9.1. Head of Lake Whakatipu Natural Hazards Adaptation

Prepared for:	Safety and Resilience Committee
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PURPOSE

[1] To update the Committee on progress towards development of a natural hazards adaptation strategy for the Head of Lake Whakatipu area.

EXECUTIVE SUMMARY

[2] The Otago Regional Council (ORC) led natural hazards adaptation programme for the area at the Head of Lake Whakatipu is progressing towards delivery of a first iteration of the Adaptation Strategy by June 2024.

[3] ORC is using the Dynamic Adaptive Pathways Planning (DAPP) approach as a framework for development of a natural hazards adaptation strategy[1]. Current work under the programme is primarily focussing on the second and third phases, *"What matters most?"* and *"What can we do about it?"*.

[4] This paper provides updates on the progress of key activities in this work programme, including pathways development, community and partner engagement, and technical and supporting assessments.

[5] Adaptation strategy development is currently focussed on drafting preferred pathways, including suitable signals, triggers and thresholds. Community values and outcome statements are informing this work.

[6] ORC conducted two community engagement sessions in Glenorchy on 31 August 2023. Each session was a two-hour long workshop, with repeated content. The total attendance over the two sessions was around 25-30 local community members. The workshops were effective at achieving the engagement objectives: testing draft community outcomes to guide the strategy; building community understanding of a range of potential adaptation responses; facilitating discussion about key aspects of responses; and providing an update on the programme plan for the next 12 months.

[7] A supplementary online survey was successful in reaching a wider audience, with a total of 47 survey responses. Survey questions focused on community values, draft outcome

[1] van Woerden T & Payan J, 2021. Natural Hazards Adaptation in the Head of Lake Whakatipu. ORC Report HAZ2105, Report to 27 May 2021 meeting of the Otago Regional Council.

statements, and feedback about how ORC should engage with local community members in the future.

[8] ORC has procured consultant expertise from Beca Group Limited (Beca) to undertake Phase 1 of the social impact assessment, and work commenced in late September 2023. The engagement work will build and expand on the programme engagement that has already been undertaken. Queenstown Lakes District Council (QLDC) and the community, through the Glenorchy Community Association, were invited to provide feedback on the consultant team's chosen methodology. That feedback has been incorporated into the methodology.

[9] ORC responded to a moderate flooding event in September 2023 which caused high flows in the Dart and Rees Rivers, and high levels in the Glenorchy Lagoon. Activities included environmental monitoring, flood forecasting, and post-event site inspections.

RECOMMENDATION

That the Safety and Resilience Committee*:*

1) ***Notes*** *this report.*
2) ***Notes*** *the Head of Lake Whakatipu natural hazards adaptation work programme and community engagement.*

BACKGROUND

[10] The area at the head of Lake Whakatipu (Whakatipu-Wai-Māori) is exposed to multiple natural hazard risks, including those due to seismic events, flooding and slope-related processes. This risk setting is compounded by a changing climate and landscape-scale geomorphic change.

[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 Whakatipu area.

[12] The Long-Term Plan (LTP) targets for the adaptation strategy are shown in Table 1.

Table 1: 2021-2023 Long-Term Plan (LTP) targets for the Head of Lake Whakatipu natural hazards adaptation strategy.

2021/22 TARGET	2022/23 TARGET	2023/24 TARGET
The Head of Lake Whakatipu natural hazards adaptation strategy progresses as per annual work plan.	The Head of Lake Whakatipu natural hazards adaptation strategy progresses as per annual work plan.	The first Head of Lake Whakatipu natural hazards adaptation strategy completed by 30 June.

[13] The adaptation project approach and work activities previously completed are outlined in the papers presented in May 2021[2], June 2022[3], May 2023[4] and August 2023[5].

[2] 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.

[3] 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.

Quarterly update papers will continue through until the delivery of the strategy in June 2024.

[14] This paper is focused on updates about the development of the natural hazards adaptation strategy; and the associated community engagement activities, and social impact assessment.

[15] Updates for other activities in this work programme are included as Paragraphs 43-54 and in Appendix 1. These include flood hazard assessment for the Buckler Burn, natural hazard risk assessment for Glenorchy and Kinloch; a feasibility assessment for flood management interventions on the Dart-Rees floodplain; and an update on the flood response to the weather event of 20-22 September 2023.

[16] Figure 1 shows an overview of key activities in the Head of Lake Whakatipu natural hazards adaptation work programme, with the programme currently focussing on the second and third phases *"What matters most?"* and *"What can we do about it?"* and building towards delivery of a first iteration of the strategy document by June 2024. Figure 1 updates the similar figure compiled for, and presented in, the previous (August 2023) committee paper.

ADAPTATION STRATEGY DEVELOPMENT

[17] Adaptation strategy development is currently focussed on drafting potential pathways, including suitable signals, triggers, and thresholds, to support community discussion and input (Figure 2, Figure 3 and Figure 4).

[18] Signals are indicators of change, and triggers are decision points that prompt a move to another pathway, before a harmful adaptation threshold is reached. Signals, triggers, and thresholds can include those based on the physical environment (e.g., riverbed levels), as well as social aspects (e.g., community outcomes), policy changes, and economic factors (e.g., funding opportunities).

[19] Community values and outcomes are a key part of adaptation pathways development and also provide a means to measure success (see paras 12-16 for details).

[20] Draft potential pathways will be part of the next stage of community engagement.

[4] van Woerden T & Payan J, 2023. Head of Lake Whakatipu floodplain and liquefaction hazard intervention assessments. ORC Report OPS2256, Report to the 10 May 2023 meeting of the Otago Regional Council Safety and Resilience Committee.

[5] Conroy A, van Woerden T, MacKenzie J & Payan J, 2023. Head of Lake Whakatipu Natural Hazards Adaptation. ORC Report HAZ2301, Report to 10 August 2023 meeting of the Otago Regional Council Safety and Resilience Committee.

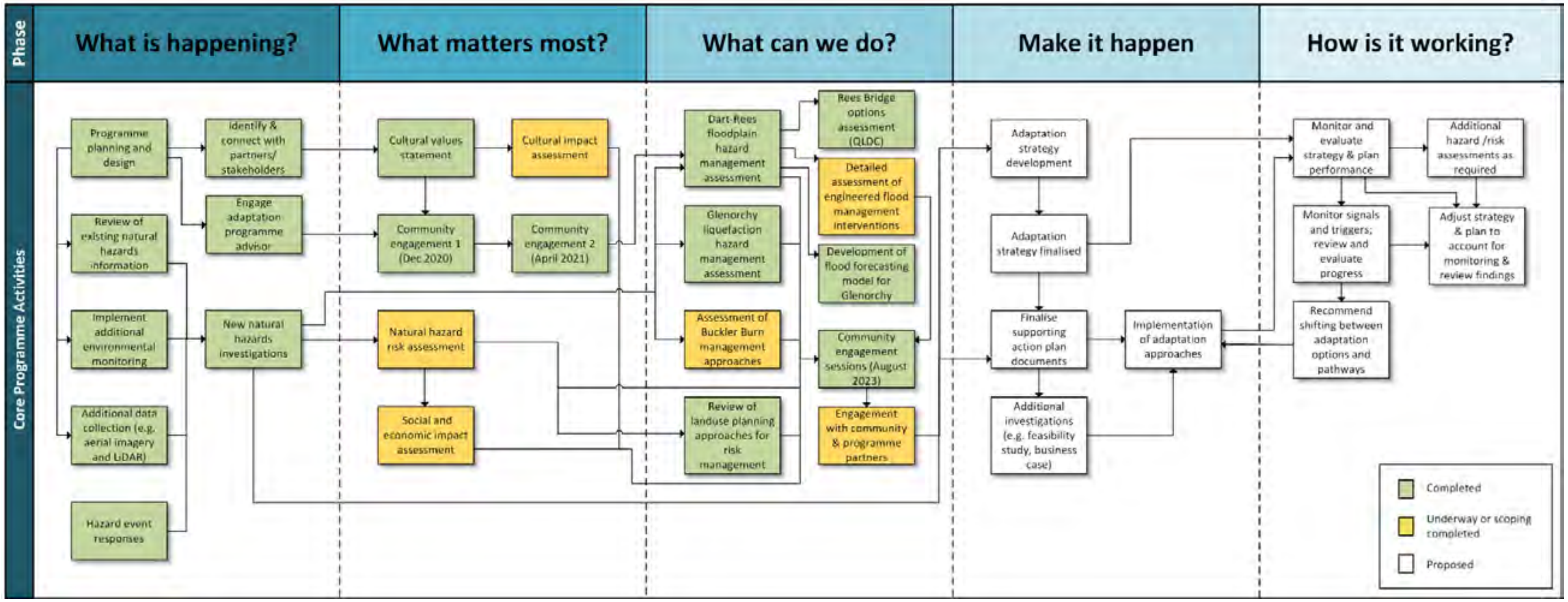

Figure 1: Head of Lake Whakatipu programme overview of key activities. This diagram updates from the previous (August 2023) committee paper.

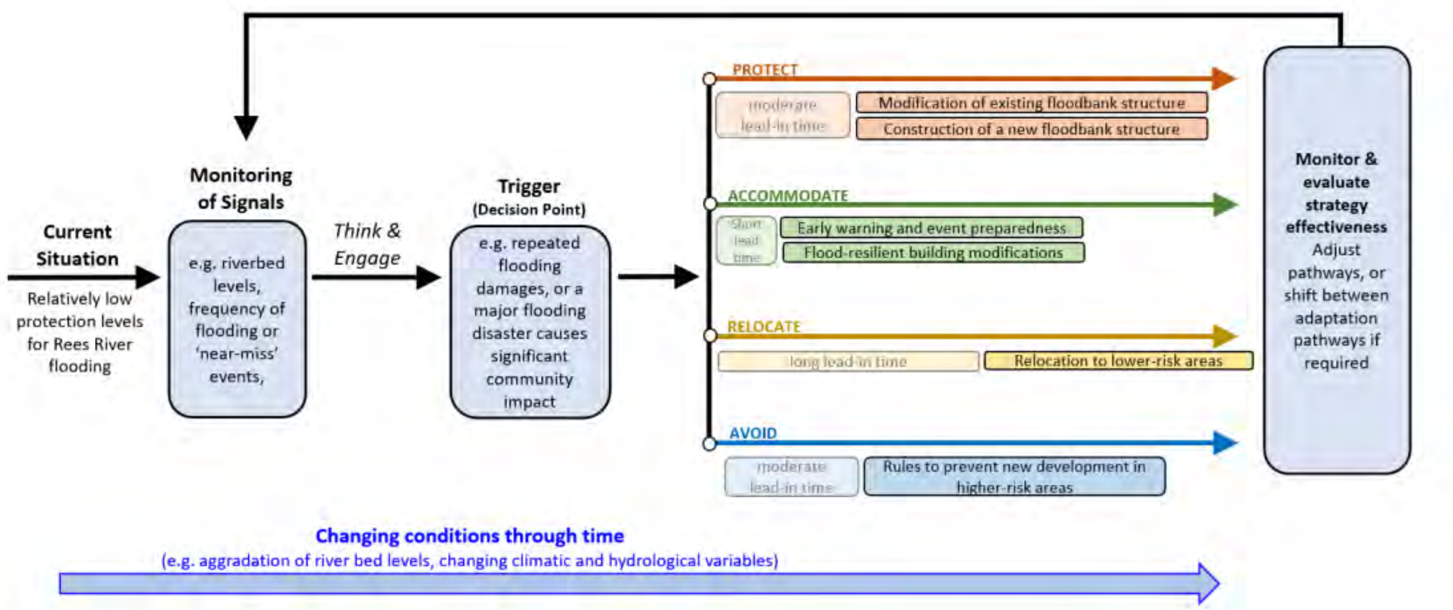

Figure 2: Example of the adaptation pathways concept showing some possible management responses for flood hazard

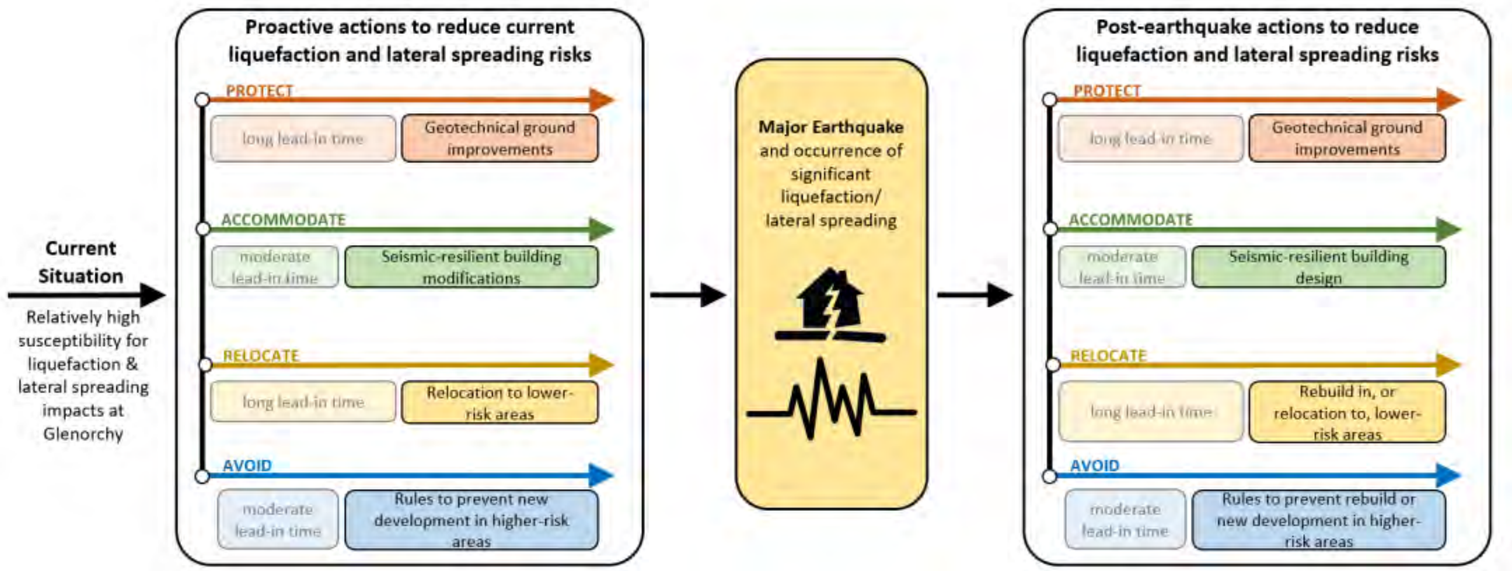

Figure 3: Example of the possible hazard management responses for liquefaction and lateral spreading hazards.

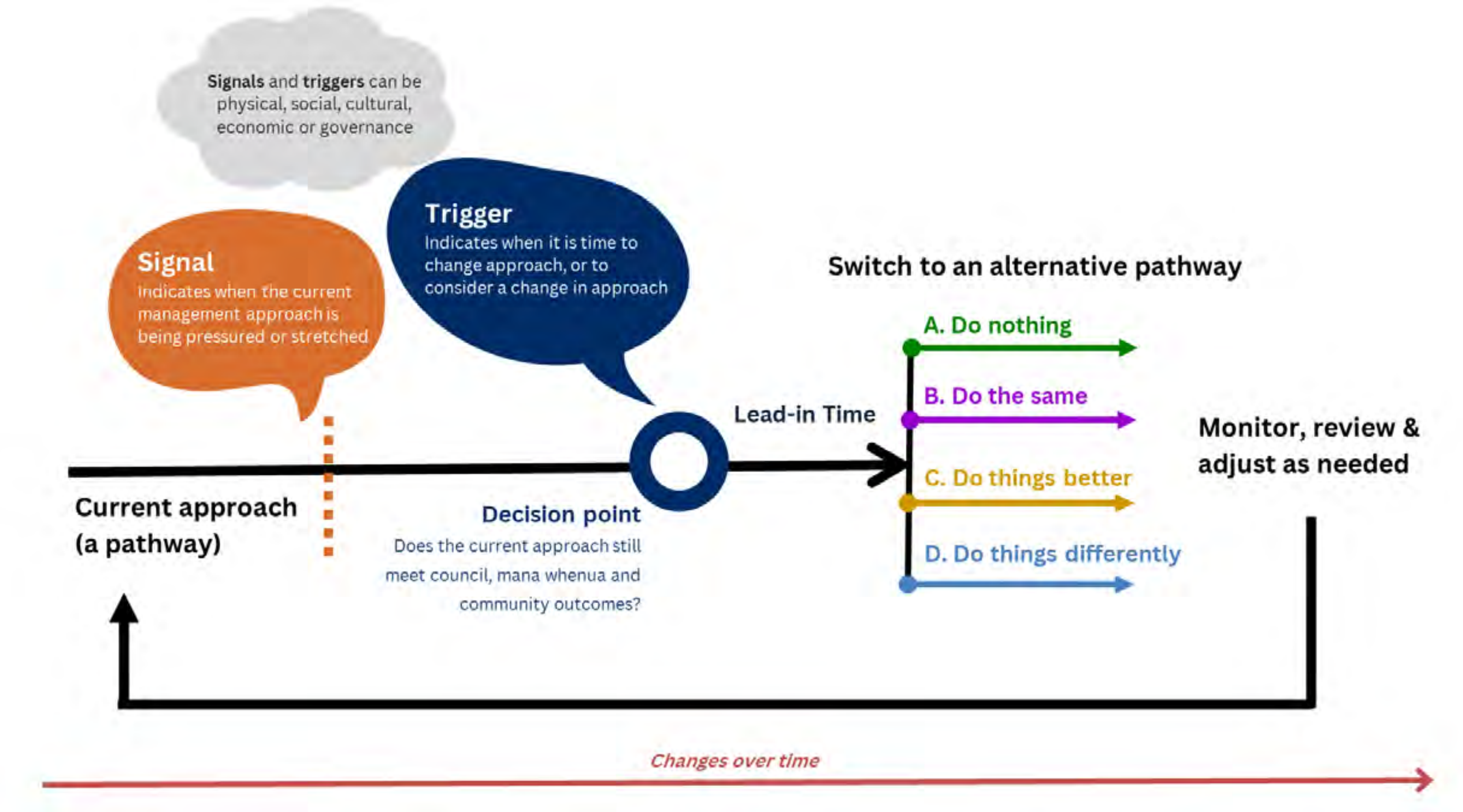

Figure 4: High level overview of the adaptation pathways concept, including signals and triggers.

COMMUNITY ENGAGEMENT

[21] ORC recently conducted two community engagement sessions in Glenorchy on 31 August 2023 in the afternoon and evening. Each session was a two-hour long workshop, with repeated content. The total attendance over the two sessions was around 25-30 local community members (resident population of approx. 350-450 the head of Lake Whakatipu area). Figure 5 displays several photos from the workshop sessions.

[22] Attendees were a mix of people who had previously attended ORC engagement sessions as part of this work programme, and some new to this programme. A gap of engagement so far has been youth and families with young children. Future engagement through the social impact assessment and our broader engagement process aims to target these demographics to better incorporate their values, views, and knowledge into strategy development.

[23] It took a collaborative approach with support from staff at ORC, QLDC, Emergency Management Otago (EMO), NIWA and Dunedin City Council[6] to facilitate and deliver the workshops.

[24] ORC supported the Glenorchy School Parents, Teachers and Friends Association to run a sausage sizzle fundraiser during the evening session.

[25] The workshop objectives were: build upon draft community outcomes to guide the strategy; build community understanding of a range of potential adaptation responses; facilitate discussion about key aspects of responses and provide an update on the programme plan for the next 12 months.

[26] The workshop format included an introductory presentation outlining the programme plan, followed by a short group activity about draft community outcome statements. The remainder of the workshop took place as a series of 'world café' style table discussions about possible adaptation responses organised in the following groups: 'readiness and recovery', 'river and roading', 'flood and liquefaction resilience' and 'land-use planning and relocation'. Several ORC and QLDC staff members took notes throughout the workshops to capture discussion.

[27] Data analysis of workshop discussion notes and staff debrief sessions will be used to turn the 'long-list' of possible adaptation responses presented at the engagement session into potential adaptation pathways that reflect community values, views, and aspirations.

[28] Key sentiments ORC heard from participants during the workshops are listed below and were also reported back to the community in the October 2023 newsletter update[7]:

- We are a resilient community.
- Across the community, there is a lot of local knowledge about the natural environment.

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[6] A staff member from the South Dunedin Future team (DCC) assisted in the delivery of the workshop. This demonstrates one of the ways in which we are sharing learnings across Otago adaptation programmes.

[7] https://www.orc.govt.nz/managing-our-environment/natural-hazards/head-of-lake-whakatipu/community-get-in-touch-be-involved

- We need to ensure that, at a household, business, and community level, we are prepared for potential hazard events (i.e., an Alpine Fault event), including taking care of visitors and tourists.
- We are concerned about the impacts of the ORC hazard investigations on our property values, insurances, and businesses.
- We want to better understand what we can do at a property level to improve our resilience to various hazards and risks.
- We value nature-based solutions that have multiple benefits.
- Alternative transport links, such as wharfs, jetties and air, should be considered in adaptation planning.
- Generally, we prefer adaptation responses that address more frequent hazard events rather than large-scale adaptation responses that would drastically impact the character of the area.
- We want to discuss the details about what adaptation action is on the table now and in the future.
- The Head of Lake Whakatipu Adaptation Strategy needs to enhance the already high level of resilience of the community.

[29] Community workshop participants provided feedback on draft community outcome statements (Table 2). The workshop feedback, combined with feedback from a supplementary online survey, was then used to refine and expand the community outcome statements (Table 2). The revised community outcome statements will be taken back to the next engagement and in the newsletter to show community members how their feedback was incorporated and finalized for use in the strategy.

Table 2: Comparison of draft community outcome statements presented to community for feedback (workshop, survey) and revised community outcome statements.

Draft community outcome statements		Revised community outcome statements
A community that feels safe from both physical and financial harm	Revisions based on workshop and survey feedback	A community that feels supported and safe from the impacts of natural hazards
Residents feel at home and connected to their environment		Residents feel at home, connected to their environment and supported by the experience of community
A beautiful environment and a feeling of connection with nature (e.g. access to nature, can undertake recreational activities)		A beautiful environment and a feeling of connection with nature
Functioning natural systems		Sustainable functioning natural ecosystems
The ability to make a living		The opportunity to make a living
Be resilient and self-reliant		Be resilient and self-determining
Functional and accessible infrastructure and support services (e.g. roads, financial services)		Functional, resilient and accessible infrastructure, support services and emergency response
	NEW IDEAS	Heritage is safeguarded and accessible
		A healthy community that promotes wellbeing of all

Figure 5: Series of photos taken at Glenorchy workshops. River and roading discussion table (top), hall during discussion activity (middle) and land-use planning and relocation discussion table (bottom).

[30] ORC undertook a supplementary online survey over an 18-day period during September and early October 2023, targeting local community members by geolocation and local network sharing. ORC collected a total of 47 survey responses.

[31] Survey questions focused on community values, draft outcome statements, and feedback about how ORC should engage with community members in the future.

[32] Data analysis found that most survey respondents “agreed” or “strongly agreed” with the draft community outcomes statements presented (ranging from 70% to 100% across each statement). Some survey respondents included suggestions for improvement (see Table 2).

[33] Survey feedback on community values will be added to the information collected so far, including through previous engagement, and other source materials. The combined values information will be used to inform the social impact assessment, and more broadly the development of the adaptation strategy so that it reflects these values.

[34] Feedback from workshops and the survey around the logistics, structure, and communications of the engagement with the community will be useful to improve future engagement. Suggestions included evening or weekend sessions, online or hybrid sessions, and including submissions or presentations from community members as part of the session.

[35] ORC has continued to provide an update newsletter monthly to the Head of Lake Whakatipu community. This newsletter was established in August 2020 and gives progress updates and an indication of upcoming work. ORC gained over 20 new subscribers from the August workshops and online survey. There are 97 total newsletter subscribers at time of writing.

[36] ORC and EMO staff plan to apply for a stall at the Glenorchy Village Fair in November to talk about community resilience and preparedness for natural hazard event response and recovery. This is an opportunity to build community awareness and understanding of community response planning and what is currently in place to manage hazard risk (i.e., flood forecasting, flow, and lake level monitoring system).

[37] Planning is underway for the next engagement activity in Glenorchy to be held before the end of the year. The focus will be to present the revised community outcome statements and discuss potential adaptation pathways. This will include insights on signals, triggers, and thresholds to incorporate into the decision-making process. ORC will consider community suggestions when planning the format, design, and timing of upcoming engagement.

SOCIAL IMPACT ASSESSMENT

[38] A social impact assessment for the Head of Lake Whakatipu area is a key piece of work under the DAPP process to support decision making (Figure 1).

[39] ORC has procured consultant expertise from Beca Group Limited (Beca) to undertake Phase 1 of the social impact assessment, and work commenced in late September 2023. A draft report is expected to be completed by mid-December 2023.

[40] QLDC and the community, through the Glenorchy Community Association, were invited to provide feedback on the consultant team's chosen methodology. The feedback received was incorporated into the methodology.

[41] The methodology proposed by Beca includes both desktop analysis and fieldwork to develop the community profile. The goal is "*to ensure a wide range of stakeholders and community members experiences are captured and different types of local knowledge, experience and cultural values are reflected in the assessment*". Desktop analysis will include collating the available programme, community, and economic data, and identifying and filling gaps. The work will build and expand on the programme engagement that has already been undertaken. Some stakeholders and community members have already volunteered to be interviewed.

[42] Phase 1 of the social impact assessment findings are intended to be used for the following purposes:

- To provide an understanding of the community profile and social and economic impacts of various hazard events under "status quo" management actions. This information has been specifically requested by the community to help inform decision-making alongside technical and risk studies.
- To complement and provide information which will feed into other proposed studies, such as a risk assessment and Phase 2 of the social impact assessment.
- To provide information to inform next steps, for example, to help determine preferred adaptation pathways and to develop a robust evidence base for decision-making in the strategy.

[43] Between late 2023 and early 2024 (to be confirmed), Phase 2 will focus on the impacts of preferred adaptation pathways once these are identified and defined.

SEPTEMBER 2023 FLOOD RESPONSE

[44] In the weather event of 20-22 September 2023, there was widespread heavy rain in the Otago headwaters (Figure 6). As a consequence of rainfall, the Rees River rose to a peak flow of 235 cumecs, the highest flow since ORC commenced flow measurements in December 2021 (Figure 7). Glenorchy Lagoon rose rapidly in response to high river flows and reached a peak level of 312.49 m (DUN58 datum), approaching the level of the floodbank crest and reaching the highest level recorded since ORC has been monitoring water levels at this location (Figure 8).

[45] This was only a moderate flooding event for the head of Lake Whakatipu, with flows and water levels being well below those estimated for a major (1% AEP, or 100-year ARI) flooding event (Table 3).

Table 3: Comparison of monitored peak river flows and water levels for the September 2023 event, compared to estimates[8] [9] for a major (1% AEP) flood event.

	Dart at the Hillocks (flow, m^3/s)	Rees at Invincible (flow, m^3/s)	Glenorchy Lagoon (water level in m, DUN 58 datum)	Lake Whakatipu (water level in m, DUN 58 datum)
September 2023 event	904	235	312.49	310.83
Estimates for 1% AEP event	2,420	769	313.43	312.57

[46] This weather event has demonstrated the value of improvements to the ORC environmental monitoring network in the head of Lake Whakatipu area, to allow for near real-time observations of river flows and water levels. During the event, several technical issues were identified with the telemetry system for the Glenorchy Lagoon. These issues have now been rectified.

[47] The recently developed flood forecasting model for the Glenorchy Lagoon was tested in this weather event as a tool for forecasting the floodwater level within the lagoon. This is a newly developed model and is still in a testing phase, and so requires application in a wider range of future rainfall and flood events to better evaluate model performance and accuracy.

[48] The event of September 2023 lies significantly above the range of lagoon level rises which were used in the flood forecast model development (Figure 8). The model performance and accuracy in this event are being evaluated by the model developer and the model will be refined to take into account monitoring observations from this new event.

[49] The ORC Engineering team carried out aerial monitoring of the Dart and Rees floodplains immediately following the weather events, in order to capture observations of flooding behaviour and identify any river management issues. A selection of aerial photographs from this monitoring are included as Figures 9-11

[8] ORC, 2021. *Analysis of Flood Hazards for Glenorchy.* Appendix C in: Land River Sea Consulting Ltd, 2022. *Dart-Rees flood hazard modelling.* Report prepared for Otago Regional Council.
[9] Land River Sea Consulting Ltd, 2022. *Dart-Rees flood hazard modelling.* Report prepared for Otago Regional Council.

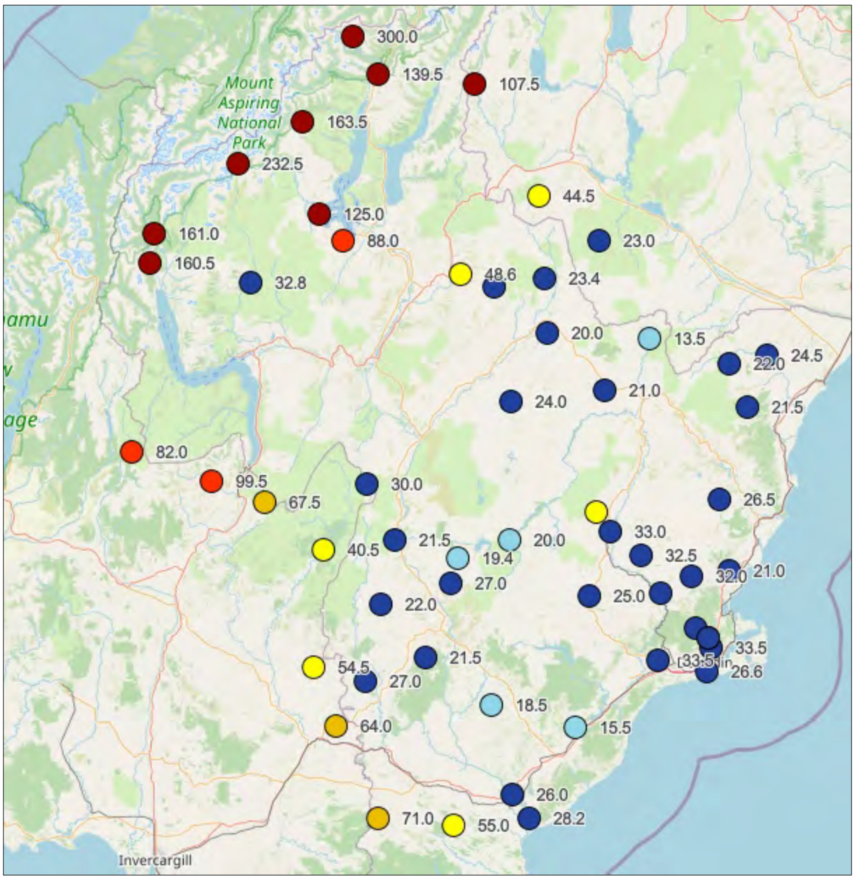

Figure 6: Rainfall totals (in mm) for the 48-hour period to 4.30 pm, 22nd September 2023. ORC's rainfall monitoring stations at the Hillocks and Paradise both measured totals of ~160 mm precipitation.

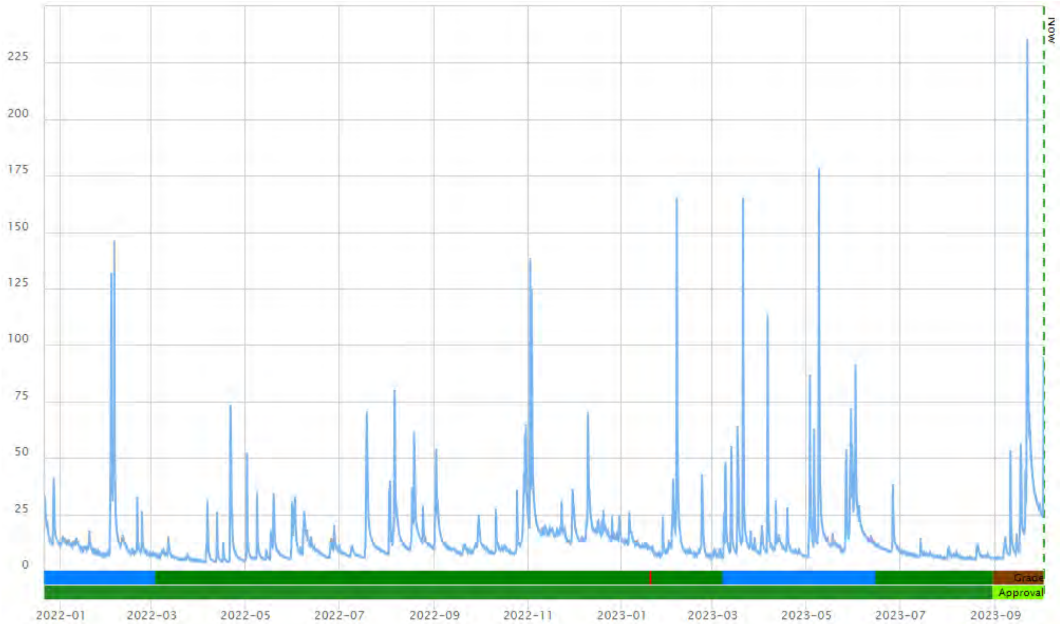

Figure 7: Rees River flows at ORC's Invincible Creek monitoring station, December 2021 to October 2023. In the September 2023 event, the Rees River peaked at a flow of 235 cumecs.

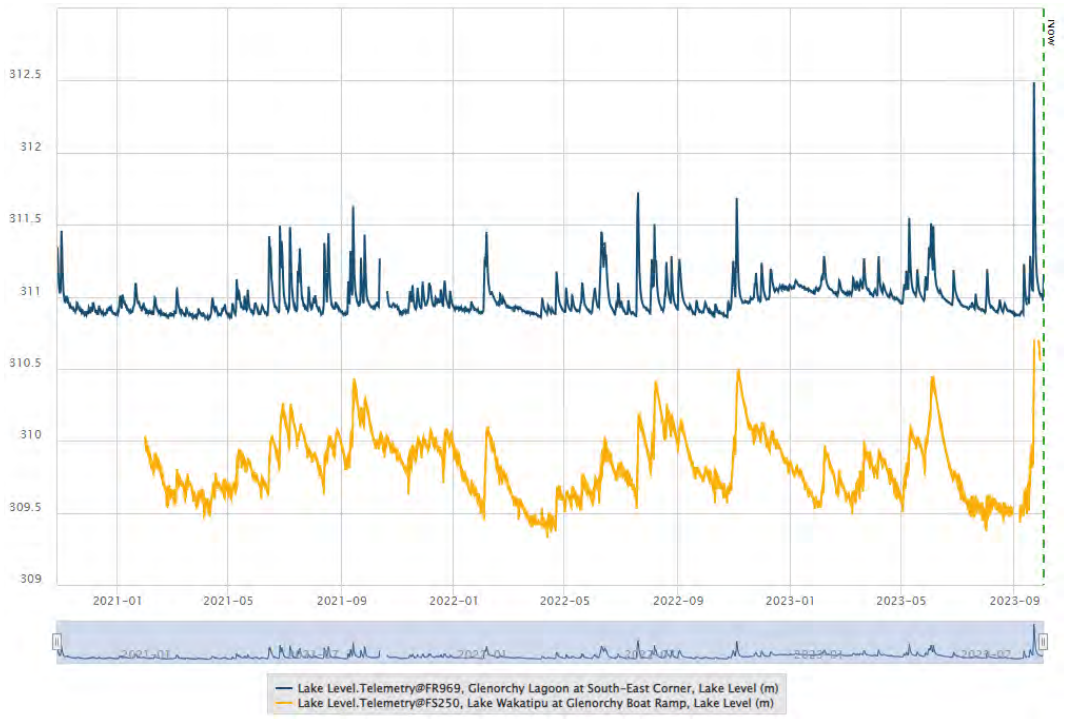

Figure 8: Glenorchy Lagoon level (blue) and Lake Whakatipu level (orange), October 2020 to October 2023. In the September 2023 event, Glenorchy Lagoon peaked at a level of 312.48 m, and the plot shows this level significantly exceeding the previous highest recorded level in this three-year period (311.72 m in July 2022).

Figure 9: View of Glenorchy Lagoon and Glenorchy township, taken 22 September 2023.

Figure 10: View upriver on the lower Rees floodplain towards Mount Alfred and the Rees bridge, taken 22 September 2023.

