate Change Risk Assessment*. ORC report HAZ2101, report to the 1st March 2021 meeting of the Otago Regional Council Data and Information Committee.

NATURAL HAZARD RISK

[16] This section outlines the key concepts and approaches in the assessment of natural hazard risk.

[17] The International Standards Organisation (ISO) definition of risk[4] has been adopted by Standards New Zealand for risk management. The ISO defines risk as the "*effect of uncertainty on objectives*" and makes the following notes:

1. An effect is a deviation from the expected – positive and/or negative.
2. Objectives can have different aspects (such as financial, health and safety and environmental goals) and can apply at different levels (such as strategic, organisation wide, project, product and process).
3. Risk is often characterised by reference to potential events … and consequences …, or a combination of these.
4. Risk is often expressed in terms of a combination of the consequences of an event (including changes in circumstances and the associated likelihood … of occurrence).
5. Uncertainty is the state, even partial, of deficiency of information related to understanding or knowledge of an event, its consequence or likelihood.

[18] Natural hazard risk is commonly expressed[5] as a product of event likelihood and consequence (i.e., *Risk = Likelihood x Consequence*) and can be plotted on a simple matrix of these two factors (e.g., Table 3).

[19] In natural hazards and climate change assessments, risk is often expressed as: *Risk = Hazard x Exposure x Vulnerability*. For example, the IPCC's conceptual risk framework (Figure 1) which was used as a basis for the Otago Climate Change Risk Assessment.[6]

[20] More advanced natural hazard risk definitions include additional elements accounting for complexity such as recognition of feedback loops and cascading hazard interactions, gradual onset impacts on systems or processes, vulnerability, capacity to adapt, and presence of hazard mitigation actions or residual risks.[7]

[21] The key terms commonly used in natural hazard risk characterisation are explained in Table 2.

[22] The risk assessment approach will be based on the principles of the risk assessment framework outlined in the proposed Otago Regional Policy Statement 2021 (pORPS).

Table 2: Explanation of key terms in natural hazard risk assessment.[8]

Term	Definition
Natural hazard	A natural process or phenomenon that may cause loss of life, injury or other

[4] AS/NZS ISO 31000:2009

[5] e.g. in the New Zealand Coastal Policy Statement (2010) and the Civil Defence Emergency Management Act (2002).

[6] Tonkin + Taylor Ltd, 2021. *Otago Climate Change Risk Assessment*. Prepared for Otago Regional Council.

[7] Clarke LB et al., 2021. *Stocktake of Existing Risk Tolerance Frameworks*. GNS Science Consultancy Report 2021/71, October 2021.

[8] Adapted from: Ministry of Civil Defence and Emergency Management, 2019. *National Disaster Resilience Strategy, Rautaki ā-Motu Manawaroa Aituā*

	health impacts, property damage, social and economic disruption or environmental degradation.
Disaster	A serious disruption of the functioning of a community or a society at any scale due to hazardous events interacting with conditions of exposure, vulnerability and capacity, leading to one or more of the following: human, material, social, cultural, economic and environmental losses and impacts
Natural hazard risk	The potential loss of life, injury, or destroyed or damaged assets which could occur to a system, society or a community in a specific period of time, determined as a function of hazard, exposure, vulnerability and capacity
Exposure	People, infrastructure, buildings, the economy, and other assets that are exposed to a hazard
Vulnerability	The conditions determined by physical, social, economic and environmental factors or processes which increase the susceptibility of an individual, a community, assets or systems to the impacts of hazards
Capacity	The combination of all the strengths, attributes and resources available within an organisation, community or society to manage and reduce disaster risks and strengthen resilience
Risk assessment	An assessment of the nature and extent of risk by analysing potential hazards and evaluating existing conditions of exposure and vulnerability to determine likely consequences
Residual risk	The risk that remains after risk treatment has been applied to reduce the potential consequences.

Table 3: The risk classification matrix included in the proposed Otago Regional Policy Statement 2021 (pORPS).

