5.1. Head of Lake Wakatipu flooding and liquefaction hazard investigations

Prepared for:	Data and Information Committee
Report No.	HAZ2202
Activity:	Safety & Hazards - Natural Hazards
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Endorsed by:	Gavin Palmer, General Manager Operations
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PURPOSE

[1] To inform the Committee of the findings of investigations of flooding and liquefaction hazards at the Dart-Rees floodplain and Glenorchy township and to provide an update on other activities in the ORC-led work programme to develop a natural hazards adaptation strategy for the area at the head of Lake Wakatipu.

EXECUTIVE SUMMARY

[2] Previous Otago Regional Council (ORC) reports[1] have identified the Dart-Rees floodplain and Glenorchy township as exposed to the potential impacts of natural hazard events such as flooding and liquefaction.

[3] A geotechnical investigation commissioned by ORC and completed by Tonkin + Taylor Ltd (T+T) has assessed the susceptibility of the Glenorchy township area to liquefaction and lateral spreading caused by a major earthquake, and the anticipated impacts of these hazards.

[4] A hydraulic modelling and flood hazard investigation commissioned by ORC and completed by Land River Sea Consulting Ltd (LRS) has assessed the flood hazard to the Dart-Rees floodplain and Glenorchy township from the Dart and Rees rivers, and high levels in Lake Wakatipu.

[5] This paper presents the key findings of the Tonkin + Taylor Ltd and Land River Sea Consulting Ltd technical reports, investigating liquefaction and flood hazards respectively.

[6] These new investigations contribute to a significant advance in natural hazards understanding for the Dart-Rees floodplain and Glenorchy, being the most detailed hydraulic modelling study at the Dart-Rees rivers, and the first liquefaction hazard assessment for Glenorchy based on comprehensive subsurface geotechnical data and analysis.

[1] e.g. ORC (2010). Natural hazards at Glenorchy; Tonkin + Taylor (2021). Head of Lake Wakatipu natural hazards assessment; and van Woerden and Payan (2021). Natural Hazards Adaptation in the Head of Lake Wakatipu. ORC Council report HAZ2105, 27 May 2021

[7] Natural hazard investigations have confirmed a major earthquake or flooding event would have severe impacts, and help understand in more detail the hazard characteristics, spatial extents and likelihoods.

[8] The purpose of the natural hazards investigations is to inform adaptation planning and decision-making in the Dart-Rees floodplain and Glenorchy township. The information will also assist emergency services response and the community readiness for natural hazards events.

[9] Natural hazards adaptation at the Dart-Rees floodplain and Glenorchy township will require a strategic, holistic approach, which incorporates consideration of all potential natural hazard types, future climate change, landscape changes, and multiple and cascading natural hazards.

RECOMMENDATION

That the Data and Information Committee:

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.*
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.*

BACKGROUND

[10] The area at the head of Lake Wakatipu (Whakatipu-Wai-Maori) is exposed to multiple natural hazard risks, including those due to flooding and seismic hazards.

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

[12] The adaptation project approach is outlined in the Council paper *Adaptation in the head of Lake Wakatipu*,[2] considered by Council in May 2021. Council made the following resolutions:

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

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[2] *Natural Hazards Adaptation in the Head of Lake Wakatipu*. ORC Report HAZ2105, Report to 27 May 2021 meeting of the Otago Regional Council.

[13] This paper is an update on new technical investigations completed up to June 2022. These are, an investigation of the liquefaction susceptibility in Glenorchy township, and a flood hazard investigation for the Dart-Rees floodplain including Glenorchy.

[14] This paper also includes brief updates on other project activities:

- The ORC environmental monitoring network in the head of Lake Wakatipu area, including the installation of a river flow monitor for the Rees River.
- A study in progress to assess potential floodplain hazard mitigation approaches for the Dart-Rees floodplain.
- A summary of a new investigation into alluvial fan hazards at the Buckler Burn.
- An overview of response to a debris flow event in April 2022 impacting on the Queenstown-Glenorchy road access (Shepherds Hut Creek).
- An update on natural hazards research projects in the head of Lake Wakatipu area that are supported by ORC.

[15] The occurrences of liquefaction and lateral spreading following the 2010-2011 Christchurch and 2016 Kaikoura earthquakes has created a greater awareness of, and focus on, the potential for liquefaction events in New Zealand. In response to recommendations[3] of the Royal Commission of Inquiry into Building Failure caused by the Canterbury Earthquakes, the Ministry of Business, Innovation and Employment (MBIE) and the Ministry for the Environment (MfE) released a guidance document in 2017 presenting a risk-based approach for the management of liquefaction-related risk in land use planning and development decision-making.[4]

[16] Recommendation 187 of the Royal Commission states that "*Regional councils and territorial authorities should ensure that they are adequately informed about the seismicity of their regions and districts. Since seismicity should be considered and understood at a regional level, regional councils should take a lead role in this respect and provide policy guidance as to where and how liquefaction risk ought to be avoided or mitigated*."

[17] In 2019 ORC commissioned GNS Science to complete an assessment of the liquefaction hazards in the Queenstown Lakes, Central Otago, Clutha and Waitaki districts[5] (the

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[3] 186. Sections 6 and 7 of the Resource Management Act 1991 should be amended to ensure that regional and district plans (including the zoning of new areas for urban development) are prepared on a basis that acknowledges the potential effects of earthquakes and liquefaction, and to ensure that those risks are considered in the processing of resource and subdivision consents under the Act.

187. Regional councils and territorial authorities should ensure that they are adequately informed about the seismicity of their regions and districts. Since seismicity should be considered and understood at a regional level, regional councils should take a lead role in this respect, and provide policy guidance as to where and how liquefaction risk ought to be avoided or mitigated. In Auckland, the Auckland Council should perform these functions.

188. Applicants for resource and subdivision consents should be required to undertake such geotechnical investigations as may be appropriate to identify the potential for liquefaction risk, lateral spreading or other soil conditions that may contribute to building failure in a significant earthquake. Where appropriate, resource and subdivision consents should be subject to conditions requiring land improvement to mitigate these risks.

[4] MBIE & MfE. (2017). *Planning and Engineering Guidance for Potentially Liquefaction-prone Land*. New Zealand Ministry of Business, Innovation and Employment, Building System Performance Branch.

assessment of the liquefaction hazards for the Dunedin City district was completed by GNS Science in 2014).[6] The purpose of the assessment was to better understand the susceptibility of land to earthquake-induced liquefaction at a regional scale. The liquefaction susceptibility assessment highlights areas where liquefaction hazard may warrant further scrutiny (such as ground testing and detailed liquefaction assessments) for future planning and development activities. The GNS Science assessment was presented to the ORC Technical Committee in August 2019[7] and provided to the relevant district councils.

[18] Previous liquefaction studies (including the GNS 2019 study) in the Glenorchy area were largely based on geomorphic observations such as interpretation of landforms and sedimentary environments, and other characteristics such as the inferred depth to groundwater table. This level of detail is sufficient for identification and communication of a potential liquefaction hazard and are classified as Level A assessments (a basic desktop assessment) by the MBIE/MfE guidance for potentially liquefaction-prone land. The GNS Science assessment identified the Glenorchy area as an area where "liquefaction damage is possible".

[19] In early 2021, site-specific geotechnical investigations were undertaken for a proposed development near the Glenorchy waterfront.[8] These investigations identified the potential for significant liquefaction and lateral spreading to occur in that location, prompting the current study by ORC to understand the extent of which similar ground conditions or hazards impacts may occur elsewhere in the township area.

[20] Liquefaction and lateral spreading occur when strong ground shaking during an earthquake disturbs unconsolidated, saturated sediments, causing these to behave as a fluid. Lateral spreading occurs near an unsupported 'free face' such as riverbank or lake margin, and causes lateral movement, ground deformation and fissures at the ground surface. Liquefaction and lateral spreading effects are illustrated in Figure 1.

[21] Major earthquakes causing liquefaction and lateral spreading are natural hazards capable of causing significant risks to safety and social wellbeing, and severe damage and disruption to buildings, infrastructure, and businesses. These hazard consequences are illustrated by events of the 2010-2011 Canterbury Earthquake sequence, where widespread and damaging liquefaction occurred within Christchurch city, and which was likely the most extensive urban liquefaction event ever recorded.[9]

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[5] Barrell D (2019). *Assessment of liquefaction hazards in the Queenstown Lakes, Central Otago, Clutha and Waitaki Districts of the Otago region*. GNS Science report 2018/67, prepared for Otago Regional Council.
[6] Barrell D et al (2014). *Assessment of liquefaction hazards in the Dunedin City District*. GNS Science report 2014/68, prepared for Otago Regional Council.
[7] *General Manager Operations Report to Technical Committee*, Report EHS1857, Report to 1 August 2019 meeting of the Technical Committee.
[8] ENGEO Ltd (2021). Detailed Design Support – The Grand Mt Earnslaw Hotel, 1 Benmore Place, Glenorchy. Report prepared for Blackthorn Ltd.
[9] Cubrinovski M (2013). *Liquefaction-induced damage in the 2010-2011 Christchurch (New Zealand) earthquakes*. International Conference on Case Histories in Geotechnical Engineering. 1.

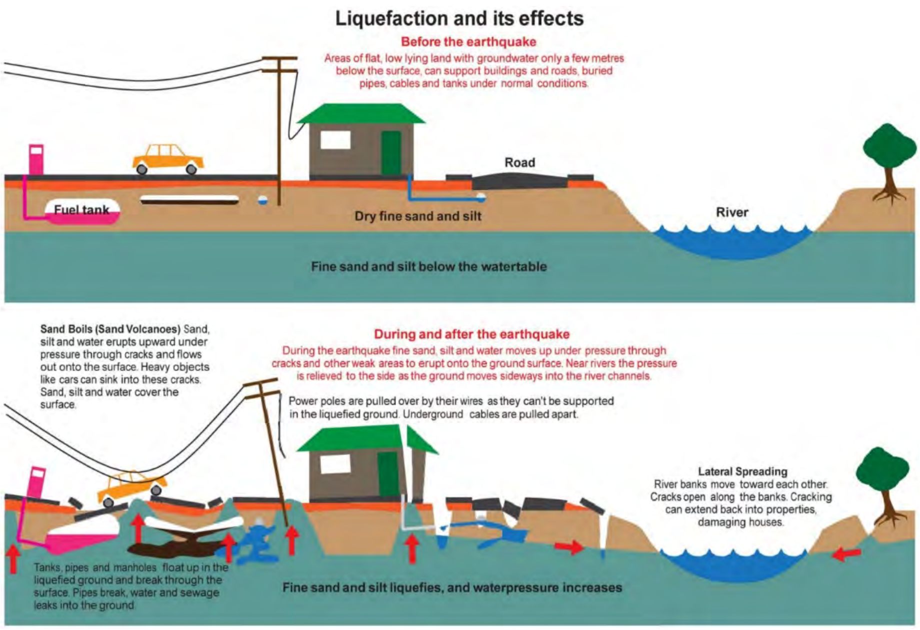

Figure 1: A diagrammatic illustration of liquefaction and lateral spreading and their effects (IPENZ, 2012).