Figure 11: View upriver on the upper Rees floodplain, taken 22 September 2023.

BUCKLER BURN FLOOD HAZARD ASSESSMENT

[50] Glenorchy township is developed on the alluvial fan formed by the Buckler Burn and therefore may be exposed to flooding, debris-flooding, or debris flow hazards from this catchment.

[51] A flood hazard assessment for the Buckler Burn and Glenorchy has been completed by Land River Sea Consulting Ltd (LRS). The report is titled Buckler Burn Flood Hazard Modelling and is attached as Appendix 2. Peer review of the technical report was carried out by Tonkin + Taylor Ltd and peer review comments have been addressed and incorporated into the final Land River Sea Consulting report. Peer reviewer comments are attached as Appendix 3.

[52] The investigation was undertaken to understand in more detail the flooding characteristics (e.g., floodwater extent, depth, velocity) and potential impacts of the flooding hazard from the Buckler Burn for the Glenorchy township.

[53] The investigation confirmed that there is a potential flood hazard to Glenorchy from the Buckler Burn. Investigation findings are summarised in Appendix 1 and presented in the technical report (Appendix 2). The technical report has been provided to Queenstown-Lakes District Council and a staff briefing offered.

[54] To follow on from the hazard assessment report, ORC is currently assessing potential flood hazard management approaches for the Buckler Burn. This will include a high-level evaluation of flood hazard management approaches and a summary of recommendations for additional work to fill information gaps.

[55] The natural hazard risk assessment project which is in progress for Glenorchy township will make use of these flood hazard investigation findings.

DISCUSSION

[56] The ORC-led natural hazards adaptation programme for the area at the Head of Lake Whakatipu is progressing towards delivery of a first iteration of the Adaptation Strategy document by June 2024.

[57] Signals, triggers, and thresholds related to community values and outcome statements will be developed and incorporated into the draft preferred adaptation pathways. Community values and outcomes will also be used to measure success.

[58] Continued collaborations and consideration of all engagement input will be essential to ongoing progress in development and implementation of an adaptation strategy.

[59] ORC continue to collaborate with QLDC at a staff level across various projects within the broader work programme.

[60] Conversations continue with Aukaha Ltd about the approach and scope of a cultural impacts assessment for the Head of Lake Whakatipu area which will complement and align with the scope of the social impact assessment. Following discussions on 24 October it was agreed that Aukaha will take a te ao Māori approach to initial screening and comments on a long list of potential pathways (to be provided by ORC).

[61] Toka Tū Ake EQC recently led a workshop with ORC staff from the Natural Hazards and Policy and Planning teams about their new risk tolerance methodology. Identifying and

detailing risk tolerance is an important aspect of the development of adaptation pathways and decision-making. Guidance from Toka Tū Ake EQC on the use of their methodology will help inform ORC adaptation programmes.

CONSIDERATIONS

Strategic Framework and Policy Considerations

[62] 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.

[63] The proposed Otago Regional Policy Statement June 2021[10], states that ORC and territorial authorities are both responsible for specifying objectives, policies, and methods in regional and district plans for managing land subject to natural hazard risk. ORC specifically is responsible for *"identifying areas in the region subject to natural hazards and describing their characteristics as required by Policy HAZ–NH–P1, mapping the extent of those areas in the relevant regional plan(s) and including those maps on a natural hazard register or database."*[11]

[64] There is no clear, specific, mandated requirement to reduce risk through planning and implementation of adaptation or relocation. Gaps identified in the current adaptation planning and planned relocation frameworks include the lack of national direction, insufficient powers, tools and mechanisms, and the lack of articulated roles and responsibilities.[12]

Financial Considerations

[65] The budget in the 2023/24 Annual Plan provides for the forward work programme described in this paper. The budget for the 2023/24 financial year for professional services for the Head of Lake Whakatipu natural hazards adaptation programme is $470,000.

[66] ORC has been successful in its application for funding from The Ministry for the Environment (MfE) funding programme, *Nature Based Solutions for Resilience Planning* towards the investigation of 'soft engineering' flood protection responses for Head of Lake Whakatipu area (see Appendices 1 and 4).

Significance and Engagement Considerations

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

Legislative and Risk Considerations

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

[69] Possible reforms of the Resource Management system[13] and strengthening of provisions to do with local authority leadership for climate change adaptation are noted.[14]

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[10] Section HAZ-NH-M1

[11] ORC Natural Hazards Portal: http://hazards.orc.govt.nz

[12] Expert Working Group on Managed Retreat. 2023. Report of the Expert Working Group on Managed Retreat: A Proposed System for Te Hekenga Rauora/Planned Relocation. Wellington: Expert Working Group on Managed Retreat.

Climate Change Considerations

[70] 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 risks and potential hazard management responses for those hazards.

Communications Considerations

[71] ORC will continue to make all investigation findings available to the Head of Lake Whakatipu community and provide regular programme updates via the newsletter.[15]

[72] The flood hazard assessment report (Appendix 2) for the Buckler Burn and Glenorchy is planned to be shared with the community. It has already been provided to QLDC along with the offer of a briefing.

[73] A series of engagement activities are part of the adaptation strategy development process. Engagement input from the community will continue to inform the next stages of the DAPP process as we move through *"What can we do about it?" and "Make it happen"*.

NEXT STEPS

[74] The key next step activities for the work programme which are in progress or scheduled are identified in Figure 1.

[75] These activities will include:

- Continued planning for community engagement activities aiming to be delivered by the end of the year.
- Completion of social and cultural impact assessment studies and a natural hazard risk assessment.

[76] Quarterly programme updates for ORC Councillors are scheduled for February 2024 and June 2024. These may include workshops and/or committee papers, as appropriate.

ATTACHMENTS

1. Update on other activities in the adaptation programme [**9.1.1** - 5 pages]
2. Land River Sea Consulting 2023 Buckler Burn flood hazard modelling report [**9.1.2** - 160 pages]
3. Tonkin + Taylor peer review of Buckler Burn flood hazard modelling report [**9.1.3** - 5 pages]
4. MfE Application for Nature- Based Solutions funding for Dart- Rees floodplain [**9.1.4** - 5 pages]

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[13] A summary of reform work programmes is outlined here: https://www.dia.govt.nz/diawebsite.nsf/Files/Local-Government-2023/$file/Central-government-reformsimpacting-on-local-government-July-2023.pdf
[14] Government is expecting to introduce a Climate Adaptation Bill into Parliament by the end of 2023.
[15]https://www.orc.govt.nz/managing-our-environment/natural-hazards/head-of-lake-whakatipu/community-get-in-touch-be-involved

Appendix 1: Updates on activities in the Head of Lake Whakatipu natural hazards adaptation programme.

1. INTRODUCTION

The paper presented to the committee provides an update focused on development of the natural hazards adaptation strategy for the head of Lake Whakatipu area, and the associated community engagement activities and social impact assessments.

This appendix provides supporting information summarising other technical activities in this work programme completed since the August 2023 paper.

2. BUCKLER BURN FLOOD HAZARD ASSESSMENTS

2.1. Introduction

Glenorchy township is developed on the alluvial fan formed by the Buckler Burn and therefore may be exposed to flooding, debris-flooding or debris flow hazards from this catchment (Figure 1).

A flood hazard assessment for the Buckler Burn and Glenorchy has been completed by Land River Sea Consulting Ltd (LRS). The report is titled *Buckler Burn flood hazard modelling* and is attached as Appendix 2. Peer review of the technical report was carried out by Tonkin + Taylor Ltd, and peer review comments have been addressed and incorporated into the final Land River Sea Consulting report. Peer reviewer comments are attached as Appendix 3.

The investigation was undertaken to understand in more detail the flooding characteristics (e.g. floodwater extent, depth, velocity) and potential impacts of the flooding hazard from the Buckler Burn for the Glenorchy township.

Modelled flooding scenarios included combinations of large (up to 300 cumecs) river flows, and the effects of alluvial fan aggradation on fan morphology. There is uncertainty in the magnitude of floodwater flows from the Buckler Burn catchment, but most of the design flows modelled exceed the previous estimates[1] [2] of the 1% AEP (100-year ARI) flood event.

2.2. Findings

In many of the larger-magnitude modelled scenarios, there is some floodwater spillover northwards from the stream into the township area. Modelled floodwater flow paths typically follow road alignments into and through the township, primarily along Oban Street, Shiel Street and Invincible Drive (e.g. Figures 2, 3).

Modelled floodwater depths in the residential parts of the township are generally relatively shallow (<0.5 metre depth) even in the largest magnitude scenarios modelled (e.g. Figure 3), with the exception being deeper and faster floodwaters modelled along the roadway alignments.

Flood hazard was categorised[3] based on the combination of floodwater depth and velocity characteristics. Where there is modelled floodwater flow through the township area from the Buckler

[1] 170 m^3/s (± 28% std. error) estimate by URS (2007). Glenorchy Floodplain Flood Hazard Study.
[2] 82 m^3/s (± 45 m^3/s std. error) by Henderson and Collins (2018). NIWA NZ River Flood Statistics webpage.
[3] Hazard categorisation was based on the Australian Rainfall and Runoff guide to flood estimation.

Burn, this has generally been classified as H1 (‘*generally safe for vehicles, people and buildings*’), although with localised areas of the higher hazard classes, up to H5 and H6 (e.g. Figure 4).

2.3. Discussion

The findings of the Land River Sea investigation confirm previous interpretations that the Buckler Burn poses a potential flooding hazard to the township,[4] [5] and provide a much higher level of detail than the previous flood modelling study for Buckler Burn flooding hazards.[6]

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

Following completion of the flood hazard assessment, ORC is reviewing the potential engineered or river management approaches to managing the flood hazard from the Buckler Burn. These are being assessed in a similar high-level approach to that which was carried out for the Dart-Rees floodplain.[7]

Information gaps identified which may need to be addressed by additional investigations or monitoring include detail of hydrological and geomorphic processes, the need for increased documentation of flooding events and impacts, and potential for further investigation of debris flow hazards.

[4] ORC, 2010. *Natural Hazards at Glenorchy.*
[5] 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.
[6] URS, 2007. *Glenorchy floodplain flood hazard study*. Report prepared for Otago Regional Council.
[7] Damwatch Engineering Ltd, 2022. *Dart-Rees floodplain adaptation – Report on 23-24 February workshop*. Report prepared for Otago Regional Council.

Figure 1: *Overview of the Buckler Burn stream and alluvial fan, with Glenorchy township located the northern side of stream's active channel. The full township area is developed on Buckler Burn alluvial fan deposits, and the higher terraces to each side of the stream are remnants of older alluvial fan-delta surfaces formed when the lake was at higher levels. Photograph dated May 2018.*

Figure 2: *Model results for a Buckler Burn flooding scenario with a 300 cumec peak flow (<1% AEP). In this scenario minor floodwaters flow into the township area, mainly flowing northwards along Oban Street and around the eastern margin of the township. Colouring shows peak floodwater depths according to the included legend.*

Figure 3: *Model results for a Buckler Burn flooding scenario with a 300 cumec peak flow (<1% AEP) and a 3 metre thickness of channel aggradation on the mid-upper reaches of the alluvial fan. In this scenario floodwaters flow into the township area mainly flowing northwards along Oban Street, and along Invincible Drive and Shiel Street. Colouring shows peak floodwater depths according to the included legend. The flood hazard categorisation for this scenario is shown as Figure 4.*

Figure 4: *Flood hazard categorisation for a Buckler Burn flooding scenario with a 300 cumec peak flow (<1% AEP) and 3 metres channel aggradation on the mid-upper reaches of the alluvial fan. Colouring shows hazard categorisation according to the included legends.*

3. NATURAL HAZARD RISK ASSESSMENT

A natural hazard risk assessment project for Glenorchy and Kinloch was introduced in the August 2023 update paper presented to this committee.[8] This project is currently in progress and is expected to be completed in early 2024. Findings will be presented to both the community and to councillors once they are available.

The project will systematically assess the natural hazard risks in the Glenorchy and Kinloch areas, including those from flooding, seismic and alluvial fan hazards. Qualitative assessments will be completed, and where appropriate a more detailed quantitative approach will also be applied.

4. FLOOD PROTECTION FEASIBILITY ASSESSMENTS

Procurement is being finalised for specialist expertise to undertake a technical feasibility study to investigate potential floodplain hazard management approaches for the Dart-Rees floodplain. This study will build on the initial assessments of benefits, challenges and constraints for flood hazard management interventions outlined in the report compiled by Damwatch Engineering Ltd.[9]

For the lower Rees floodplain and Glenorchy township flood hazard, the proposed investigation scope includes consideration of (at least) the following potential engineered flood management interventions for the lower Rees River floodplain and Glenorchy township;

a) raising or modifying the existing Rees-Glenorchy floodbank structure;
b) construction of bunding or new floodplain structures to reduce overland flood flows from the Rees River into Glenorchy Lagoon; or
c) the use of innovative 'nature based' approaches such as vegetative buffers to modify overland flood flows from the Rees River into Glenorchy Lagoon; or
d) any combinations of these interventions a-c.

For the Dart floodplain, and the upper Rees floodplain (upstream of the road bridge), the scope includes assessment of potential flood or erosion management interventions, with a focus on the use of 'nature-based' innovative approaches such as vegetative buffers for flood mitigation or erosion management.

Investigations are proposed to assess and describe the conceptual designs of interventions, associated technical challenges for implementation, the identification of environmental impacts, a review of consenting requirements and indicative costings. The existing hydraulic model[10] for the Dart-Rees floodplain will be used to assess the flood hazard performance provided by the range of approaches assessed.

ORC has been successful in gaining a funding contribution of $100,000 towards the 'nature-based solutions' aspects of the investigation through the Ministry for the Environment (MfE) funding programme, *Nature Based Solutions for Resilience Planning*. The ORC application for this funding programme is attached as Appendix 4.

This project is currently in the final stages of procurement and is expected to be completed in early 2024. Findings will be presented to both the community and to councillors once they are available.

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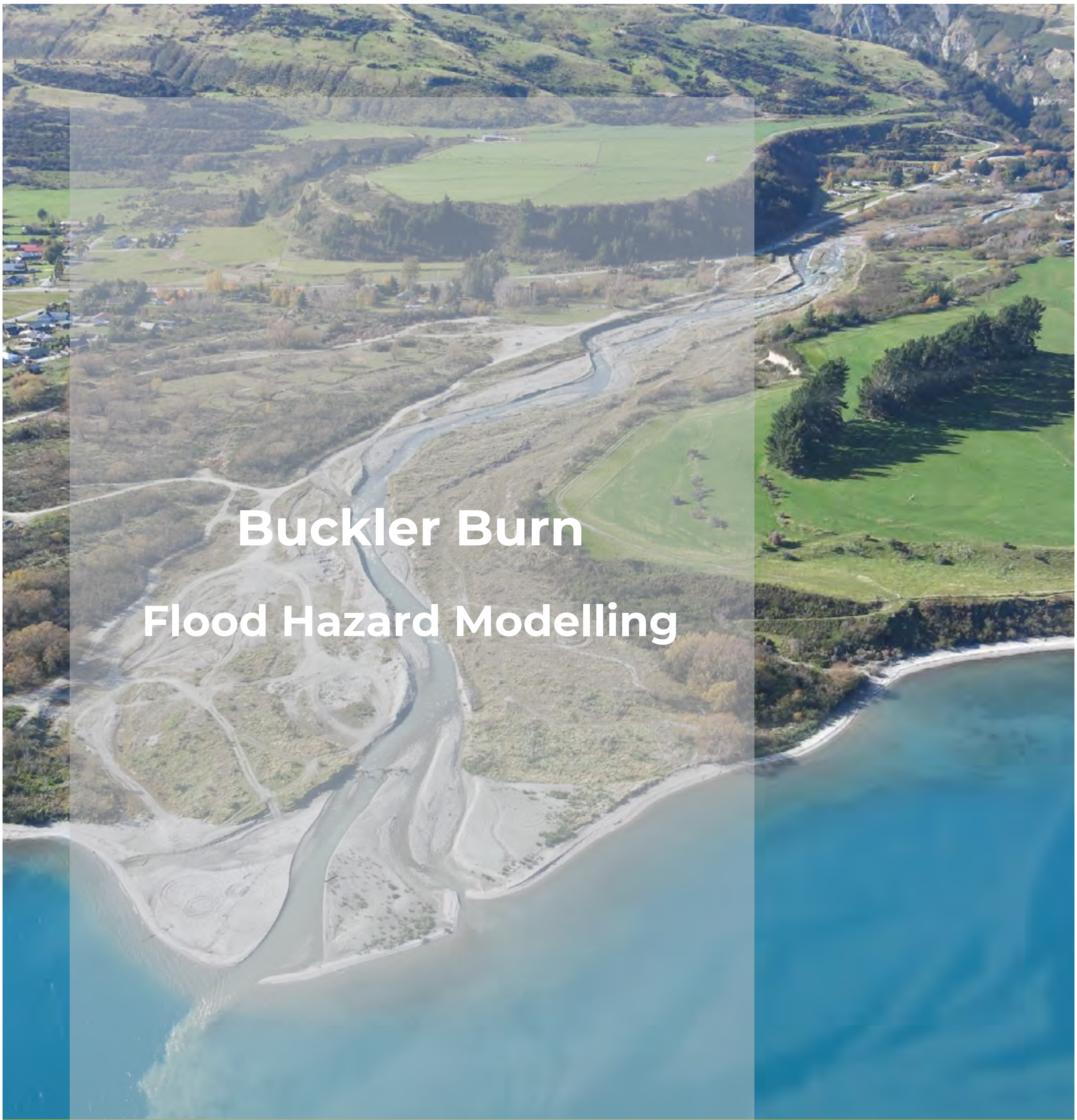
[8] Appendix 1, Section 4 of the August 2023 paper,

[9] Damwatch Engineering Ltd, 2022. *Dart-Rees floodplain adaptation – Report on 23-24 February workshop*. Report prepared for Otago Regional Council.

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



Buckler Burn

Flood Hazard Modelling

7 August 2023

Client: Otago Regional Council

Report by: Matthew Gardner & Rose Beagley
Land River Sea Consulting Limited
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Land River Sea CONSULTING

Otago Regional Council

REVISION HISTORY

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Date:	7 August 2023	
Revision:	4	
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TABLE OF CONTENTS

1. INTRODUCTION

1.1. SCOPE

Land River Sea Consulting (LRS) has been contracted by the Otago Regional Council (ORC) to develop a detailed flood model of the Buckler Burn alluvial fan area from the Glenorchy-Queenstown Rd bridge downstream to Lake Wakatipu.

The purpose of the model is to:

- Inform landowners and residents of the potential hazards posed by the Buckler Burn; and
- Provide input into the ongoing Head of Lake Wakatipu Hazards Adaption project, providing a better understanding of hazard and risk characteristics of the Buckler Burn flooding threat.

The area of interest for this project is presented in Figure 1-1 below.

Figure 1-1: Area of interest showing the Buckler Burn, Glenorchy and Campbelltown.

The scope of the project involves:

- Upgrading the LRS 'Dart/Rees Rivers MIKE21FM model' by converting it to HECRAS, and then extending the mesh to include the entire Buckler Burn fan, creating a new roughness layer, and recalibrating it to the February 2020 flood event.
- Simulating a range of design flow scenarios on the fan.
- Simulating a range of simplified aggradation scenarios on the fan.
- Generating peak depth, floodwater elevation, velocity, hazard, and extent maps for the above scenarios.

1.2. PREVIOUS MODELLING

The Buckler Burn and alluvial fan have been modelled previously by both URS NZ Ltd and Land River Sea Consulting Ltd as part of larger projects. Glenorchy Floodplain Flood Hazards for the former, and the Dart-Rees Rivers model for the latter.

In 2007, URS NZ Ltd completed modelling of the Glenorchy floodplain including Buckler Burn(Whyte & Ohlbock, 2007). The modelling was carried out using MIKE11 software with the 1D model based on the limited cross sectional survey (2006). It included an assessment of the hydrology as well as an assessment of the level of service of the Glenorchy stopbank. However, none of the scenarios modelled showed flooding from the Buckler Burn onto the Glenorchy-Queenstown Rd. It is believed that this was due to the bedload transport being a more complex process during a flood than what had been modelled, or under-estimation of the design flows.

In 2022, Land River Sea Consulting Ltd built a detailed MIKE21 hydraulic model of the Dart-Rees Rivers using the 2019 LiDAR data as well as available cross section survey data. The purpose of the model was to provide a better understanding of the potential flood hazard from both rivers to Glenorchy as well as the surrounding rural land for a range of return period events, including the potential impacts of climate change and stopbank failure. The Buckler Burn fan was included in the extent of the model, but no flood hazard assessments were carried out on it.

Debris flow modelling of the Buckler Burn has also been completed by Geosolve Ltd (not publicly available). This was not a comprehensive investigation, rather a test of sensitivity to factors such as failure locations, debris volumes and release mechanisms (van Woerden & Payan, 2022).

In addition, the geomorphology of the Buckler Burn alluvial fan has been documented in several memos and reports prepared by ORC and Massey University. These include:

- URS - Glenorchy area geomorphology and geo-hazard assessment (Mabin, 2007).
- GNS - Otago alluvial fans project: Supplementary maps and information on selected areas of Otago. GNS Science consultancy report 2009/052, prepared for ORC (Barrell et al., 2009).
- ORC - Natural Hazards of Glenorchy (Otago Regional Council, 2010).
- Massey University - Key notes and observations from preliminary assessment of debris flood and flow hazard potential at Glenorchy (Fuller & McColl, 2021).
- ORC - memorandum on the Buckler Burn aggradation scenarios (van Woerden, 2023).

1.3. SITE VISIT

On the 12th and 14th of October 2021 Matthew Gardner visited the Glenorchy area for the Dart-Rees flood model investigation. He was accompanied by Tim van Woerden and Magdy Mohssen on the 12th ofOctober.

The focus of the site visit was to observe the terrain in person which is invaluable for gaining a full appreciation for the characteristics of the site. Key areas for the Dart-Rees model were traversed over the two days with photography captured using both a drone and standard camera.

Special attention was paid to several areas, and those that are relevant to the current Buckler Burn project have been listed below:

- Glenorchy township and potential inundation areas
- Glenorchy stopbank
- Buckler Burn was briefly viewed.

2. LIMITATIONS OF STUDY

This study has been carried out using the information and data made available to the author at the time of this study. There are a number of uncertainties which should be acknowledged which include but are not limited to:

- LiDAR data – whilst there is good coverage, LiDAR data comes with a degree of vertical uncertainty typically considered to be in the range of +/-0.15m.
- The model is a fixed bed model and does not allow for bed mobilisation / gravel transport. This is especially relevant, given we are modelling an alluvial fan which is an inherently dynamic system that experiences significant channel movement and geomorphic change during and outside of flood events.
- Input hydrology data is based on hydrological modelling. There is no physical flow gauge in the Buckler Burn nor raingauge in the catchment.

3. HYDROLOGY

3.1. CATCHMENT

The Buckler Burn is a steep catchment to the south of Glenorchy township, with its active channel belt located just shy of the developed residential area (Figure 3-1). The headwaters begin on the eastern slopes of the 1900m to 2300m high Richardson Mountains - from Mt McIntosh around to Mt Alaska - before the burn drops steeply down to Lake Wakatipu where an active alluvial fan and delta system has formed.

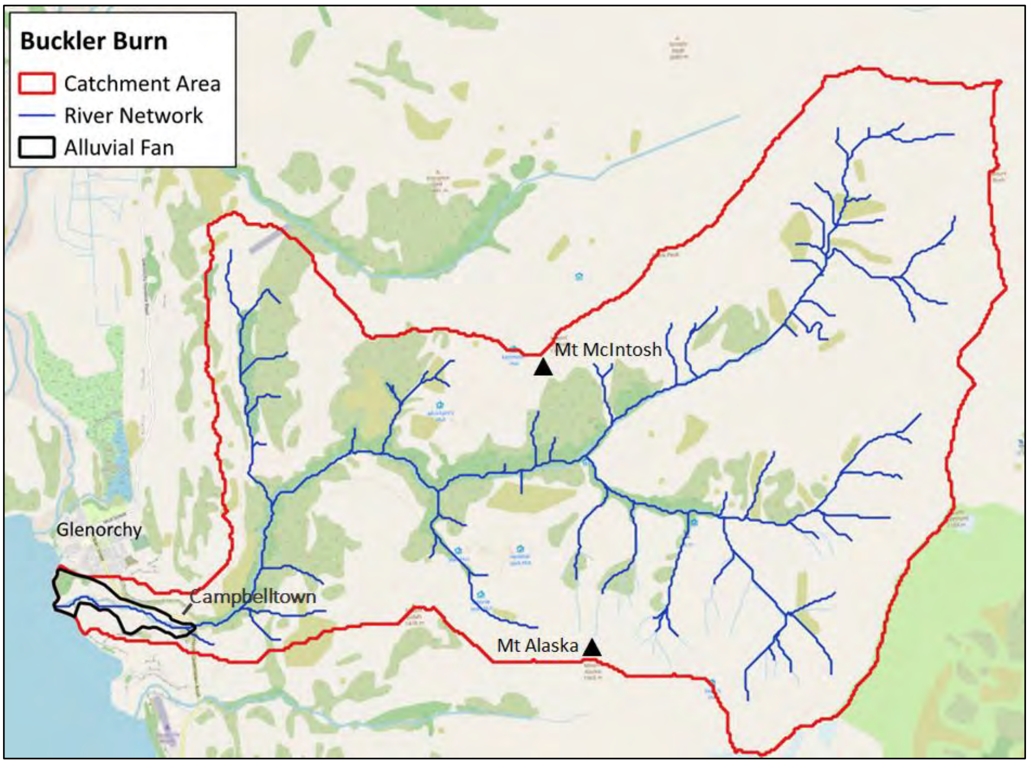

Figure 3-1 – Buckler Burn catchment.

Due to its steep gradient and origin in the Richardson Mountains – largely unvegetated in the tops and schist dominated – the burn has a high bedload, which can be moved downstream during high flow events. These events are largely rainfall-driven, but there is also the risk of dambreak flood occurrence from the upper reaches and/or the gorge. As a result, the alluvial fan at the burn and lake junction undergoes several dynamic processes including avulsion, channel migration and aggradation which pose a threat to the bridge, Glenorchy-Queenstown Rd, Glenorchy, and Campbelltown.

3.2. FLOOD AND FAN HISTORY

3.2.1. FLOOD EVENTS

The Buckler Burn is not monitored for water level or flow, and there are no rainfall gauges within its catchment. Therefore, knowledge of past floods events is based upon the relatively few observations of events, and the NIWA NZ Historic Weather Events Catalogue (Table 3-1).

Table 3-1 – Observations of weather events which have resulted in flooding from the Buckler Burn impacting on Glenorchy and/or Campbelltown (NIWA, 2018a).

Event/Observation	Description	Impact
1937	Buckler Burn flood risk to the Glenorchy School.	The school was forced to relocate.
1970s onwards	Buckler Burn was threatening the southside of Glenorchy and the Glenorchy Queenstown Rd.	Various protection works were built. Gravel was removed from the channel.
1978 - October	4-day weather event with warm rain resulting in snow melt.	1978 - Numerous slips closed the Queenstown Glenorchy Rd.
1979 - December	Torrential rainfall in Central Otago resulting in widespread flooding. Lake Wakatipu rose by 1m.	The Glenorchy dam on the Ox Burn/Twelve Mile Ck (which has a very similar catchment to the Buckler Burn) filled with gravel, rocks and trees and took months to clear. Many bridge approaches in West Otago badly affected. 1978 and 1979 - Several cottages on the southern side of Glenorchy, a few hundred metres upstream of the lake were reported to have flooded. This was also the location of the old school site which had been relocated earlier due to flood hazard.
1994 – January	3-day event with serious flooding occurring in the Queenstown-Lakes district from streams bursting their banks.	400 people evacuated from Glenorchy by boat.
1999 - November	5-day event with an estimated return period of 150 years. The Rees Valley Station recorded 275mm in 4 days (ARI of 100yrs). Lake Wakatipu rose extremely high and flooded its foreshore, peaking at 312.7m asl, 0.5m higher than the previous high record set in 1878. Aggradation of up to 2m occurred in the Buckler Burn channel.	Surface flooding and slips closed roads throughout the region, with civil defence emergencies declared in Otago. It experienced some of its worst flooding in the century. Road washouts isolated Glenorchy and Kinloch. The Buckler Burn inundated a section of the Queenstown-Glenorchy Rd with water and debris.

3.2.2. ALLUVIAL FAN

The Buckler Burn has formed an alluvial fan-delta system between where it departs the confines of the Richardson Mountains and flows into Lake Wakatipu.

Given the steep and mountainous nature of the upstream basin which is dominated by alpine weathering processes, rockfall, and mass movements, the fan has a high sediment supply. As a result, it's a very dynamic system with active geomorphic change. This is readily identified through the available aerial imagery from the last century, and photographs from the 1994 and 1999 events when floodwaters reached close to the southern margin of the Campbelltown and Glenorchy residential areas (Figure 3-1).

Survey datasets have also been used to show channel belt and fan surface changes. The few surveys available in addition to observations during larger flood events have been used to infer that the fan surface is aggrading or may aggrade in the future, and that this is leading to an increasing hazard (Mabin, 2007; Otago Regional Council, 1999, 2022).

In the section below, we will briefly discuss the aerial imagery in relation to the morphological characteristics of the fan, with the focus largely on the 1999 event as this is the most significant flood on record for the burn and is being used to validate the model.

In order to be consistent with any observations or references made to the alluvial fan in the section and the report as a whole, we have used the chainage created by ORC, measured in kilometres from the Glenorchy-Queenstown Rd bridge down the Buckler Burn alluvial fan to Lake Wakatipu (Figure 3-2).

Figure 3-2 – The Buckler Burn fan edge outlined in red, overlain by chainage measured in kilometres downstream from the road bridge.

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Aerial Imagery

The aerial imagery, photographs and observations indicate a very dynamic alluvial fan, with decadal scale fluctuations in activity. Quiescent phases are associated with a contracted active channel belt, whilst active phases are associated with an expanded active channel belt.

In the aerial imagery from the 1930's to the present day (1937, 1966, 2008, 2019), the alluvial fan experiences large-scale geomorphic changes as it shifts from an active phase into increasingly quiescent phases. The active river channel belt significantly narrows with each image, and as the width of the active channel belt changes, so too does the amount of vegetation present on the fan (Figure 3-3), with the amount of vegetation increasing as the belt narrows. This suggests that there are periods of time when flows do not exceed the threshold of the active channel belt frequently enough to inhibit vegetation growth and are therefore the more quiescent phases of the fan's lifecycle.

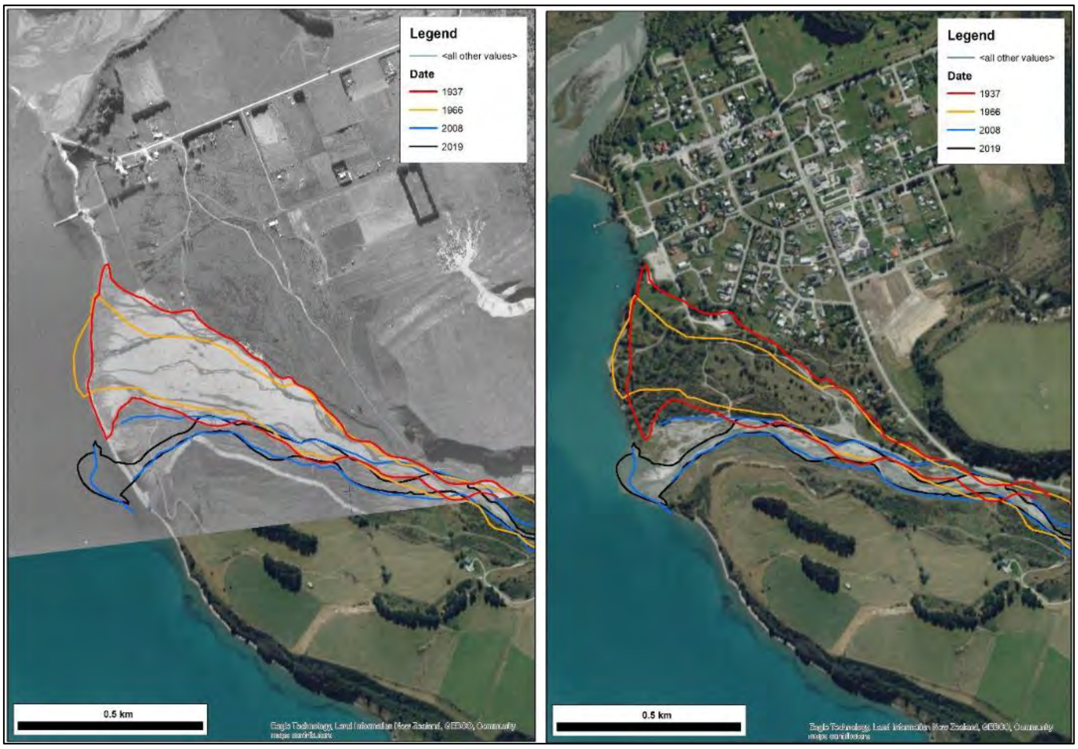

Figure 3-3 - Comparison of aerial imagery at the Buckler Burn in 1937 (left) and 2019 (right), annotated to show approximate extent of the active riverbed at four dates (1937, 1966, 2008, 2019) (ORC, 2022).

The aerial imagery from 1937, 1994, and 1999 (Figure 3-3 and Figure 3-4) suggest a much more active phase of the fan's lifecycle, with wider active channel belts and larger areas of exposed gravel compared to imagery post 2000 through to 2019, and in the 1960s. In these periods it is likely that sediment laden flood events occurred frequently enough to aggrade the fan and force channel changes through processes such as infilling, bifurcation, lateral migration, and avulsion.

Furthermore, in the aerial imagery from the January 1994 flood event, vegetation is still present between the Buckler Burn fan surface and the Queenstown-Glenorchy Rd (0.7 to 0.8km chainage). This vegetation and the road was then inundated with debris and water during the November 1999 flood (Figure 3-4).

Figure 3-4 – January 1994 and November 1999 aerial imagery.

The 1999 flood also generated a far greater active surface upstream of about the 1.15km chainage on the fan than the 1994 flood. This suggests sediment mobilisation and transportation downstream to the fan was likely greater during the 1999 flood, or simply that flooding between the 1994 and 1999 events infilled enough of the channels that by the time the 1999 flood occurred, there was little capacity to handle flows and large amounts of sediment. Thus, in the 1999 flood, the sediment supply exceeded the ability of fan to move it through the system, resulting in aggradation of the fan surface and as a result the overtopping of the Queenstown-Glenorchy Rd (Figure 3-5). This overtopping is a crucial part of the model validation and is discussed further in Section 5.

Figure 3-5 – The Buckler Burn following the November 1999 flood event, showing debris deposition over the Queenstown-Glenorchy Road on the true right bank.

In addition, between 1937 and 2019, the fan experiences progressive lateral migration of the active channel belt to the south, with the present day alignment being at the most southern limit of the fan (Figure 3-3). This indicates that northwards migration should be anticipated, particularly if the fan is to enter a more active phase as experienced in the 1930s, and between the late 1970s to late 1990s.

3.3. INPUT FLOWS AND LAKE LEVELS

Considerable discrepancy exists between the peak flows estimated by different agencies (Table 3-2).

In 2007, URS used the Regional Method (McKercher & Pearson, 1991) to estimate 10, 50, 100 and 150 ARI flows for the Buckler Burn, with a standard error between +\-21 and 29% for each flow. However, these flow values are at least double those estimated by NIWA (2018), indicating that there is considerable uncertainty as to how much water is coming down the Buckler Burn during events.

Land River Sea Consulting Ltd has taken a conservative approach to the flow estimates for the Buckler Burn design runs and used slightly higher flows than those estimated by Whyte and Ohlblock (2007)(Table 3-2). Also, due to the large uncertainty between flow estimates and return periods by URS and NIWA, and those that we have used, we have chosen not to align our flows with any particular return period (Table 3-3).

Table 3-2 –URS, NIWA and Land River Sea Consulting Ltd estimated Buckler Burn flows.

Return Period (ARI)	URS (2007)	NIWA (2018)
10-year	112m^3/s (± 21m^3/s S.E.)	52m^3/s (± 21m^3/s S.E.)
50-year	129m^3/s (± 26m^3/s S.E.)	73m^3/s (± 37m^3/s S.E.)
100-year	170m^3/s (± 28m^3/s S.E.)	82m^3/s (± 45m^3/s S.E.)
150-year	180m^3/s (± 29m^3/s S.E.)	