Likelihood	**Consequences**				
	Insignificant	Minor	Moderate	Major	Catastrophic
Almost certain					
Likely					
Possible					
Unlikely					
Rare					
Green, Acceptable *Risk*: Yellow, Tolerable *Risk*: Red, Significant *Risk*					

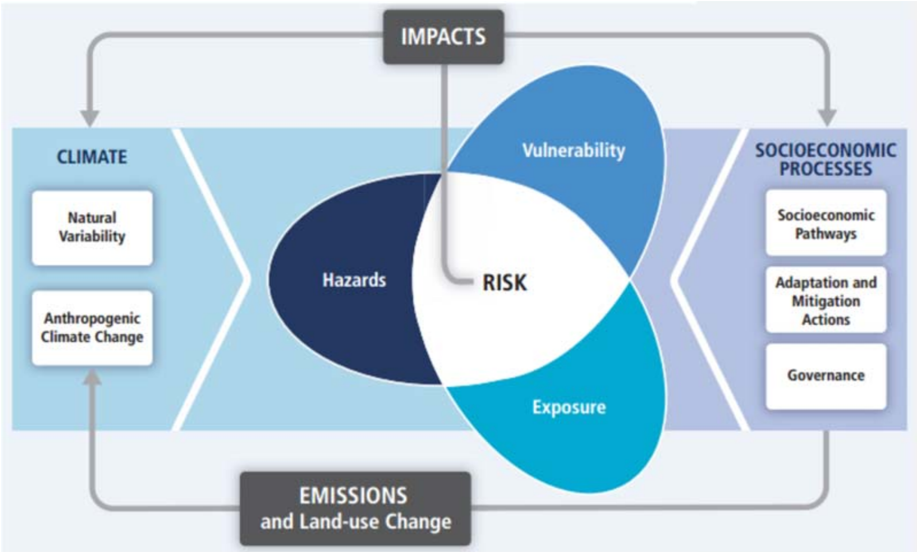

Figure 1: Illustration of the concepts of risk and vulnerability to climate change. (IPCC, 2014).[9]

PROGRAMME OBJECTIVES

[23] High-level objectives have been developed for the risk assessment work programme, these are:

1. To work towards a comprehensive, regional-scale, spatial understanding of Otago's natural hazards and risks.
2. Consistent assessment and prioritisation of risk management or adaptation responses between areas.

[24] The usage of risk assessment findings could include;

- Informing requirements of the Otago RPS, where local authorities must "assess the level of natural hazard risk in their region or district" and "continue to undertake research on the identification of natural hazard risk and amend natural hazard registers, databases, regional and/or district plans as required."[10]
- Identification and prioritisation of higher-risk locations for natural hazards risk management or adaptation responses. This will assist ORC and territorial authorities to prioritise allocation of resources towards project areas, and may include identification of potentially 'significant' risks where ORC should work with TA's to further assess risk characteristics.
- Identification of data gaps or limitations in existing regional natural hazards information, assisting with planning for completion of further studies to continue to build ORC's hazards understanding.

[25] In simple terms, the programme findings are intended to provide answers to questions such as;

- What are the top-10 natural hazard risk areas in the region?
- What might be the highest natural hazard risk areas in the region in 100 years?
- Why is ORC focusing resources on development of an adaptation plan for _____ area?

[9] IPCC, 2014. *Fifth Assessment Report, Working Group 2*. Chapter 19, Figure 19-1.
[10] RPS method HAZ-NH-M2, page 168

- In what locations should ORC be planning for establishment of our next adaptation work programme(s)?
- How many people (or houses/schools etc.) in the region are located within flood-prone areas (or potentially active alluvial fans, or liquefaction-prone ground etc.)?
- How many people (or houses/schools) in the region are located within a specific elevation of sea level, and therefore vulnerable to sea level rise impacts?

PROGRAMME APPROACH

[26] The phased approach to the risk assessment programme is outlined in Table 4.

[27] Assessments will consider those natural hazard types where ORC holds regional-scale hazard mapping, and use the statistical areas defined by Statistics New Zealand[11] to provide a consistent spatial breakdown of the region.

[28] Phases 1-3 are an initial hazards exposure analysis and risk screening, planned to be completed by end of the 2023 calendar year as a peer-reviewed technical report detailing all analysis and findings.

Table 4: Summary of the natural hazards risk assessment approach for the Otago region.

Phase	Description	Purpose
Preparation	Programme planning, collation and review of natural hazard and elements-at-risk datasets.	Ensure all relevant information is available for consideration.
1	Regional-scale natural hazards exposure analysis	Initial exposure analysis to understand spatial distribution of natural hazard, and elements-at-risk to those hazards.
2	Preliminary regional-scale risk analysis.	An initial screening to identify risk characteristics and spatial distribution for each hazard type.
3	Multi-hazard, analytical risk-based assessment of community areas.	Develop a combined multi-hazard risk characterisation for each community area.
4	Prioritisation assessment based on both analytical and subjective factors. This step would be end of risk assessment phase.	Develop a prioritised list of higher-risk community areas for potential development of a risk management or adaptation programme.
5	Targeted natural hazard risk analysis for higher-risk community areas.	Development of additional natural hazard risk understanding as first step of a risk management or adaptation programme.