[22] The flooding hazard at Glenorchy township is known from observations of several flooding events in recent decades. Flooding most recently impacted on the residential area of the township in February 2020 (Figure 2b). Previous recent floods include that November 1999 (Figure 2a).

[23] Flood hazard modelling has been previously completed for Glenorchy township by URS New Zealand Ltd (2007).[10] The resolution of the URS flood modelling was limited by a number of factors, for example, LiDAR topography was not yet available so topographic control was based only on sparse cross-section surveys, and the hydraulic modelling approach used allowed only a relatively simple analysis.

[24] Flooding of the lower Dart River floodplain is a relatively frequent occurrence, causing disruption to road access to Kinloch and the Greenstone area (Figure 3). A long-term westwards migration of the Dart River's active riverbed is also causing increasing erosion pressure on sections of this road.

[10] URS (2007). *Glenorchy floodplain flood hazard study*. Prepared for Otago Regional Council.

[25] Observations of past flooding extents, together with the flooded areas modelled by URS (2007), are the basis for the 'flood-prone area' layer displayed in ORC's natural hazards database[11] for the Dart-Rees floodplain and the Glenorchy township area.

[26] The investigations of liquefaction susceptibility and flood hazard reported in this paper are designed to provide greater understanding of these hazards, including hazard characteristics, spatial extents, and likelihoods. This level of details is a pre-requisite to inform the development of the natural adaptation strategy for the head of Lake Wakatipu.

Figure 2: Flooding in Glenorchy township in November 1999 (a, left) and February 2020 (b, right). (photo of 2020 event provided by Luke Hunter).

Figure 3: Flooding of the Dart floodplain in March 2019. The image is looking northwards (upvalley), with Glacier Burn flowing into the Dart River at centre. The approximate location of Kinloch Road is annotated as a dashed line.

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

LIQUEFACTION HAZARD INVESTIGATION
REPORT CONTENT AND STRUCTURE

[27] The report is titled *Glenorchy Liquefaction Vulnerability Assessment and* is attached as Appendix 1. The main report sections are listed below.

- Sections 1-5 provide a summary of report scope and description of the study area, and wider context including characteristics of liquefaction hazards, the MBIE/MfE guidance, and regional-scale seismicity.
- Sections 6-9 describe the relevant physical characteristics of the study area, including geology and geomorphology, topography, and groundwater, and give an overview of the geotechnical field investigations completed for this study.
- Sections 10-13 provide details of the geotechnical analysis completed for assessment of liquefaction and lateral spreading susceptibility.
- Section 14 outlines the report's conclusions regarding liquefaction and lateral spreading hazards in Glenorchy.
- Appendix A of the Tonkin + Taylor report is a map showing liquefaction and lateral spreading vulnerability categorization developed according to the criteria in the MfE/MBIE Guidance.
- Appendix B pf the Tonkin + T aylor report shows examples of liquefaction and lateral spreading observed following the 2010-2011 Darfield-Christchurch earthquakes and 2016 Kaikoura earthquakes.

METHODOLOGY

[28] Liquefaction hazard investigations were completed in accordance with MBIE/MfE[12] guidance for the management of liquefaction-related risk in land use planning and development decision-making.

[29] The MBIE/MfE guidance categorises liquefaction vulnerability studies based on their level of detail. In this categorisation, this Glenorchy township investigation is a Level C study, a 'detailed area-wide assessment'.

[30] The extent of investigations was limited to the Glenorchy township area (Figure 4). The study extent was bounded to the north, west and south by the Glenorchy Lagoon and Rees floodplain, Lake Wakatipu, and the Buckler Burn, respectively. The eastern extent of the study area was the base of Bible Terrace and the bedrock hillslopes.

[31] Field investigations completed were four boreholes to maximum depths of 20 metres, and cone penetrometer tests (CPT) at 19 locations (Figure 4). All borehole and CPT data from this investigation is publicly available on the New Zealand Geotechnical Database (NZGD).[13] A small number of additional borehole and CPT data were publicly available via the NZGD and were also used in analysis.

[32] Borehole geology, CPT results, groundwater data and LiDAR[14]-derived topography data were used in development of geological and groundwater models.

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[12] MBIE & MfE. (2017). *Planning and Engineering Guidance for Potentially Liquefaction-prone Land*. New Zealand Ministry of Business, Innovation and Employment, Building System Performance Branch.
[13] https://www.nzgd.org.nz/
[14] Light Detection And Ranging: LiDAR data is essentially a mass of spot height information captured over a wide area using an aircraft mounted sensor

[33] Seismic scenarios used in assessments were based on NZGS/MBIE Guidelines for earthquake geotechnical engineering practice,[15] for event likelihoods ranging from 25-year to 2500-year return periods. An update to these NZGS/MBIE guidelines was released in late November 2021, and analysis takes into account these updated PGA (peak ground acceleration) values.

[34] The New Zealand Seismic Hazard Model (NSHM) is currently being revised, with an update due to be released in August 2022. The revised NSHM ground motion values may differ, and may be of greater magnitude, than those used in seismic scenarios for this investigation.

[35] An Alpine Fault seismic scenario was also assessed. The Alpine Fault has an estimated recurrence interval of 250-340 years. However, due to the elapsed time since the last Alpine Fault rupture, the fault is estimated to have a conditional probability equivalent to a 30-year ARI event, or a 75% likelihood of rupture within the next 50 years. This is considered high.

[36] Liquefaction triggering and land damage modelling were completed for a lower bound, upper bound, and Alpine Fault Rupture Scenarios at 16^{th}, 50^{th}, and 84^{th} shaking percentiles, with PGA and M_w (moment magnitude) values for each scenario based on NZGS/MBIE guidance (2021).

[37] Probabilistic liquefaction land damage modelling was completed to estimate liquefaction severity numbers (LSNs),[16] giving a simulated, possible realization of liquefaction land damage across the study area.[17]

[38] Lateral spreading was estimated using empirical relationships based on the thickness of liquefiable material and free face height for arrange of seismic scenarios. A key factor in lateral spreading assessments is the height of the 'free face', which was estimated based on assessment of LiDAR topography, and lake bathymetry data provided by NIWA.

[39] Peer review of the technical report was carried out by Wentz-Pacific Limited, and peer review comments have been addressed and incorporated into the final Tonkin + Taylor report. Peer reviewer comments are attached as Appendix 2.

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[15] NZGS & MBIE. (2021). *Earthquake geotechnical engineering practice, Module 1: Overview of the Guidelines*. Wellington: New Zealand Geotechnical Society and Ministry of Business, Innovation and Employment.

[16] The liquefaction severity number is a parameter summarising vulnerability of land to liquefaction-induced damage, developed by comparison of measured liquefaction damage attributes with ground parameters from geotechnical investigation.

[17] Note that this liquefaction damage modelling is for the effects of liquefaction only and does not include impacts of lateral spreading.

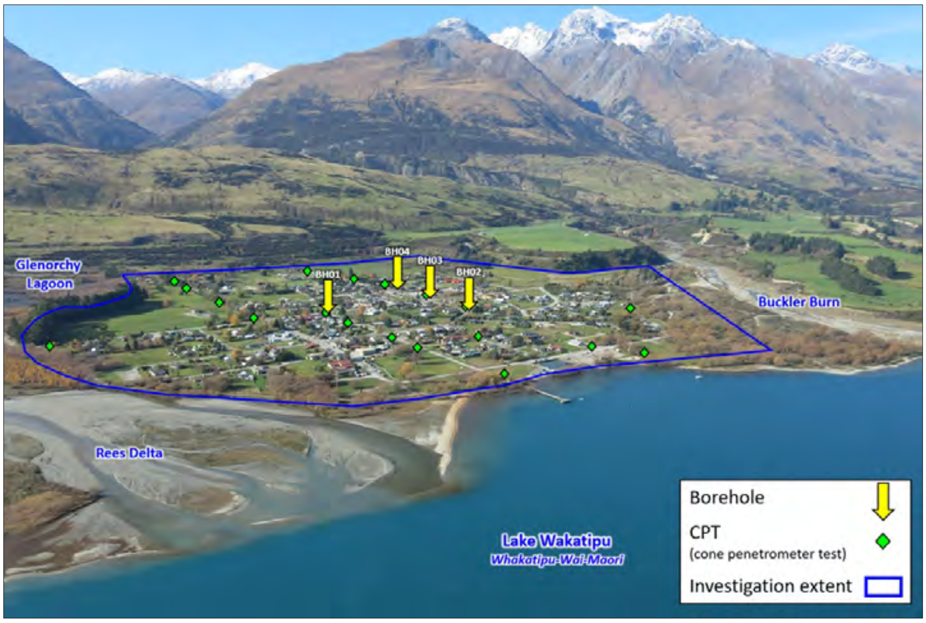

Figure 4: Overview of Glenorchy township showing geotechnical investigations completed for the liquefaction susceptibility study. This image also illustrates several of the factors influencing liquefaction susceptibility; the relatively recent sediment deposits formed by the Rees River and Buckler Burn, and low-relief terrain relative to the surface water bodies at the Glenorchy Lagoon, Lake Wakatipu, and the Buckler Burn stream.

KEY FINDINGS

[40] Geological investigations show the township area is underlain by a thick sequence of deltaic and alluvial sediments. The lower sedimentary units are interpreted as sub-lacustrine deltaic and fan delta sediments deposited when the post-glacial Lake Wakatipu was at a higher level (coloured yellow and orange in Figure 5).

[41] In the north-eastern part of the study area, the sedimentary sequence is interpreted to contain silts formed in a lower-energy backwater environment, such as an infilled lake arm or river oxbow channel (coloured pink in Figure 5).

[42] The deltaic and low-energy sediments are typically overlain by a surficial, 3-7m thickness, layer of coarser gravels interpreted as fluvial/alluvial fan sediments deposited during flood events from the Buckler Burn (coloured blue in Figure 5).

[43] All sediments underlying the surficial Buckler Burn gravels are highly susceptible to liquefaction, from their beginning at 3-7m below the ground but extending down to 20m depth and beyond.