Table 3-3 – Peak flows used for the Buckler Burn design runs in the Land River Sea Consulting modelling.

Design number	Design flows
1	100m^3/s
2	150m^3/s
3	180m^3/s
4	200m^3/s
5	250m^3/s
6	300m^3/s

The corresponding hydrographs used with these design flows are a scaled down version of those used in the LRS 2022 Dart-Rees model. They have also been shortened to allow for the smaller catchment of the Buckler Burn. Figure 3-6 shows all six of the hydrographs.

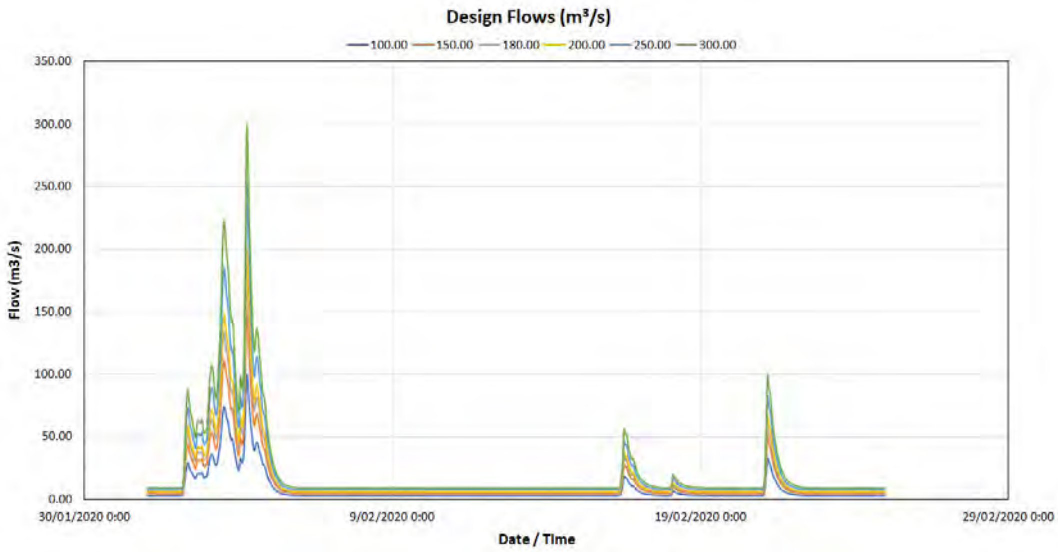

Figure 3-6 - LRS design flow hydrographs for the Buckler Burn.

ORC staff have carried out a detailed lake level frequency analysis based on the available records (Mohssen, 2021). The adopted lake levels based on this analysis are presented in Table 3-4. To put these levels into context, the highest lake level was recorded in November 1999 with a level of 312.78m, whilst the peak level recorded on the 4th of February 2020 was 311.35m. This was 1.43m lower than the 1999 event, but was a part of a significant weather event for the region.

Table 3-4 – Adopted Lake Wakatipu levels.

Return Period	Lake Level – DUN58 (m)
2-year ARI	310.7
10-year ARI	311.5
100-year ARI	312.9

For the Buckler Burn design and aggradation scenario model runs Land River Sea Consulting has used the Lake Wakatipu February 2020 event stage hydrograph. This peaks at 311.35m, which is just under a 10-year ARI.

Given the steepness of the fan, and that the flooding hazard is largely from its upper reach, it is unlikely to be overly sensitive to higher lake levels than that used (5 – 10 year ARI). Therefore, no simulations were run with any higher lake levels.

4. CONVERSION OF MODEL FROM MIKE21 FM TO HECRAS

The Dart-Rees MIKE21FM model has been used as the basis for this study and has first been converted to HECRAS, which is a freely available software package made by the US Army Corp of Engineers and is utilised inhouse at the Otago Regional Council. For details of the Dart-Rees model please refer to the *Dart/Rees Rivers: Flood Hazard Modelling* report, 2022.

The following updates have been made to the model as part of this study.

4.1. MESH

The mesh has been converted to a 10m x 10m rectangular mesh and has been expanded to cover the entire Buckler Burn floodplain.

In order to prevent leakage between the cell faces along linear features and hydraulic controls such as the Glenorchy-Queenstown Rd and Oban St and unrealistic overtopping, break lines have been included in the mesh (Figure 4-1). In addition, to ensure that the crest level of the Glenorchy stopbank (Figure 4-1) is represented in the model, the stopbank crest has been removed from the 2D terrain and has been represented using a 1D DIKE feature based on actual ground survey (Figure 4-1). This ensures the precise crest level is represented in the model.

The computational regime of HEC-RAS also differs significantly from MIKE21FM.

In HEC-RAS the computational cell faces control the flow movement from cell to cell rather than the average elevation of the cell as is the case in MIKE21FM. In HEC-RAS, the terrain and the computational mesh are pre-processed in order to develop detailed elevation/volume relationships for each cell based on the underlying digital elevation model (DEM; which is 1m in this case). This allows for a larger cell resolution to be adopted, however to still utilise the detail of the higher resolution DEM which underlies the model.

A visualisation of the mesh for the Buckler Burn / Glenorchy portion of the model is presented in Figure 4-1.

Figure 4-1 - Visualisation of the mesh with the inclusion of the Glenorchy stopbank (black line) and the Glenorchy-Queenstown Rd and Oban St break line (dark red).

4.2. INPUT DATA

The base DEM for the model build was the 2019 LiDAR utilised in the Dart-Rees flood model (Figure 4-2) which has a vertical accuracy of +\-0.15m. All three of the DEMs used in the aggradation scenarios were developed from this 2019 DEM.

However, additional runs have looked at the impact of recent changes in the Buckler Burn alluvial fan utilising 2022 LiDAR flown by the University of Canterbury (Figure 4-3). The main changes between 2019 and 2022 were:

- Localised aggradation in the lower reach of the fan in the order of 01.m to 1.1.m
- Localised aggradation in the upper fan reach between chainages 0.7 and 0.85km in the order of 0.1m to 0.4m.
- Localised bank erosion in the upper reach of the fan.

Figure 4-2 - 2019 LiDAR from the Dart-Rees flood model

Figure 4-3 - 2022 LiDAR for the Buckler Burn alluvial fan

4.3. FLOODPLAIN RESISTANCE

Floodplain resistance has been represented in the model using a spatially varying Manning's 'n' coefficient.

To account for varying roughness values on the floodplain, a raster of roughness values with a grid size of 1m has been created where each cell has been assigned a Manning's 'n' value based on the land use visible in the latest aerial imagery.

This task has been carried out using a combination of manual and automatic image classification techniques to ensure the most accurate classification of land uses.

- Buildings have been located based on a digitised building footprint shapefile supplied by Land Information New Zealand (LINZ).
- Road centrelines were manually drawn due to discrepancies between the online datasets and the aerial imagery, and a buffer polygon was created around the road centreline since the available GIS datasets did not have sufficient accuracy.

For the manning's 'n' value of the gravel in the active channel belt of the Buckler Burn, we have taken a different approach to the above.

- Despite the grain size of the fan material, evidence presented in international research suggests that the Manning's 'n' value increases significantly in steep, active bed load dominated gravel river systems (Jarrett, 1985) such as is the case for the Buckler Burn.
- Therefore, we have assessed the potential bed roughness using the Jarretts equation (Equation 1) with the required parameters taken from 8 cross sections extracted from the 2019 LiDAR data.

$$n = 0.39 * (S^{0.38}) * (R^{-0.16})$$

Where, n = Manning's 'n', S = Slope and R = Hydraulic radius

Equation 1 – Jarretts Equation

As a result of the above, we have adopted a manning's 'n' value of 0.1 for the gravel in the active channel belt of the Buckler Burn.

The adopted Manning's 'n' values for the entire model build are summarised in Table 4-1, and an example of the Manning's delineation is shown (Figure 4-4 and Figure 4-5).

Table 4-1 – Adopted Manning's 'n' coefficients for the Buckler Burn model.

Landuse	Manning's 'n'
Buildings	2.0
Grass	0.033
Gravel	0.019
Gravel - Buckler Burn	0.10
Lagoons	0.029
Lake	0.01
Road - Concrete	0.02
Road - Unpaved	0.025
Vegetation - Light	0.07
Vegetation - Medium	0.09
Vegetation - Dense	0.12

Figure 4-4 – Aerial imagery

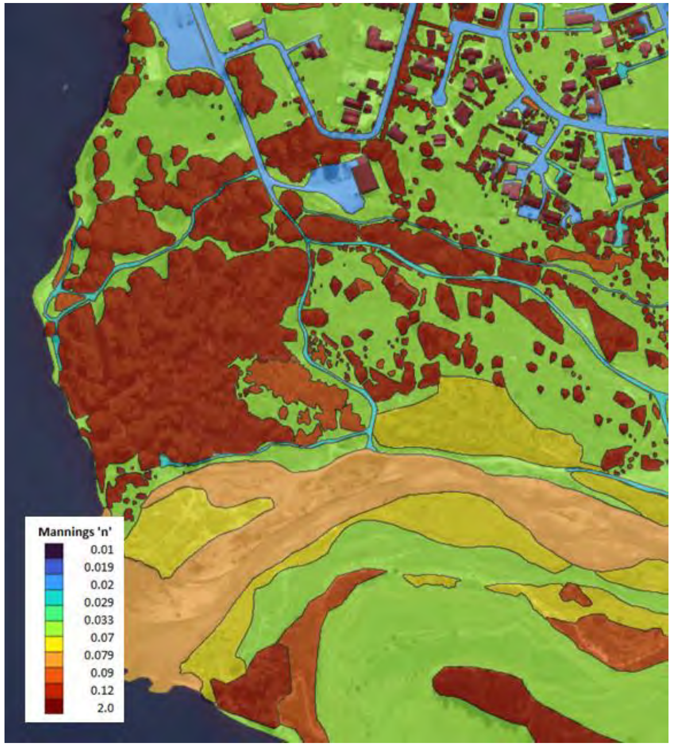

Figure 4-5 – Land use classification.

4.4. MODEL CALIBRATION / VALIDATION

In order to ensure the HEC-RAS model is giving outputs consistent with the original MIKE21FM model, the model has been used to simulate the February 2020 flood event.

Model results have shown that the model gives a very similar flood extent to the calibrated MIKE21 model (Figure 4-6).

Figure 4-6 – Comparison of HEC-RAS results (red) with MIKE21FM results (blue) at Glenorchy

Comparison of peak water levels at key locations show a slight improvement in model calibration:

- Records from the event indicate that the peak water level at the footbridge crossing Lagoon Creek was estimated to be around 312.7 to 312.8m.
- The MIKE21FM model results indicated a water level of 313.0m at this location, however the HEC-RAS model gives a level of 312.96m which shows a marginally improved fit (of 1 decimal place).

However, the HEC-RAS does not show overtopping of the Glenorchy stopbank, likely as a result of interpolating from larger triangles to squares during the conversion from a triangular mesh within MIKE to a rectangular grid for viewing within ArcGIS. Despite this, due to the general similarity in results between the two models, we are comfortable to continue using the HEC-RAS model for simulations within the Buckler Burn catchment.

4.5. ADJUSTMENT OF DEM TO INCORPORATE FAN AGGRADATION

The project scope included investigating how channel bed aggradation impacts on the flood characteristics of the Buckler Burn and resulting flood risk to the Glenorchy township.

To do this, ORC has developed and supplied three aggradation scenarios (A, B, and C), which assume a uniform thickness of aggradation occurs within the more confined upper section of the stream channel (chainage 0 – 1.0km) and then decreases at a consistent rate to zero at the lake margin.

The scenarios increase by 1m steps in elevation above the 2019 fan surface profile in the upper section of the fan (Figure 4-7):

A – 1m increase in elevation

B – 2m increase in elevation

C – 3m increase in elevation

These increases in elevation do not necessarily equate to volumes deposited during an event or consecutive events on the contemporary fan surface. Further study is required into the potential sediment sources available i.e. mass slope failure or landslide dambreak, as well as the connectivity in the catchment, so as to establish realistic supply volumes and therefore aggradation depths across the fan surface.

Furthermore, the main area of aggradation in the modelled scenarios is in the upper fan because this was identified by Ian Fuller in a note to ORC (Fuller & McColl, 2021) as a critical area in which aggradation in the channel could result in an avulsion to the north towards Glenorchy, and therefore was worthy of investigation. However, the scenarios have the aggradation thickness decrease at a consistent rate towards the lake boundary. In reality, the thickness of the deposited sediment in the long profile would vary with abrupt changes in morphology due to the unpredictable and erratic pulse like nature of sediment movement across a fan surface. Though a necessary simplification, this deviation from reality has implications on the modelled inundation, as it smooths out the fan surface, thus removing natural channel formations and processes which create nonlinear flow paths that can direct water beyond the fan's surface.

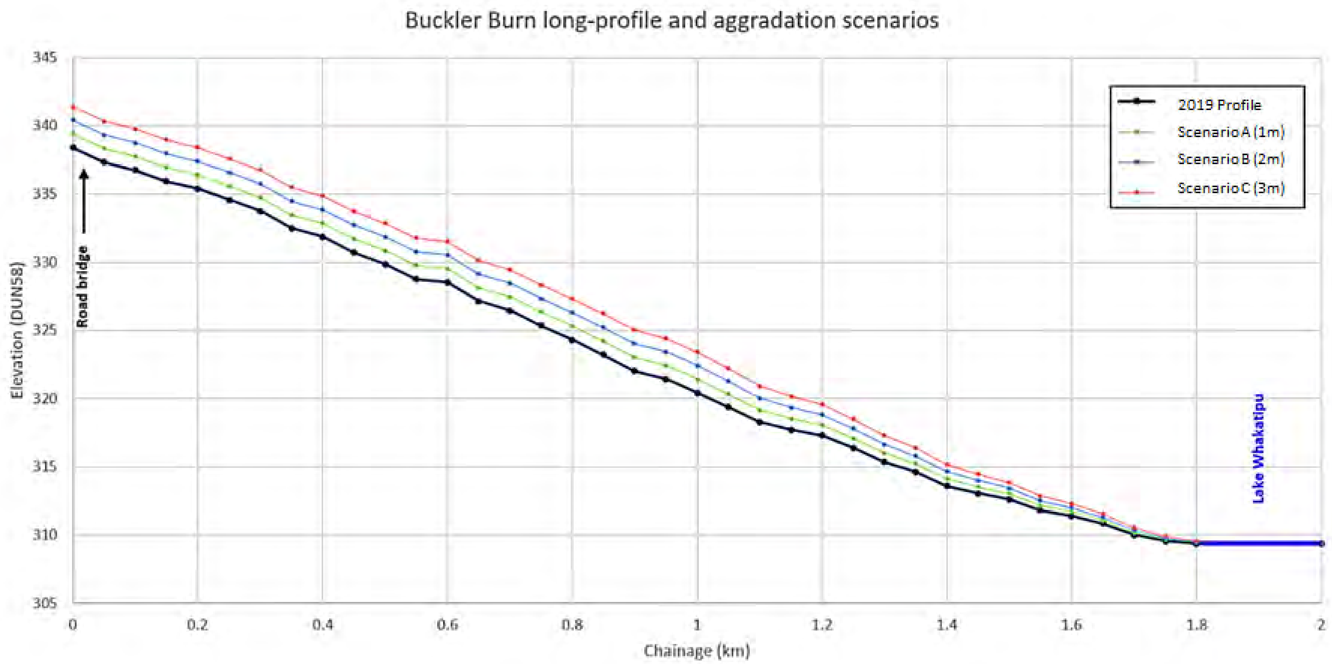

Figure 4-7 – Buckler Burn long profile and aggradation scenarios developed for use in the flood hazard modelling.

Fan Surface Adjustment

In order to model the three scenarios, we generated three DEMs with the fan surface aggraded from the 2019 DEM and based on the aggradation profiles (Figure 4-7).

We have applied these aggradation profiles to the DEM using the following steps:

1. Extract cross sections across the fan at 50m intervals down the centreline.
2. Adjust the cross sections manually to incorporate the desired level of aggradation applying judgement as to how the fan would naturally taper off at the sides (Figure 4-8).
3. Interpolate an adjustment DEM based on the cross sections from step 2.
4. Adjust the DEM using the output from step 3.
5. Interpolate the edges of the fan surface where necessary to ensure it ties in neatly with the surrounding terrain.

An example of an adjusted cross section is shown in Figure 4-8.

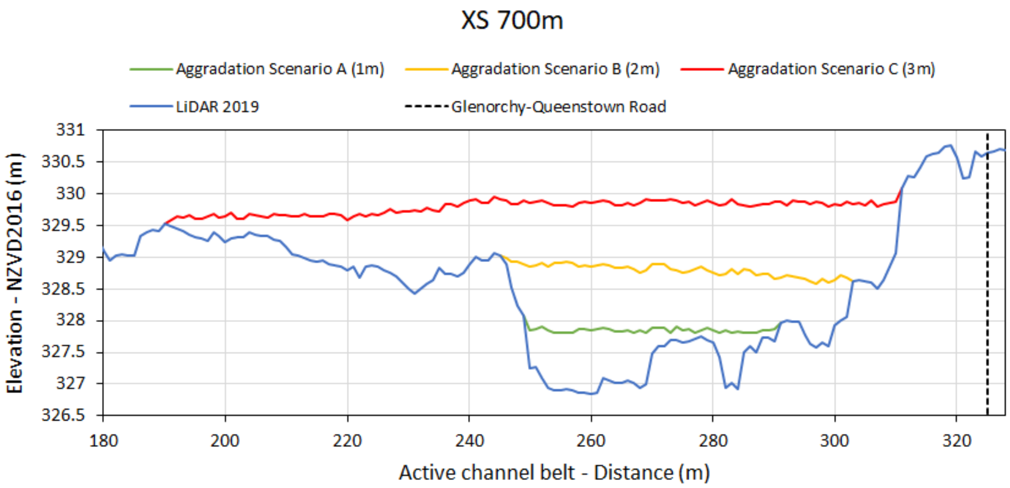

Figure 4-8 – Example of how the bed level of the active channel belt has been adjusted to account for the three aggradation scenarios. Note that the model extent itself extends beyond the active channel belt.

5. MODEL VALIDATION

In order to optimise the model run times, the model has been clipped to cover only the Buckler Burn Fan and Glenorchy township for the remainder of the simulations.

To validate the model behaviour for the Buckler Burn catchment we have compared the results of the simulations with aerial photography and ORC file notes from the 1999 flood event.

The November 1999 flood event is the biggest event on record for Lake Wakatipu, and also has photographic evidence available of the resulting flooding of the Buckler Burn. As there is no flow data available for the Buckler Burn and too little documentation of its past flood events to know what the largest event was or to provide comparison between events, the 1999 event has been used for its known status as a large event.

5.1. NOVEMBER 1999 FLOOD

The 1999 flood occurred in response to a significant weather event that affected the southern part of the South Island. During the event, the Buckler Burn overtopped the Glenorchy-Queenstown Rd on the true right and cut off Glenorchy and Kinloch from Queenstown.

Though there wasn't (and isn't) a flow/water level site on the Buckler Burn, the nearby Dart Rv at Hillocks flow site recorded a double peak; with the first peak in the early hours of the 16th of November, and a second prolonged peak at the end of the 16th and into the early hours of the 17th (Figure 5-1). This double peak is also evident in the rainfall data at the Dart Rv at Hillocks site (Figure 5-1).

We also draw on newspaper articles to describe what was happening during the November 1999 event, though we note that these aren't fact, rather as close as we can get to documentation of what occurred.

An article from the Otago Daily Times on the 18th of November, states that "*slips and debris closed the* [Glenorchy-Queenstown] *road yesterday early morning*".

- Whilst this could be referring to other sections of the road, we have assumed that it was in fact referring to the Buckler Burn and the adjacent Glenorchy-Queenstown Rd, given the debris deposited by the burn onto the road during the event.
- Therefore, ignoring the difference in catchment size, and assuming that the response of the Buckler Burn to the weather event was similar to that of the Dart River, then the article indicates that the Glenorchy-Queenstown Rd was likely overtopped early in the morning on the 17th of November, after a potential second peak from the Buckler Burn.

Additionally, an article from the Oamaru Mail on the 17th of November states that "*excavation was being done on the Buckler Burn at Campbelltown as it was threatening to break its banks*."

- The reach adjacent to Campbelltown (0.2 to 0.6km chainage) is narrow, and if the burn was in flood, then it is likely that the floodwaters would have occupied the entire active channel belt in this reach.
- Therefore the term 'threatening to break its banks" would be referring to the floodwaters spilling out onto the wider expanse of Buckler Burn fan surface.

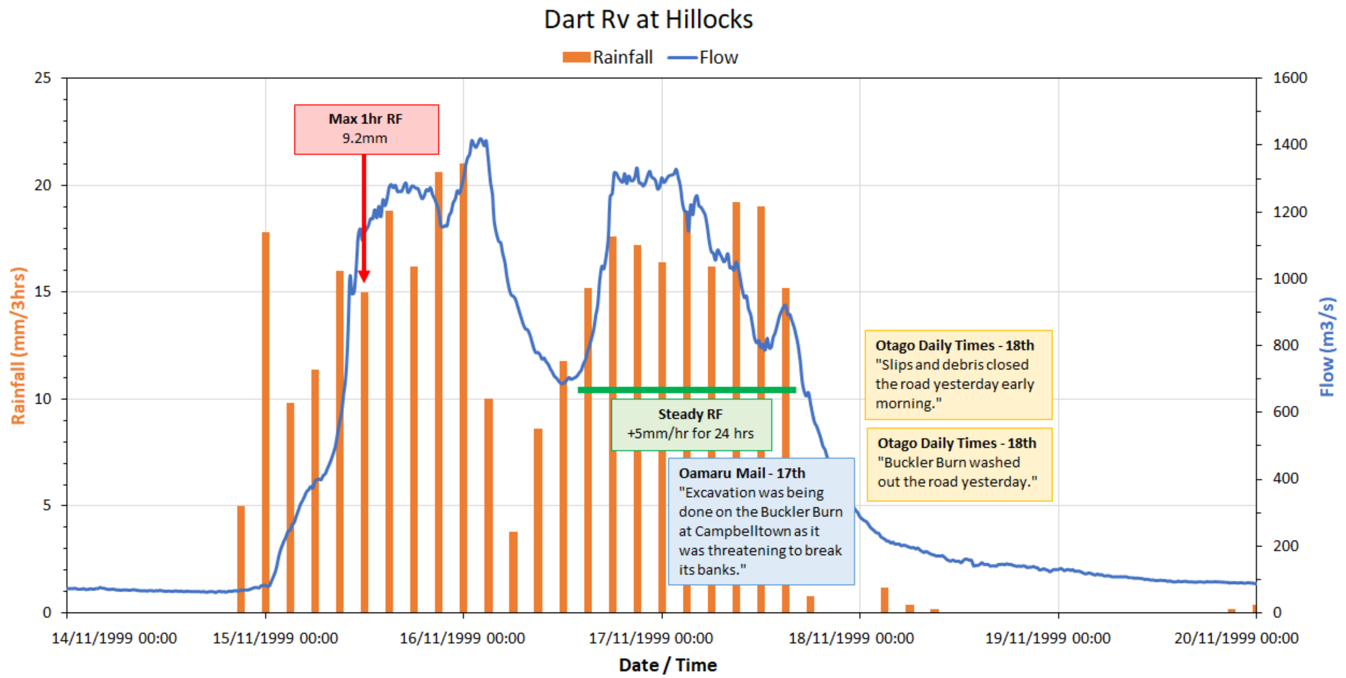

Figure 5-1 - Rainfall and flow data and stats from the nearby Dart Rv at Hillocks monitoring site and newspaper articles from the November 1999 event.

Land River Sea
CONSULTING

5.2. VALIDATION SUMMARY

Previous modelling by URS (Whyte & Ohlbock, 2007) was unable to replicate the November 1999 flood event as none of the scenarios modelled overtopped the Glenorchy-Queenstown Rd.

The current modelling by Land River Sea Consulting Ltd, was also initially unable to show overtopping of the Glenorchy-Queenstown Rd. We had to considerably increase the design flows from those estimated by both URS and NIWA, to produce flooding across the road. However, this flooding is not from the burn in the reach immediately adjacent to the road (0.7 to 0.85km chainages), but from spillover onto the inactive fan surface upstream between the 0.25 and 0.5km chainages adjacent to Campbelltown and then down the Glenorchy-Queenstown Rd. This is where the burn was "*threatening to break its banks*" in the November 1999 event according to the Oamaru Mail article, which suggests that the "success" of the excavation works may have forced more water and sediment downstream, resulting in the overtopping of the burn in the reach adjacent to the road.

Regardless, the design flows do not produce inundation of the road as a result of overtopping from the reach immediately adjacent to it. Therefore, knowing the inherent difficulty in modelling dynamic systems like alluvial fans where sediment movement, dominates during and outside of events, we hypothesise that the difficulties found with reproducing the 1999 event could be in part due to the combined effect of the excavation works as well as:

- The inability to model the complexities of the fan response to a large pulse of sediment which is likely to have occurred during the 1999 event (as also hypothesised by ORC); and
- A difference in the morphological characteristics of the fan between 1999 and recent years which made the fan susceptible to rapid channel infilling and subsequent overtopping, during the 1999 event.

Each of these is discussed further below.

5.2.1. A LARGE PULSE OF SEDIMENT

Alluvial fans are formed and evolve as a result of primary and secondary processes:

- Primary processes are those that transport sediment into the system and are therefore vital in the formation of the fan. These are often events with a high sediment concentration such as debris loaded flood flows and mass movements (Vincent et al., 2022).
- Secondary processes are those that occur during smaller events such as low sediment concentration flood events, or at low flows, and remobilise and rework sediment that has been previously deposited on the fan (Vincent et al., 2022).

Primary processes are likely to involve aggradation of the fan surface, infilling of the main channel, and bifurcation of flow, whilst secondary processes lend towards increased flow channelization and channel incision (Vincent et al., 2022).

The Buckler Burn upper basin is comprised of steep, mountainous terrain dominated by sub-alpine weathering processes (scree generation), as well as instability as rockfall deposits, and some deeper-seated mass movements, which provide a ready supply of sediment to the alluvial fan below (Fuller &

McColl, 2021; NIWA, 2018b). The catchment is therefore likely to be capable of producing flood flows with high sediment concentrations, resulting in primary processes dominating during such events.

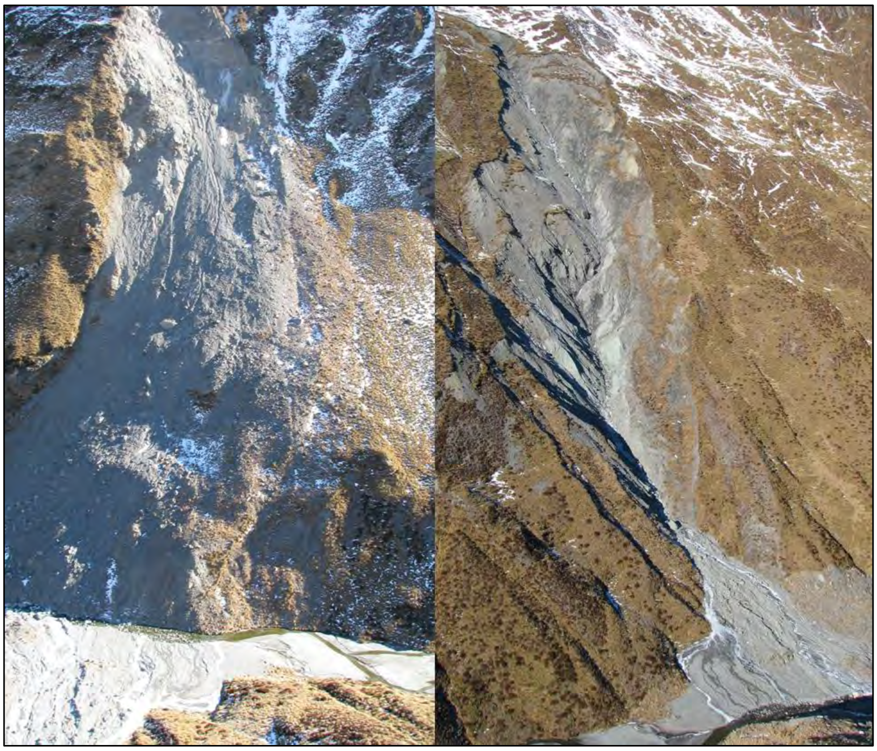

Figure 5-2 – ORC photos showing a large landslide in the upper Buckler Burn catchment on the TR of the channel (left image) and the TL of the channel (right image).

The 1999 event has been reported in the NIWA Historical Weather Events Catalogue as a significant weather event, with widespread slips and flooding across Otago.

- Analysis of the Dart Rv peak flow (~1450m^3/s) for the event suggests an ARI in the range of 5 – 10 years (Mohssen, 2021).
- The Dart at Hillocks rainfall gauge, which is the nearest to the Buckler Burn catchment recorded a 5 day total of 343.2mm, whilst the Rees Valley Station recorded a 4 day total of 275mm which at the time had a return period of a 100 years (NIWA, 2018b). Though these totals relate to different (nearby) catchments they suggest that rainfall in the Buckler Burn was likely prolonged and over several days, which would have resulted in saturated soils and therefore increased likelihood of slope failure and mass movement.

- The maximum hourly rainfall intensity recorded by the Hillocks site during the event was ~9.2mm/hr on the 15th of November (beginning at 12:30pm), though this is not significant in terms of HIRDs statistics for the area, it does indicate heavy rainfall.
- Rainfall eased during the first half of the 16th of November, before falling steadily (+5mm/hr) for a 24 hour period from midday onwards on the 16th, again indicating prolonged rainfall with subsequent effect on soil saturation.
- Photographs from after the 1999 event show a much aggraded upper fan surface, with debris strewn across the Glenorchy-Queenstown Rd (Figure 3-5), whilst aerial imagery shows a far greater area of active fan surface (exposed gravels) compared to the 1994 event (Figure 3-4).

It is highly likely that given the nature of the upper catchment, the probable double peaked nature of the event, and the intensity and duration of the rainfall that a large sediment pulse entered the system during the second part of the event and was distributed across the upper reach of the Buckler Burn fan.

However, the HEC-RAS model does not simulate sediment erosion, transport, and deposition nor channelbifurcation and lateral migration. Therefore, this sediment pulse has been modelled by beginning the run with an already aggraded fan surface (aggradation scenarios A, B, and C), and so is unable to capture theprimary processes of bifurcation, channel infilling, and lateral migration that would have occurred during the 1999 event and contributed to the overtopping of the Glenorchy-Queenstown Rd. However, it does still allow for an understanding of the inundation hazard from the Buckler Burn should the bed aggradein the future.

5.2.2. A DIFFERENCE IN THE MORPHOLOGICAL CHARACTERISTICS OF THE FAN SURFACE

The size, shape and slope of a fan have long been documented to be reflective of the inputs of water and sediment, determined by the upper drainage basin relief, size, and geology, as well as the accommodation space (Harvey et al., 2005; Kochel, 1990; Schumm et al., 1987). However, more recently, experimental fan studies have focussed on how changes in sediment supply can affect alluvial fan morphology, and the resulting effect on flood risk.

The studies have found that sudden increases or decreases in supply, or changes in the frequency between primary and secondary processes result in considerable morphological variation in experimental fans and over decadal, annual, and even monthly timescales of fans in the field, with:

- An increase in supply, or more frequent high supply events resulting in the primary fan-building processes dominating, and therefore less time for the fan to undergo remobilization and reworking under the secondary processes. Thus, experiments found these scenarios produced shorter, steeper, and more “stacked” fans, with numerous braided channels, negligible incision, and mainstem aggradation(Leenman & Eaton, 2022; Leenman & Tunnicliffe, 2020; Vincent et al., 2022).
  The negligible incision was shown to play a key role in flood risk, as it reduces the channel capacity and therefore it takes a smaller amount of flow to overtop the channel and inundate the surrounding fan and land, or trigger an avulsion.

- A decrease in supply, or less frequent high supply events allows for the secondary processes to dominate. In these scenarios, the experimental fans were able to redistribute sediment from the upper to the lower fan, form a fan-head trench (channel incision), centralize flow paths, and develop a telescoping lower fan (Leenman & Eaton, 2022; Vincent et al., 2022).
  Thus, in these scenarios, flood risk is reduced, because as the channel capacity increases it is better able to contain aggradational events (Wasklewicz & Scheinert, 2016) so it will take larger flows to overtop the channel and more time for the channel to infill and trigger an avulsion (Vincent et al., 2022).

The Buckler Burn is nestled in a part of the country where frequency and intensity of weather events appear to be affected by the positive and negative phases of the Interdecadal Pacific Oscillation (IPO) cycles (McKerchar & Henderson, 2003).

The IPO is the long-term oscillation of sea surface temperatures in the Pacific Ocean which affects the strength and frequency of El Niño and La Niña cycles. When in a positive IPO phase, New Zealand receives stronger west to southwest winds which means the southern and western parts of the South Island are wetter than average. So, they experience more extreme rainfall and therefore more frequent flooding than average (Wratt et al., 2022). As a result of the increasing rainfall, sediment supply volume and frequency to river and fan systems increases through mobilization of sediment and an increase in the frequency of mass movement events such as shallow landslides (Jakob & Owens, 2021).

Rainfall data from the longest rainfall record in the area – the Earnslaw gauge in the Rees River catchment – as well as observations, coincide with changes in the IPO (Figure 5-3).

- As the average annual rainfall at Earnslaw increased by more than 500mm between 1950 and 2000 (Otago Regional Council, 2010), the IPO shifted from a negative phase (1950’s to the late 1970s) to a positive phase (late 1970s to 21st century).
- Then, since the turn of the century, the Earnslaw site has recorded a decline in average annual rainfall (Otago Regional Council, 2010), corresponding to a return to a negative IPO phase.
- Additionally, between 1950 and 2000 a significant increasing trend in total precipitation, rain days, consecutive wet days, and number of very wet days in the vicinity of Glenorchy have been identified (Otago Regional Council, 2010).

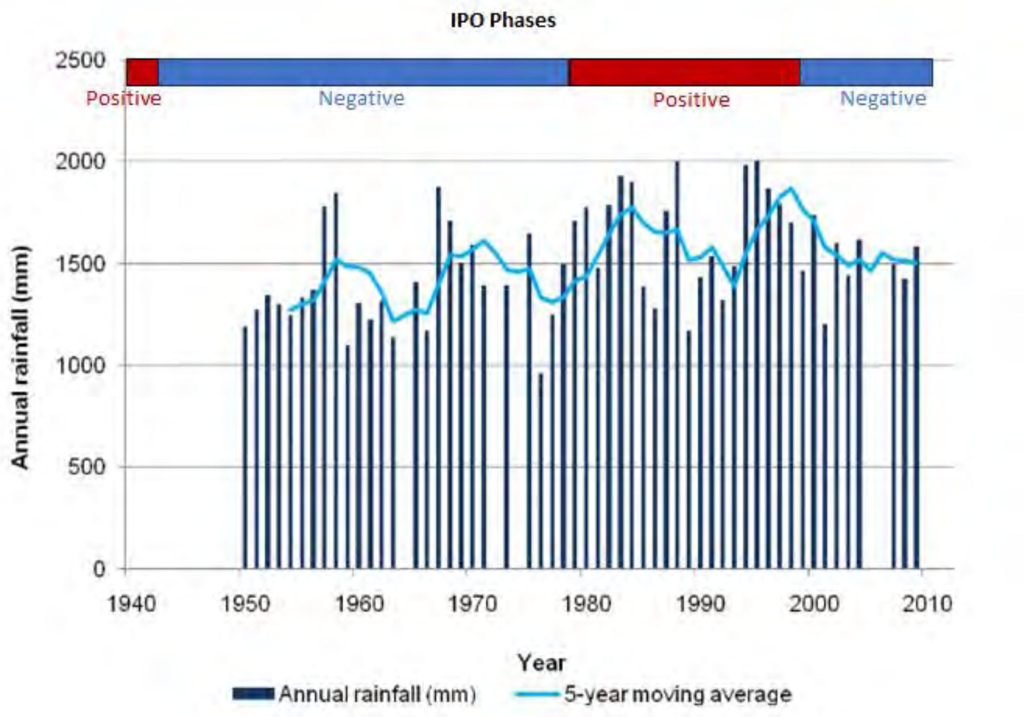

Figure 5-3 – Annual rainfall totals for the Rees at Earnslaw gauge, 1950 to 2009 with the positive and negative IPO phases above. The rainfall data is missing: 1964, 1972, 1974, 2005, and 2006.