Natural Hazard Risk Prioritisation (Phase 4)

[29] ORC manages natural hazard impacts through undertaking natural hazard management or adaptation work programmes. ORC has programmes underway or identified, to develop natural hazards management or adaptation strategies for a number of locations within Otago.

[30] These programmes either focus on a response to single types of natural hazard (e.g. Roxburgh, Middlemarch, Water of Leith and Lindsay Creek), or more complex multi-

[11] Stats NZ, 2017. *Statistical standard for geographic areas 2018.*

hazard environments (e.g., South Dunedin,[12] Balclutha & the Clutha Delta, Head of Lake Wakatipu[13]).

[31] A risk-based prioritisation approach will allow ORC to systematically identify and define key projects and allocation of work within the overall Natural Hazards work programme.

[32] To identify a subset of 'significant' risk locations as higher priority for natural hazard risk management and adaptation action planning, prioritisation must be based on a combination of factors.

[33] These factors are expected to include both 'technical' factors (such as risk characteristics), but also external factors which may influence the success of any potential work programme (such as opportunities to collaborate with a TA or community group).

DISCUSSION

[34] The natural hazards risk assessment programme described in this paper will be a valuable addition to the understanding of natural hazards and risks in the Otago region.

[35] Because hazard and risk understanding is continually growing in response to hazard events, research and hazard investigations, any risk assessment findings will not ever be a complete or 'final' classification or prioritisation of risks.

[36] These risk assessments are intended only as a preliminary stocktake of risk understanding, which will require review and revision in future iterations of the risk assessment.

[37] The prioritisation approach described will inform ORC's natural hazard risk management and adaptation planning and implementation.

[38] As for the risk assessment, any prioritisation will not be a definitive 'final' listing, and will require review/revision as necessary, for example to consider new hazard/risk information, the occurrence of major hazards events, or new opportunities for collaboration.

[39] Natural hazards risk management or adaptation responses could be relatively small-scale (e.g., investigation of immediate or shorter-term hazard management interventions), or establishment of a comprehensive hazard risk management or adaptation project.

[40] A significant investment and resourcing is required for establishment and completion of a comprehensive adaptation work programme (time, funding, consultant expertise, community engagement), so it is only possible to undertake a small number of these work programmes at one time.

CONSIDERATIONS

Strategic Framework and Policy Considerations

[12] https://www.dunedin.govt.nz/council/council-projects/south-dunedin-future
[13] https://www.orc.govt.nz/managing-our-environment/natural-hazards/head-of-lake-wakatipu

[41] The natural hazards risk assessment work programme 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

[42] The project is included in the ORC 2021-31 Long Term Plan with funding of $150,000 (excluding staff time) in the 2023/24 financial year.

Significance and Engagement Considerations

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

Legislative and Risk Considerations

[44] The natural hazard risk assessment work programme will help ORC to understand and manage the risks associated with natural hazards in the region, required by legislation such as the Civil Defence Emergency Management Act[14] and the Resource Management Act.[15]

[45] 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

[46] Climate change is an important consideration in assessment of natural hazard risks, particularly for those hazards expected to be impacted by projected changes to hydrological (e.g., rainfall, river flows) or coastal (e.g., sea level) characteristics.

[47] This risk assessment programme will complement and build on the findings of the Otago Climate Change Risk Assessment (OCCRA).[16]

Communications Considerations

[48] Risk assessment findings will be documented in a technical report and made available to the public, territorial authorities and other stakeholders.

[49] Findings will be specifically communicated to the relevant territorial authorities and those communities identified as being higher-risk locations.

NEXT STEPS

[50] The ORC Natural Hazards team will continue with natural hazard risk analysis and reporting for this programme, following the approach presented in Table 4.

[51] As specified in the LTP, the first iteration of the risk assessment and prioritisation approach will be completed by June 2024.

ATTACHMENTS

Nil

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[14] Section 17 of the CDEMA (2002) states that a function of a Civil Defence membership group is to identify, assess, and manage natural hazards and risks.

[15] The management of significant risks from natural hazards is included as a matter of national importance in the RMA (Section 6(h).

[16] Gore E & Payan J, 2021. *Otago Climate Change Risk Assessment*. ORC report HAZ2101, report to the 1st March 2021 meeting of the Otago Regional Council Data and Information Committee.