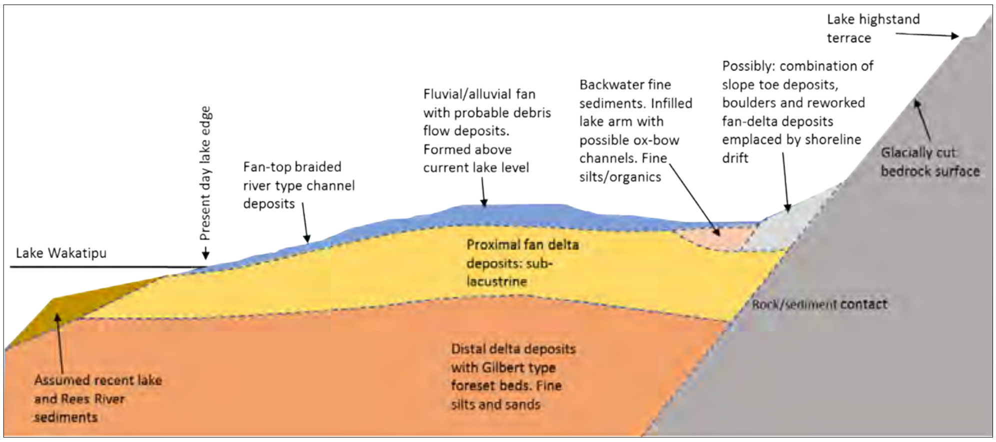

Figure 5: A conceptual geological cross section showing the main geological units interpreted in the Glenorchy township area. Note this is an informal section only for illustrative purposes and is not to scale.

[44] Assessments of liquefaction triggering show between 15 to 20m of the soil profile is predicted to liquefy at higher levels of earthquake shaking. Liquefaction triggering is initiated at 25 to 50-year return period levels of earthquake shaking and is fully developed at the 50 to 100-year return period levels of earthquake shaking. Liquefaction triggering is also likely for an Alpine Fault scenario.

[45] Liquefaction land damage modelling show that severe liquefaction land damage can occur at earthquake shaking levels as low as 25-year return periods. Between 25 and 100-year return period levels of shaking the liquefaction land damage becomes far more significant and widespread across all the lower lying areas of Glenorchy in the north and west.

[46] For the upper bound scenarios, and for 50th (median) and 84th percentile Alpine Fault rupture scenarios, there are widespread areas of the study area where the median Liquefaction Susceptibility Number (LSN) is 25 or greater, indicating ‘high to severe’ liquefaction damages are likely. For example, the 50th percentile Alpine Fault scenario shown as Figure 6.

[47] The T+T report shows examples from the 2011 Christchurch earthquake of the type of liquefaction land damage expected where the LSN is 25 or greater. These examples are Figures B10, B11 and B12 of Appendix B, with one of these shown as Figure 7.

[48] The maps of liquefaction land damages[18] are developed through an inherently probabilistic process and so these maps should not be used as a basis for site-specific assessment for any particular site. Instead, they show broad trends in liquefaction vulnerability across the Glenorchy study area.

[18] Tables 12.1 and 12.2 in the T+T report.

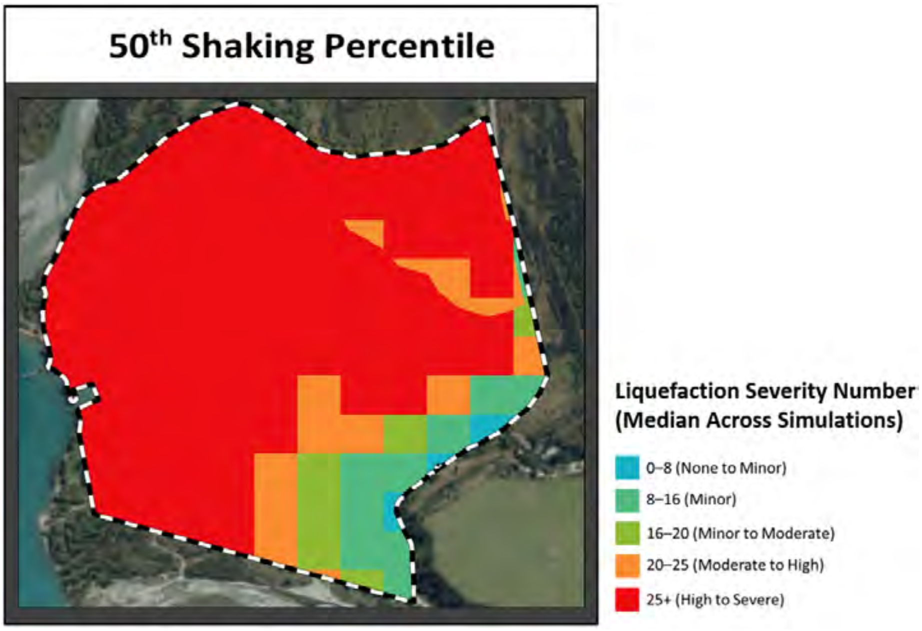

Figure 6: Median Liquefaction Susceptibility Number (LSN) from a large number of simulations, for the Alpine Fault rupture scenario, at 50th percentile shaking levels.

Figure 7: Example of liquefaction following the 2011 Christchurch earthquake, showing the type of liquefaction land damage expected where the LSN is 25 or greater.

[49] Lateral spreading assessments show the amount of lateral spreading is highest near the lake edge and decreases with an increasing distance from the lake. The magnitude of lateral spreading increases with earthquake shaking at larger return periods.

[50] At 500-year return period levels of earthquake shaking, the lateral spreading estimates range from 0.5m (lower bound) to 4m (upper bound) at the lake edge (Figure 8). For the

Alpine Fault Scenario, lateral spreading estimates range from 0 metres (16th percentile) to 3 metres (84th percentile) at the lake edge.

[51] The predicted lateral spreading near the lake in Glenorchy for the 500-year return period levels of shaking is comparable or worse to that observed in the worst parts of the residential red zone in Christchurch, which was typically in the order of 1m to 3m.

[52] The T+T report shows examples from the 2010 Darfield and 2011 Christchurch earthquakes of the type of lateral spreading damage expected where lateral spread is in the order of 1m to 3m. These are Figures B4 to B9 of Appendix B, with two of these examples shown as Figure 9.

[53] Lateral stretch is the differential spreading amount caused by lateral spreading. Assessments of lateral stretch show that for the 500-year and Alpine Fault scenarios a significant western portion of Glenorchy would experience severe or major levels of lateral stretch, defined as differential stretch of >500mm (severe), or >200mm (major), across a 25-metre length scale (Figure 11). Residential buildings cannot be expected to safely withstand these levels of lateral stretch without specific engineering design.

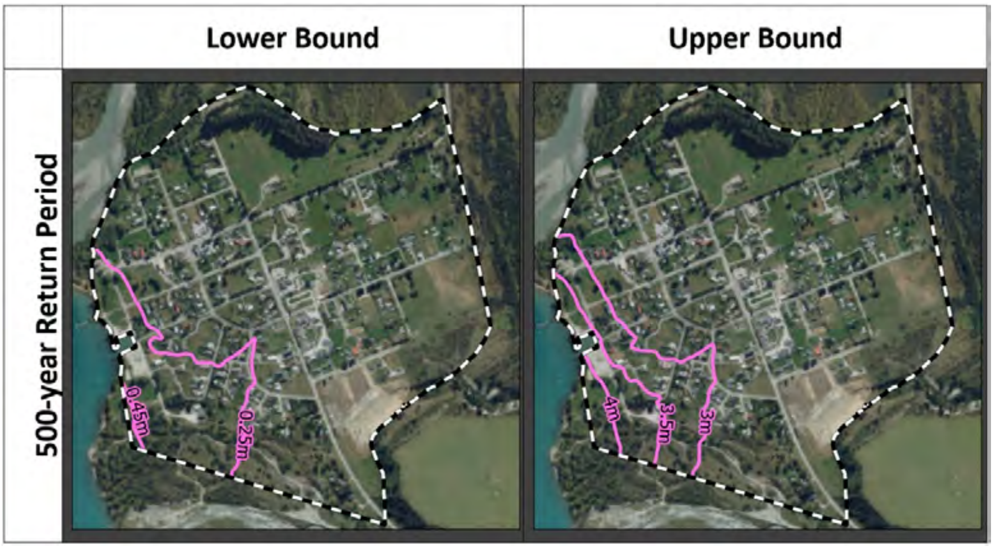

Figure 8: Lateral spreading for 500-year return period levels of earthquake shaking, showing the lower bound (left) and upper bound (right) cases. The ground would be expected to move towards the lake by the annotated distance (pink lines).

Figure 9: Example of lateral spreading damages following the 2010 Darfield and 2011 Christchurch earthquake, showing the type of damage to buildings or roads expected where lateral spreading is in the range of 1-3 metres.

[54] Liquefaction and lateral spreading effects can cause significant vertical subsidence due to volumetric consolidation, liquefaction ejecta, and lateral stretch. In the area of severe stretch, the vertical drop could be in the order of 0.5 to 1m, in addition to that caused by consolidation and ejecta effects. These levels of vertical settlement are likely to cause extensive damage to existing structures in the spreading zone.

[55] Figure 10 shows the liquefaction and lateral spreading vulnerability categorization developed for the Glenorchy township study area according to the criteria in the MfE/MBIE Guidance. This was developed based on the modelled liquefaction effects of vertical subsidence as well as lateral spread and stretch across the multiple earthquake scenarios assessed, especially the 100-year and 500-year scenarios.

[56] The boundaries between the hazard categories shown in Figure 11 are indicative of the spatial distribution of the liquefaction and lateral spreading vulnerability but are uncertain and not intended as a precise boundary between hazard categories. In reality, areas of damage might well occur on either side of the boundaries illustrated.

[57] The occurrence of liquefaction and lateral spreading in Glenorchy would also have secondary consequences through cascading impacts on other natural hazard risks. For example, widespread ground subsidence would increase the areas exposed to flooding hazards. Severe liquefaction would also be expected to cause damage to floodbank structures, reducing the levels of flood protection to those areas currently receiving flood protection by the Glenorchy floodbank.

[58] The T+T report shows an example from the 2016 Kaikoura earthquake where lateral spreading damage caused approximately 1 metre of vertical drop to land adjacent to a river channel, causing flooding and increased flood exposure. This example is Figure B3 of Appendix B.

[59] Strong ground shaking from an Alpine Fault rupture or other major earthquake may generate a tsunami on Lake Wakatipu, triggered either by a large landslide into the lake or a large-scale collapse of the delta sediments. Assessment of the potential lake tsunami hazard is one focus of a current PhD research project supported by ORC.[19] Paragraphs 119-121 and Figure 22 in this paper provide an update on recent research activities in this project.