The November 1999 event occurred at the end of a ~20 year positive IPO phase, when the average annual rainfall at the Earnslaw gauge was at its highest.

- It is hypothesised that between the late 1970's and 1990's, sediment supply increased with the increased frequency and intensity of weather events, resulting in aggradation at the Buckler Burn fan head, steepening of the fan slope, channel infilling, and a widening of the active channel belt and therefore increase in the active fan surface area.
- Aerial imagery from 2001 (just after the end of a positive IPO) indicates a larger area of exposed gravels compared to the 1966 imagery (negative IPO) (Figure 5-4).
- Satellite imagery in the early 2000's, though of poor quality, also indicates a larger area of exposed gravels compared to imagery from the last few years.

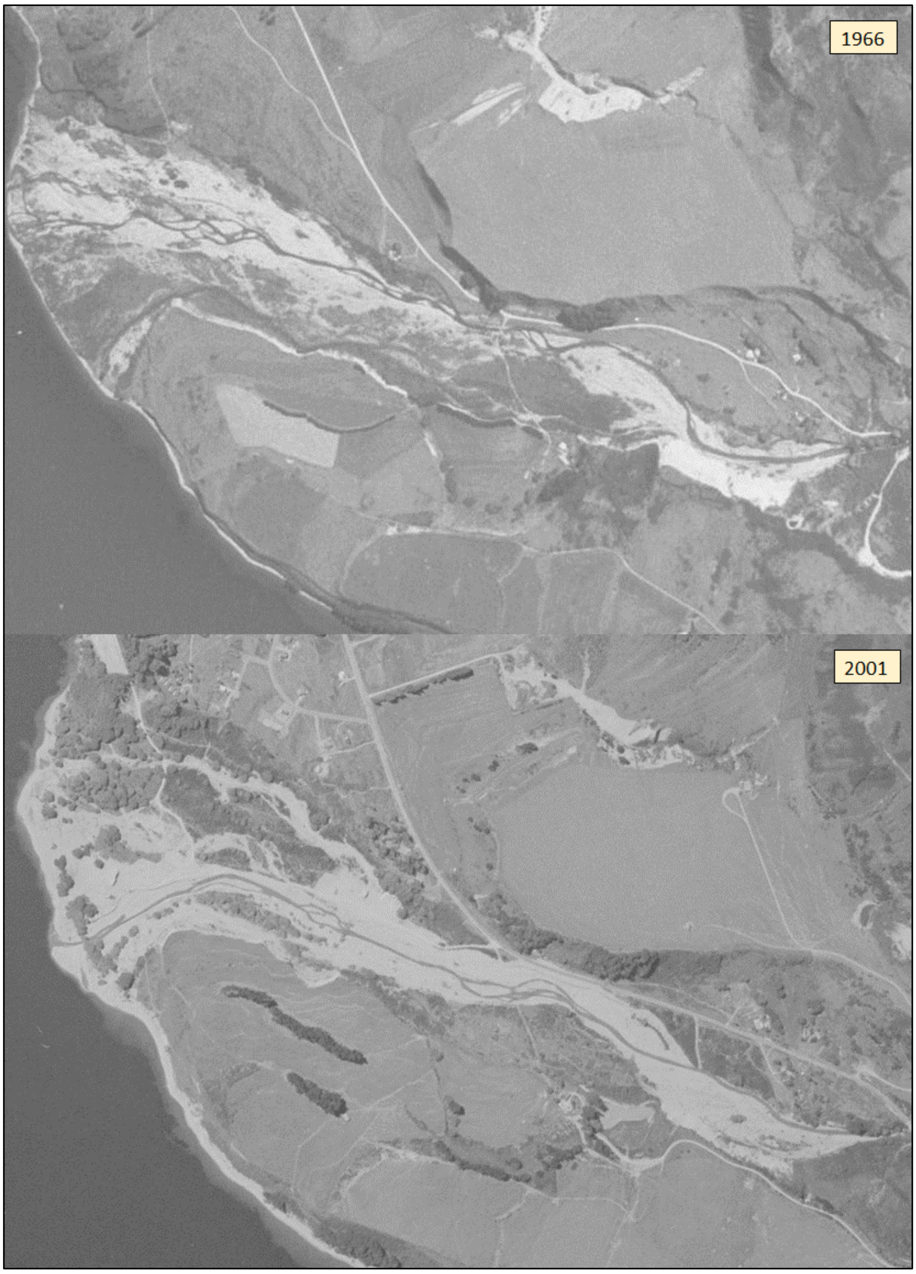

Figure 5-4 - aerial imagery from 1966 and 2001 downloaded from Retrolens.

The IPO has been in a negative phase since the 1999 flood up until 2016.

- With fewer and less intense weather events, sediment supply likely decreased, and secondary processes dominated, reworking the existing sediment through the system.
- As the experiments by Vincent et al (2022) indicate, this could have resulted in a gentler fan slope, progradation of the fan toe, as well as increasing channelization and entrenchment of the main flow.
- The aerial imagery also shows a prograded toe out into Lake Wakatipu in the 1966, 2008 and 2019 imagery (negative phase), compared to the 1937 imagery (positive phase) (Figure 3-3).
- And as noted above, the aerial imagery confirms a narrower active channel belt and decreased active fan area with increasing vegetation growth over this time. The 1966 and 2001 aerial imagery provide an excellent comparison between positive and negative IPO fan surfaces, whilst more recent imagery from 2019 (in the early years of a positive IPO phase) show a narrow and well vegetated active fan surface (Figure 5-5).

Figure 5-5 - 2019 aerial imagery of the Buckler Burn.

Therefore, it seems likely that when the 1999 event occurred, as a result of the increase in sediment supply and frequency from the preceding 20 years of positive IPO, the aggraded and steepened upper Buckler Burn fan surface was closer in elevation to the Glenorchy-Queenstown Rd, and with negligible incision in the main channel, a sediment laden flow or sudden pulse of sediment (as hypothesised) could have rapidly infilled the channel, resulting in the road overtopping. It is possible, that this was assisted by the excavation works forcing more flow and sediment downstream from the fan surface adjacent to Campbelltown.

In terms of the modelling, what this means is that the fan surface during the 1999 event was likely very different to the 2007 and 2023 modelled fan surfaces.

The 2007 model used cross sectional data from 2006, whilst the current HEC-RAS model has used the 2019 LiDAR data.

- Though within seven years of the 1999 event, and so not long into the negative IPO cycle, the 2006 cross sections are sparse, and do not cover the area immediately alongside the road where it overtopped in 1999, but rather above and below the reach of interest, with cross sections at chainage points 0.45km and 1.05km (Figure 5-6). It is therefore unlikely that the generated DEM could have accurately captured the fan surface, the degree of channel incision, and slope at that time.

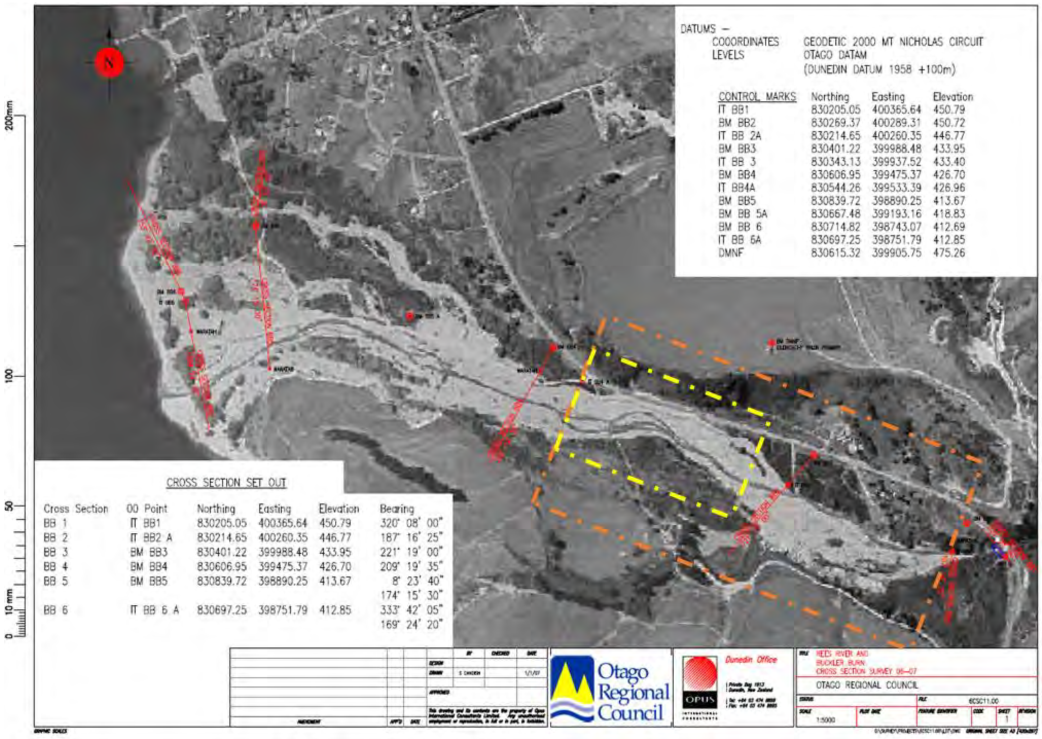

Figure 5-6 – Locations of the 2006 cross sections (red lines) used in the 2007 modelling. The upper reach of the Buckler Burn alluvial fan has been indicated by the dashed orange lines, and the area of interest (where the road overtopped in the 1999 event) by the yellow dashed lines.

- The 2019 and 2022 LiDAR has been taken only a couple of years into the current positive IPO phase. A Geomorphic Change Detection (GCD) analysis shows that the latest 2022 LiDAR has aggraded in the order of 0.1m to 0.4m compared to the 2019 LiDAR in the reach alongside the road (Figure 5-7), as well as eroded the banks of both sides of the main channel at the head of the fan indicating early channel expansion. Thus showing how fan morphology varies over time. However, given it is in the early years of the positive phase, the 2019 and 2022 fan surfaces are unlikely to have reached a similar state to that of 1999 which was at the end of ~20 years of positive IPO.

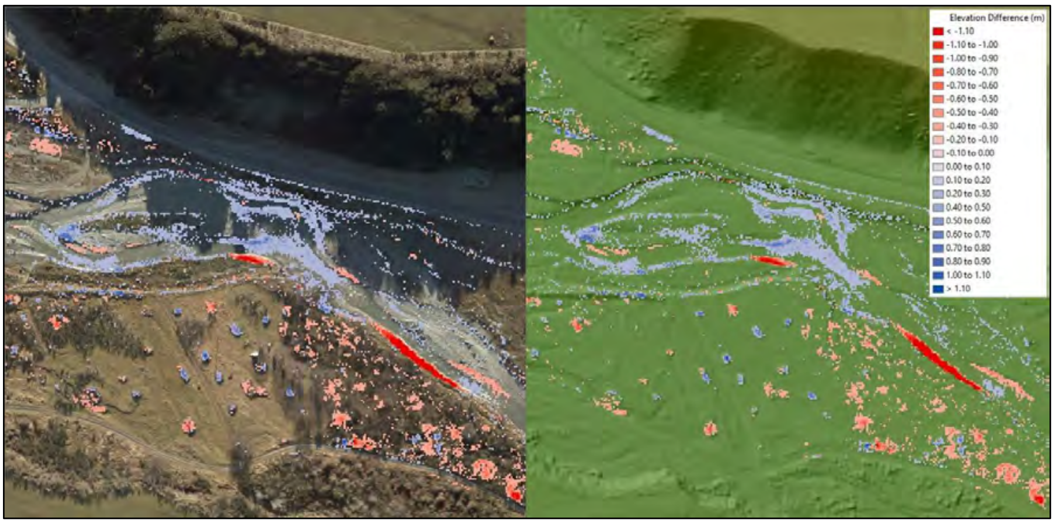

Figure 5-7 – GCD result between the 2019 and 2022 LiDAR, shown on the aerial imagery and hillshade layer.

Thus, the DEMs used in the 2007 and 2023 models would have had:

- a gentler fan slope,
- more incised channels with increased flow capacity,
- and an upper fan surface much lower in elevation compared to the Glenorchy-Queenstown Rd, which therefore prevents overtopping during the model runs, unless the runs begin with aggradation added to the DEM.

6. MODEL RESULTS

Two categories of scenarios have been simulated:

- **Design scenarios** (Table 6-1 and Table 6-2)
  A range of six flows from 100m³/s to 300m³/s were simulated. Each flow was run twice, once with the 2019 LiDAR, and a second time with the 2022 LiDAR. This was because we received the 2022 LiDAR part way through the project, and wanted to utilize the latest data to see if that affected the results. Fan morphology is very dynamic, and we hypothesised that the three years between the two LiDAR surveys would be enough to produce morphological change, and therefore a difference in the resulting inundation.
- **Aggradation scenarios** (Table 6-3)
  In order to test the sensitivity of the Buckler Burn and flood hazard to channel bed aggradation, the six design flows were simulated with each of the three aggradation scenarios. In these scenarios, the channel belt of the Buckler Burn in the 2019 LiDAR was aggraded by 1m, 2m and 3m, creating the three new DEMs used in the simulations.

Table 6-1 The 2019 LiDAR design scenario with each of the six design flows.

Run name	Flow (m³/s)	LiDAR
Design Scenario 2019 – 100 m³/s	100	2019
Design Scenario 2019 – 150m³/s	150	2019
Design Scenario 2019 – 180m³/s	180	2019
Design Scenario 2019 – 200m³/s	200	2019
Design Scenario 2019 – 250m³/s	250	2019
Design Scenario 2019 – 300m³/s	300	2019

Table 6-2- The 2022 LiDAR design scenario with each of the six design flows.

Run name	Flow (m³/s)	LiDAR
Design Scenario 2022 – 100 m³/s	100	2022
Design Scenario 2022 – 150m³/s	150	2022
Design Scenario 2022 – 180m³/s	180	2022
Design Scenario 2022 – 200m³/s	200	2022
Design Scenario 2022 – 250m³/s	250	2022
Design Scenario 2022 – 300m³/s	300	2022

Table 6-3 – Eighteen runs in total, as each of the six design flows was run with each of the three aggradation scenarios.

Run name	Flow (m^3/s)	Aggradation
Aggradation Scenario A – 100m³/s	100	A (1m)
Aggradation Scenario A – 150m³/s	150	A (1m)
Aggradation Scenario A – 180m³/s	180	A (1m)
Aggradation Scenario A – 200m³/s	200	A (1m)
Aggradation Scenario A – 250m³/s	250	A (1m)
Aggradation Scenario A – 300m³/s	300	A (1m)
Aggradation Scenario B – 100m³/s	100	B (2m)
Aggradation Scenario B – 150m³/s	150	B (2m)
Aggradation Scenario B – 180m³/s	180	B (2m)
Aggradation Scenario B – 200m³/s	200	B (2m)
Aggradation Scenario B – 250m³/s	250	B (2m)
Aggradation Scenario B – 300m³/s	300	B (2m)
Aggradation Scenario C – 100m³/s	100	C (3m)
Aggradation Scenario C – 150m³/s	150	C (3m)
Aggradation Scenario C – 180m³/s	180	C (3m)
Aggradation Scenario C – 200m³/s	200	C (3m)
Aggradation Scenario C – 250m³/s	250	C (3m)
Aggradation Scenario C – 300m³/s	300	C (3m)

The design scenario peak depth and velocity, and hazard maps have been presented in appendices A, B and C, whilst the aggradation scenario peak depth and velocity, and hazard maps have been presented in appendices D, E and F.

There are a large number of potential hazard categorisations to use. However, ORC have requested that we use the Australian Rainfall and Runoff guidelines, as we have already used these for the maps created for the Dart-Rees model results, and the council would like to maintain consistency between maps.

The hazard categorisations in the Australian Rainfall and Runoff Guidelines are based on a combination of speed and velocity (Cox, 2016). These have been summarised in Table 6-4 and presented graphically in Figure 6-1. More detailed information on the derivation of the Hazard Categories can be found in the Australian Rainfall and Runoff guidelines which can be accessed online at http://arr.ga.gov.au/arr-guideline (NB. hazard categories are discussed in Chapter 7 of Book 6 – Hydraulics).

We note there is a range of more specific hazard categorisations available which are more specific for evacuation planning etc, however the categories adopted for these maps are the most general and suitable for a wide range of purposes.

Table 6-4 - Description of Hazard Categories

Hazard Vulnerability Classification	*Description*
H1	Generally safe for vehicles, people and buildings.
H2	Unsafe for small vehicles.
H3	Unsafe for vehicles, children and the elderly.
H4	Unsafe for vehicles and people.
H5	Unsafe for vehicles and people. All buildings vulnerable to structural damage. Some less robust buildings subject to failure.
H6	Unsafe for vehicles and people. All building types considered vulnerable to failure.

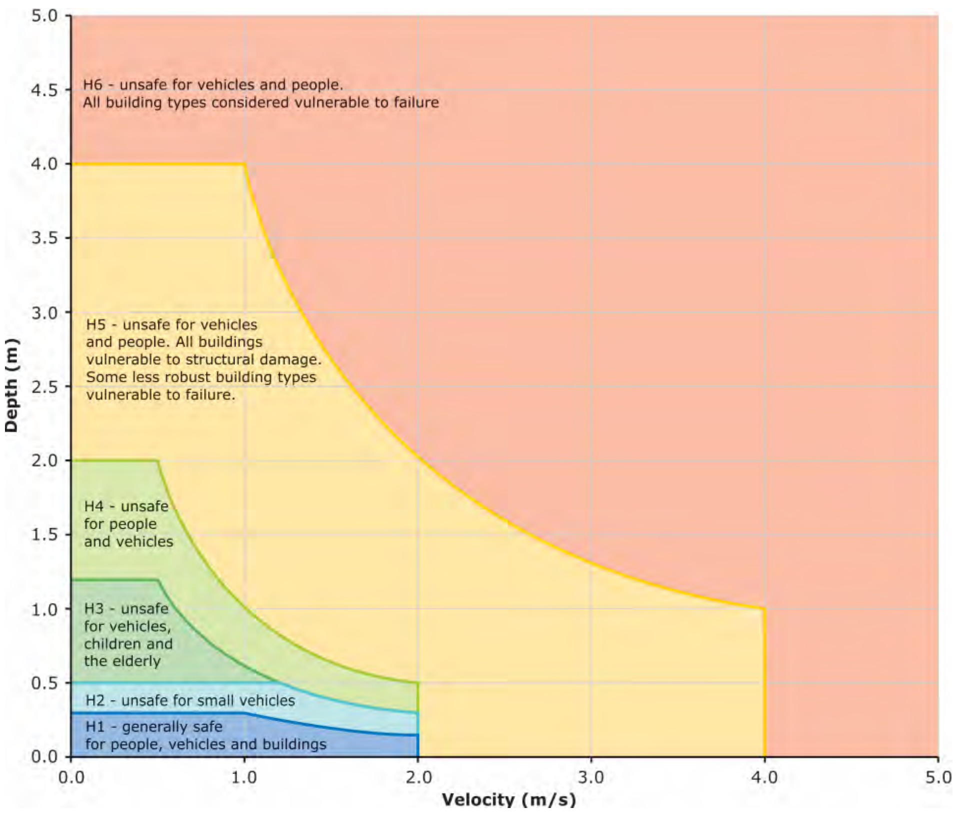

Figure 6-1 - Graphical representation of the Hazard Categories

6.1. RESULTS ANALYSIS – DESIGN RUNS

6.1.1. DESIGN SCENARIO 2019

In none of the 2019 LiDAR design runs does inundation of the Glenorchy-Queenstown Rd alongside chainage 0.7 to 0.85km occur as a result of overtopping from the burn at that location. Instead, in scenarios with peak flows equal to and greater than 150m³/s, floodwaters spilling out over the inactive fan surface between the 0.25 and 0.5km chainages on the true right result in floodwaters running alongside, over, and down the road into the Glenorchy township (Figure 6-2).

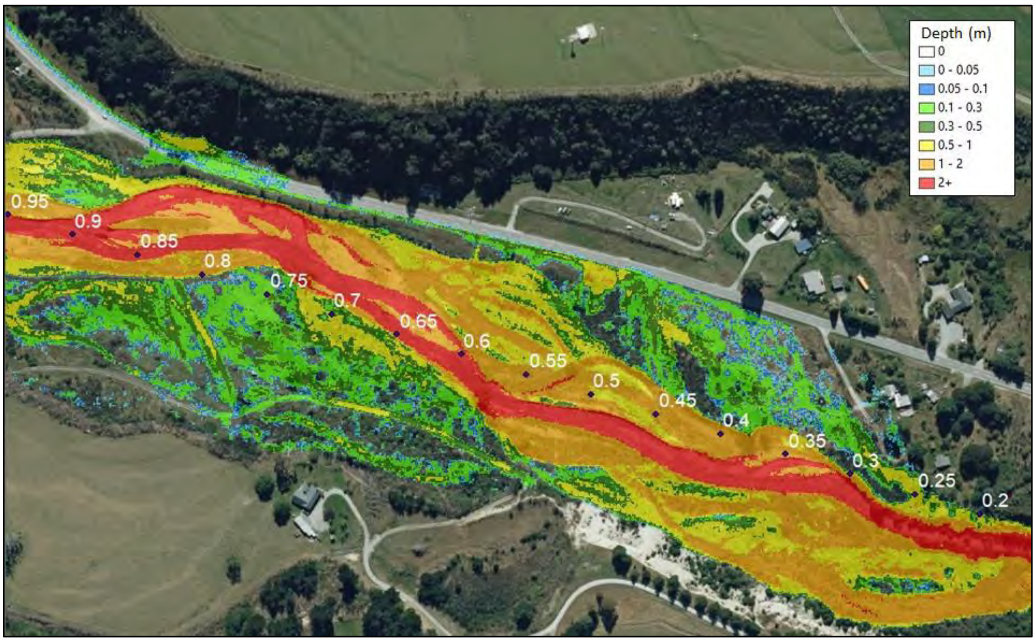

Figure 6-2 – 300m³/s design (2019) run showing the spillover at 0.25km chainage, and the additional breakouts at 0.35 and 0.45 that occur at the higher end design flows.

From the 180m³/s scenario onwards, the flow path from the spillover on the true right of the upper fan results in floodwaters pooling behind the Glenorchy stopbank (that protects the town from the Dart-Rees system) and to the south of the eastern end of Mull St (Figure 6-3), as well as inundation of the Oban St and Shiel St (street names are shown in Figure 1-1).

Figure 6-3 – Floodwaters from the Buckler Burn pooling behind the Glenorchy stopbank and eastern end of Mull St in the 250m^3/s design (2019) run.

Downstream, the vegetated northern end of the lower fan reach is activated in all the 2019 design runs, with inundation extent and depth increasing with each step up in peak flow. This inundation also contributes to pooling of floodwaters behind the Glenorchy stopbank (Figure 6-3) and leads to localised inundation in the western end of Lochburn Ave, with depths up to 1m in a low lying point relative to the surrounding land.

Aside from the upper fan spillovers and northern lower fan surface inundation, the burn remains largely confined to its active fan surface. It does not flow into the larger channel on the true right around chainage point 1.1km, despite this channel being activated in both the 1994 and 1999 floods, as shown by aerial imagery after the events (Figure 3-4). However, this does not mean that it could not access this area under future channel configurations and fan morphology.

Additionally, any inundation within the town (i.e. roads and the buildings on either side) is for the most part classed as hazard category 1 with a few localised spots as high as 6 on some roads. Inundation of the Glenorchy-Queenstown Rd and the southern end of Oban St also results in hazard categories as high as 6 (Figure 6-4). On the active fan surface, the hazard category is either 5 or 6 as result of the steep gradient, and fast flowing deep water.

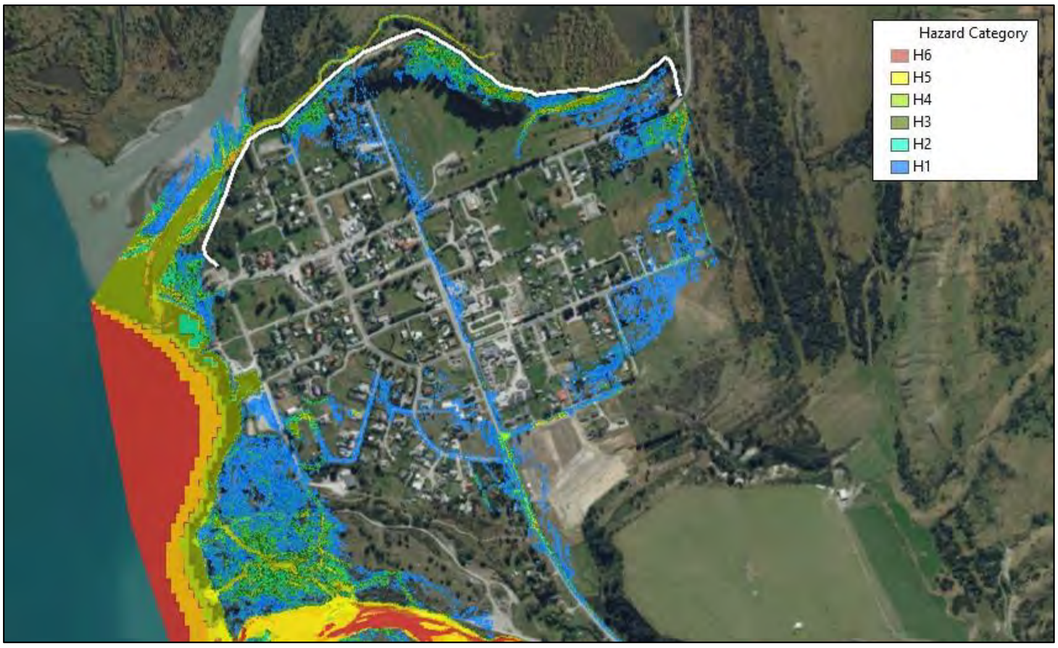

Figure 6-4 – Hazard map for the 300m³/s 2019 design run.

6.1.2. DESIGN SCENARIO 2022

In a similar respect to the 2019 LiDAR design runs, the 2022 LiDAR design runs do not produce inundation of the Glenorchy-Queenstown Rd as a result of overtopping from the burn from chainage 0.7 to 0.85km. Like the 2019 LiDAR, it is the spillover between the 0.25 and 0.5km chainages that produces the inundation of the road. However, the extent at which this inundation occurs in the 150m³/s 2019 LiDAR run, requires a larger flow with the 2022 LiDAR of 250m³/s, this is likely due to an increase in channel capacity in this upper reach due to erosion of the banks as shown by the 2019-2022 GCD analysis (and discussed in sections 5.2.2 and 7.1).

Another difference between the two LiDAR design run sets occurs in the lower fan reach downstream of the 1.4km chainage. The 2022 LiDAR runs results in slightly greater inundation and deeper channelised flows in this location, compared to the 2019 LiDAR runs (Figure 6-5). This becomes more noticeable with each step up in design flow. Additionally in the areas where the bed has aggraded, flow becomes shallower in the 2022 runs.

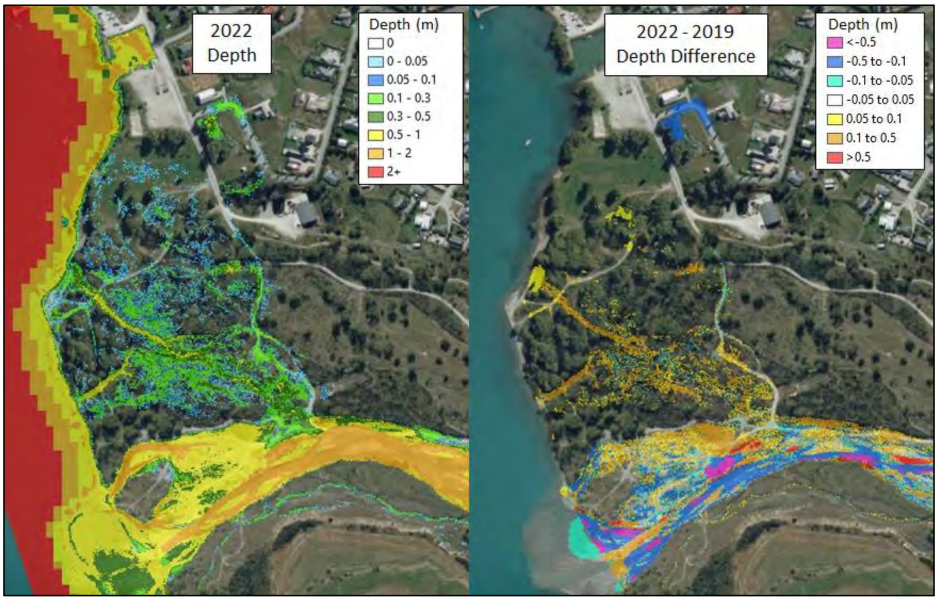

Figure 6-5 – 100m³/s 2022 design run with a depth map to the left and a depth difference map (with the 100m³/s 2019 design run) to the right.

This difference is validated by the fact that the GCD analysis between the 2019 and 2022 shows that the main channel and parts of the fan surface in this lower reach have aggraded by 0.3 to 1.2m between 2019 and 2022 (Figure 6-6). This will have reduced the channel capacity, and therefore resulted in more flow into the northern side of the fan in the 2022 design runs.

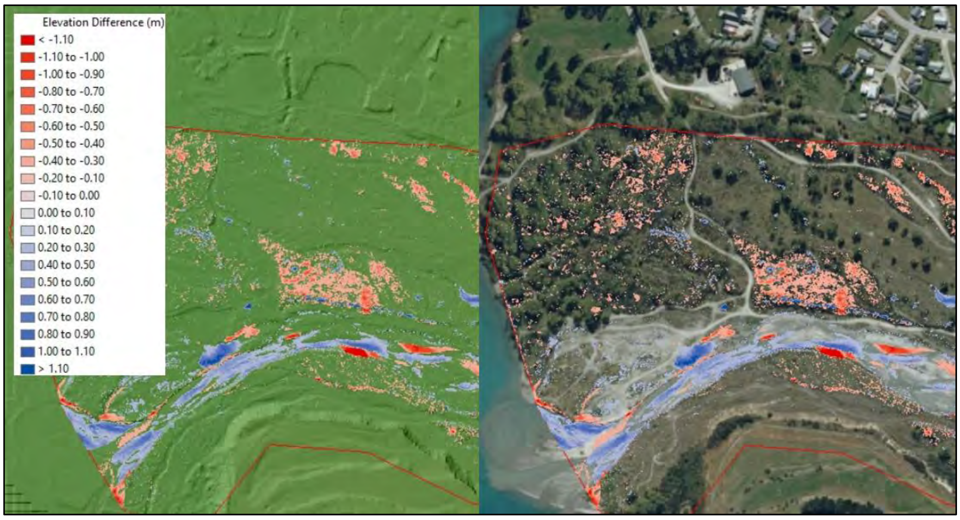

Figure 6-6 – GCD analysis between the 2022 and 2019 LiDAR data sets zoomed in on the lower reach of the Buckler Burn fan-delta system. Two different base layers - hillshade and aerial imagery have been used to better show the elevation difference.

In terms of inundation of the Glenorchy township, in this modelled scenario with the 2022 fan morphology, the western end of Lochburn Ave experiences localised inundation in all of the scenarios. However, unlike the 2019 LiDAR design runs, Glenorchy-Queenstown Rd, Oban St, and Shiel St only become inundated in the 250m^3/s and 300m^3/s scenarios, and even then, this is mostly under 0.3m deep (hazard category 1) with a few localised spots peaking around 1m in depth (hazard category is 4). Additionally, there is not enough spillover from the upper fan and along the Glenorchy-Queenstown Rd to produce pooling behind the Glenorchy stopbank nor at the eastern end of Mull St.

6.2. RESULTS ANALYSIS – AGGRADATION SCENARIOS

In the aggradation scenarios, the fan surface has been aggraded and the main channel infilled, therefore reducing the channel capacity and its ability to handle flood flows. As a result, compared to the design runs, smaller peak flows from the Buckler Burn result in greater activation of the northern side of the lower fan, as well as inundation of the Glenorchy-Queenstown Rd and Glenorchy township itself, relative to the level of aggradation (i.e., A – 1m, B – 2m, and C – 3m).

The results from each of the three aggradation scenarios with the range of peak flows, have been described below. Unless stated otherwise, any comparisons made to the design runs are to the 2019 LiDAR design set.

6.2.1. AGGRADATION SCENARIO A (1M)

100m^3/s

In this smallest of peak flow scenarios, the 1m of aggradation halves the capacity of the burn and fan to handle flood flows, and results in similar inundation of the Glenorchy-Queenstown Rd, behind the Glenorchy stopbank, and Glenorchy township to a slightly smaller extent than that of the 250m^3/s design run (Figure 6-7).

The Glenorchy-Queenstown Rd and Oban St are both inundated with depths under 0.5m, and Lochburn Ave and Shiel St are also inundated, peaking under 1m where there are low lying areas relative to the surrounding land.

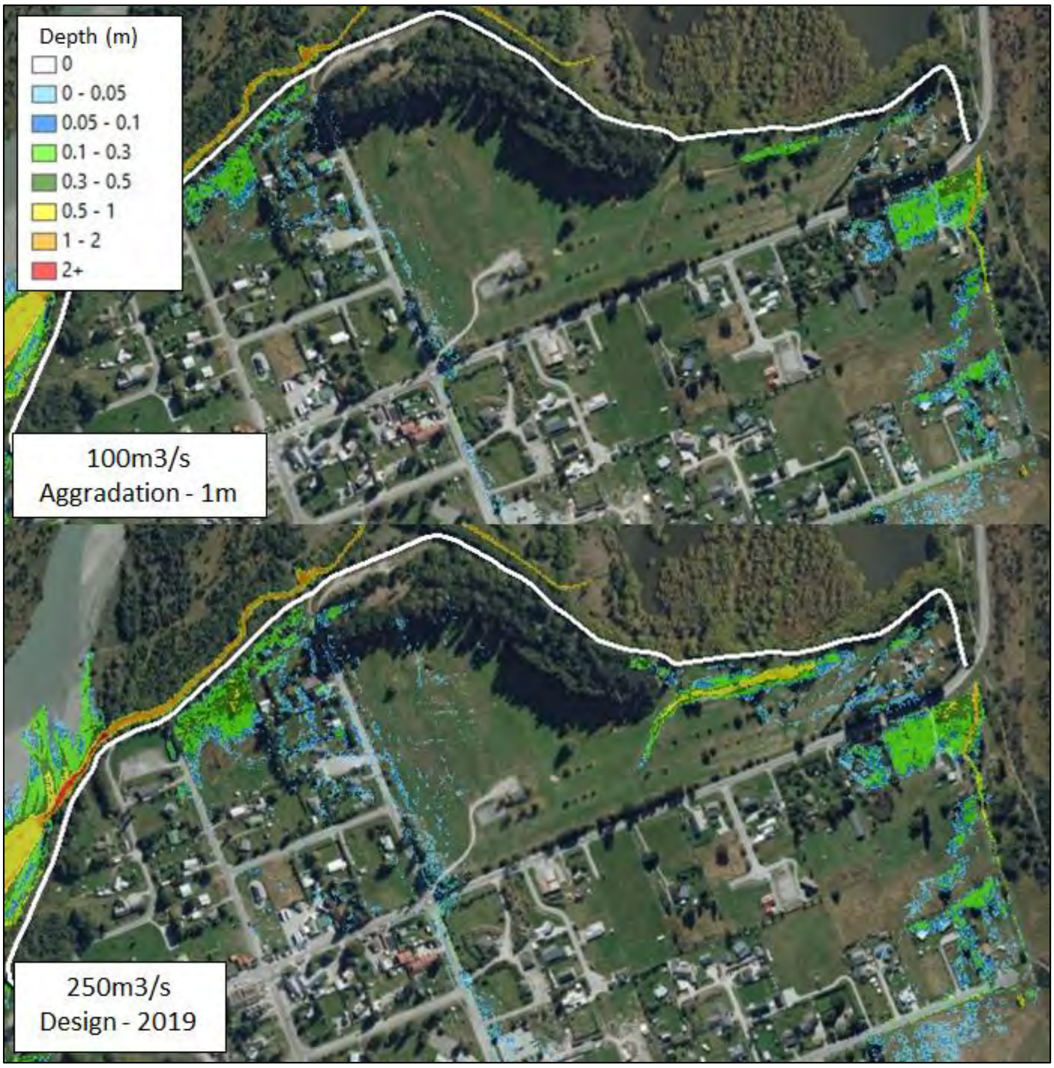

Figure 6-7 - Depth maps for the 250m3/s design 2019 run and the 100m^3/s aggradation (1m) run.

In the active fan surface, compared to the 100m^3/s design run, depths are up to 0.8m shallower in the main channel, notably between chainages 0.1 and 0.6km, and between 0.9 and 1.15km (Figure 6-8), whilst the section from chainage 0.7 to 0.9km where the road overtops, shows depths decreasing by only up to 0.5m. Outside of the main channel – across the active fan surface – flow is up to 0.5m deeper.

Additionally, several small flow paths and patchy inundation develop on the northern side of the fan in the bottom half of the lower reach (downstream of chainage 1.5km). This is similar (though slightly deeper) to the 100m³/s design run (Figure 6-8).

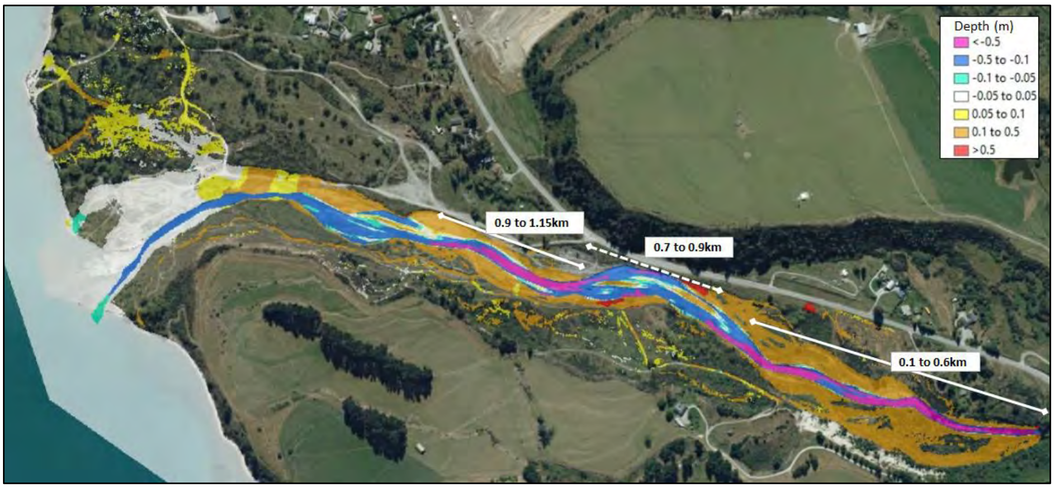

Figure 6-8 – DEM of Difference between the 100m3/s 1m aggradation scenario and the 100m3/s design (2019) run.

150m³/s to 300m³/s

The 1m aggradation scenarios with peak flows between 150m³/s and 300m³/s all result in floodwaters pooling behind the Glenorchy stopbank and at the eastern end of Mull St, with depths slowly increasing with each step up in flow (Figure 6-9). Patchy inundation is also expected along and to the sides of Lochburn Ave, Lancaster Pl, Invincible Dr, Shiel St, and Jetty St, with deeper inundation along the Glenorchy-Queenstown Rd and Oban St (Figure 6-9).

In these five scenarios, flow begins to break out earlier onto the northern side of the lower fan reach with each step up in flow, with flow path depths and inundation of the northern fan surface increasing. However, the breakouts don't quite reach the channel activated in the 1994 and 1999 flood events that begins between chainages 1 and 1.2km.

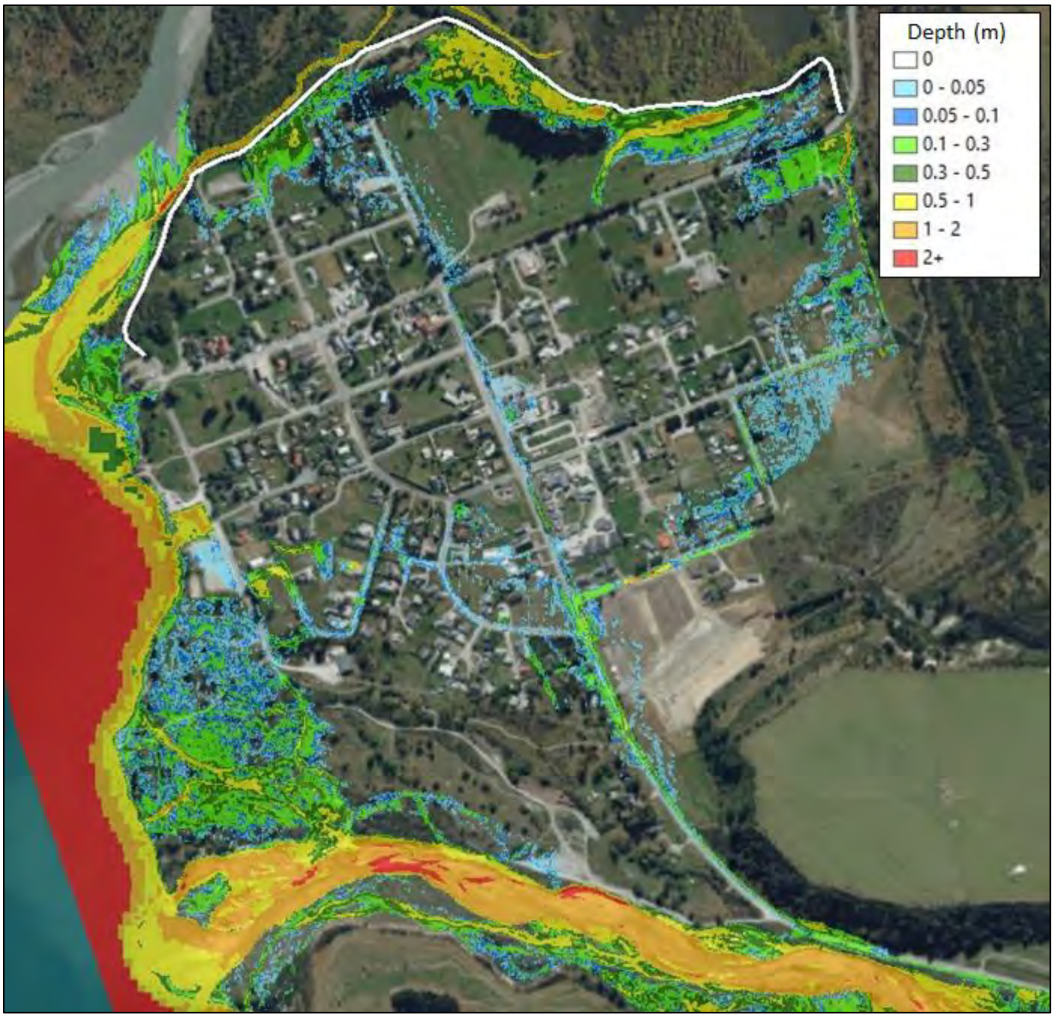

Figure 6-9 – 200m³/s aggradation (1m) inundation depths along the Glenorchy stopbank, with shallower inundation through the township.

6.2.2. AGGRADATION SCENARIO B (2M)

100m³/s

In the 100m³/s scenario, 2m of aggradation across the fan surface results in greater inundation of the Glenorchy township than the largest of the design scenarios (300m³/s), despite being a much smaller flow (Figure 6-10).

In this scenario most of the flow entering the town comes from the where the burn spills over onto the Glenorchy-Queenstown Rd between chainages 0.25 and 0.5km, and results in the water pooling behind the Glenorchy stopbank and eastern end of Mull St reaching depths as high as 2m.

Figure 6-10 – Depth difference map between the 100m³/s aggradation (2m) and 300m³/s design (2019) runs. Despite the smaller flow, the aggradation scenario produces greater inundation.

The northern side of the lower fan reach does not show significant inundation, with only a few of the small channels activated and patchy inundation through the vegetation of less than 0.3m.

150m³/s to 300m³/s

In the five flow scenarios ranging from 150m³/s to 300m³/s with 2m of aggradation, a similar depth of floodwaters accumulates behind the Glenorchy stopbank and eastern end of Mull St in all of them (Figure 6-11).

However, as flows increase, inundation depths along the Glenorchy-Queenstown Rd and Oban St also increases, peaking around 1.5m, whilst several roads within the Glenorchy township i.e., Lochburn Ave, Lancaster Pl, Invincible Dr, Shiel St, and Jetty St experience increasing inundation with depths largely below 0.3m but in places peaking as high as 1m (Figure 6-11). These results indicate that the spillover from the upper fan does not take the natural flow paths of the bajada that the township is built on, but rather is forced along the roadways, which creates potential inundation of adjacent properties.

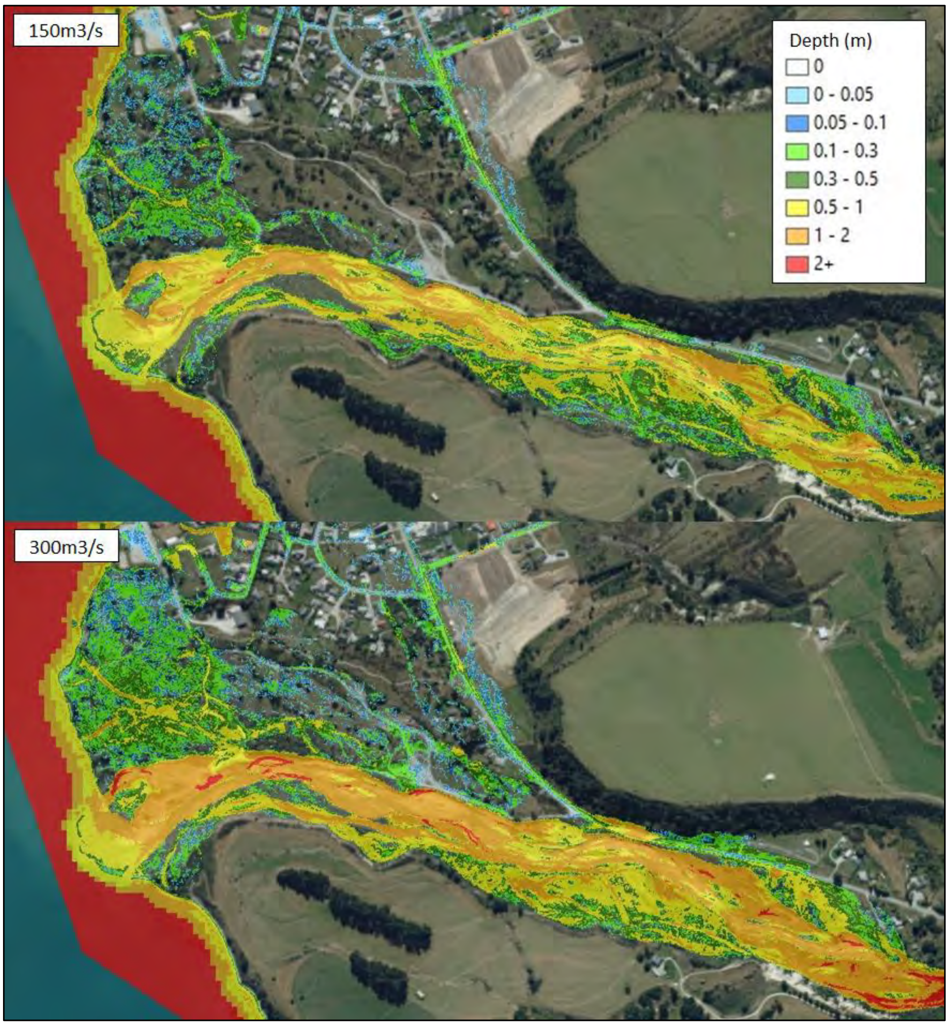

Figure 6-11 – 2m aggregation scenarios showing inundation of the 150m^3/s and 300m^3/s runs.

Where the five runs differ is in the amount of inundation across the northern side of the lower fan reach. In the 150m^3/s this is still patchy, and largely confined to the most downstream part of the fan. However, by the 300m^3/s scenario, there are flow paths across the entire vegetated northern side of the lower fan reach, though depths remain below 1m (Figure 6-11).

In the main fan surface, instream channel depths range between 0.5 and 2m with small places exceeding 2m.

Similar to the design runs and slightly lower aggradation scenario (1m), for the most part inundation within the Glenorchy township is classed as hazard category 1 with small areas up to 4. However, there are localised spots as high as 6 along the Glenorchy-Queenstown Rd and Oban St where flow velocities peak above 2m/s (Figure 6-12), and the floodwaters behind the Glenorchy stopbank, have crept up to category 3.

Again, the main active fan surface is classed as hazard category 5, with flow velocities in the main channel exceeding 1m/s in all scenarios, whilst the northern side of the lower fan reach has velocities largely between 0.5 and 1m/s, with a hazard category of 1.

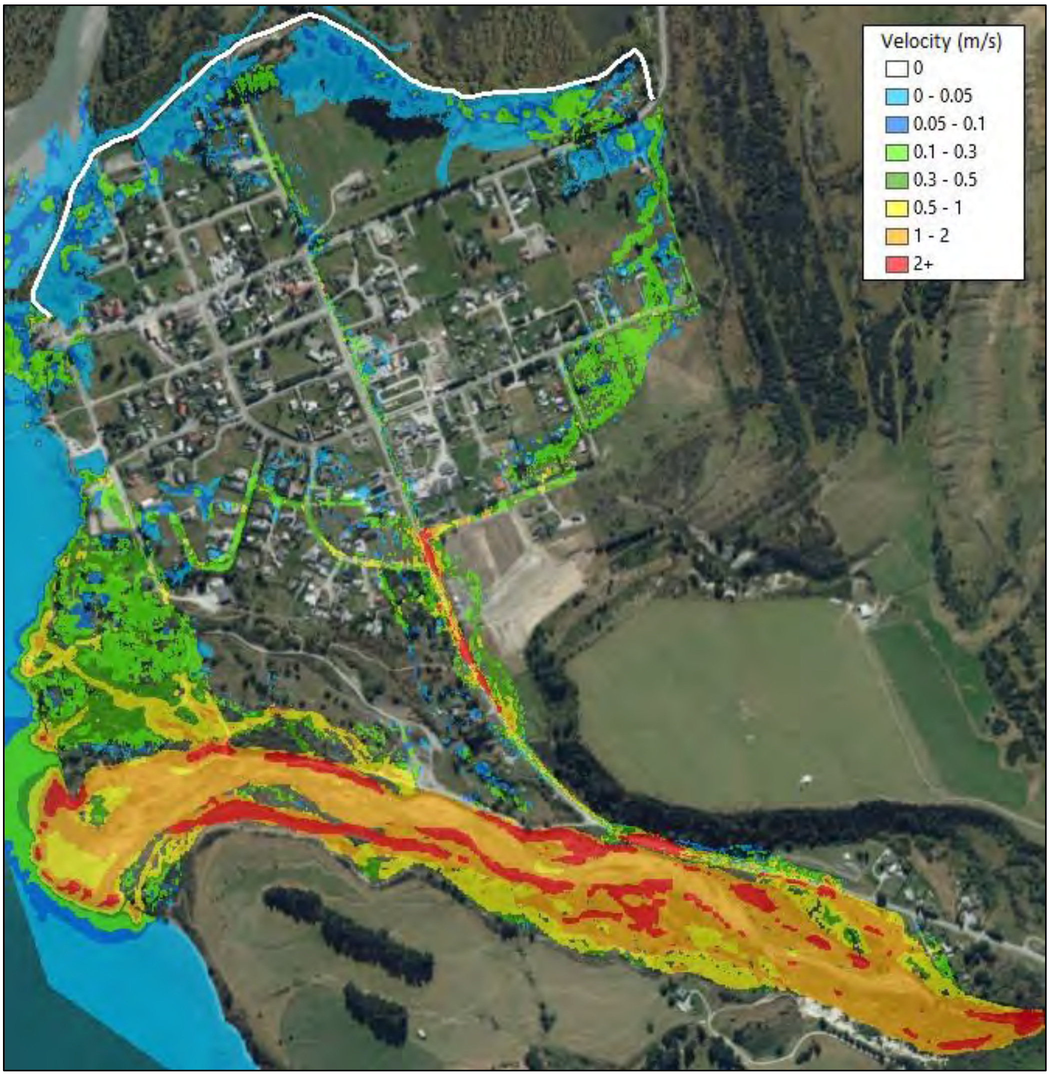

Figure 6-12 – Velocity map for the 200m³/s aggradation (2m) scenario.

AGGRADATION SCENARIO C (3M)

100m³/s

The 100m³/s scenario with 3m of aggradation results in activation of the entire upper fan surface area, with overtopping of the Glenorchy Queenstown Rd, but only patchy inundation of the northern side of the lower fan reach (Figure 6-13).

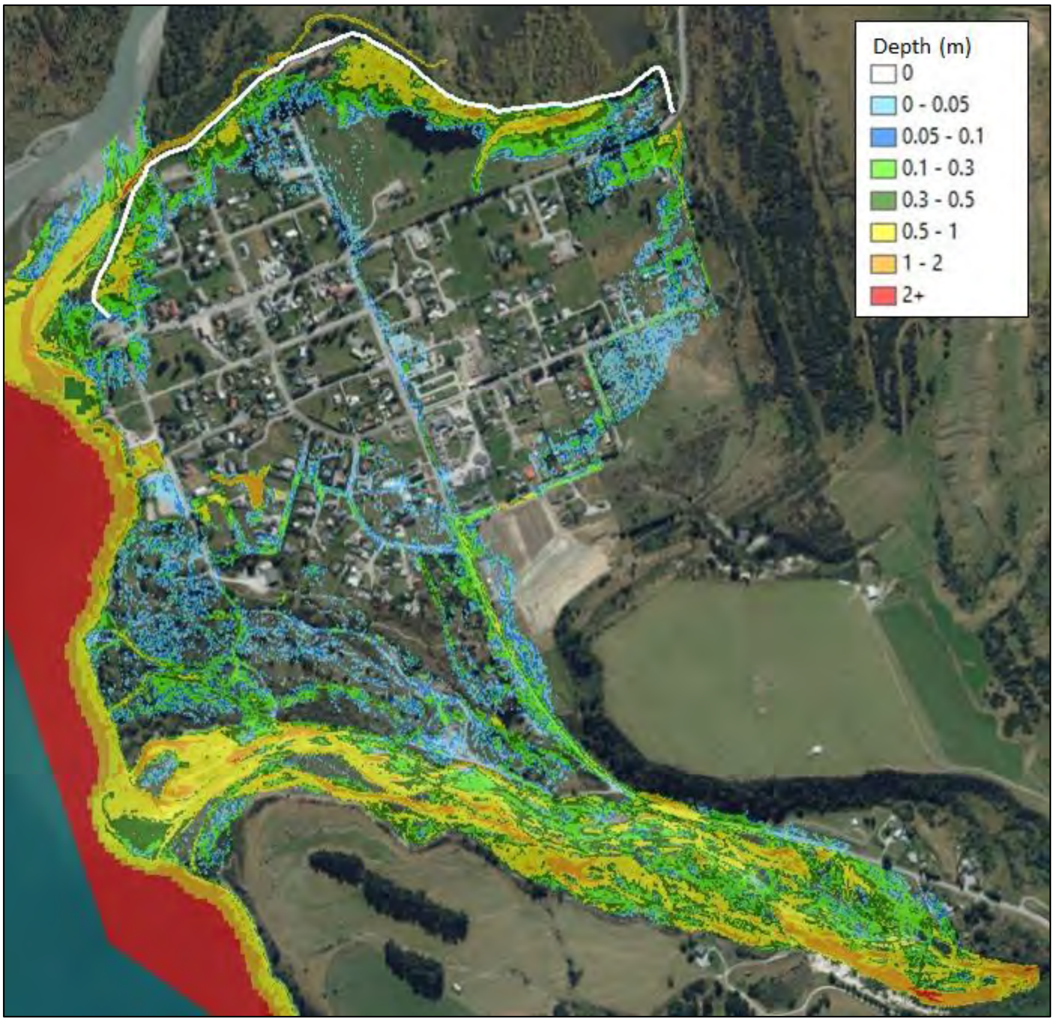

Figure 6-13 – Depth map for the 100m³/s aggradation (3m) scenario.

Inundation in the Glenorchy township is similar to that of 300m³/s flow with 2m aggradation scenario, with flood waters settling behind the Glenorchy stopbank, eastern end of Mull St and in locally low areas on the western side of the township. Most of this inundation is classed as hazard category 1, however there are localised spots reaching as high as category 3, and along Oban St and the Glenorchy-Queenstown Rd, as high as category 6.

150m³/s to 300m³/s

Similar to the 2m aggradation scenarios, in the 3m scenarios, the results for the 150m³/s to 300m³/s peak flows indicate that most of the change in inundation occurs across the northern side of the lower fan surface, and along the Glenorchy-Queenstown Rd.

As flows increase, flow paths and inundation coverage across the northern lower fan surface increases, as do depths along the Glenorchy-Queenstown Rd and Oban St, peaking +2m in depth and +2m/s in velocity, rendering them impassable (Figure 6-14).

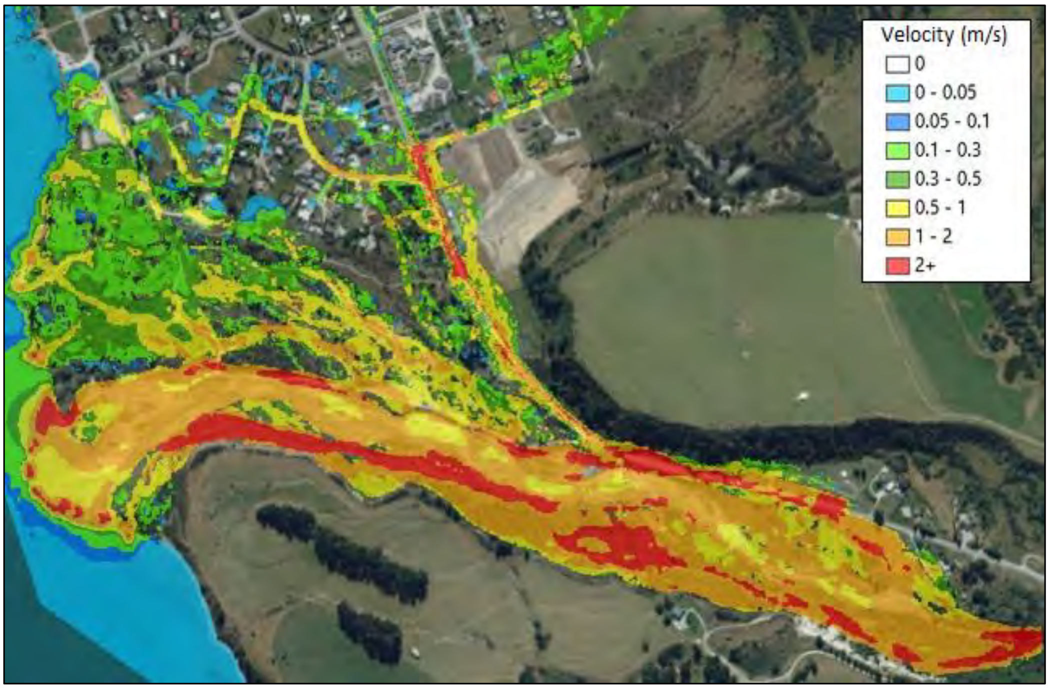

Figure 6-14 – Velocity map for the 200m³/s aggradation (3m) scenario.

Several roads within the Glenorchy township i.e., Lochburn Ave, Lancaster Pl, Invincible Dr, Shiel St, and Jetty St also experience inundation with depths largely below 0.3m but in places peaking as high as 1.5m.

Properties along these roads may experience some inundation. However, the hazard category for much of the town remain at 1, with only a few areas creeping up to 4, and along the Glenorchy-Queenstown Rd and Oban St, to 6 (Figure 6-15).

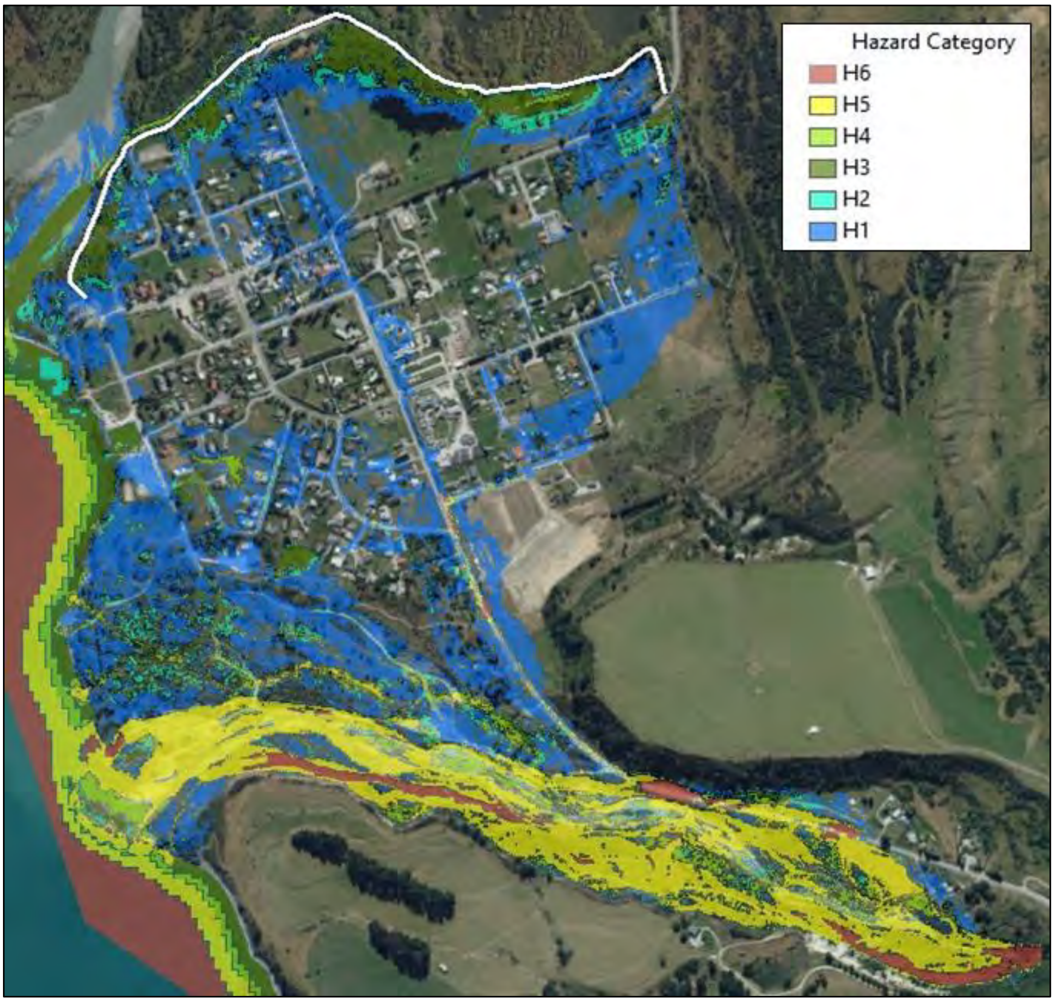

Figure 6-15 – Hazard category map for the 300m³/s aggradation (3m) scenario.

7. RESULTS DISCUSSION

In both sets of design runs and in all three of the aggradation scenarios, the modelling shows that with the fan morphology unique to the DEM of each design run or aggradation scenario, the Glenorchy township and Glenorchy-Queenstown Rd should expect to experience inundation as a result of spillover:

- from the upper fan between 0.25 and 0.5km chainages,
- from the lower fan downstream of the 1.4km chainage,
- and in some of the higher flow aggradation scenarios from adjacent to the road around the 0.7 and 0.85km chainages.

In all situations, the flow (mostly from the upstream spillover) generally follows the natural contouring of the bajada* that has formed from the northern depositional lobe of the Buckler Burn fan and the Bible Stream fan, which the town has been built on, before pooling at the toe of the bajada behind the Glenorchy stopbank.

The flow typically goes:

- Down the apex of the bajada, though given the potential flow paths it could follow this appears to be enforced by Oban St; and
- Down the sides of the bajada – Benmore Pl, Lochburn Ave, Shiel St and the eastern end of Mull St.

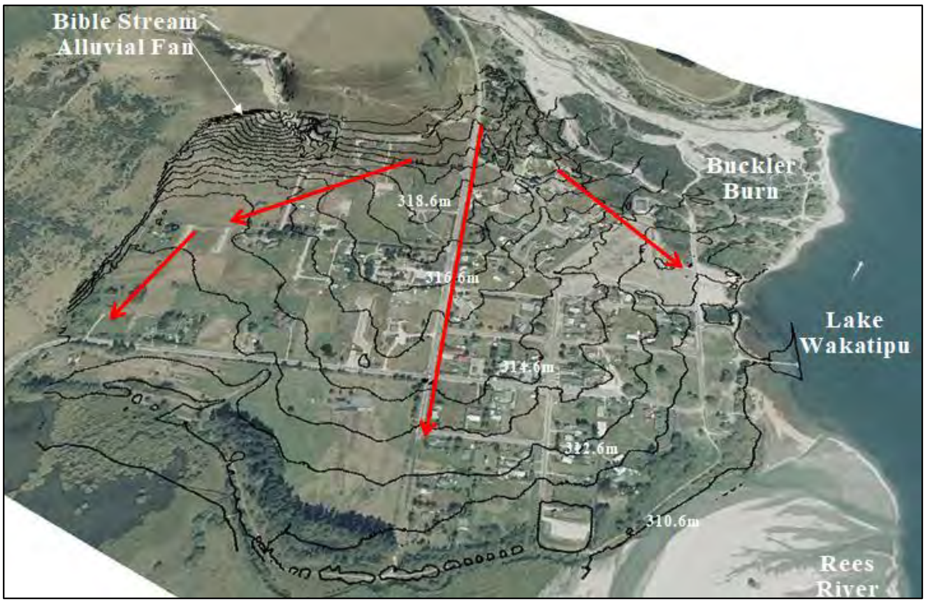

Figure 7-1 - ORC generated image. Land River Sea Buckler Burn model flow paths drawn on in red.

** Bajada: a broad slope of alluvium formed from multiple coalescing alluvial fans* (Fairbridge, 1968).

7.1. DESIGN RUNS

In the design runs, the modelling shows that in both sets (2019 and 2022 LiDAR) the Glenorchy township and access road (Glenorchy-Queenstown Rd) experience increasing inundation with each step up in flow. However, the fan surface has changed between the 2019 and 2022 LiDAR surveys, and as a result the two sets of design runs show differences in inundation, thus highlighting the sensitivity of the model (and therefore the flood hazard to the Glenorchy township) to subtle changes in fan morphology.

- Aggradation in the lower fan reach (below chainage 1.4km) in the 2022 design runs results in slightly greater inundation of the northern side of the lower fan surface compared to the 2019 design runs. This becomes more obvious in the depth difference maps with bigger flows.
- Inundation of the town and Glenorchy-Queenstown Rd from spillover from the upper fan occurs with smaller flows in the 2019 runs (150m^3/s) compared to the 2022 runs (250m^3/s), and as a result floodwaters pool behind the Glenorchy stopbank in the 2019 runs but not in the 2022 runs.

This latter point seems counterintuitive given the hypothesis of an aggrading fan surface under a positive IPO climate, and that the 2022 active fan surface has experienced some aggradation in places compared to the 2019 fan surface. However, a close inspection of the GCD analysis between the 2019 and 2022 LiDAR shows erosion to the banks on both sides of the channel in the upper fan with only small changes in depth, thus increasing the channel capacity in the 2022 LiDAR and model runs (Figure 7-2). Thus, the 2022 design runs require larger flows to spillover the fan boundaries and inundate the Glenorchy township.

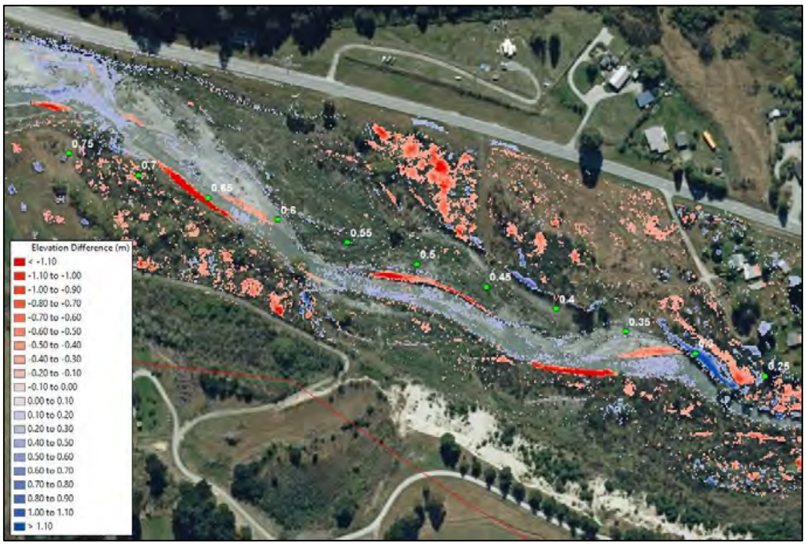

Figure 7-2 – GCD analysis between the 2022 and 2019 LiDAR. The dark red areas along the edges of the active braid plain indicate erosion and widening, whilst the dark blue between 0.25 and 0.3km likely indicates vegetation growth.

Additionally, it should be noted that the classification of ground points and vegetation was not done to as high a quality in the processing of the 2022 LiDAR compared to the 2019 LiDAR. Therefore, vegetation growth such as that between the 0.25 and 0.3km chainage (as shown by the positive change in elevation in the GCD) may have resulted in overflow paths being blocked off in the 2022 model runs thus preventing overtopping in smaller flows (Figure 7-2).

In both design sets, the Glenorchy-Queenstown Rd does not overtop as a result of flooding from the chainage immediately adjacent to the road in any of the design runs (2019 and 2022), but rather from spillover upstream at the 0.25km chainage.

With the modelled fan morphology, inundation, when it does occur in the township is for the most part confined to roads with depths under 1m and has been give the lowest hazard category of 1, with smaller areas up to 4. However, there are a few localised spots as high as 6 where the Glenorchy-Queenstown Rd is inundated and at the southern end of Oban St in the bigger flow design runs.

7.2. AGGRADATION SCENARIOS

In the aggradation scenarios, due to the main channel infilling and therefore reducing the channel capacity, it takes less flow for the channel to fill (shallower depths). Thus there is an increase in spillover beyond the active channel belt and subsequently greater activation of the northern side of the lower fan with depths increasing across the fan surface.

- Inundation of the Glenorchy Queenstown Rd occurs via two mechanisms, flooding from upstream between the 0.25 and 0.5km chainages, and in the 3m aggradation scenarios with flows between $200m^3/s$ to $300m^3/s$, from the fan surface immediately adjacent to the road. However, in these situations the flooded area appears larger than what is inferred on the 1999 photos.
- Velocities in the township vary between 0.1 and 1m/s, but along the southern end of Oban St and the Glenorchy Queenstown Rd, peak above 2m/s.
- Inundated areas in the township are for the most part classed as hazard category 1, with smaller areas getting as high as 4, and up to category 6 along the Glenorchy-Queenstown Rd and Oban St in the 2m and 3m aggradation scenarios.
- The fan surface is categorised as either 5, 6 or a mixture of both, depending on the scenario, as expected given its steep nature.

Additionally, despite the increasing activation of the northern side of the lower fan, the modelled inundation of the township that results from this, is still minimal. This is not necessarily realistic; but more likely an underestimation of the depths and frequency of inundation in the township due to the simplified nature of the elevated fan surface in the aggradation scenarios. Tapering the slope to the lake margin, and smoothing out the fan surface, removes the braided and 'lumpy' nature of the lower fan surface, and hence the inability to direct flow to the north (or south) which would result in greater inundation.

7.3. RISK OF AVULSION

Finally, in all of the design and aggradation scenarios, and most notably those with the larger flows (+200m^3/s), there is consistently high velocities along the northern (true right) bank of the Buckler Burn, in the vicinity of the Glenorchy-Queenstown Rd. Though the model assumes a static bed so erosion can't be modelled using this approach, these velocities indicate that erosion of the bank is highly likely in this location with the associated risk of avulsion. The avulsion would likely take a northerly direction, reoccupying former channel pathways (Fuller and McColl, 2021) and may ultimately direct flow into the Glenorchy township with significant consequences.

8. CONCLUSIONS

The following conclusions can be drawn from this study.