[19] The research project title is *Post-glacial geomorphic evolution of Lake Wakatipu basin and landslide-generated tsunami hazards*. The research is being undertaken by NIWA, Massey University, and the University of Otago.

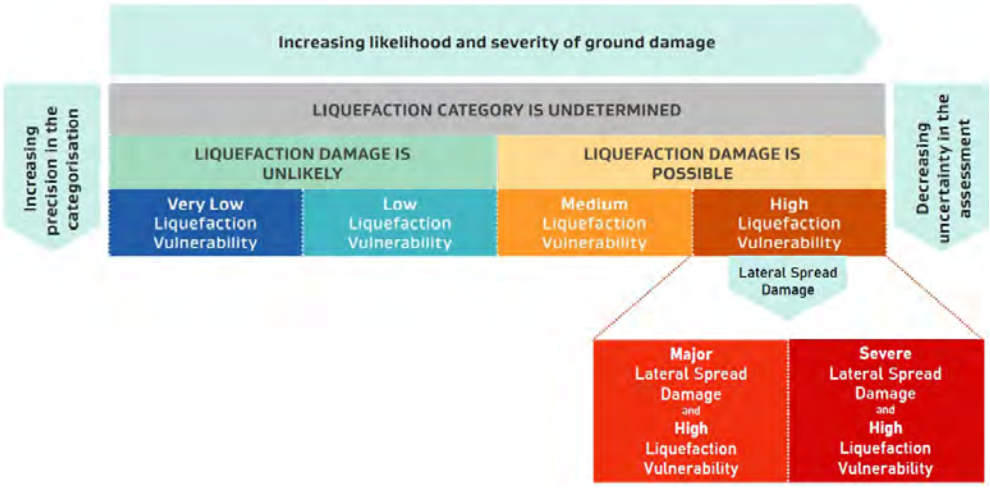

Figure 10: Liquefaction vulnerability categorization developed for the Glenorchy township study area. This follows the criteria in the MfE/MBIE Guidance (2017), with the addition of categories for those areas with high vulnerability to both liquefaction and lateral spreading damages.

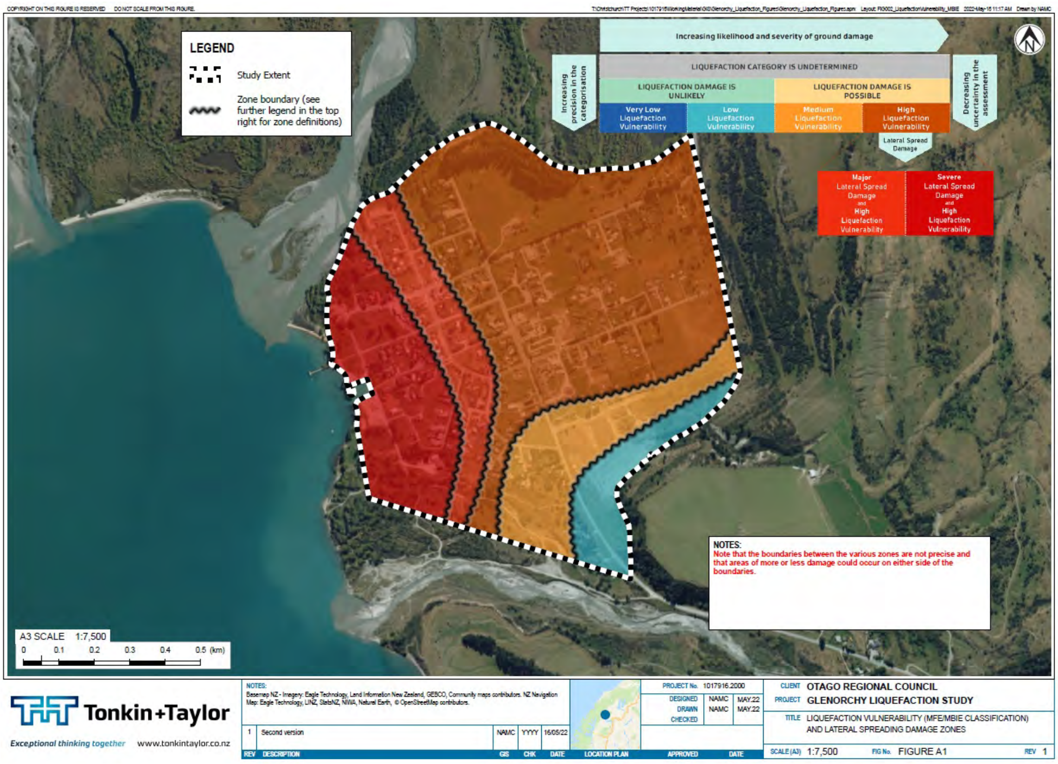

Figure 11: Liquefaction vulnerability categorization for Glenorchy township, based on the categorisation scheme shown in Figure 10.

FLOOD HAZARD ASSESSMENT

REPORT CONTENT AND STRUCTURE

[60] The report is titled *Dart-Rees flood hazard modelling* and is attached as Appendix 3. The main report sections are listed below.

- Section 1 introduces the study purpose and extent.
- Section 2 acknowledges uncertainties and limitations of the study.

- Sections 3 and 4 detail input data to the model such as topography, bathymetry and hydrology.
- Section 5 provides details of hydraulic model build and development.
- Section 6 describes model calibration and validation against the February 2020 flooding event.
- Section 7 summarises the model runs completed.
- Section 8 is an analysis of results and a commentary on findings.
- Appendices A-E provide supporting information to the study, such photographs from site visits, and detail of ORC's hydrology and climate change analysis.
- Appendices F-H contain maps of peak flood depths, peak flow velocities, and hazard classifications for all model runs.

METHODOLOGY

[61] Hydraulic modelling and flood hazard assessment was undertaken for the Dart-Rees floodplain and delta for the extent shown in Figure 12.

[62] Numerical hydraulic modelling for flood event scenarios was completed using MIKE21, an industry-standard 2D hydraulic modelling software.

[63] Model topography is based on a 2019 LiDAR dataset, with channel bathymetry interpolated based on surveyed cross-section data.

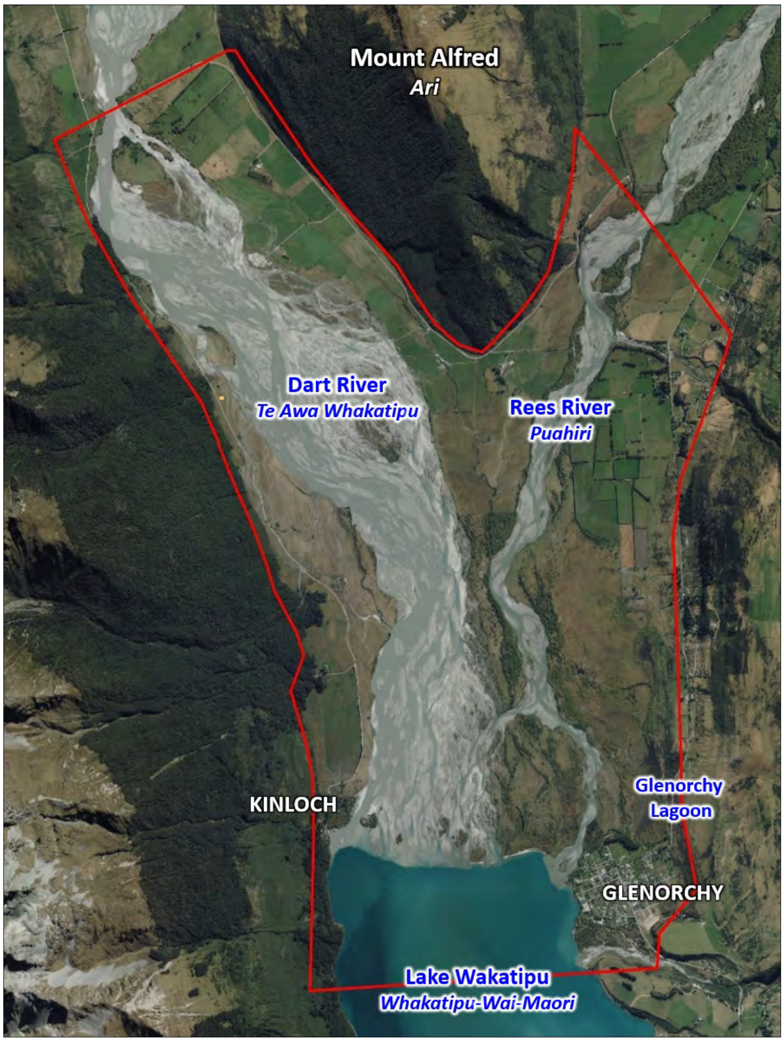

Figure 12: Overview of the lower Dart and Rees Rivers systems, showing the extent of hydraulic modelling and flood hazard assessment (red outline).

[64] Modelled flooding scenarios included combinations of large (up to 100-year ARI)[20] river flows and lake levels, and the effects of climate change on future river flows and flood events. Additional factors modelled include an avulsion of the lower Rees River channel, and a breach of the Rees-Glenorchy floodbank[21].

[65] Hydrology inputs such as design flow hydrographs and lake levels were based on analysis completed by ORC[22] and which is appended to the LRS report. For the Dart River and Lake Wakatipu analysis was based on the data record from ORC and NIWA monitoring stations, respectively. The Rees River has only a limited flow record, so flood flows were estimated by use of a rainfall-runoff model developed in HEC-HMS hydrological model.

[20] Annual Recurrence Interval. A 100-year ARI event has a 1% probability of occurrence in any specific year (Annual Exceedance Probability, AEP), and a 39% probability of occurrence within a 50-year time period.
[21] The floodbank is owned by QLDC.
[22] Mohssen M (2021). Analysis of flood hazards for Glenorchy. December 2021.

[66] Climate change effects on Dart and Rees River flows were estimated by ORC[23] for RCP6.0[24] and RCP8.5 scenarios.

[67] A breakout flood (avulsion) from the lower Rees River eastwards towards the Glenorchy lagoon area is considered an expected and inevitable future consequence of floodplain and braided river development.[25] [26] This scenario was modelled through simulation of an avulsion channel by modification of the riverbed and floodplain topography within the model. The modelled avulsion location was considered a probable site for a major avulsion based on modelled floodwater pathways, review of satellite imagery from past flood events, and anecdotal reports of floodwater spillover during the February 2020 flood event.

[68] Geotechnical assessments[27] of the Rees-Glenorchy floodbank structure have identified concerns regarding floodbank stability. Floodbank breach parameters were estimated based on additional geotechnical assessment completed to inform modelling of breach scenarios.[28]

[69] Model validation was undertaken through comparison of modelled floodwater extents with those observed in Glenorchy township during the February 2020 flood event.

[70] Flood hazard was classified as a function of floodwater depth and velocity, using the classification scheme of the Australian Rainfall and Runoff guidelines,[29] shown as Figure 13.

[71] Peer review was carried out by Tonkin + Taylor Limited, and peer review comments have been addressed and incorporated into the final Land River Sea Consulting Limited report. Peer reviewer comments are attached as Appendix 4.

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[23] Mohssen M (2021). Analysis of flood hazards for Glenorchy. December 2021.

[24] Future climate change projections are considered under a range of emission scenarios, called Representative Concentration Pathways (RCPs) by the Intergovernmental Panel on Climate Change (IPCC).

[25] Brasington J (2021). *Fluvial hazards at the top of the lake, living with rivers on the edge*. Public presentation in Glenorchy, 7th April 2021.

[26] This hazard threat has been identified in many previous reports, for example URS (2007) comment that "*there is a significant risk that the Rees River could change its course to flow directly into the lagoon area*."

[27] e.g. WSP (2020). *Glenorchy Rees floodbank: floodbank assessment*. Prepared for Otago Regional Council.

[28] Tonkin + Taylor (2021). *Rees-Glenorchy Floodbank structure failure modes assessment*. Prepared for Otago Regional Council.

[29] Ball et al (2019). *Australian Rainfall and Runoff - A Guide to Flood Estimation*.

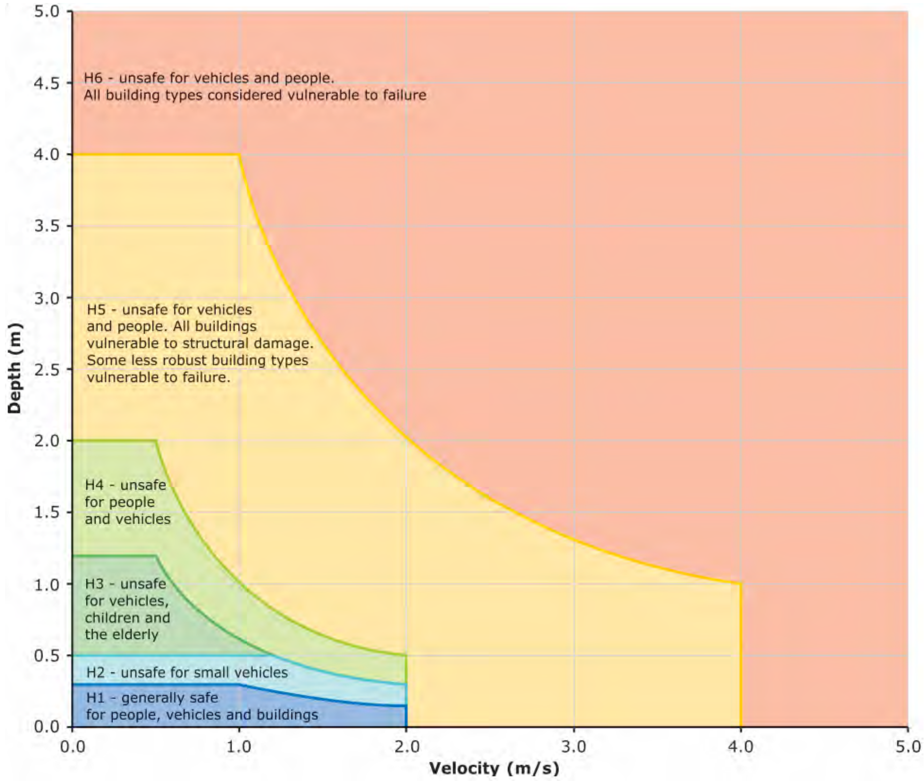

Figure 13: The flood hazard categorisation of the Australian Rainfall and Runoff Guidelines (Cox, 2016), based on a combination of floodwater depth and velocity.

KEY FINDINGS

[72] An overview of model results is shown in Figure 14. This shows modelled floodwater depths for a flooding scenario with 100-year ARI river flows, and a moderate lake level (10-year ARI).

[73] For Glenorchy township, model results showing flooding extents for a 100-year ARI flood event are shown in Figure 15.

[74] In this scenario, there is widespread overtopping by floodwaters over the Glenorchy floodbank, and floodwater inundation of a large northern portion of the township.

[75] In this scenario, the greatest floodwater depths within the township area are in the range 0.5-2 metres. The highest floodwater velocities are in the range 0.5-2 m/s, with a strong eastwards flow as floodwaters flow towards the lake.

[76] Effects of climate change on river flows, or an avulsion of the Rees River channel eastwards towards the Glenorchy lagoon, both exacerbate flooding however do not cause major increases in flooding severity due to the control of floodwater extents by the natural alluvial fan topography.

[77] Figure 16 shows model results for a flooding scenario including the effects of climate change on river flows, and an avulsion of the Rees River channel eastwards towards the Glenorchy Lagoon. Comparison with Figure 15 shows only minor increases in floodwater extents and depths due to these effects.

[78] Flood hazard classification (Figure 17) shows areas within the township where the hazard is categorised as H4 (‘*unsafe for vehicles and people*’) or H5 (‘*unsafe for vehicles and people, buildings vulnerable to structural damage, some less robust buildings vulnerable to failure*’).

[79] The Glenorchy floodbank is overtopped in all modelled flood scenarios, and it is estimated that this structure will not prevent flooding in the township for river flow events of a 20-year ARI or greater.

[80] A failure of the floodbank structure during modelled flood scenarios has no impact on overall flood extents, however the flood onset within the township is slightly sooner than would otherwise be the case.

[81] Flood hazard scenarios where Lake Wakatipu is at high levels (100-year ARI) show lake levels have an effect on flooding extents, particularly in locations nearer the lake, but also act to lower peak floodwater velocity near the lake (Figure 18).

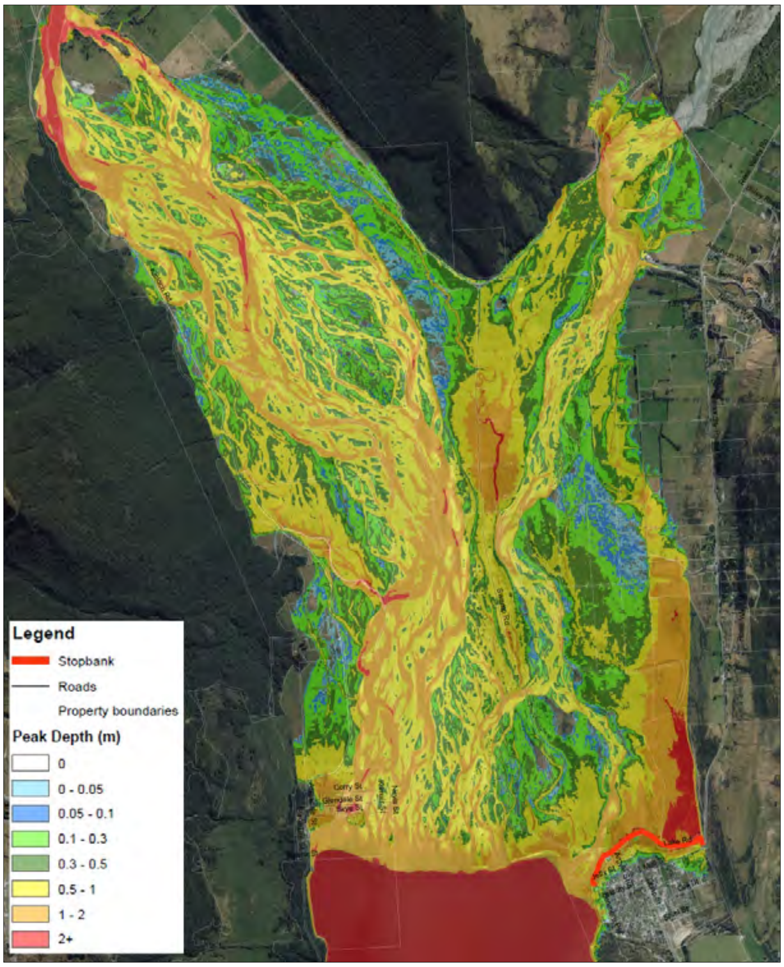

Figure 14: Model results for a Dart-Rees flooding scenario with 100-year ARI river flows, and Lake Wakatipu at 10-year ARI levels. Colouring shows peak floodwater depths according to the included legend. Figure 15 shows detail of the Glenorchy township area for this scenario.

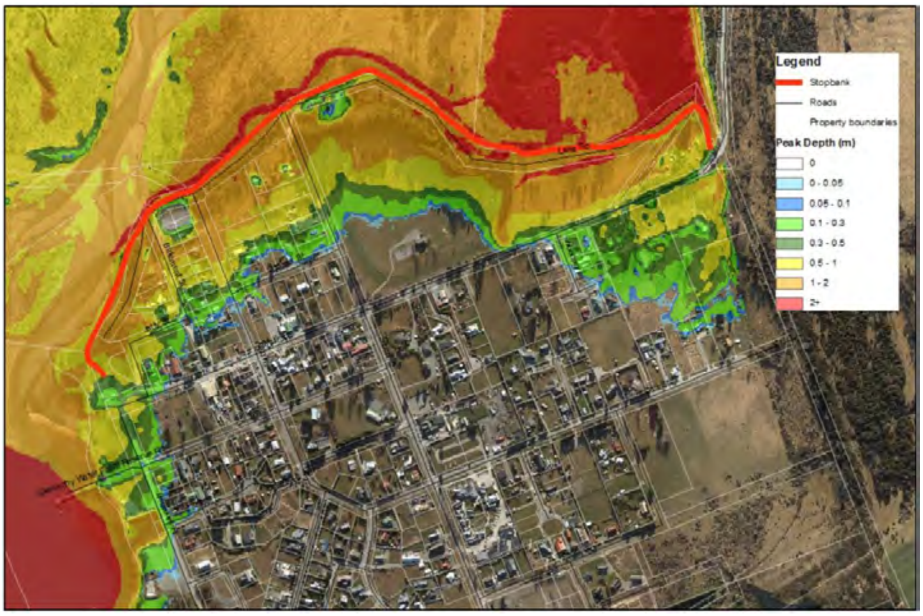

Figure 15: Model results for a Glenorchy flooding scenario with 100-year ARI river flows, and Lake Wakatipu at 10-year ARI levels. Colouring shows peak floodwater depths according to the included legend.