- Flood flows have the potential to overtop the active channel belt, spill out across the fan surface and inundate the township. The extent of this inundation depends on the state of the fan surface and alignment of channels. However, should a sizeable event occur, due to the natural contouring of the Buckler and Bible bajada, and forcing of the roadways, the flow generally goes down the apex (Oban St) and the sides of the bajada (Lochburn Ave and Shiel St) with only localised flooding to the buildings alongside the roads in these locations.
- Aggradation across the fan surface and infilling of the active channel belt, leads to a reduction in the amount of flow required to spill out onto the fan surface, which leads to an increase in inundation along the Glenorchy-Queenstown Rd and within the Glenorchy township.
- Flood behaviour is therefore sensitive to aggradation on the fan and the exact nature of a flood will change based on that.
- However, simplification of the aggradation profiles, though necessary, may have resulted in an underestimation of the inundation extents to the north, and warrant further study with greater detail.
- Further, subtle changes in the fan morphology between the 2019 and 2022 LiDAR surveys results in differences in the extent and depth of inundation, and the size of flow required to fill the active channel belt and spillover onto rest of fan surface in the two sets of design runs. This shows that the modelling cannot capture the full range of such a dynamic system, but rather provide only a generalised prediction of behaviour and resulting inundation for these design and aggradation scenarios.
- Given the steep nature of the fan, flood flows across the fan surface are classed as hazard category 5, 6 or a mixture of both, whilst the floodwaters which enter the township, are for the most part given the lowest hazard category of 1, with localised spots there and along the Glenorchy-Queenstown Rd and Oban St as high as 6, rendering these roads impassable and likely damaged should such an extreme event occur.
- High velocities along the true right in the vicinity of the Glenorchy-Queenstown Rd also suggest that rates of erosion would be significant in this location, and therefore there is the risk of avulsion to the north.
- Imagery, cross sections, and past behaviour of the fan, suggest that its surface is actively changing over time with resulting effect on flood risk. For example, the active channel belt is currently aligned at the most southern limit of the fan; therefore northwards migration should be anticipated, with subsequent changes expected in the inundation to the north compared to that which has been modelled. To better understand the relationship between the fan surface morphology and flood risk, the fan would benefit from ongoing monitoring.

9. RECOMMENDATIONS

The following recommendations can be made from this study:

Modelling

Further modelling could be completed to better understand the risk of the hazards posed by the Buckler Burn:

- More detailed aggradation scenarios that have a more realistic distribution of sediment across the entire fan surface could be simulated. As could a scenario where the spillover onto the inactive fan surface between the 0.25 and 0.5km is prevented. This latter scenario will likely force more water down the fan to where the road overtopped in the 1999 flood, and may be a more realistic simulation of what actually happened in the 1999 event.
- Delft 3D could be used to model sediment transport and channel morphology within the Buckler Burn. This would provide further insight into the potential and vulnerability of the Buckler Burn switching channels whilst in a more aggraded state (as opposed to its currently incised state).
- Rapid Mass Movement Simulation (RAMMS) could be used to assess the potential magnitude of near-instantaneous bed aggradation in response to mass flows (debris flows/floods) by investigating the risks posed by slope failures in delivering large volumes of sediment.
- To better determine the risk of flooding to the Glenorchy township, a detailed catchment hydrology review could be completed to determine best-estimate flood frequency flows (annual return intervals) and provide an estimation on future flows under the climate change projection scenarios.

Fan morphology and behaviour

- Annual/biannual cross section monitoring to better understand flood risk from the burn, by keeping track of the change in channel capacity, fan surface elevation, and gradient over time. Periods where the main channel has infilled will result in reduced channel capacity and subsequently susceptibility to rapid infilling and higher flood risk from the burn, during events.
- Annual or significant event-based monitoring using LiDAR or drone survey (photogrammetry) to capture high resolution detail of the fan surface, will allow for GCD analysis to show change in the fan surface and channel topography over time.
- These successive DEMs should then be incorporated into future model runs to better understand changes in risk of inundation as the channel morphology adjusts.
- Document behaviour of the fan (main and subsidiary channels and delta) during and immediately after flood events.

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APPENDIX A – DESIGN RUNS – PEAK FLOOD DEPTH MAPS

Legend

- Stopbank

Peak Depth(m)

- 0
- 0 - 0.05
- 0.05 - 0.1
- 0.1 - 0.3
- 0.3 - 0.5
- 0.5 - 1
- 1 - 2
- 2+

LANDRIVERSEA CONSULTING

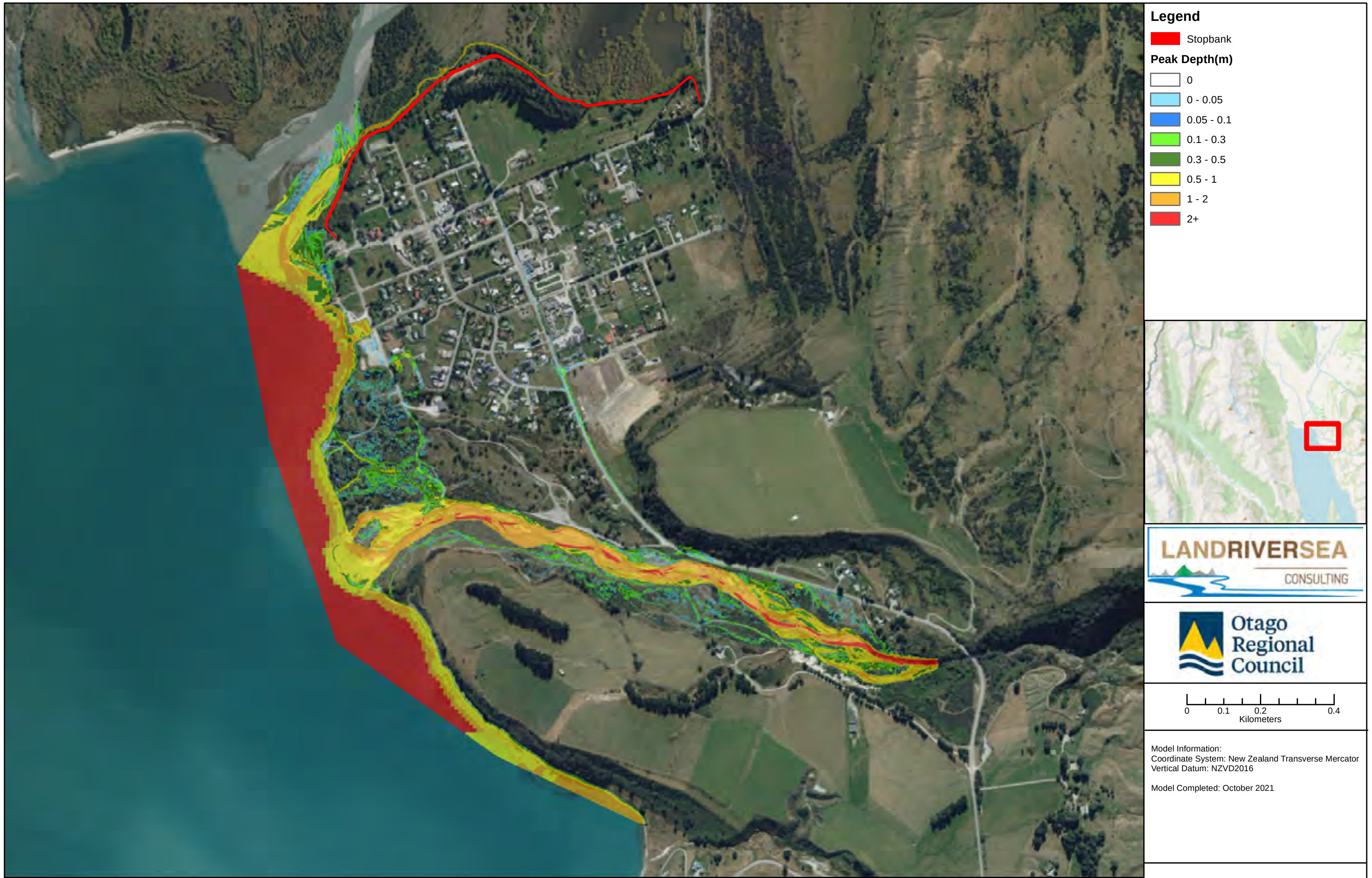
Otago Regional Council

0 0.1 0.2 0.4
Kilometers

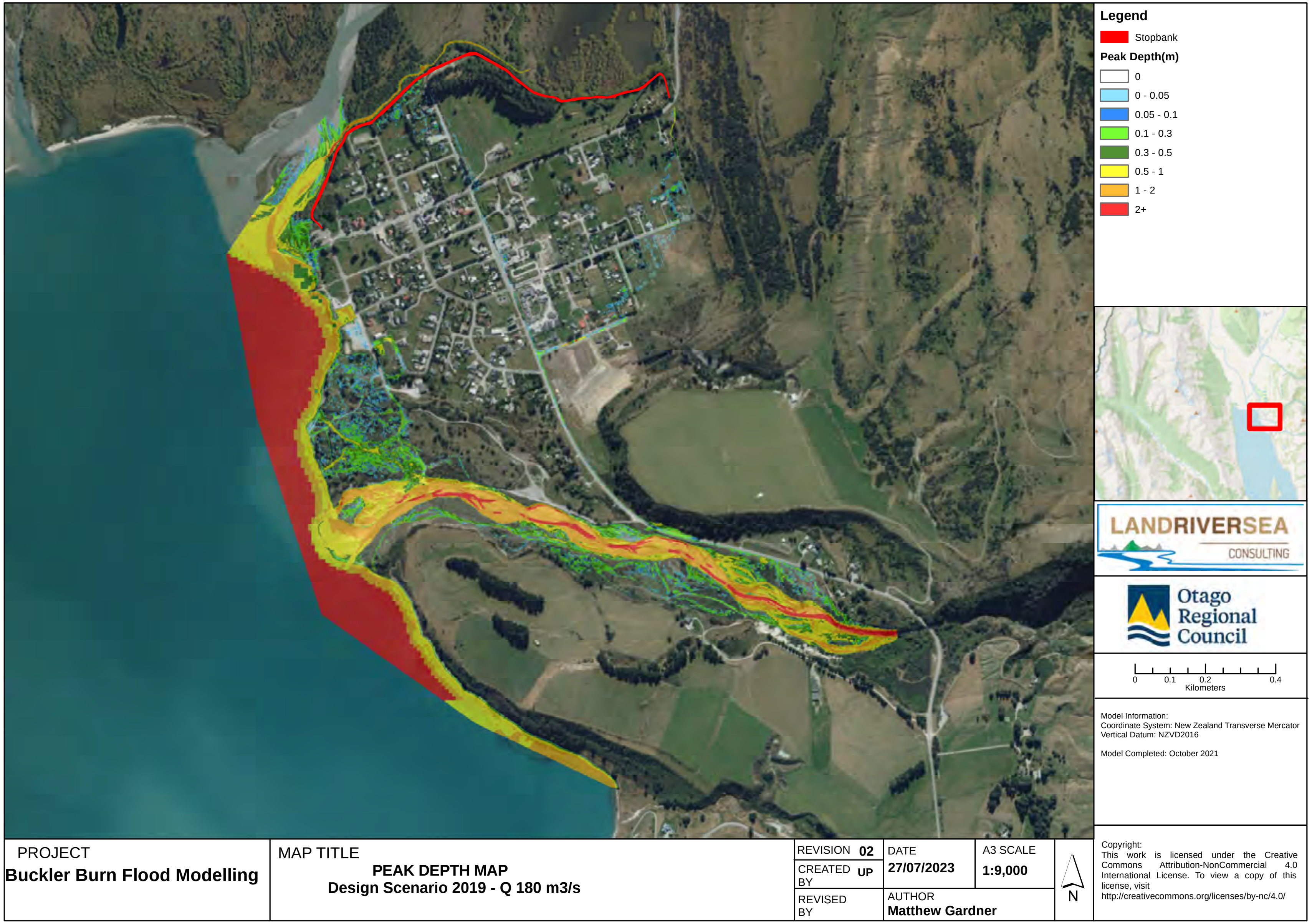
Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION	DATE	A3 SCALE	
Buckler Burn Flood Modelling	**PEAK DEPTH MAP** **Design Scenario 2019 - Q 100 m3/s**	02			N
		CREATED BY UP	27/07/2023	1:9,000	
		REVISED BY	AUTHOR **Matthew Gardner**		



PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE
Buckler Burn Flood Modelling	**PEAK DEPTH MAP** **Design Scenario 2019 - Q 150 m3/s**	CREATED BY **UP**	**27/07/2023**	**1:9,000**
		REVISED BY	AUTHOR **Matthew Gardner**	N


Legend
Stopbank
Peak Depth(m)
0
0 - 0.05
0.05 - 0.1
0.1 - 0.3
0.3 - 0.5
0.5 - 1
1 - 2
2+
LANDRIVERSEA
CONSULTING
Otago Regional Council
0
0.1
0.2
0.4
Kilometers
Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016
Model Completed: October 2021
PROJECT
Buckler Burn Flood Modelling
MAP TITLE
PEAK DEPTH MAP
Design Scenario 2019 - Q 180 m3/s
REVISION 02
CREATED BY UP
REVISED BY
DATE
27/07/2023
A3 SCALE
1:9,000
AUTHOR
Matthew Gardner
N
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Legend

Stopbank

Peak Depth(m)

- 0
- 0 - 0.05
- 0.05 - 0.1
- 0.1 - 0.3
- 0.3 - 0.5
- 0.5 - 1
- 1 - 2
- 2+

LANDRIVERSEA CONSULTING

Otago Regional Council

0 0.1 0.2 0.4
Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE
Buckler Burn Flood Modelling	**PEAK DEPTH MAP** **Design Scenario 2019 - Q 200 m3/s**	CREATED BY **UP**	**27/07/2023**	**1:9,000**
		REVISED BY	AUTHOR **Matthew Gardner**	

N

Legend

Stopbank

Peak Depth(m)

- 0
- 0 - 0.05
- 0.05 - 0.1
- 0.1 - 0.3
- 0.3 - 0.5
- 0.5 - 1
- 1 - 2
- 2+

LANDRIVERSEA CONSULTING

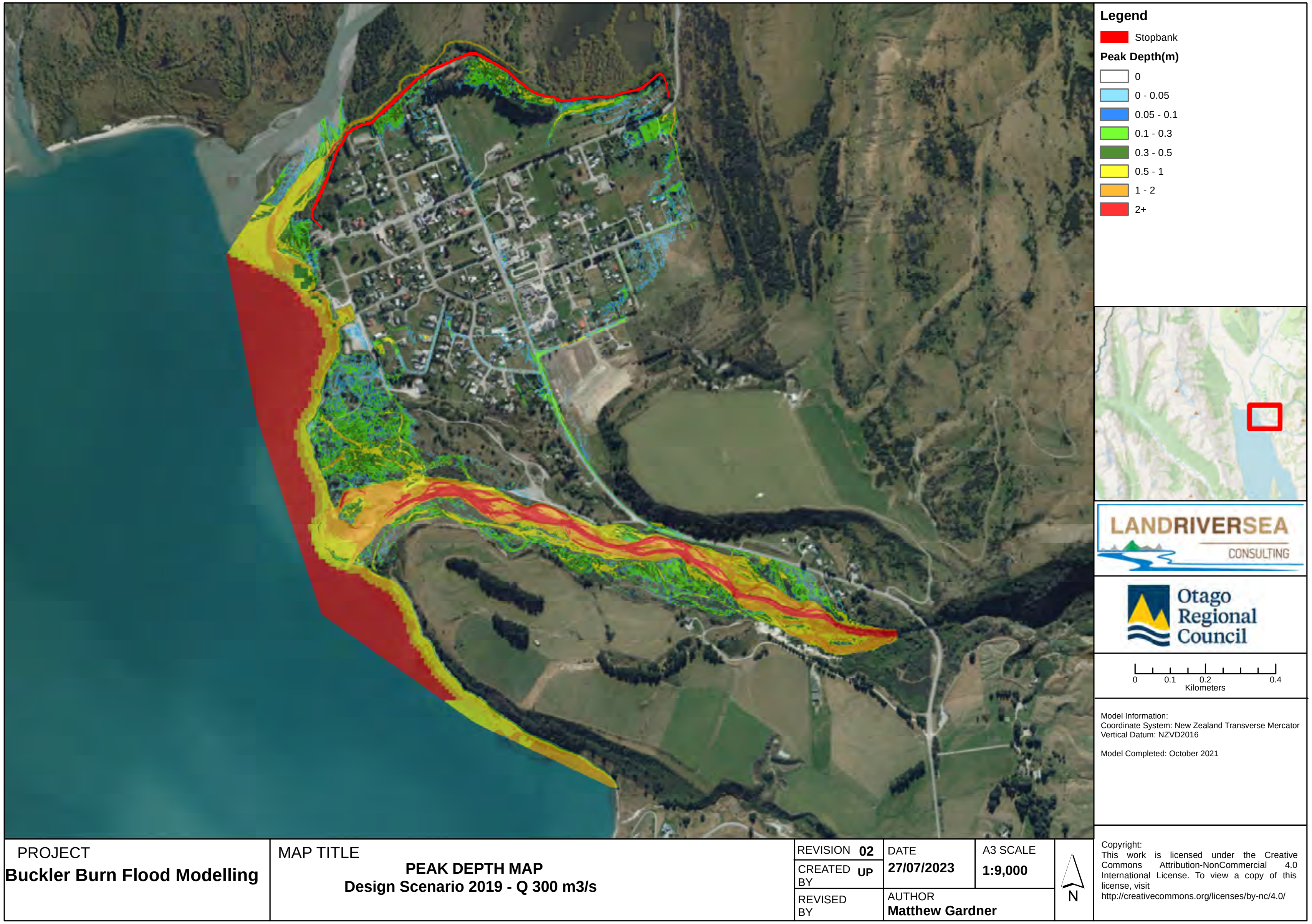
Otago Regional Council

0 0.1 0.2 0.4
Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE	N
Buckler Burn Flood Modelling	**PEAK DEPTH MAP** **Design Scenario 2019 - Q 250 m3/s**	CREATED BY **UP**	**27/07/2023**	**1:9,000**	
		REVISED BY	AUTHOR **Matthew Gardner**		


Legend
Stopbank
Peak Depth(m)
0
0 - 0.05
0.05 - 0.1
0.1 - 0.3
0.3 - 0.5
0.5 - 1
1 - 2
2+
LANDRIVERSEA
CONSULTING
Otago Regional Council
0 0.1 0.2 0.4
Kilometers
Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016
Model Completed: October 2021
PROJECT
Buckler Burn Flood Modelling
MAP TITLE
PEAK DEPTH MAP
Design Scenario 2019 - Q 300 m3/s
REVISION 02
CREATED BY UP
REVISED BY
DATE
27/07/2023
A3 SCALE
1:9,000
AUTHOR
Matthew Gardner
N
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Legend

- Stopbank

Peak Depth(m)

- 0
- 0 - 0.05
- 0.05 - 0.1
- 0.1 - 0.3
- 0.3 - 0.5
- 0.5 - 1
- 1 - 2
- 2+

LANDRIVERSEA CONSULTING

Otago Regional Council

0 0.1 0.2 0.4 Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE	
Buckler Burn Flood Modelling	**PEAK DEPTH MAP** **Design Scenario 2022 - Q 100 m3/s**	CREATED BY UP	**27/07/2023**	**1:9,000**	N
		REVISED BY	AUTHOR **Matthew Gardner**		

LANDRIVERSEA CONSULTING

Otago Regional Council

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION	DATE	A3 SCALE
Buckler Burn Flood Modelling	**PEAK DEPTH MAP** **Design Scenario 2022 - Q 150 m3/s**	02	27/07/2023	1:9,000
		CREATED BY: UP	AUTHOR: **Matthew Gardner**	
		REVISED BY:		

Legend

Stopbank	Stopbank

Peak Depth(m)

- 0
- 0 - 0.05
- 0.05 - 0.1
- 0.1 - 0.3
- 0.3 - 0.5
- 0.5 - 1
- 1 - 2
- 2+

LANDRIVERSEA CONSULTING

Otago Regional Council

0 0.1 0.2 0.4 Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION	DATE	A3 SCALE
Buckler Burn Flood Modelling	**PEAK DEPTH MAP** **Design Scenario 2022 - Q 180 m3/s**	02	27/07/2023	1:9,000
		CREATED BY: UP	AUTHOR: **Matthew Gardner**	N
		REVISED BY:		

Legend

Stopbank

Peak Depth(m)

- 0
- 0 - 0.05
- 0.05 - 0.1
- 0.1 - 0.3
- 0.3 - 0.5
- 0.5 - 1
- 1 - 2
- 2+

LANDRIVERSEA CONSULTING

Otago Regional Council

0 0.1 0.2 0.4
Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE	
Buckler Burn Flood Modelling	**PEAK DEPTH MAP** **Design Scenario 2022 - Q 200 m3/s**	CREATED BY UP	**27/07/2023**	**1:9,000**	N
		REVISED BY	AUTHOR **Matthew Gardner**		

Legend

Stopbank

Peak Depth(m)

- 0
- 0 - 0.05
- 0.05 - 0.1
- 0.1 - 0.3
- 0.3 - 0.5
- 0.5 - 1
- 1 - 2
- 2+

LANDRIVERSEA CONSULTING

Otago Regional Council

0 0.1 0.2 0.4
Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE	
Buckler Burn Flood Modelling	**PEAK DEPTH MAP** **Design Scenario 2022 - Q 250 m3/s**	CREATED BY UP	**27/07/2023**	**1:9,000**	N
		REVISED BY	AUTHOR **Matthew Gardner**		

Legend

- Stopbank

Peak Depth(m)

- 0
- 0 - 0.05
- 0.05 - 0.1
- 0.1 - 0.3
- 0.3 - 0.5
- 0.5 - 1
- 1 - 2
- 2+

LANDRIVERSEA CONSULTING

Otago Regional Council

0 0.1 0.2 0.4 Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE
Buckler Burn Flood Modelling	**PEAK DEPTH MAP** **Design Scenario 2022 - Q 300 m3/s**	CREATED BY UP	**27/07/2023**	**1:9,000**
		REVISED BY	AUTHOR **Matthew Gardner**	

N

APPENDIX B – DESIGN RUNS – PEAK SPEED MAPS

Legend

- Stopbank

Peak Velocity(m/s)

- 0
- 0 - 0.05
- 0.05 - 0.1
- 0.1 - 0.3
- 0.3 - 0.5
- 0.5 - 1
- 1 - 2
- 2+

LANDRIVERSEA CONSULTING

Otago Regional Council

0 0.1 0.2 0.4
Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE	
Buckler Burn Flood Modelling	**PEAK VELOCITY MAP** **Design Scenario 2019 - Q 100 m3/s**	CREATED BY UP	**27/07/2023**	**1:9,000**	N
		REVISED BY	AUTHOR **Matthew Gardner**		

PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE	
Buckler Burn Flood Modelling	**PEAK VELOCITY MAP** **Design Scenario 2019 - Q 150 m3/s**	CREATED BY **UP**	**27/07/2023**	**1:9,000**	N
		REVISED BY	AUTHOR **Matthew Gardner**		

Legend

- Stopbank

Peak Velocity (m/s)

- 0
- 0 - 0.05
- 0.05 - 0.1
- 0.1 - 0.3
- 0.3 - 0.5
- 0.5 - 1
- 1 - 2
- 2+

LANDRIVERSEA CONSULTING

Otago Regional Council

0 0.1 0.2 0.4
Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE
Buckler Burn Flood Modelling	**PEAK DEPTH MAP** **Design Scenario 2019 - Q 180 m3/s**	CREATED BY UP	**27/07/2023**	**1:9,000**
		REVISED BY	AUTHOR **Matthew Gardner**	

N

Legend

Stopbank

Peak Velocity (m/s)

- 0
- 0 - 0.05
- 0.05 - 0.1
- 0.1 - 0.3
- 0.3 - 0.5
- 0.5 - 1
- 1 - 2
- 2+

LANDRIVERSEA CONSULTING

Otago Regional Council

0 0.1 0.2 0.4
Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE
Buckler Burn Flood Modelling	**PEAK DEPTH MAP** **Design Scenario 2019 - Q 200 m3/s**	CREATED BY UP	**27/07/2023**	**1:9,000**
		REVISED BY	AUTHOR **Matthew Gardner**	

N

Legend

Red	Stopbank

Peak Velocity (m/s)

- 0
- 0 - 0.05
- 0.05 - 0.1
- 0.1 - 0.3
- 0.3 - 0.5
- 0.5 - 1
- 1 - 2
- 2+

LANDRIVERSEA CONSULTING

Otago Regional Council

0 0.1 0.2 0.4
Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE	
Buckler Burn Flood Modelling	**PEAK DEPTH MAP** **Design Scenario 2019 - Q 250 m3/s**	CREATED BY **UP**	**27/07/2023**	**1:9,000**	N
		REVISED BY	AUTHOR **Matthew Gardner**		

Legend

- Stopbank

Peak Velocity(m/s)

- 0
- 0 - 0.05
- 0.05 - 0.1
- 0.1 - 0.3
- 0.3 - 0.5
- 0.5 - 1
- 1 - 2
- 2+

LANDRIVERSEA CONSULTING

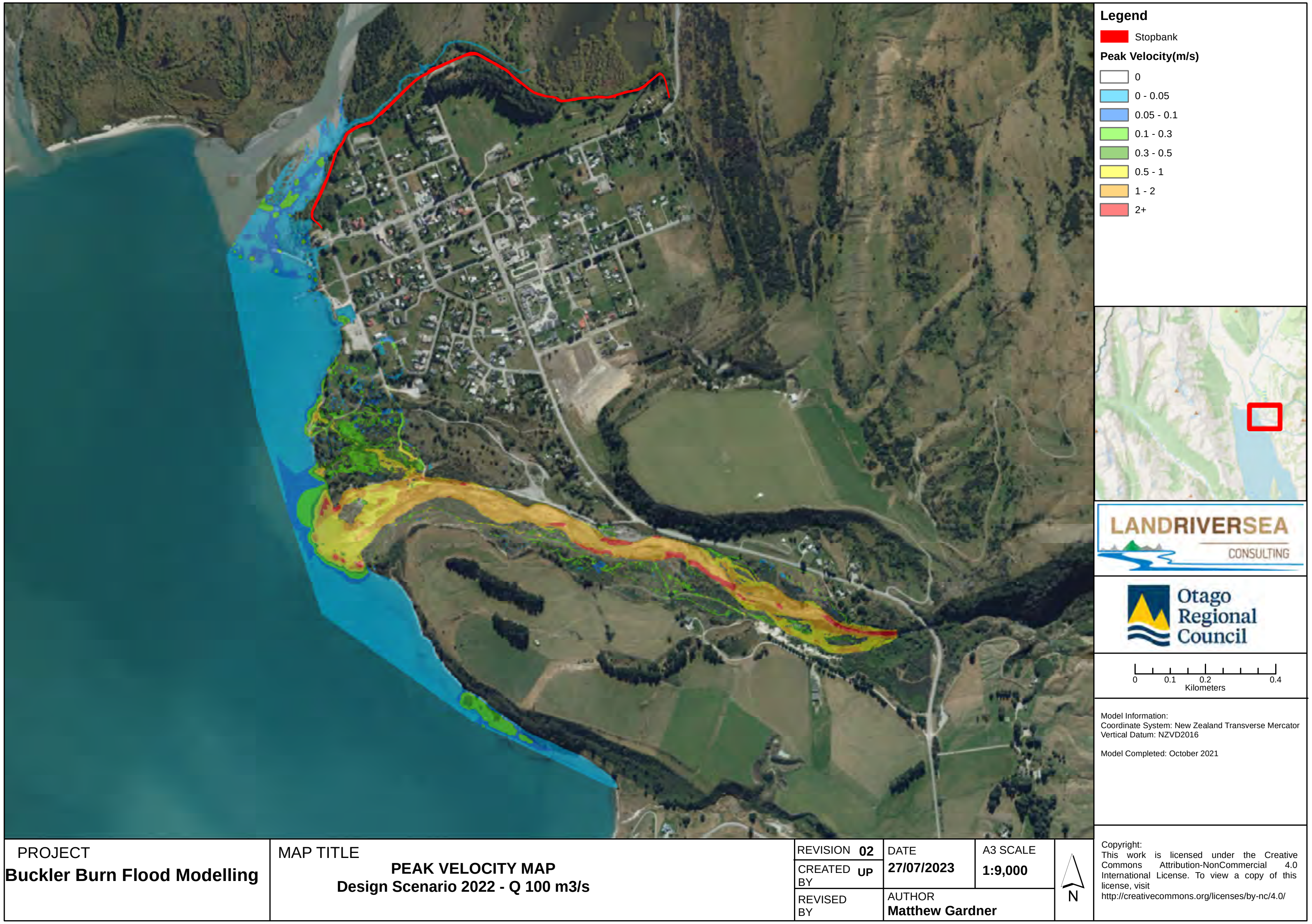
Otago Regional Council

0 0.1 0.2 0.4
Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE
Buckler Burn Flood Modelling	**PEAK DEPTH MAP** **Design Scenario 2019 - Q 300 m3/s**	CREATED BY UP	**27/07/2023**	**1:9,000**
		REVISED BY	AUTHOR **Matthew Gardner**	N


Legend
Stopbank
Peak Velocity(m/s)
0
0 - 0.05
0.05 - 0.1
0.1 - 0.3
0.3 - 0.5
0.5 - 1
1 - 2
2+
LANDRIVERSEA
CONSULTING
Otago Regional Council
0 0.1 0.2 0.4
Kilometers
Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016
Model Completed: October 2021
PROJECT
Buckler Burn Flood Modelling
MAP TITLE
PEAK VELOCITY MAP
Design Scenario 2022 - Q 100 m3/s
REVISION 02
CREATED BY UP
REVISED BY
DATE
27/07/2023
A3 SCALE
1:9,000
AUTHOR
Matthew Gardner
N
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Legend

Stopbank

Peak Velocity(m/s)

- 0
- 0 - 0.05
- 0.05 - 0.1
- 0.1 - 0.3
- 0.3 - 0.5
- 0.5 - 1
- 1 - 2
- 2+

LANDRIVERSEA CONSULTING

Otago Regional Council

0 0.1 0.2 0.4
Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT **Buckler Burn Flood Modelling**	MAP TITLE **PEAK VELOCITY MAP Design Scenario 2022 - Q 150 m3/s**	REVISION **02**	DATE **27/07/2023**	A3 SCALE **1:9,000**	N
		CREATED BY **UP**			
		REVISED BY	AUTHOR **Matthew Gardner**		

Legend

- Stopbank

Peak Velocity(m/s)

- 0
- 0 - 0.05
- 0.05 - 0.1
- 0.1 - 0.3
- 0.3 - 0.5
- 0.5 - 1
- 1 - 2
- 2+

LANDRIVERSEA CONSULTING

Otago Regional Council

0 0.1 0.2 0.4
Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT **Buckler Burn Flood Modelling**	MAP TITLE **PEAK VELOCITY MAP** **Design Scenario 2022 - Q 180 m3/s**	REVISION **02** CREATED BY **UP** REVISED BY	DATE **27/07/2023** AUTHOR **Matthew Gardner**	A3 SCALE **1:9,000**

N

Legend

Stopbank

Peak Velocity(m/s)

- 0
- 0 - 0.05
- 0.05 - 0.1
- 0.1 - 0.3
- 0.3 - 0.5
- 0.5 - 1
- 1 - 2
- 2+

LANDRIVERSEA CONSULTING

Otago Regional Council

0 0.1 0.2 0.4 Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE	
Buckler Burn Flood Modelling	**PEAK VELOCITY MAP** **Design Scenario 2022 - Q 200 m3/s**	CREATED BY UP	27/07/2023	1:9,000	N
		REVISED BY	AUTHOR **Matthew Gardner**		

Legend

- Stopbank

Peak Velocity(m/s)

- 0
- 0 - 0.05
- 0.05 - 0.1
- 0.1 - 0.3
- 0.3 - 0.5
- 0.5 - 1
- 1 - 2
- 2+

LANDRIVERSEA CONSULTING

Otago Regional Council

0 0.1 0.2 0.4
Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE
Buckler Burn Flood Modelling	**PEAK VELOCITY MAP** **Design Scenario 2022 - Q 250 m3/s**	CREATED BY UP	**27/07/2023**	**1:9,000**
		REVISED BY	AUTHOR **Matthew Gardner**	N

Legend

Stopbank

Peak Velocity(m/s)

- 0
- 0 - 0.05
- 0.05 - 0.1
- 0.1 - 0.3
- 0.3 - 0.5
- 0.5 - 1
- 1 - 2
- 2+

LANDRIVERSEA CONSULTING

Otago Regional Council

0 0.1 0.2 0.4
Kilometers

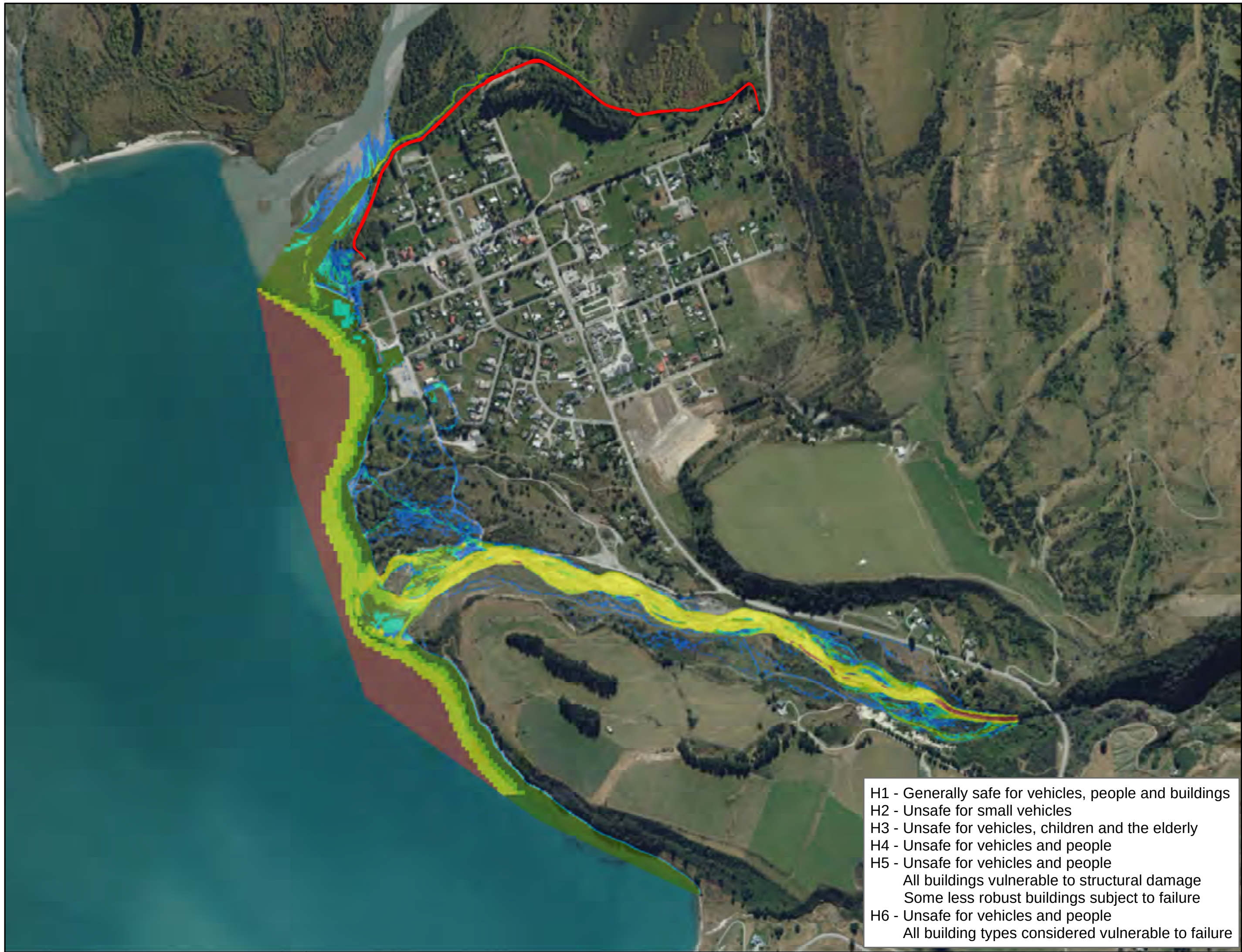
Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE
Buckler Burn Flood Modelling	**PEAK VELOCITY MAP** **Design Scenario 2022 - Q 300 m3/s**	CREATED BY UP	**27/07/2023**	**1:9,000**
		REVISED BY	AUTHOR **Matthew Gardner**	