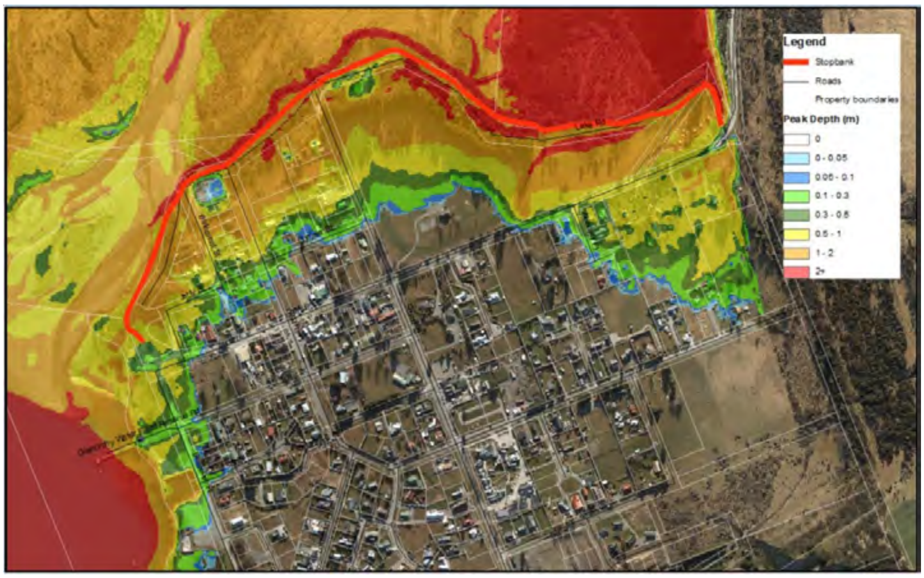

Figure 16: Model results for a Glenorchy flooding scenario with 100-year ARI river flows, and Lake Wakatipu at 10-year ARI levels. This scenario also includes the effects of climate change on river flows (RCP 8.5), and an avulsion of the Rees River channel eastwards towards the Glenorchy Lagoon. Colouring shows peak floodwater depths according to the included legend. The flood hazard categorisation for this scenario is shown as Figure 17.

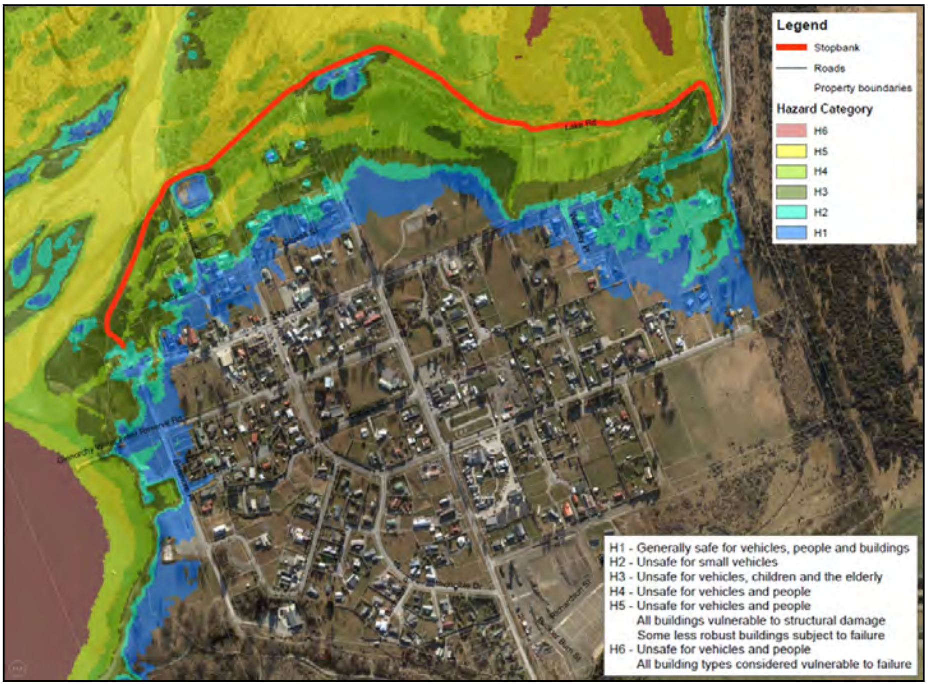

Figure 17: Flood hazard categorisation for a Glenorchy flooding scenario with 100-year ARI river flows, and Lake Wakatipu at 10-year ARI levels. This scenario also includes the effects of climate change on river flows (RCP 8.5), and an avulsion of the Rees River channel eastwards towards the Glenorchy Lagoon. Colouring shows hazard categorisation according to the included legend.

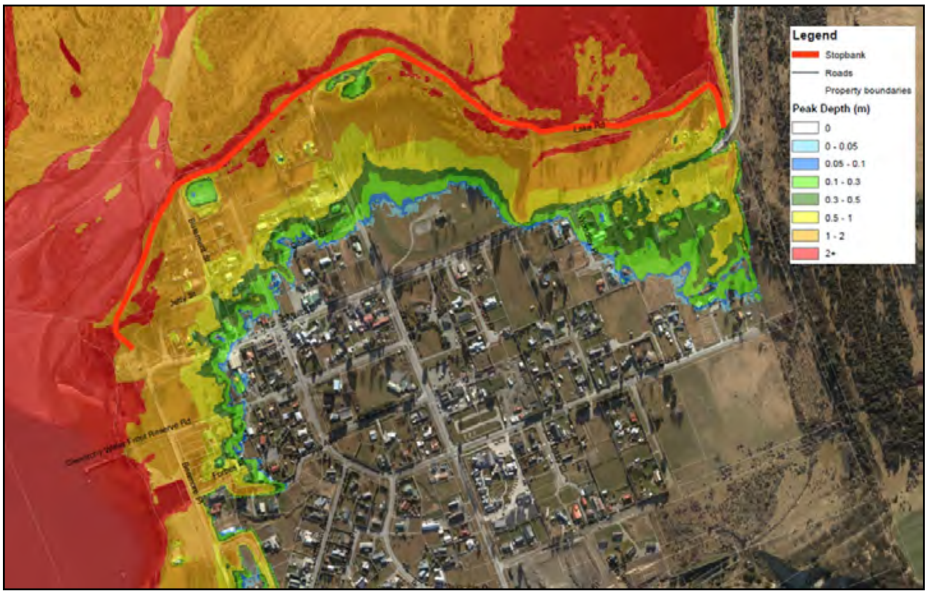

Figure 18: Model results for a Glenorchy flooding scenario with 100-year ARI river flows, and Lake Wakatipu at 100-year ARI levels. Colouring shows peak floodwater depths according to the included legend.

[82] Model results show large sections of the Kinloch Road, as well as parts of the Glenorchy-Routeburn road at the foot of Mount Alfred, would be inundated in a 100-year ARI flooding event (Figure 14).

[83] Along Kinloch Road, floodwater depths are up to within the 1-2 metre range (Figure 14), and velocities are up to the range 1-2 m/s.

[84] Model topography is based on that surveyed in 2019, but river bed levels will continue to rise through ongoing sediment deposition, raising flood stage relative to river banks and exacerbating flood hazards. This model will need to be revised with new topographic datasets in future to assess the influence of changing riverbed morphology and mean bed levels.

[85] As a fixed bed hydraulic model, the modelling does not account for any changes due to sediment movement or erosion during flood events.

[86] There is limited flow data at Rees River for hydrological analysis, so there is uncertainty in the flow estimates developed as model input. Flow data from the recently installed monitoring station near Invincible Creek (Figure 19) will help with improving future estimations of Rees River flows.

[87] There are a number of possible flood model refinements which could be made in the Glenorchy area, for example the addition of inflows from Bible Stream, and the inclusion of rainfall runoff from the hillslopes adjacent to the township. However, it would not be expected that these refinements would significantly alter the flood characteristics or hazard classification shown by the current modelling project.

UPDATE ON OTHER ACTIVITIES

Environmental Monitoring

[88] A Rees River flow recorder was installed by ORC in December 2021 near Invincible Creek. Following development of flow rating relationships, river flow data has been displayed online in near real-time from early-April 2022 at ORC's WaterInfo webpage.[30]

[89] This Rees River flow recorder will be a key site for use in continued assessments of flood hazard at the Rees floodplain and Glenorchy, allowing measurement of peak flows for future flooding events.

[90] In January 2021, ORC installed a water level recorder in Lake Wakatipu at the Glenorchy marina. Comparison of monitored water levels at Glenorchy with those measured at NIWA's monitoring station within Frankton Arm showed an apparent level offset of ~0.15m. ORC has re-surveyed benchmark points at both sites to determine the cause of this observed difference in water levels. Analysis of this data is currently underway.

[91] The Glenorchy Lagoon water level recorder has now been operating since October 2020. Alarms and actions linked to lagoon water levels have been put in place for the ORC flood response team in coordination with Emergency Management Otago.

[92] As a key monitoring site for flood hazard information at Glenorchy, ORC is investigating options to build resilience at this monitoring station to ensure effective operation during all flood events.

[30] www.orc.govt.nz/managing-our-environment/water/water-monitoring-and-alerts

[93] These three recently installed environmental monitoring stations were suggested by community members as actions to improve awareness of flood hazard following the February 2020 flooding event.

[94] Following these additions to ORC's previously established monitoring stations at the Hillocks (since 1996) and at Paradise (since 2003), the current environmental monitoring network provides greatly improved monitoring coverage and understanding of hydrological responses to major weather events. ORC's current environmental monitoring stations in the head of Lake Wakatipu area are shown in Figure 19.

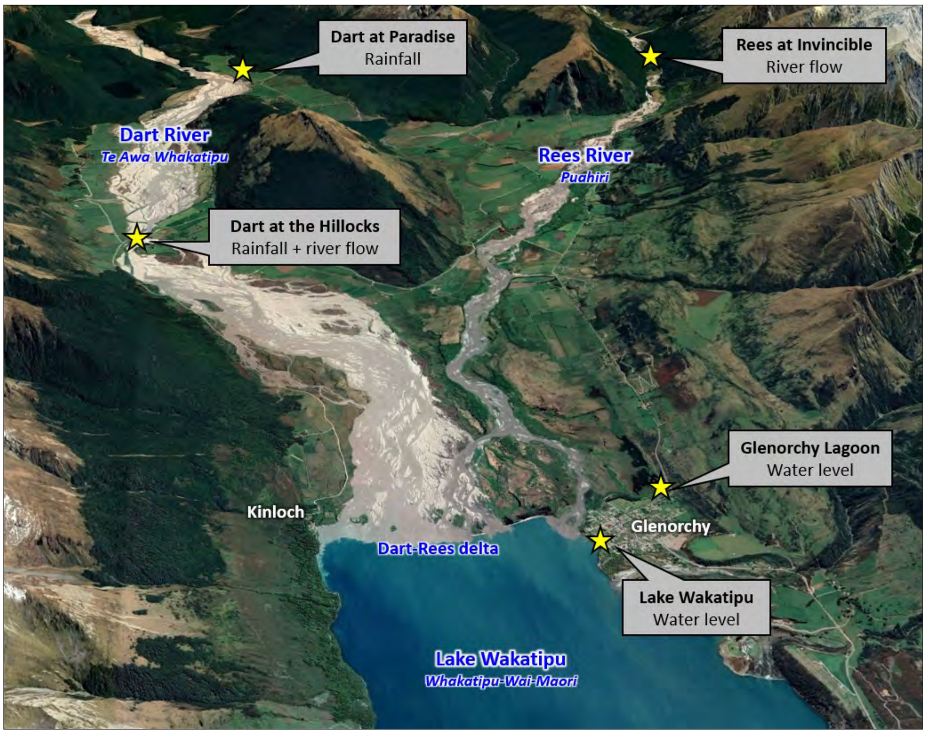

Figure 19: ORC environmental monitoring stations in the head of Lake Wakatipu area.

Buckler Burn alluvial fan hazards

[95] Glenorchy township is developed on an alluvial fan landform formed by sediments deposited by the Buckler Burn, so is exposed to the potential hazard of flooding or debris inundation from this catchment.

[96] The boreholes recently completed for the Glenorchy liquefaction study provide an opportunity to also view and assess sedimentary characteristics of the surficial deposits and interpret their depositional environment and processes (borehole locations are shown in Figure 4).

[97] A review of these borehole sediments has been undertaken by Professor Ian Fuller and Dr Sam McColl of Massey University, complemented by a site visit and assessment of LiDAR topography and aerial imagery.[31]

[31] Fuller I and McColl S (2021). *Key notes and observations from preliminary assessment of debris flood and flow hazard potential at Glenorchy, Otago*. Prepared for Otago Regional Council.

[98] The coarser gravel units seen in the upper parts of these boreholes have been deposited in a high-energy fluvial or lake-margin environment, with some evidence for deposition as debris-flood deposits.

[99] Assessments have confirmed flooding or debris-flooding is a potential hazard for Glenorchy township. There is geomorphic evidence for a former Buckler Burn flow channel northwards into the township area, indicating a potential breakout pathway which may be exploited by floodwaters in high-flow events.

[100] Flooding could be triggered by either a high-intensity rainfall event, or a catastrophic breach of a landslide dam formed in the Buckler Burn catchment. Aggradation of the Buckler Burn channel prior to, or during, a high flow event would exacerbate the flood hazard through reducing channel capacity.

[101] Additional assessments are planned to further investigate geomorphic changes at the Buckler Burn alluvial fan, and to improve understanding of the flood hazard. Findings will also be used to assess effectiveness of current river management approaches at the Buckler Burn, and to inform development of a river management plan.

[102] Debris flow hazards from the Buckler Burn have been assessed through numerical modelling by Geosolve Ltd.[32] Modelling was completed for a series of hypothetical large-magnitude debris flow scenarios originating in the Buckler Burn catchment.

[103] This modelling was not a comprehensive investigation of the Buckler Burn debris flow hazard for Glenorchy township, rather a test of sensitivity to factors such as failure locations, debris volumes and release mechanisms.

[104] Assessments show debris flow impacts to the Glenorchy township area to be possible but unlikely.[33] The occurrence of a major debris flow into the township requires both abundant debris (e.g. as would be caused by widespread coseismic landsliding) and a large stream flow (e.g. 100-year ARI flooding event or greater). The estimated joint probability of these events occurring is greater than a 100-year ARI event, and possibly closer to a 500-year ARI event.

Dart-Rees floodplain hazard mitigation approaches

[105] An investigation is in progress to evaluate the viability of river management or engineered approaches for mitigation of Dart-Rees floodplain hazards such as flooding and erosion. This study is being undertaken by Damwatch Engineering Ltd.

[106] The key questions this investigate will assess are:

- What river management approaches are viable and sustainable in the natural landscape around the Dart-Rees floodplain, and what are their potential outcomes?
- What does sustainable flood protection look like in the Glenorchy area, and what level of protection is realistically achievable?

[32] Faulkner P (2021). *Factual report – Debris flow modelling results. Buckler Burn, Glenorchy*. Report prepared by Geosolve Ltd for Otago Regional Council.

[33] Faulkner P and Rogers N (2021). *Joint witness statement on debris flow hazard*, prepared for Environment Court ENV-2021-CHC-70.

[107] These questions will help identify a short-list of approaches for more detailed consideration.

[108] The three main floodplain hazard concerns are being considered are:

1) Glenorchy township flooding from the Rees River (e.g., Figure 2b).
2) Dart floodplain flooding and erosion hazards, causing disruption to Kinloch access (e.g., Figure 3).
3) Rees floodplain flooding and riverbed aggradation in the area of the Rees bridge.

[109] This study is focused only on the evaluation of potential river management (e.g., channel modifications) or engineered (e.g., floodbanking or other structures) approaches, but is not considering other types of interventions such as building-scale mitigations (e.g., raising of floor levels), planning restrictions (e.g., zoning changes) or managed retreat. These latter approaches need to be considered in conjunction with approaches to managing the liquefaction and lateral spreading risks.

[110] The study will consider all river management or engineered adaptation approaches suggested by community members during previous engagement sessions.

[111] The first stage in this study was a collaborative workshop discussion held in February 2022. Workshop attendees were from ORC and QLDC, with specific expertise provided by Dr Grant Webby[34] (river engineering), Matthew Gardner[35] (flood hazard assessment), and Professor James Brasington[36] (river science and geomorphic change).

[112] Following completion of this investigation, a next step may be to utilise the recently completed hydraulic model to further assess details of some of these potential interventions identified. This will also inform the natural hazard adaptation strategy for the Head of Lake Wakatipu.

Shepherd's Hut Creek debris flow

[113] On the 21st April 2022, the Glenorchy-Queenstown Road was blocked by debris from Shepherds Hut Creek, requiring extensive work to re-open the road access (Figure 20).

[114] This debris flow was likely triggered by intense rainfall from thunderstorm activity. Debris flowed onto the Shepherds Creek alluvial fan which overwhelmed the road culvert and then caused debris to spill over and block the road. Within the creek channel, debris contained boulders up to ~2m in size (Figure 21).

[115] The event impacts were road closure and disruption to road traffic; however, this debris flow could potentially have had more significant consequences if it had struck any vehicles.

[116] WSP[37] and an ORC Engineering team member completed initial inspections of the site to review event impacts and assess any immediate hazards.

[34] Damwatch Engineering Ltd.
[35] Land River Sea Consulting Ltd.
[36] Waterways Centre for Freshwater Management, University of Canterbury.
[37] A preliminary assessment completed by WSP for Downer Ltd.

[117] ORC consultants will document the debris flow processes, characteristics and triggers, and the resulting hazard from debris flows at this location. Findings will be provided to Queenstown Lakes District Council.

[118] This event illustrates the vulnerability of Queenstown-Glenorchy road access to disruption by debris flows, landslides or rockfall.

Figure 20: Aerial view of debris flow impacts at the Queenstown-Glenorchy road, annotated to show the approximate extent of debris deposition (photo provided by Maddi Phillips, WSP Ltd).

Figure 21: A lower section of Shepherd's Hut Creek following the 21 April 2022 event, showing freshly deposited debris including large boulders (photo by Scott Liddell, ORC).

Research support

[119] A PhD research project by Steph Coursey (Massey University) is in progress, titled *Post-glacial geomorphic evolution of Lake Wakatipu basin and landslide-generated tsunami hazards*. ORC is providing support for operational field costs for this research project.

[120] The first field surveys for this project have been successfully carried out. Seismic reflection data and short cores of the lake floor were obtained in November 2021, followed by bathymetric mapping of the lake floor using a multibeam echosounder in January 2022 (Figure 22). The 2022 bathymetric data are now being compared with the bathymetric data collected by NIWA in 2019, and preliminary analysis has revealed some exciting changes on the lake floor.

[121] The project, which will continue over the next two years, is already yielding some promising results which will greatly improve the understanding of the lake-floor stability and associated tsunami hazards.

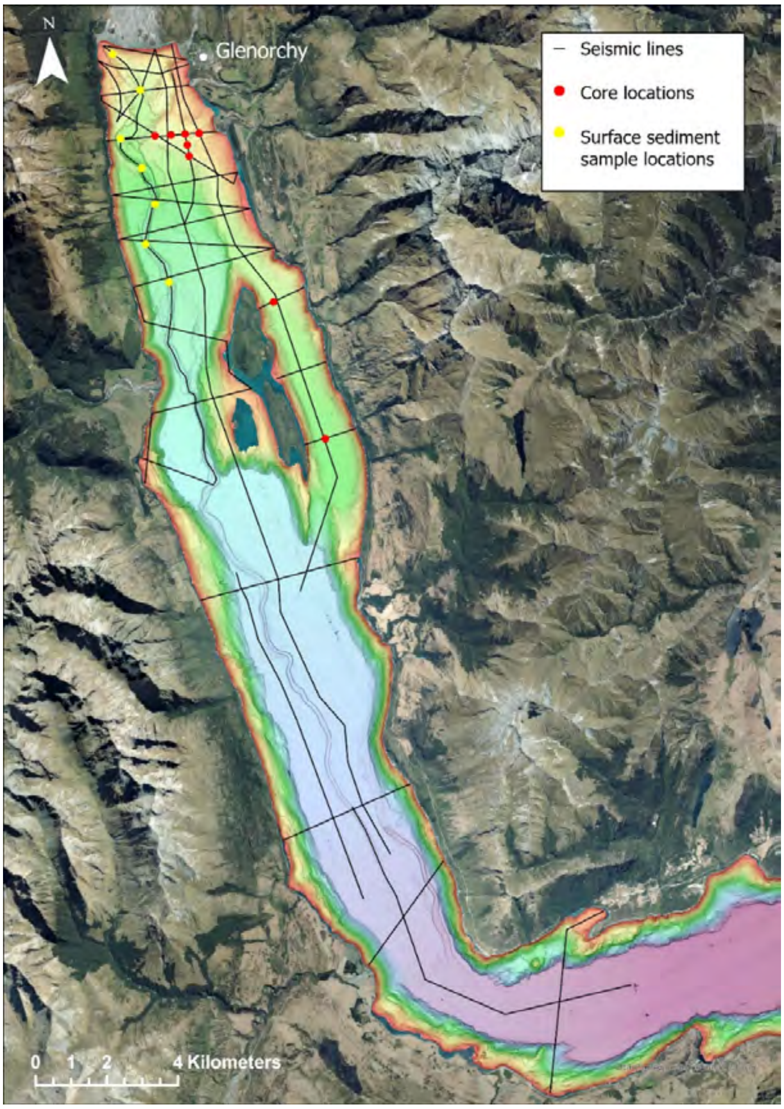

Figure 22: Lake-floor geomorphology of Lake Wakatipu, from 2019 NIWA bathymetry, and distribution of seismic, core, and surface sediment sample data obtained in 2021/2022 (Figure provided by Steph Coursey, Massey University).