N

APPENDIX C – DESIGN RUNS – HAZARD MAPS



Legend

Stopbank

Hazard Category

- H6
- H5
- H4
- H3
- H2
- H1

LANDRIVERSEA CONSULTING

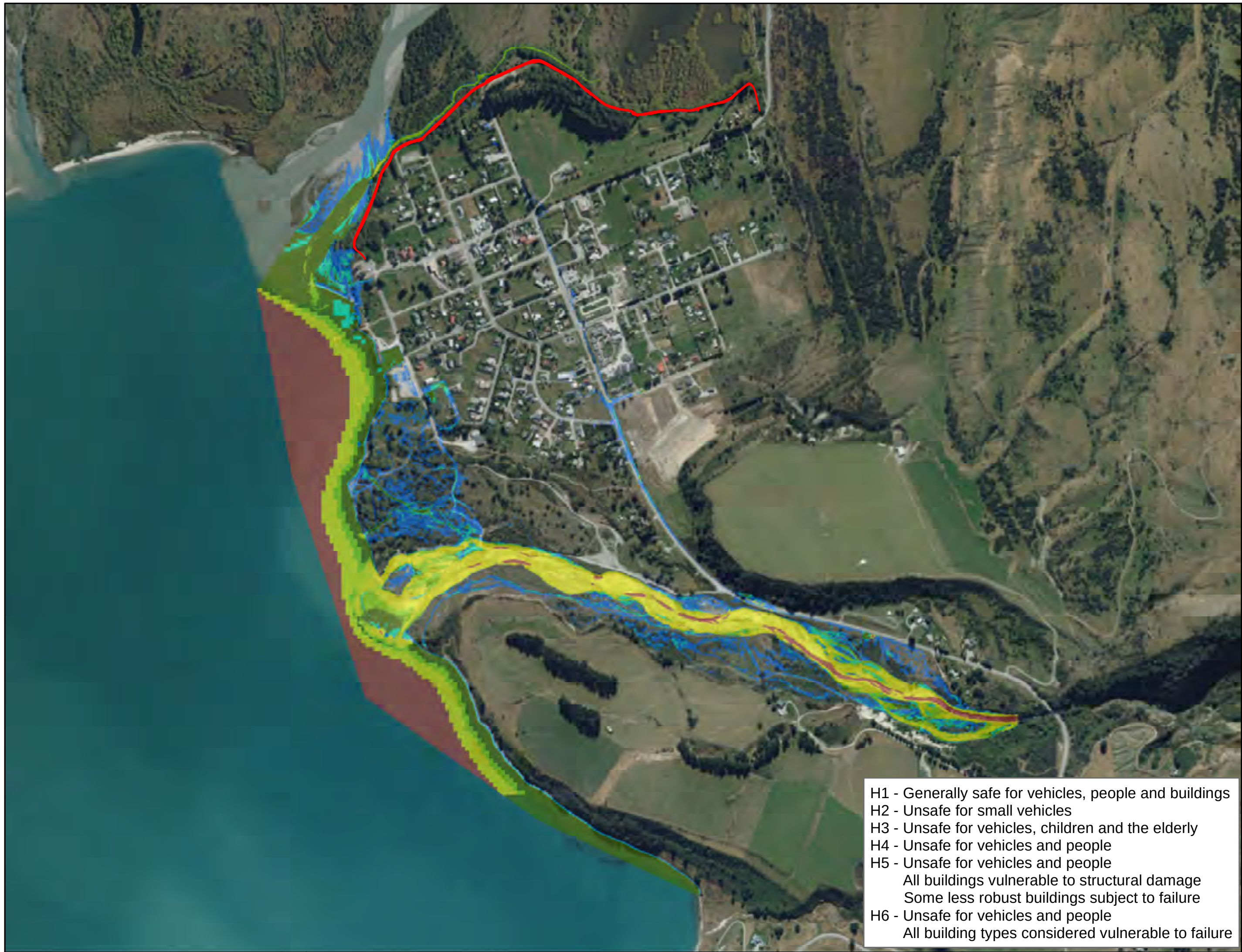
Otago Regional Council

0 0.1 0.2 0.4 Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE
Buckler Burn Flood Modelling	**HAZARD MAP** **Design Scenario 2019 - Q 100 m3/s**	CREATED BY UP	**27/07/2023**	**1:9,000**
		REVISED BY	AUTHOR **Matthew Gardner**	N



Legend

Stopbank

Hazard Category

- H6
- H5
- H4
- H3
- H2
- H1

LANDRIVERSEA CONSULTING

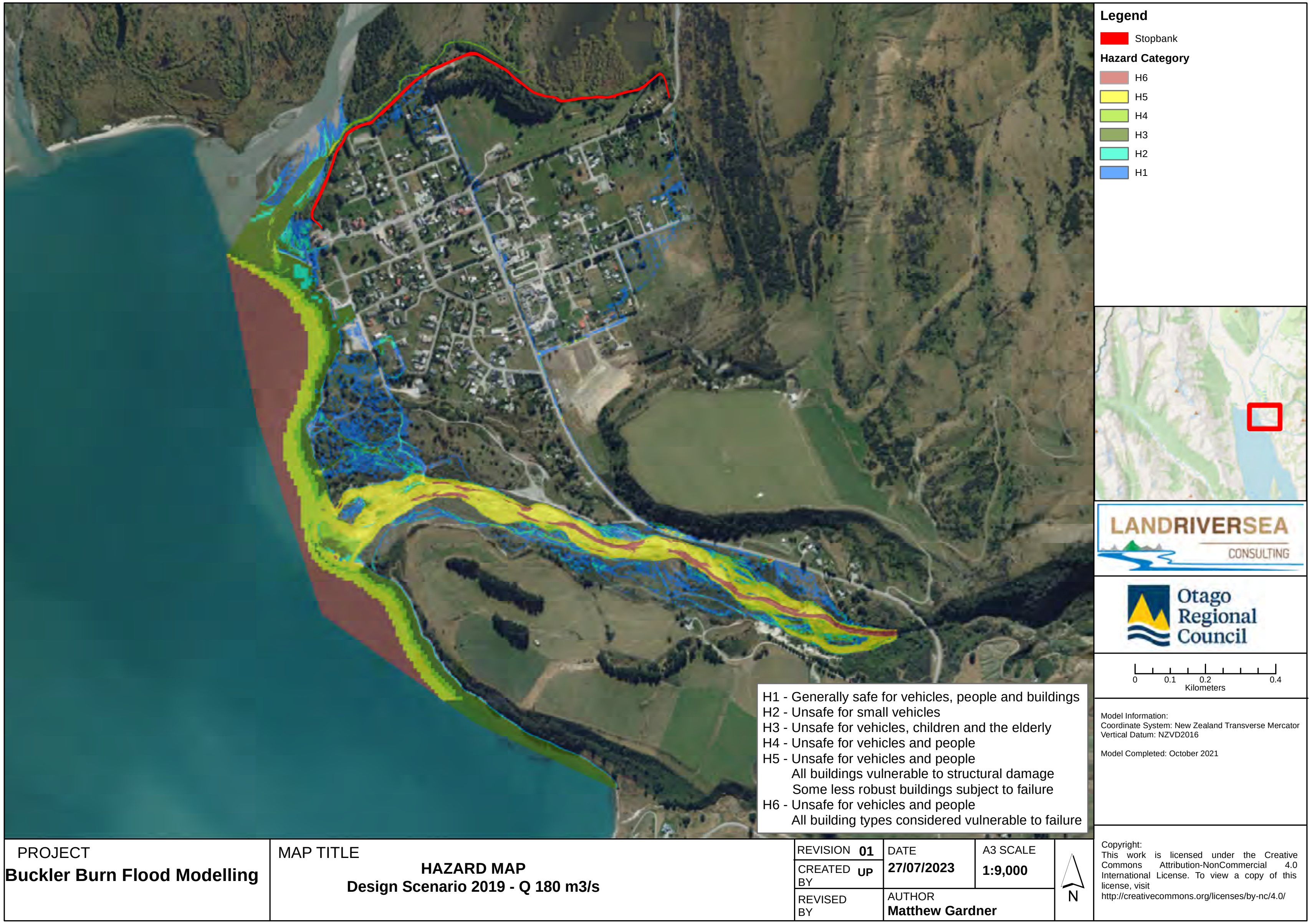
Otago Regional Council

0 0.1 0.2 0.4 Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE
Buckler Burn Flood Modelling	**HAZARD MAP** **Design Scenario 2019 - Q 150 m3/s**	CREATED BY UP	**27/07/2023**	**1:9,000**
		REVISED BY	AUTHOR **Matthew Gardner**	N


Legend
Stopbank
Hazard Category
H6
H5
H4
H3
H2
H1
LANDRIVERSEA
CONSULTING
Otago Regional Council
0 0.1 0.2 0.4
Kilometers
Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016
Model Completed: October 2021
H1 - Generally safe for vehicles, people and buildings
H2 - Unsafe for small vehicles
H3 - Unsafe for vehicles, children and the elderly
H4 - Unsafe for vehicles and people
H5 - Unsafe for vehicles and people
All buildings vulnerable to structural damage
Some less robust buildings subject to failure
H6 - Unsafe for vehicles and people
All building types considered vulnerable to failure
PROJECT
Buckler Burn Flood Modelling
MAP TITLE
HAZARD MAP
Design Scenario 2019 - Q 180 m3/s
REVISION 01
CREATED BY UP
REVISED BY
DATE
27/07/2023
AUTHOR
Matthew Gardner
A3 SCALE
1:9,000
N
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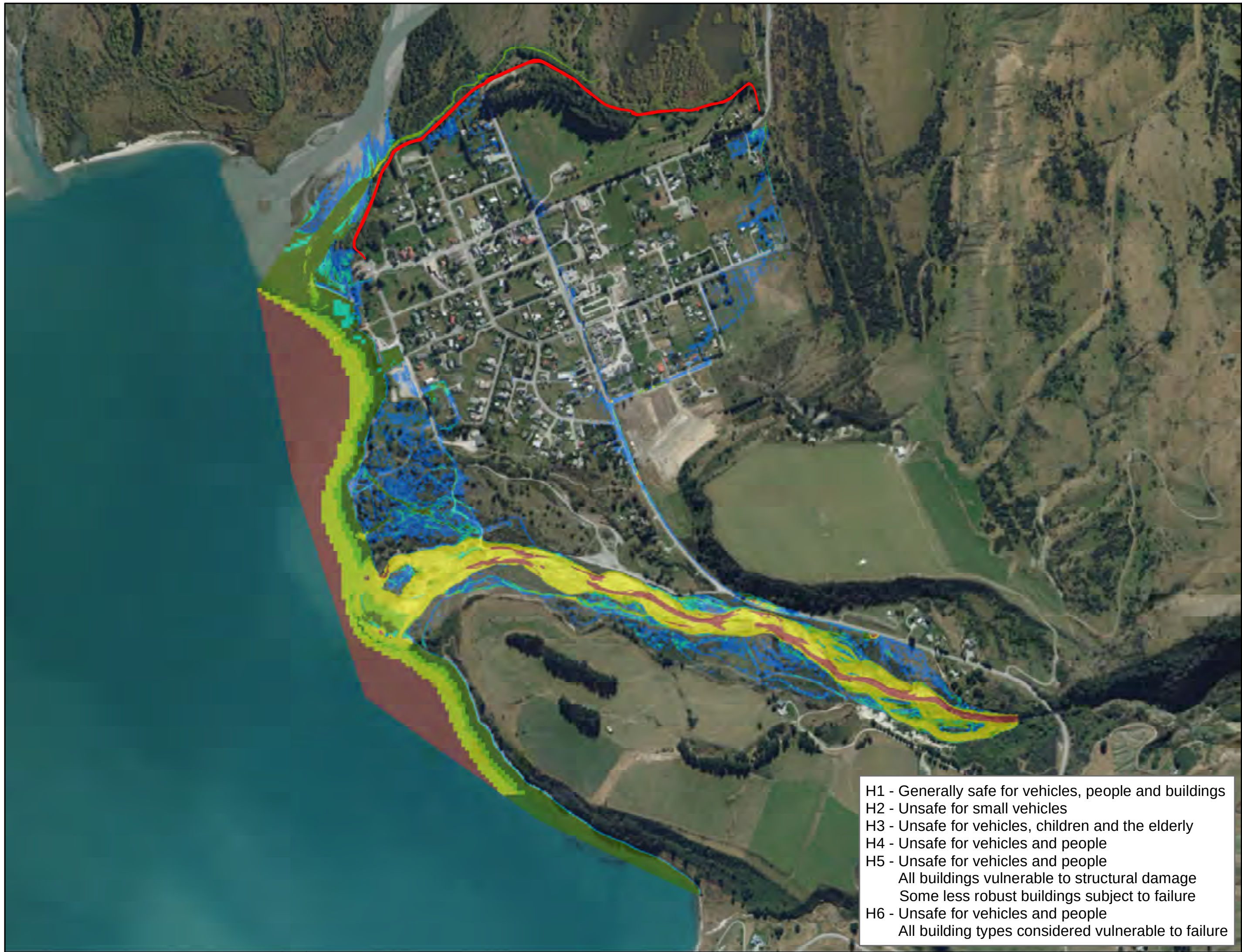


Legend

Stopbank

Hazard Category

H6
H5
H4
H3
H2
H1

LANDRIVERSEA CONSULTING

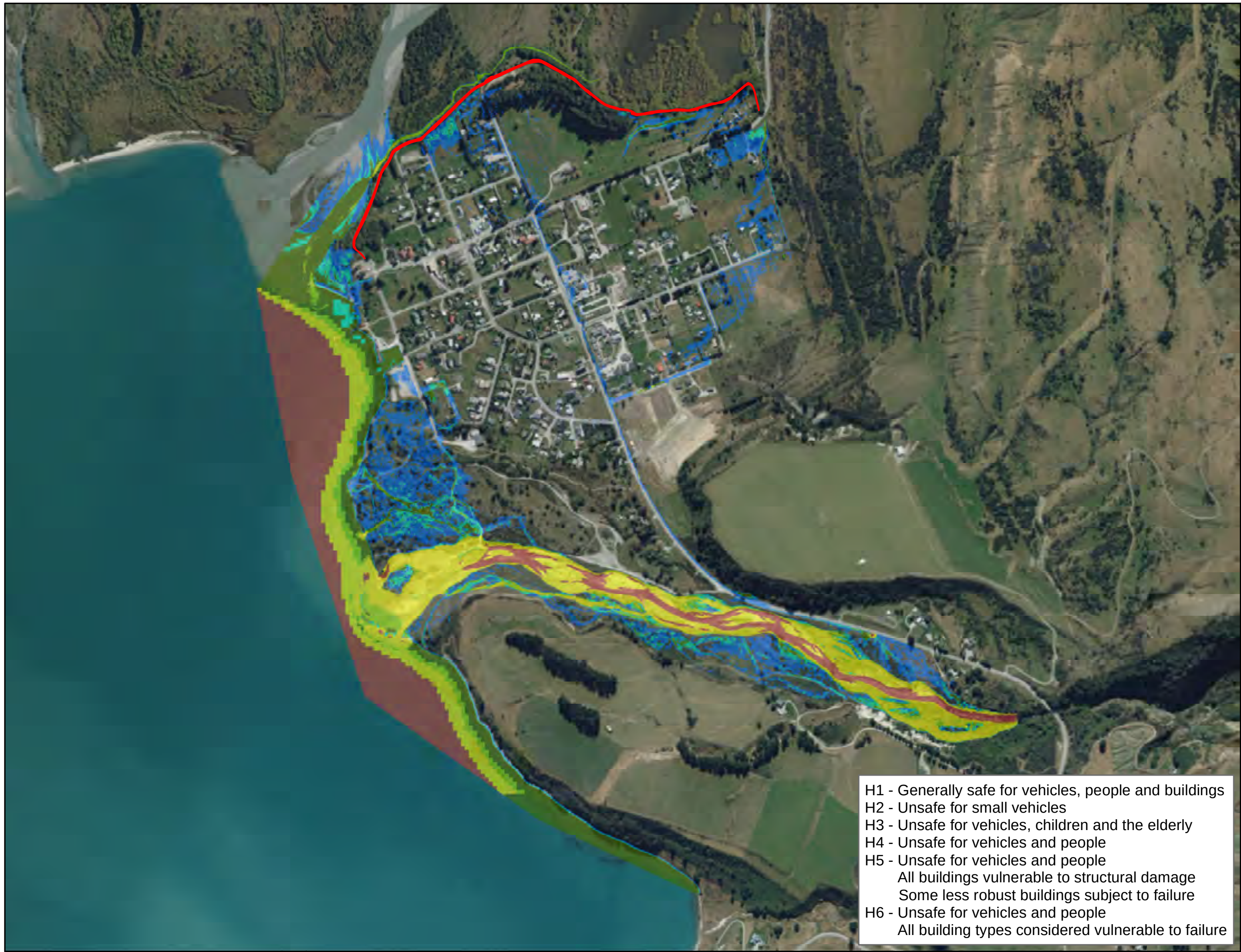
Otago Regional Council

0 0.1 0.2 0.4
Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE	
Buckler Burn Flood Modelling	**HAZARD MAP** **Design Scenario 2019 - Q 200 m3/s**	CREATED BY UP	**27/07/2023**	**1:9,000**	N
		REVISED BY	AUTHOR **Matthew Gardner**		



Legend

- Stopbank

Hazard Category

- H6
- H5
- H4
- H3
- H2
- H1

LANDRIVERSEA CONSULTING

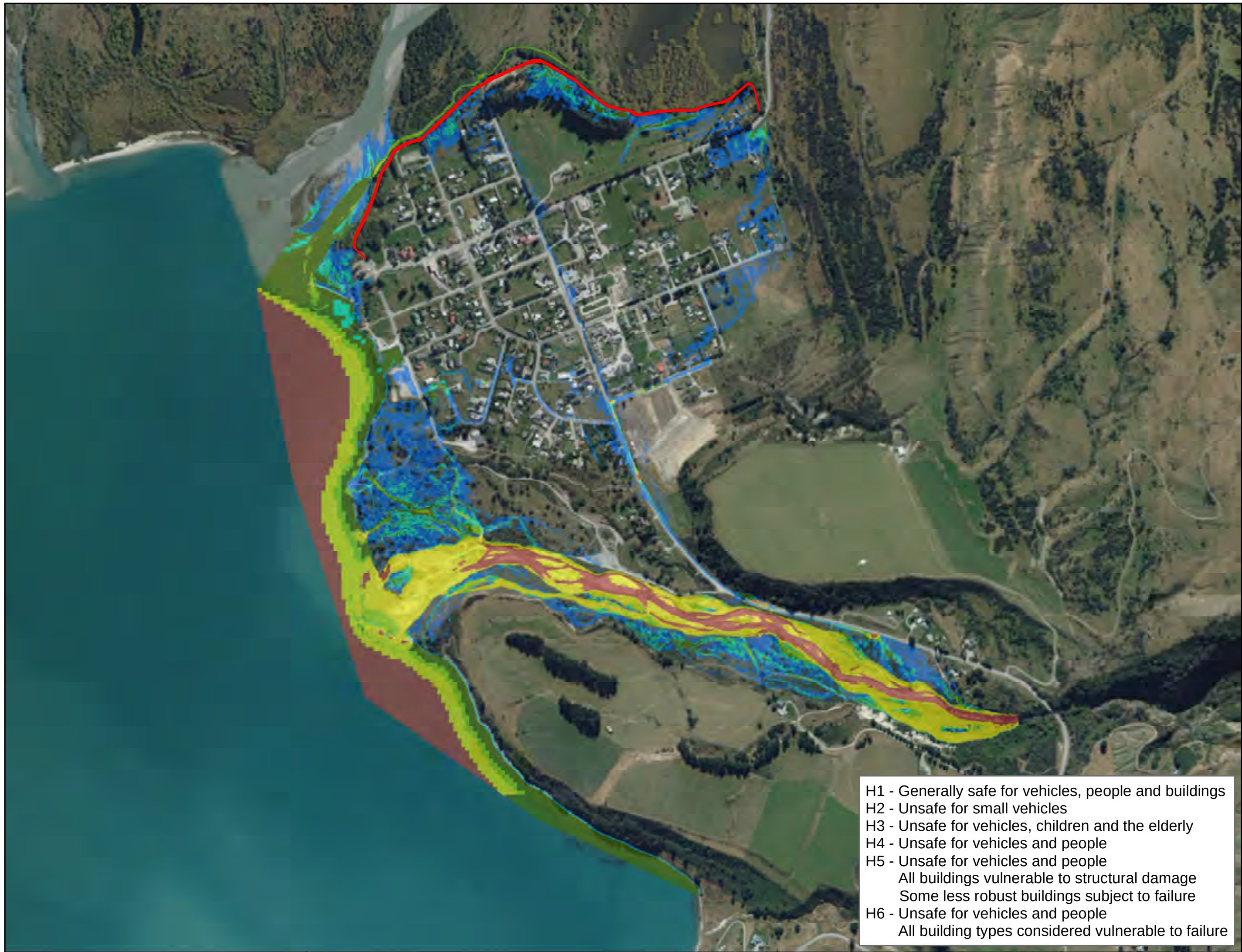
Otago Regional Council

0 0.1 0.2 0.4 Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE
Buckler Burn Flood Modelling	**HAZARD MAP** **Design Scenario 2019 - Q 250 m3/s**	CREATED BY UP	**27/07/2023**	**1:9,000**
		REVISED BY	AUTHOR **Matthew Gardner**	N



Legend

Stopbank

Hazard Category

- H6
- H5
- H4
- H3
- H2
- H1

LANDRIVERSEA CONSULTING

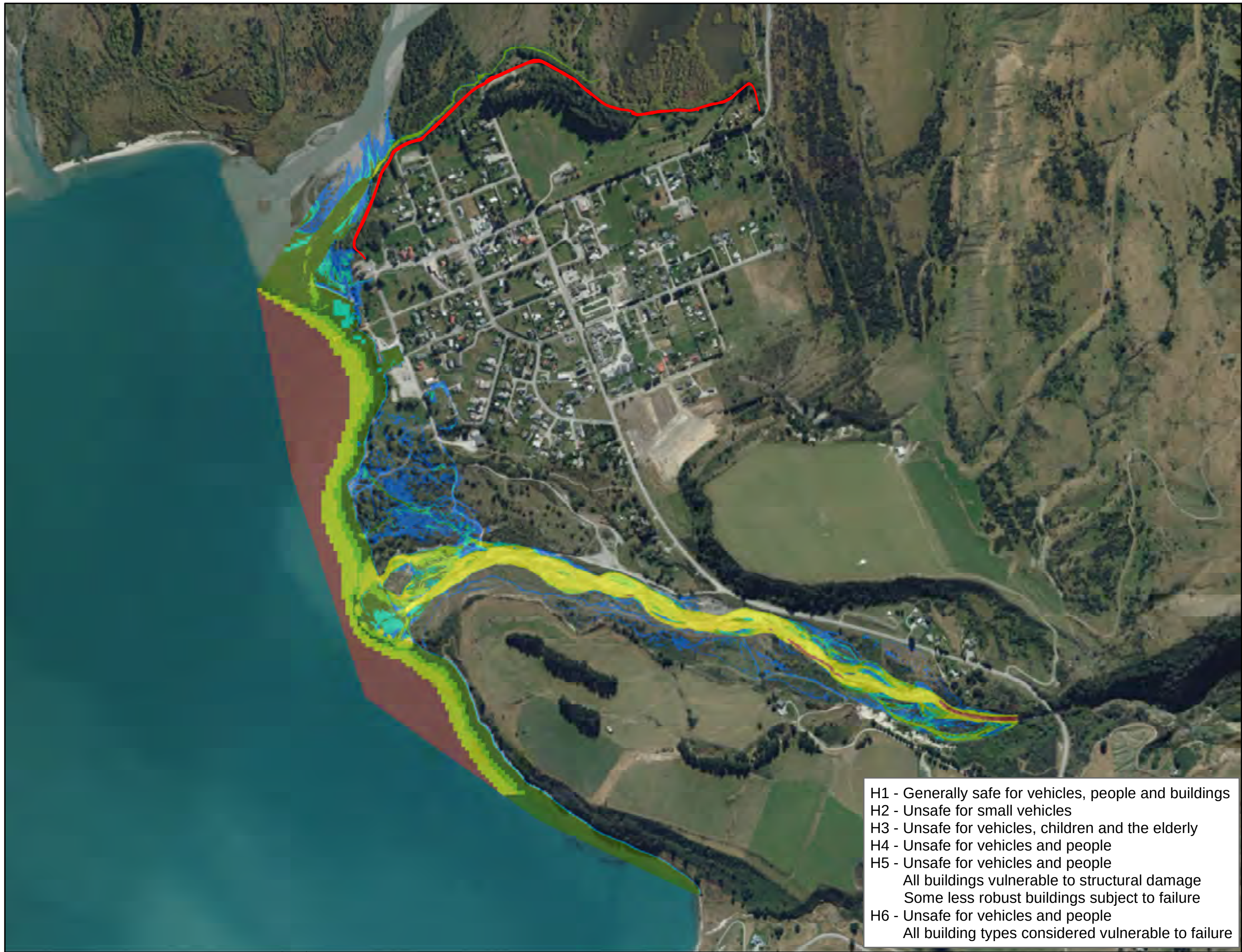
Otago Regional Council

0 0.1 0.2 0.4
Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT **Buckler Burn Flood Modelling**	MAP TITLE **HAZARD MAP** **Design Scenario 2019 - Q 300 m3/s**	REVISION **02** CREATED BY **UP** REVISED BY	DATE **27/07/2023** AUTHOR **Matthew Gardner**	A3 SCALE **1:9,000**	N



Legend

Stopbank

Hazard Category

H6
H5
H4
H3
H2
H1

LANDRIVERSEA CONSULTING

Otago Regional Council

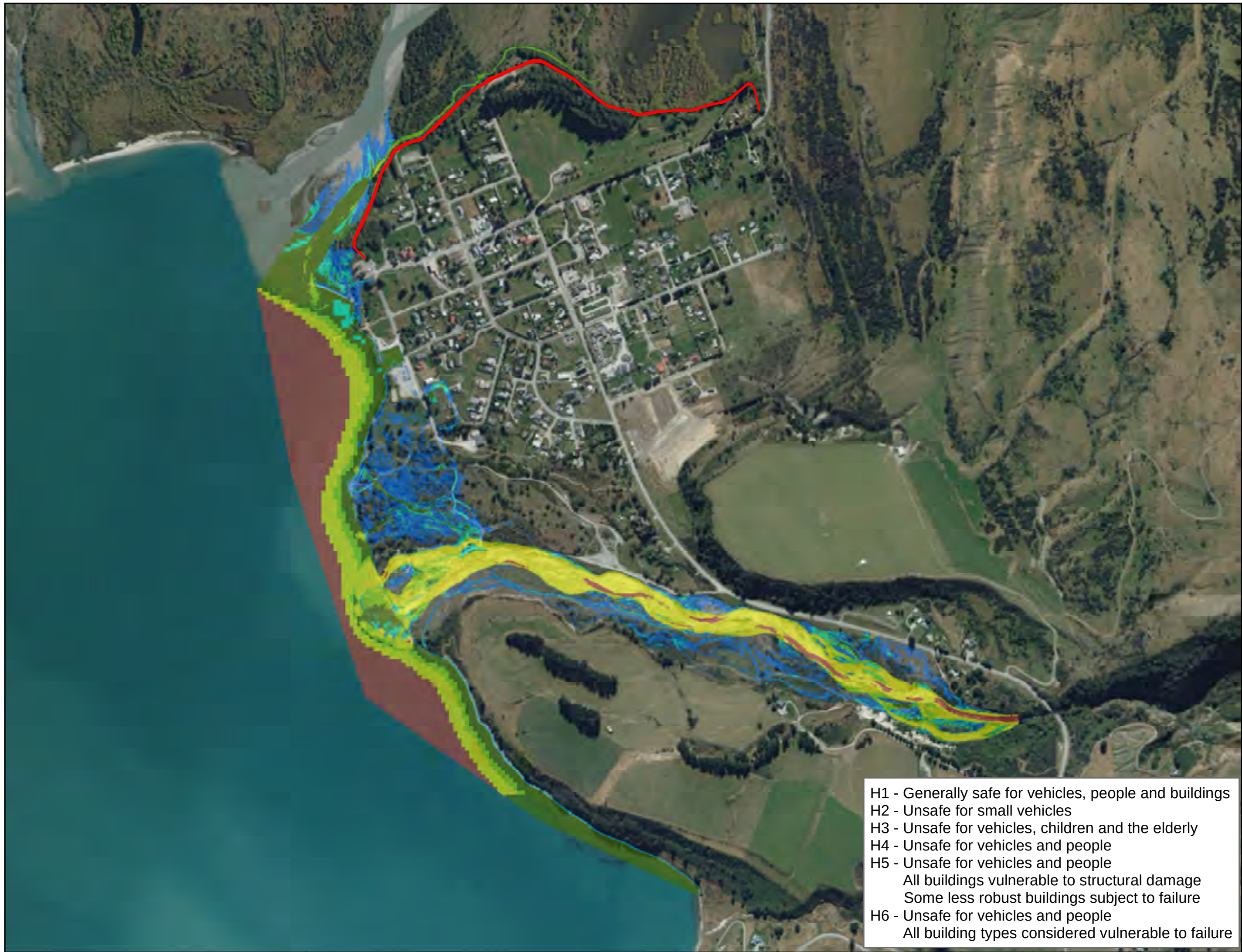
0 0.1 0.2 0.4
Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE
Buckler Burn Flood Modelling	**HAZARD MAP** **Design Scenario 2022 - Q 100 m3/s**	CREATED BY UP	**27/07/2023**	**1:9,000**
		REVISED BY	AUTHOR **Matthew Gardner**	

N



Legend

Stopbank

Hazard Category

- H6
- H5
- H4
- H3
- H2
- H1

LANDRIVERSEA CONSULTING

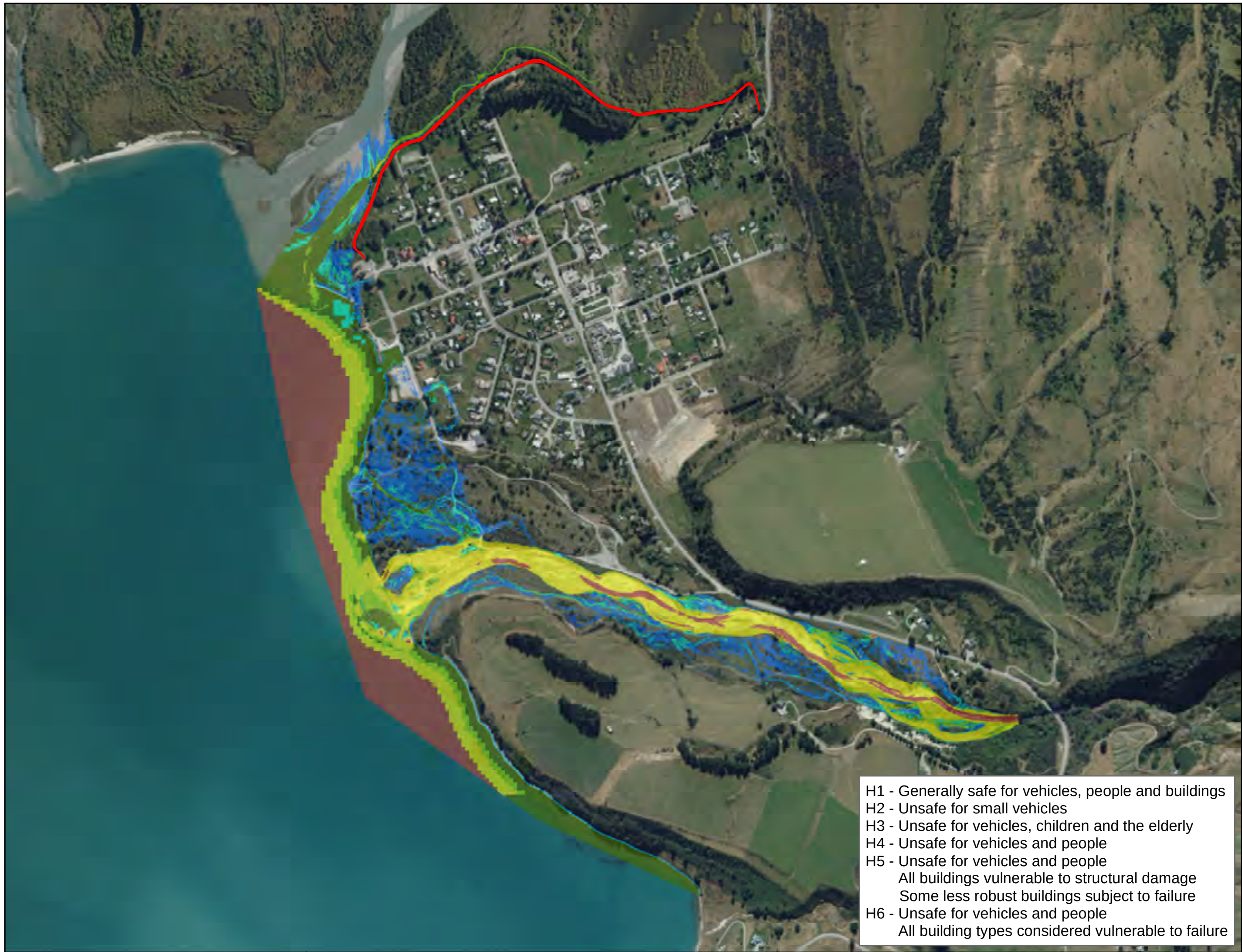
Otago Regional Council

0 0.1 0.2 0.4 Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE
Buckler Burn Flood Modelling	**HAZARD MAP** **Design Scenario 2022 - Q 150 m3/s**	CREATED BY **UP**	**27/07/2023**	**1:9,000**
		REVISED BY	AUTHOR **Matthew Gardner**	N



Legend

Stopbank

Hazard Category

- H6
- H5
- H4
- H3
- H2
- H1

LANDRIVERSEA CONSULTING

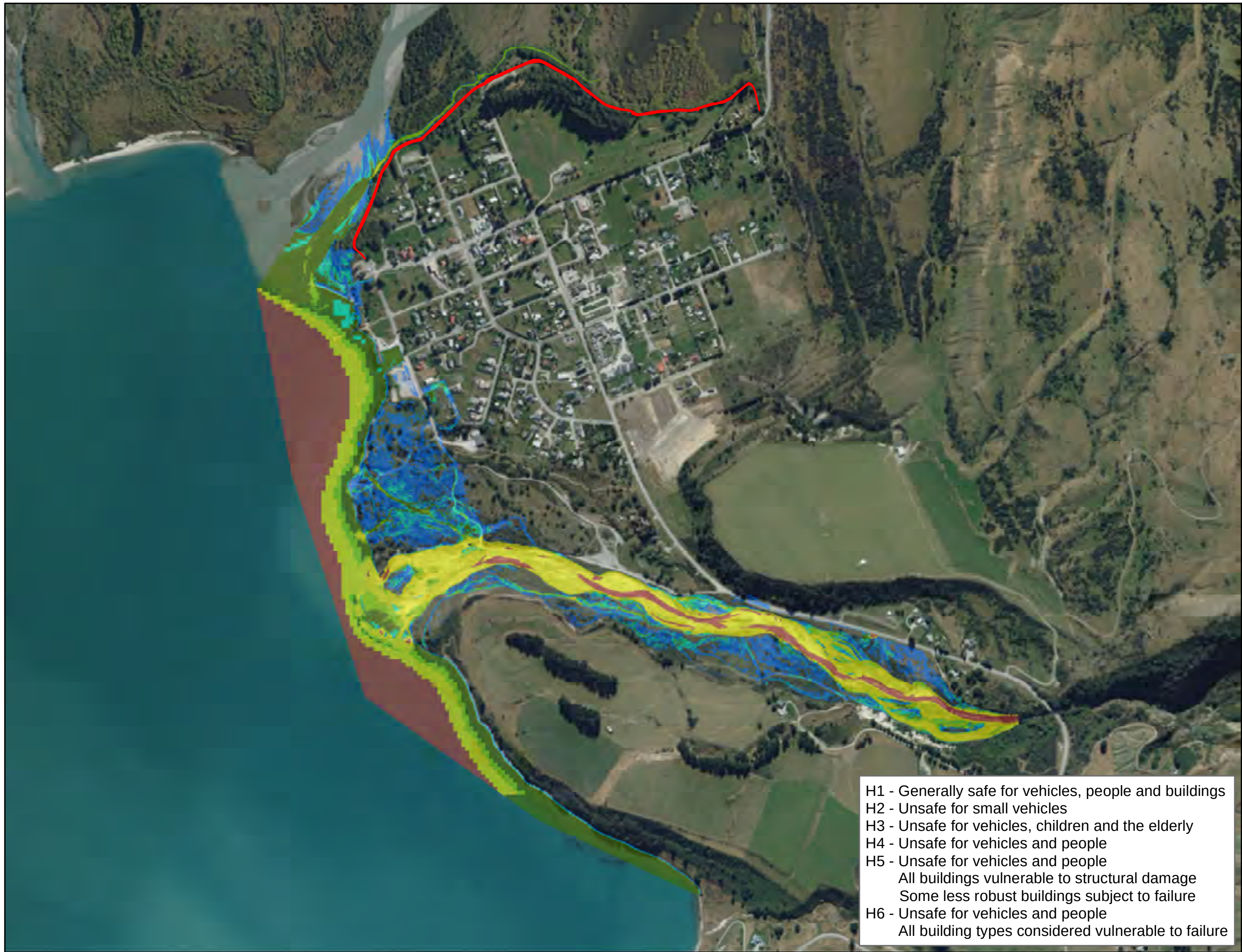
Otago Regional Council

0 0.1 0.2 0.4 Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE	
Buckler Burn Flood Modelling	**HAZARD MAP** **Design Scenario 2022 - Q 180 m3/s**	CREATED BY **UP**	**27/07/2023**	**1:9,000**	N
		REVISED BY	AUTHOR **Matthew Gardner**		