[122] A Ministry of Business, Innovation & Employment (MBIE) Smart Ideas project that aims to examine the utility of novel airborne bathymetric LiDAR to support improved river management is underway. The project is led by Professor James Brasington (University of Canterbury) and is working with key stakeholders including the ORC to trial methods to understand the effects of environmental variables that effect LiDAR retrievals through the water (clarity, bed reflectance, water roughness) and optimize acquisition and processing strategies to maximize depth penetration. If successful, the airborne bathymetric LiDAR will be a cost-effective way to capture riverbed topography for long river sections.

[123] The ORC is providing support to help design a software tool that can be used by councils and other key stakeholders to help identify freshwater systems that are suitable for bathymetric LiDAR characterization.

[124] An early trial of the new sensor being tested was undertaken in the Rees River in August 2021 and revealed effective bed penetration throughout the river below Invincible Gorge, and capture of the delta foresets in Lake Wakatipu down to depths that exceeded 15m. The team will return to Otago for further surveys on the Rees and Dart Rivers later in the winter of 2022.

DISCUSSION

[125] The flooding and liquefaction hazard investigations presented in this paper are two important components of the knowledge base required for a thorough understanding of the multi-hazard risks in the head of Lake Wakatipu area and Glenorchy township.

[126] These new investigations contribute to a significant advance in natural hazards understanding, being the most detailed hydraulic modelling study at the Dart-Rees rivers, and the first liquefaction hazard assessment for Glenorchy based on comprehensive subsurface geotechnical data and analysis.

[127] Natural hazard investigations have confirmed a major earthquake or flooding event would have severe impacts, and help understand in more detail the hazard characteristics, spatial extents and likelihoods.

[128] The flooding and liquefaction hazard risks considered individually each pose a concerning hazard threat. However, there is also considerable overlap in the likely spatial extents of these hazard impacts, and potential for cascading hazard interactions between these hazards. The cumulative multi-hazard risks will therefore be higher than the individual hazard risk.

[129] The flooding risks are also not static through time but are modified in response to geomorphic and climatic factors. Aggradation of the Dart and Rees riverbeds is an important influence on changing flood hazard, as river channel capacity is gradually reduced as a consequence.

[130] Climate change is a key consideration in the assessment of future flood hazard, incorporated in hydraulic modelling through estimation and inclusion of climate change effects on river flows. Under the highest greenhouse gases emission scenario (RCP8.5) the magnitudes of 100-year ARI flood events in the Dart and Rees Rivers are projected to increase by ~20%.[38]

[131] Climate change effects on Lake Wakatipu flood levels have not yet been assessed. It is expected that projected increases in mean rainfall and river flows,[39] and the magnitude and frequency of flood events, will cause increases in mean lake levels, and therefore an increased likelihood of the lake reaching higher levels.

[132] The acceptability of these natural hazard risks to the head of Lake Wakatipu community will depend on the community's risk perception and risk tolerance. However, it is important to note that 'the community' as a whole may not have a single, collective view on whether these natural hazards risks are acceptable or tolerable. Risk perception is not static and will depend on individual factors including exposure to potential hazard

[38] Mohssen M (2021). Analysis of flood hazards for Glenorchy. December 2021.
[39] NIWA (2019). *Climate change projections for the Otago Region*. Prepared for Otago Regional Council.

events, vulnerability and ability to cope with disruption, and understanding of the hazards and their potential consequences.[40]

[133] Community and stakeholder input and collaboration is central to the Adaptation Pathways approach adopted by ORC and developed by the Ministry for the Environment (MfE),[41] shown as 10-step decision cycle in Figure 23. Any decision-making for management of these hazards should involve community input and collaboration. ORC will make all investigation findings available to the head of Lake Wakatipu community, including providing of opportunities for consultant experts to directly discuss findings with community members.

[134] The new hazards studies completed are within Step 4 (assessments of vulnerability and risk) of the Adaptation Pathways decision cycle. In-progress and future project work to identify and evaluate hazard mitigation approaches and 'pathways' of adaptation actions form Steps 5 and 6.

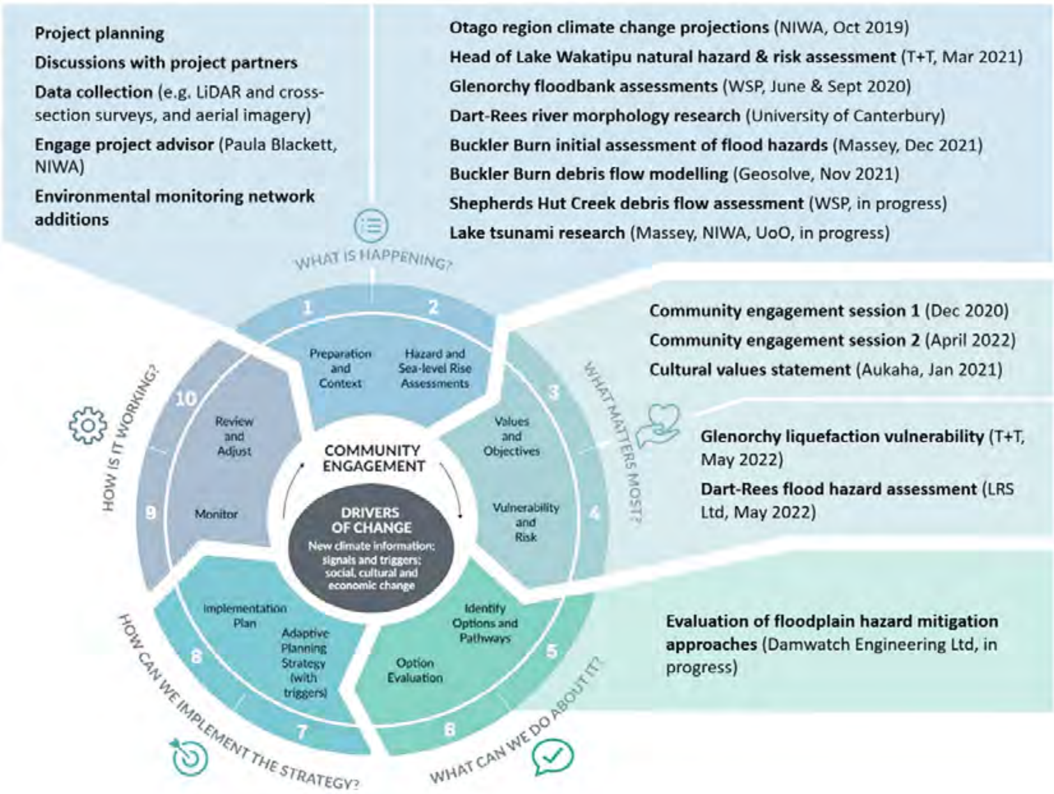

Figure 23: Overview of the 10-step decision cycle of the MfE Adaptation Pathways approach, showing the main activities which have been completed for this natural hazards adaptation project to date.

[135] ORC is considering the new natural hazards information. No assessment of potential approaches to the management of the liquefaction or flooding hazard risks have yet been made. These will be developed collaboratively in discussion with the community,

[40] Henrich et al, 2019. *Perceptions of risk characteristics of earthquakes compared to other hazards and their impact on risk tolerance*. Disasters 42 (1).
[41] Ministry for the Environment (2017), *Coastal Hazards and Climate Change: Guidance for local government*.

Queenstown Lakes District Council and other project partners. Decisions will be informed by finding of in-progress and future studies, for example the work in progress by Damwatch Engineering Ltd to assess possible approaches for mitigation of floodplain hazards.

[136] Continued ORC collaboration with QLDC will be essential to ongoing progress in development and implementation of an adaptation strategy. In March 2022, ORC and QLDC established a Natural Hazards Steering Group, to formalise the working relationship between the councils on this Head of Lake Wakatipu project, and other natural hazard projects such as the QLDC-led Brewery Creek/Reavers Lane debris flow hazards project. The steering group has the purpose of ensuring ORC and QLDC are taking a coordinated and collaborative approach to the management of natural hazards in the Queenstown Lakes District.

CONSIDERATIONS

Strategic Framework and Policy Considerations

[137] 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

[138] The project is included in the ORC 2021-31 Long Term Plan with funding of $120,000 (excluding staff time) in the 2021/22 financial year and $70,000 (excluding staff time) for the two following years.

Significance and Engagement Considerations

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

Legislative and Risk Considerations

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

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

[142] 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

[143] Climate change considerations are discussed above.

Communications Considerations

[144] ORC will make all investigation findings available to the head of Lake Wakatipu community. This will include providing opportunities for the consultant experts who undertook the investigations to directly discuss findings with community members.

[145] ORC has continued to provide a monthly update newsletter to the head of Lake Wakatipu 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 this emailed newsletter and all previous newsletters are archived on the project webpage.[42]

[146] These reports and spatial hazards information will be made publicly available through ORC's Natural Hazards Database[43] and on the project webpage.

[147] This information will be provided to Queenstown Lakes District Council for incorporation into building control, utility infrastructure and land use planning decisions.

[148] A copy of our communications plan is attached as Appendix 5.

NEXT STEPS

[149] ORC will discuss, in partnership with the head of Lake Wakatipu communities, and other partners such as QLDC, the implications of these new natural hazards assessments, and decide on the next steps required.

[150] Next steps may include review of possible mitigation or management approaches for liquefaction and lateral spreading hazards. This would complement a study already in progress which is assessing possible approaches for mitigation of floodplain hazards.

[151] This new information will also be used to inform community response plans and emergency responses.

ATTACHMENTS

1. Tonkin+Taylor Ltd 2022 Glenorchy liquefaction vulnerability assessment [**5.1.1** - 61 pages]
2. Wentz-Pacific Ltd 2022 Peer review of the T+T Glenorchy liquefaction assessment [**5.1.2** - 2 pages]
3. Land River Sea Consulting Ltd Flood Hazard Report [**5.1.3** - 130 pages]
4. T+T Peer Review of LRS Ltd Flood Hazard Report [**5.1.4** - 4 pages]
5. Summary Comms Plan [**5.1.5** - 2 pages]

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