Legend

Stopbank

Hazard Category

- H6
- H5
- H4
- H3
- H2
- H1

LANDRIVERSEA CONSULTING

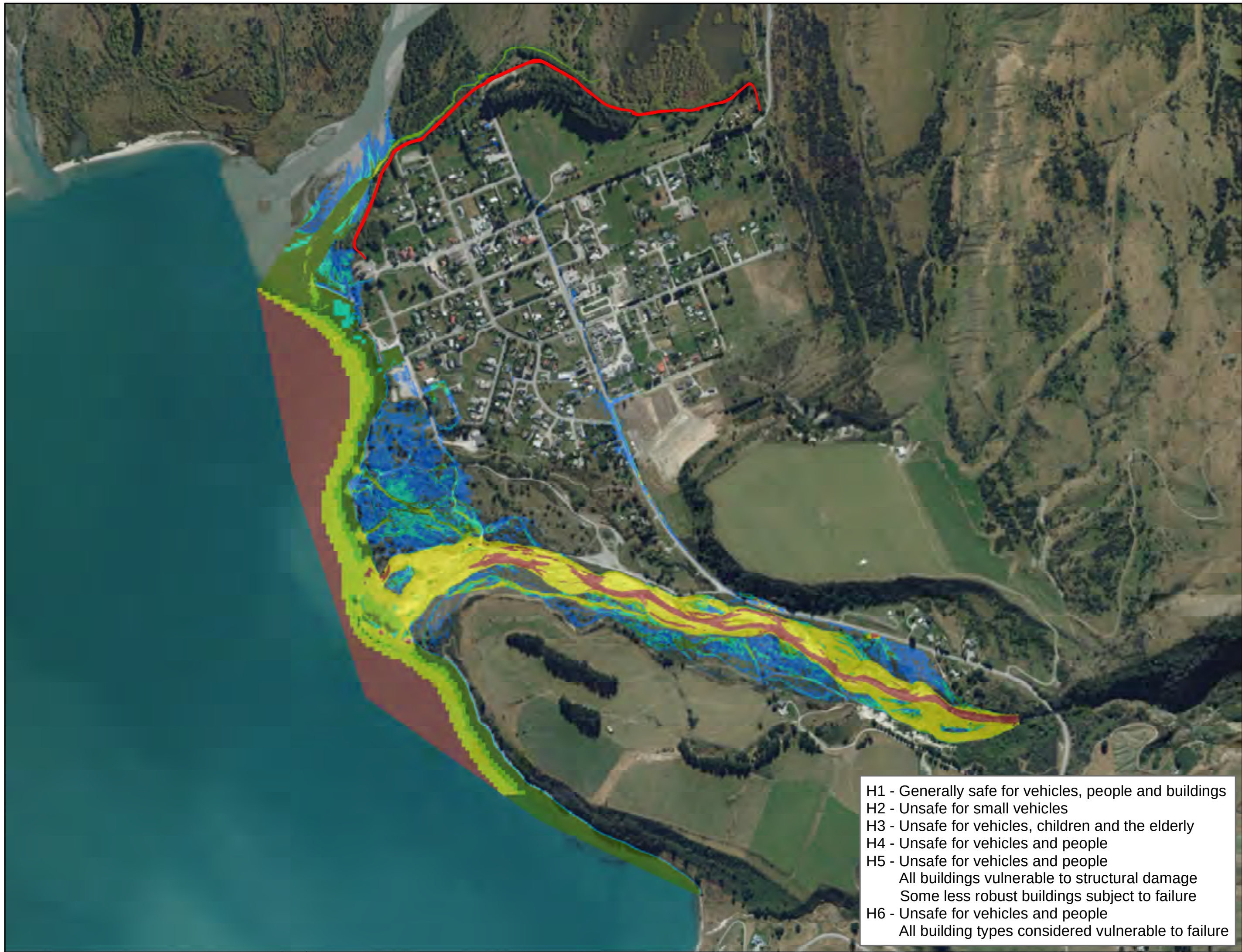
Otago Regional Council

0 0.1 0.2 0.4 Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE	N
Buckler Burn Flood Modelling	**HAZARD MAP** **Design Scenario 2022 - Q 200 m3/s**	CREATED BY UP	**27/07/2023**	**1:9,000**	
		REVISED BY	AUTHOR **Matthew Gardner**		



Legend

Stopbank

Hazard Category

H6
H5
H4
H3
H2
H1

LANDRIVERSEA CONSULTING

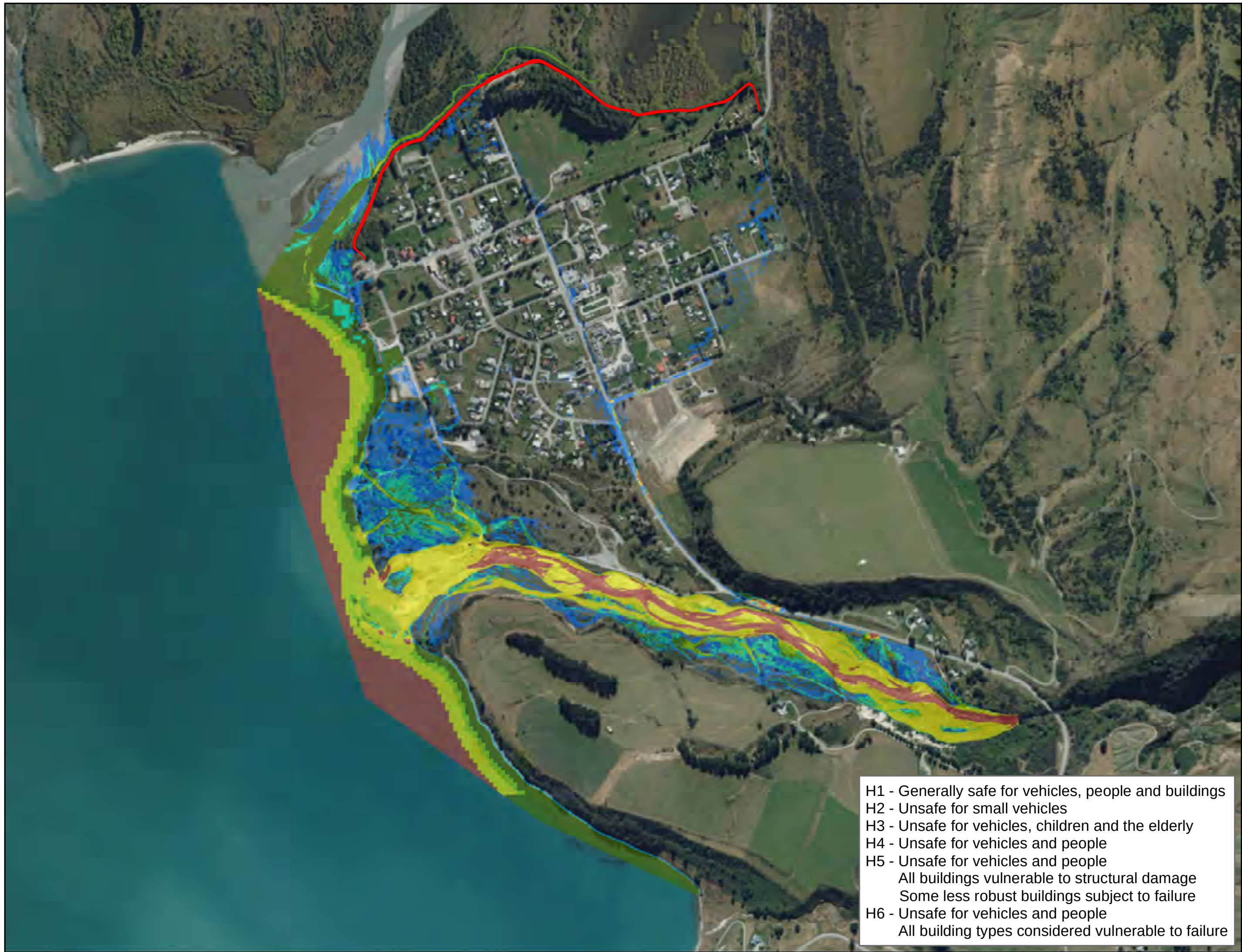
Otago Regional Council

0 0.1 0.2 0.4
Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE	
Buckler Burn Flood Modelling	**HAZARD MAP** **Design Scenario 2022 - Q 250 m3/s**	CREATED BY UP	**27/07/2023**	**1:9,000**	N
		REVISED BY	AUTHOR **Matthew Gardner**		



Legend

Stopbank

Hazard Category

H6

H5

H4

H3

H2

H1

LANDRIVERSEA CONSULTING

Otago Regional Council

0 0.1 0.2 0.4
Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION **02**	DATE	A3 SCALE	
Buckler Burn Flood Modelling	**HAZARD MAP** **Design Scenario 2022 - Q 300 m3/s**	CREATED BY **UP**	**27/07/2023**	**1:9,000**	N
		REVISED BY	AUTHOR **Matthew Gardner**		

APPENDIX D – AGGRADATION SCENARIOS – PEAK FLOOD DEPTH MAPS

LANDRIVERSEA CONSULTING

Otago Regional Council

0 0.1 0.2 0.4
Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE	
Buckler Burn Flood Modelling	**PEAK DEPTH MAP** **Aggradation Scenario A - Q 100m3/s**	CREATED BY UP	**27/07/2023**	**1:9,000**	N
		REVISED BY	AUTHOR **Matthew Gardner**		

Legend

Stopbank

Peak Depth(m)

- 0
- 0 - 0.05
- 0.05 - 0.1
- 0.1 - 0.3
- 0.3 - 0.5
- 0.5 - 1
- 1 - 2
- 2+

LANDRIVERSEA CONSULTING

Otago Regional Council

0 0.1 0.2 0.4
Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE	
Buckler Burn Flood Modelling	**PEAK DEPTH MAP** **Aggradation Scenario A - Q 150m3/s**	CREATED BY UP	27/07/2023	1:9,000	N
		REVISED BY	AUTHOR **Matthew Gardner**		

Legend

- Stopbank

Peak Depth(m)

- 0
- 0 - 0.05
- 0.05 - 0.1
- 0.1 - 0.3
- 0.3 - 0.5
- 0.5 - 1
- 1 - 2
- 2+

LANDRIVERSEA CONSULTING

Otago Regional Council

0 0.1 0.2 0.4
Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

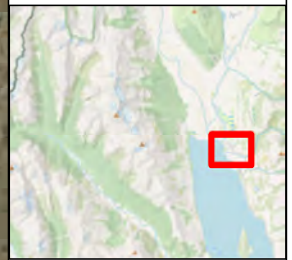
PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE	
Buckler Burn Flood Modelling	**PEAK DEPTH MAP** **Aggradation Scenario A - Q 180m3/s**	CREATED BY **UP**	**27/07/2023**	**1:9,000**	N
		REVISED BY	AUTHOR **Matthew Gardner**		

Legend

Stopbank	

Peak Depth(m)

- 0
- 0 - 0.05
- 0.05 - 0.1
- 0.1 - 0.3
- 0.3 - 0.5
- 0.5 - 1
- 1 - 2
- 2+



LANDRIVERSEA CONSULTING

Otago Regional Council

0 0.1 0.2 0.4 Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

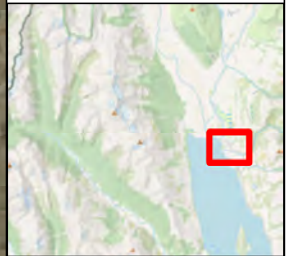
PROJECT	MAP TITLE	REVISION	DATE	A3 SCALE
Buckler Burn Flood Modelling	**PEAK DEPTH MAP** **Aggradation Scenario A - Q 200m3/s**	02		
		CREATED BY UP	27/07/2023	1:9,000
		REVISED BY	AUTHOR **Matthew Gardner**	N

Legend

Stopbank

Peak Depth(m)

- 0
- 0 - 0.05
- 0.05 - 0.1
- 0.1 - 0.3
- 0.3 - 0.5
- 0.5 - 1
- 1 - 2
- 2+



LANDRIVERSEA CONSULTING

Otago Regional Council

0 0.1 0.2 0.4
Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE
Buckler Burn Flood Modelling	**PEAK DEPTH MAP** **Aggradation Scenario A - Q 250m3/s**	CREATED BY UP	**27/07/2023**	**1:9,000**
		REVISED BY	AUTHOR **Matthew Gardner**	N

Legend

Stopbank

Peak Depth(m)

- 0
- 0 - 0.05
- 0.05 - 0.1
- 0.1 - 0.3
- 0.3 - 0.5
- 0.5 - 1
- 1 - 2
- 2+

LANDRIVERSEA CONSULTING

Otago Regional Council

0 0.1 0.2 0.4
Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE	
Buckler Burn Flood Modelling	**PEAK DEPTH MAP** **Aggradation Scenario A - Q 300m3/s**	CREATED BY UP	**27/07/2023**	**1:9,000**	N
		REVISED BY	AUTHOR **Matthew Gardner**		

Legend

- Stopbank

Peak Depth(m)

- 0
- 0 - 0.05
- 0.05 - 0.1
- 0.1 - 0.3
- 0.3 - 0.5
- 0.5 - 1
- 1 - 2
- 2+

LANDRIVERSEA CONSULTING

Otago Regional Council

0 0.1 0.2 0.4 Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE	
Buckler Burn Flood Modelling	**PEAK DEPTH MAP** **Aggradation Scenario B - Q 100m3/s**	CREATED BY UP	**27/07/2023**	**1:9,000**	N
		REVISED BY	AUTHOR **Matthew Gardner**		

LANDRIVERSEA CONSULTING

Otago Regional Council

0 0.1 0.2 0.4
Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE	
Buckler Burn Flood Modelling	**PEAK DEPTH MAP** **Aggradation Scenario B - Q 150m3/s**	CREATED BY UP	**27/07/2023**	**1:9,000**	N
		REVISED BY	AUTHOR **Matthew Gardner**		

LANDRIVERSEA CONSULTING

Otago Regional Council

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE	
Buckler Burn Flood Modelling	**PEAK DEPTH MAP** **Aggradation Scenario B - Q 180m3/s**	CREATED BY UP	**27/07/2023**	**1:9,000**	N
		REVISED BY	AUTHOR **Matthew Gardner**		

LANDRIVERSEA CONSULTING

Otago Regional Council

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE	
Buckler Burn Flood Modelling	**PEAK DEPTH MAP** **Aggradation Scenario B - Q 200m3/s**	CREATED BY UP	**27/07/2023**	**1:9,000**	N
		REVISED BY	AUTHOR **Matthew Gardner**		

LANDRIVERSEA CONSULTING

Otago Regional Council

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE
Buckler Burn Flood Modelling	**PEAK DEPTH MAP** **Aggradation Scenario B - Q 250m3/s**	CREATED BY UP	**27/07/2023**	**1:9,000**
		REVISED BY	AUTHOR **Matthew Gardner**	

N

Legend

- Stopbank

Peak Depth(m)

- 0
- 0 - 0.05
- 0.05 - 0.1
- 0.1 - 0.3
- 0.3 - 0.5
- 0.5 - 1
- 1 - 2
- 2+

LANDRIVERSEA CONSULTING

Otago Regional Council

0 0.1 0.2 0.4
Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE	
Buckler Burn Flood Modelling	**PEAK DEPTH MAP** **Aggradation Scenario B - Q 300m3/s**	CREATED BY UP	**27/07/2023**	**1:9,000**	N
		REVISED BY	AUTHOR **Matthew Gardner**		

Legend

Stopbank	
Peak Depth(m)	
0	
0 - 0.05	
0.05 - 0.1	
0.1 - 0.3	
0.3 - 0.5	
0.5 - 1	
1 - 2	
2+	

LANDRIVERSEA CONSULTING

Otago Regional Council

0 0.1 0.2 0.4
Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE	
Buckler Burn Flood Modelling	**PEAK DEPTH MAP** **Aggradation Scenario C - Q 100m3/s**	CREATED BY UP	27/07/2023	1:9,000	N
		REVISED BY	AUTHOR **Matthew Gardner**		

Legend

Stopbank

Peak Depth(m)

- 0
- 0 - 0.05
- 0.05 - 0.1
- 0.1 - 0.3
- 0.3 - 0.5
- 0.5 - 1
- 1 - 2
- 2+

LANDRIVERSEA CONSULTING

Otago Regional Council

0 0.1 0.2 0.4
Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE
Buckler Burn Flood Modelling	**PEAK DEPTH MAP** **Aggradation Scenario C - Q 150m3/s**	CREATED BY UP	**27/07/2023**	**1:9,000**
		REVISED BY	AUTHOR **Matthew Gardner**	

N

Legend

- Stopbank

Peak Depth(m)

- 0
- 0 - 0.05
- 0.05 - 0.1
- 0.1 - 0.3
- 0.3 - 0.5
- 0.5 - 1
- 1 - 2
- 2+

LANDRIVERSEA CONSULTING

Otago Regional Council

0 0.1 0.2 0.4
Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE	
Buckler Burn Flood Modelling	**PEAK DEPTH MAP** **Aggradation Scenario C - Q 180m3/s**	CREATED BY **UP**	**27/07/2023**	**1:9,000**	N
		REVISED BY	AUTHOR **Matthew Gardner**		

Legend

Stopbank	Stopbank

Peak Depth(m)

- 0
- 0 - 0.05
- 0.05 - 0.1
- 0.1 - 0.3
- 0.3 - 0.5
- 0.5 - 1
- 1 - 2
- 2+

LANDRIVERSEA CONSULTING

Otago Regional Council

0 0.1 0.2 0.4
Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE	N
Buckler Burn Flood Modelling	**PEAK DEPTH MAP** **Aggradation Scenario C - Q 200m3/s**	CREATED BY UP	**27/07/2023**	**1:9,000**	
		REVISED BY	AUTHOR **Matthew Gardner**		

Legend

- Stopbank

Peak Depth(m)

- 0
- 0 - 0.05
- 0.05 - 0.1
- 0.1 - 0.3
- 0.3 - 0.5
- 0.5 - 1
- 1 - 2
- 2+

LANDRIVERSEA CONSULTING

Otago Regional Council

0 0.1 0.2 0.4
Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE
Buckler Burn Flood Modelling	**PEAK DEPTH MAP** **Aggradation Scenario C - Q 250m3/s**	CREATED BY **UP**	**27/07/2023**	**1:9,000**
		REVISED BY	AUTHOR **Matthew Gardner**	

N

LANDRIVERSEA CONSULTING

Otago Regional Council

0 0.1 0.2 0.4
Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE	N
Buckler Burn Flood Modelling	**PEAK DEPTH MAP** **Aggradation Scenario C - Q 300m3/s**	CREATED BY UP	**27/07/2023**	**1:9,000**	
		REVISED BY	AUTHOR **Matthew Gardner**		

APPENDIX E – AGGRADATION SCENARIOS – PEAK SPEED MAPS

LANDRIVERSEA CONSULTING

Otago Regional Council

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE
Buckler Burn Flood Modelling	**PEAK VELOCITY MAP** **Aggradation Scenario A - Q 100m3/s**	CREATED BY UP	**27/07/2023**	**1:9,000**
		REVISED BY	AUTHOR **Matthew Gardner**	

N

Legend

- Stopbank

Peak velocity(m/s)

- 0
- 0 - 0.05
- 0.05 - 0.1
- 0.1 - 0.3
- 0.3 - 0.5
- 0.5 - 1
- 1 - 2
- 2+

LANDRIVERSEA CONSULTING

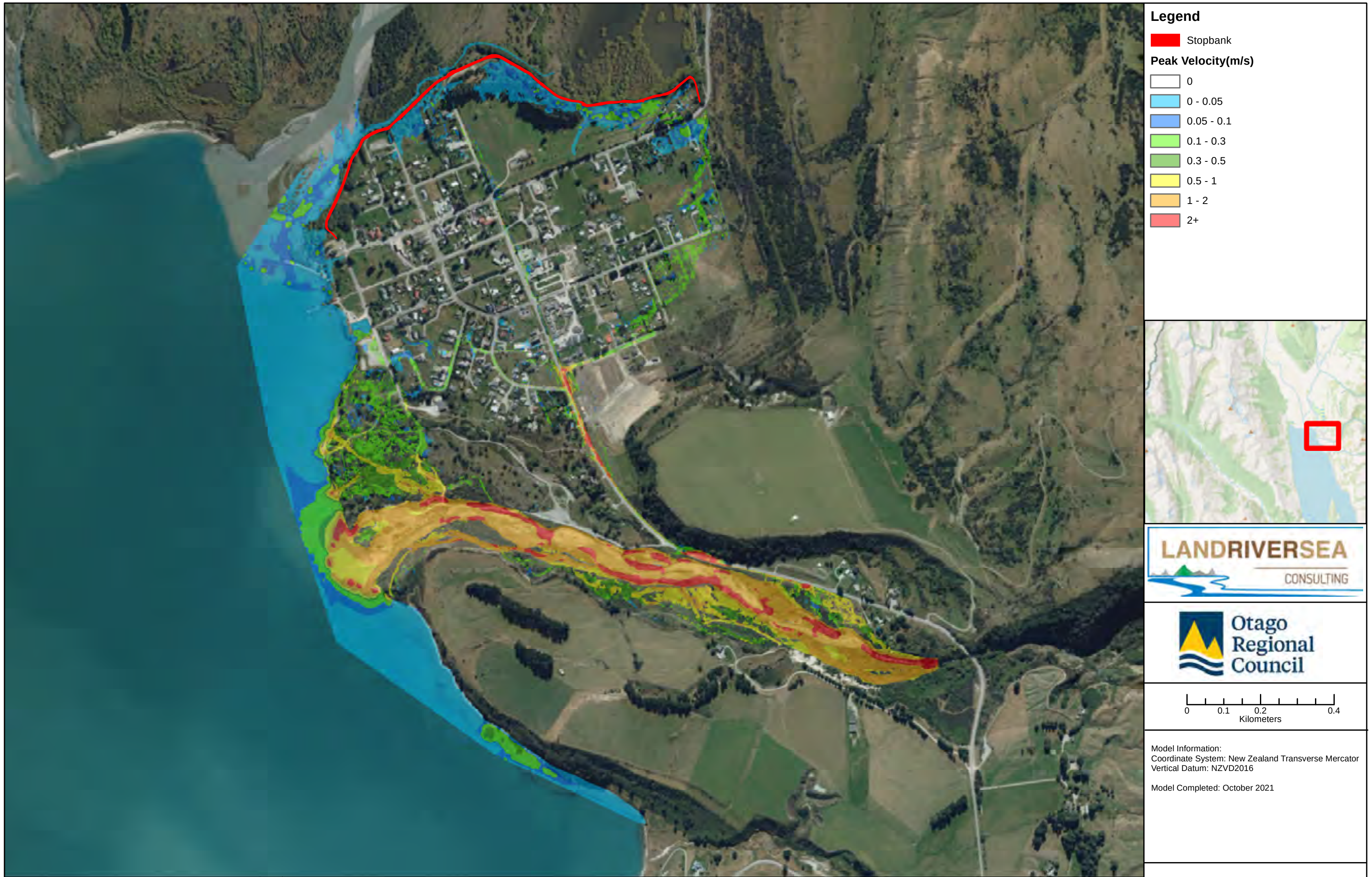
Otago Regional Council

0 0.1 0.2 0.4
Kilometers

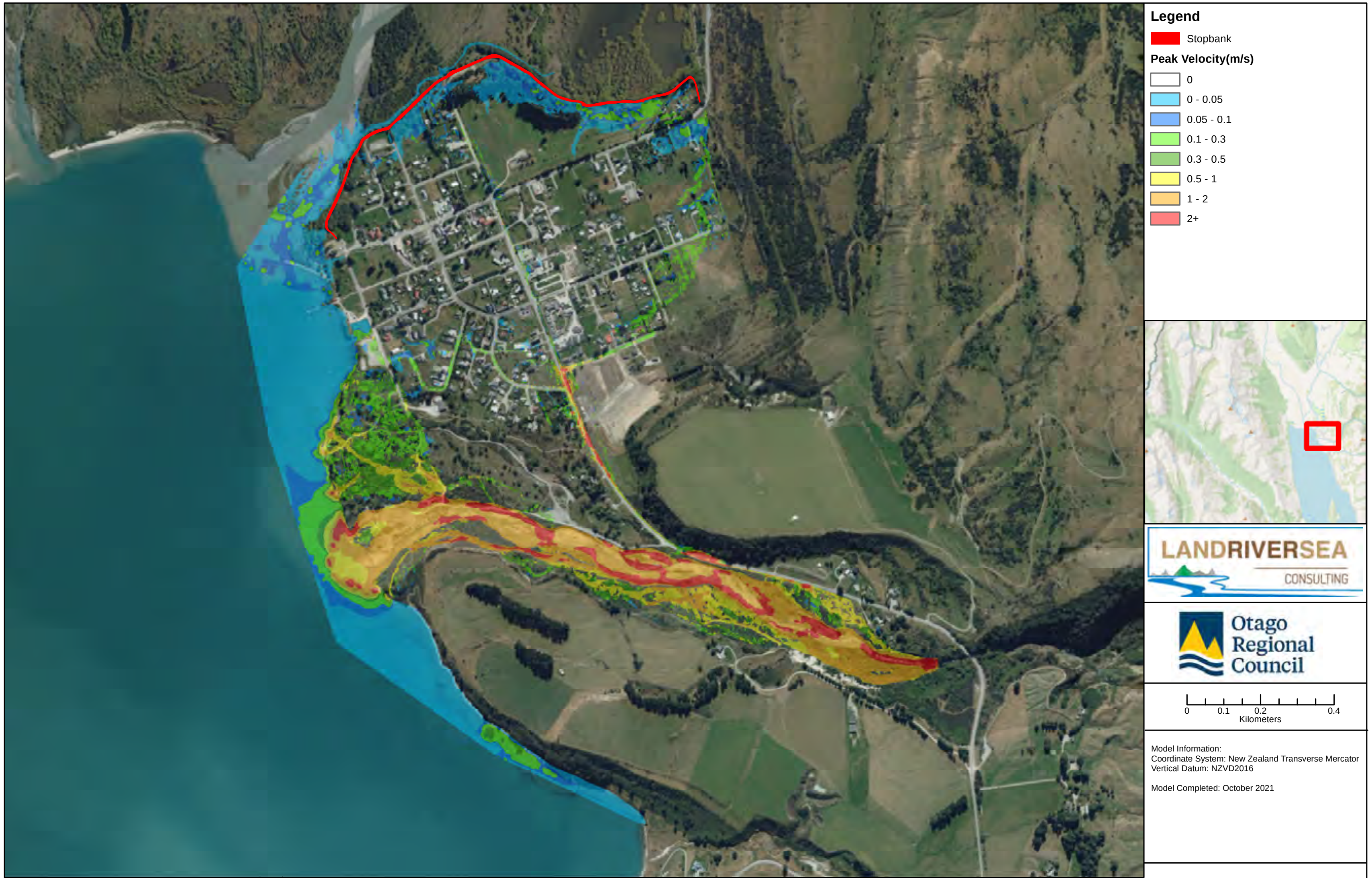
Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE	
Buckler Burn Flood Modelling	**PEAK VELOCITY MAP** **Aggradation Scenario A - Q 150m3/s**	CREATED BY UP	**27/07/2023**	**1:9,000**	N
		REVISED BY	AUTHOR **Matthew Gardner**		



PROJECT **Buckler Burn Flood Modelling**	MAP TITLE **PEAK VELOCITY MAP** **Aggradation Scenario A - Q 180m3/s**	REVISION **02** CREATED BY **UP** REVISED BY	DATE **27/07/2023** AUTHOR **Matthew Gardner**	A3 SCALE **1:9,000**	N



PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE	
Buckler Burn Flood Modelling	**PEAK VELOCITY MAP** **Aggradation Scenario A - Q 200m3/s**	CREATED BY **UP**	**27/07/2023**	**1:9,000**	N
		REVISED BY	AUTHOR **Matthew Gardner**		

Legend

Stopbank

Peak Velocity(m/s)

- 0
- 0 - 0.05
- 0.05 - 0.1
- 0.1 - 0.3
- 0.3 - 0.5
- 0.5 - 1
- 1 - 2
- 2+

LANDRIVERSEA CONSULTING

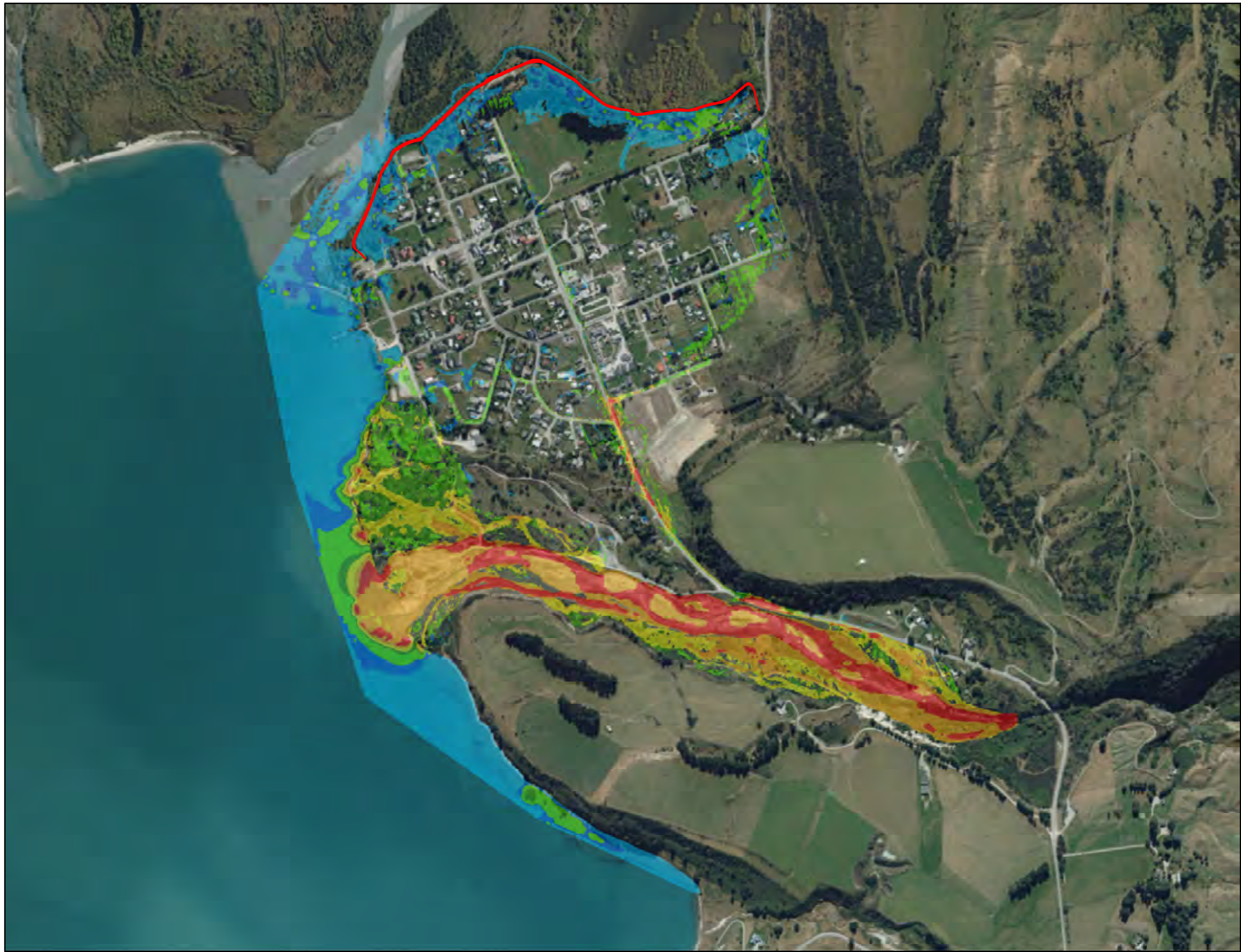
Otago Regional Council

0 0.1 0.2 0.4
Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE	
Buckler Burn Flood Modelling	**PEAK VELOCITY MAP** **Aggradation Scenario A - Q 250m3/s**	CREATED BY **UP**	**27/07/2023**	**1:9,000**	N
		REVISED BY	AUTHOR **Matthew Gardner**		



Legend

Stopbank

Peak Velocity(m/s)

- 0
- 0 - 0.05
- 0.05 - 0.1
- 0.1 - 0.3
- 0.3 - 0.5
- 0.5 - 1
- 1 - 2
- 2+

LANDRIVERSEA CONSULTING

Otago Regional Council

0 0.1 0.2 0.4
Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE	
Buckler Burn Flood Modelling	**PEAK VELOCITY MAP** **Aggradation Scenario A - Q 300m3/s**	CREATED BY **UP**	**27/07/2023**	**1:9,000**	N
		REVISED BY	AUTHOR **Matthew Gardner**		

Legend

- Stopbank

Peak Velocity(m/s)

- 0
- 0 - 0.05
- 0.05 - 0.1
- 0.1 - 0.3
- 0.3 - 0.5
- 0.5 - 1
- 1 - 2
- 2+

LANDRIVERSEA CONSULTING

Otago Regional Council

0 0.1 0.2 0.4
Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE
Buckler Burn Flood Modelling	**PEAK VELOCITY MAP** **Aggradation Scenario B - Q 100m3/s**	CREATED BY UP	**27/07/2023**	**1:9,000**
		REVISED BY	AUTHOR **Matthew Gardner**	N

Legend

- Stopbank

Peak Velocity(m/s)

- 0
- 0 - 0.05
- 0.05 - 0.1
- 0.1 - 0.3
- 0.3 - 0.5
- 0.5 - 1
- 1 - 2
- 2+

LANDRIVERSEA CONSULTING

Otago Regional Council

0 0.1 0.2 0.4 Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE
Buckler Burn Flood Modelling	**PEAK VELOCITY MAP** **Aggradation Scenario B - Q 150m3/s**	CREATED BY UP	**27/07/2023**	**1:9,000**
		REVISED BY	AUTHOR **Matthew Gardner**	

N

Legend

Stopbank

Peak Velocity(m/s)

- 0
- 0 - 0.05
- 0.05 - 0.1
- 0.1 - 0.3
- 0.3 - 0.5
- 0.5 - 1
- 1 - 2
- 2+

LANDRIVERSEA CONSULTING

Otago Regional Council

0 0.1 0.2 0.4
Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE	
Buckler Burn Flood Modelling	**PEAK VELOCITY MAP** **Aggradation Scenario B - Q 180m3/s**	CREATED BY UP	**27/07/2023**	**1:9,000**	N
		REVISED BY	AUTHOR **Matthew Gardner**		

Legend

- Stopbank

Peak Velocity(m/s)

- 0
- 0 - 0.05
- 0.05 - 0.1
- 0.1 - 0.3
- 0.3 - 0.5
- 0.5 - 1
- 1 - 2
- 2+

LANDRIVERSEA CONSULTING

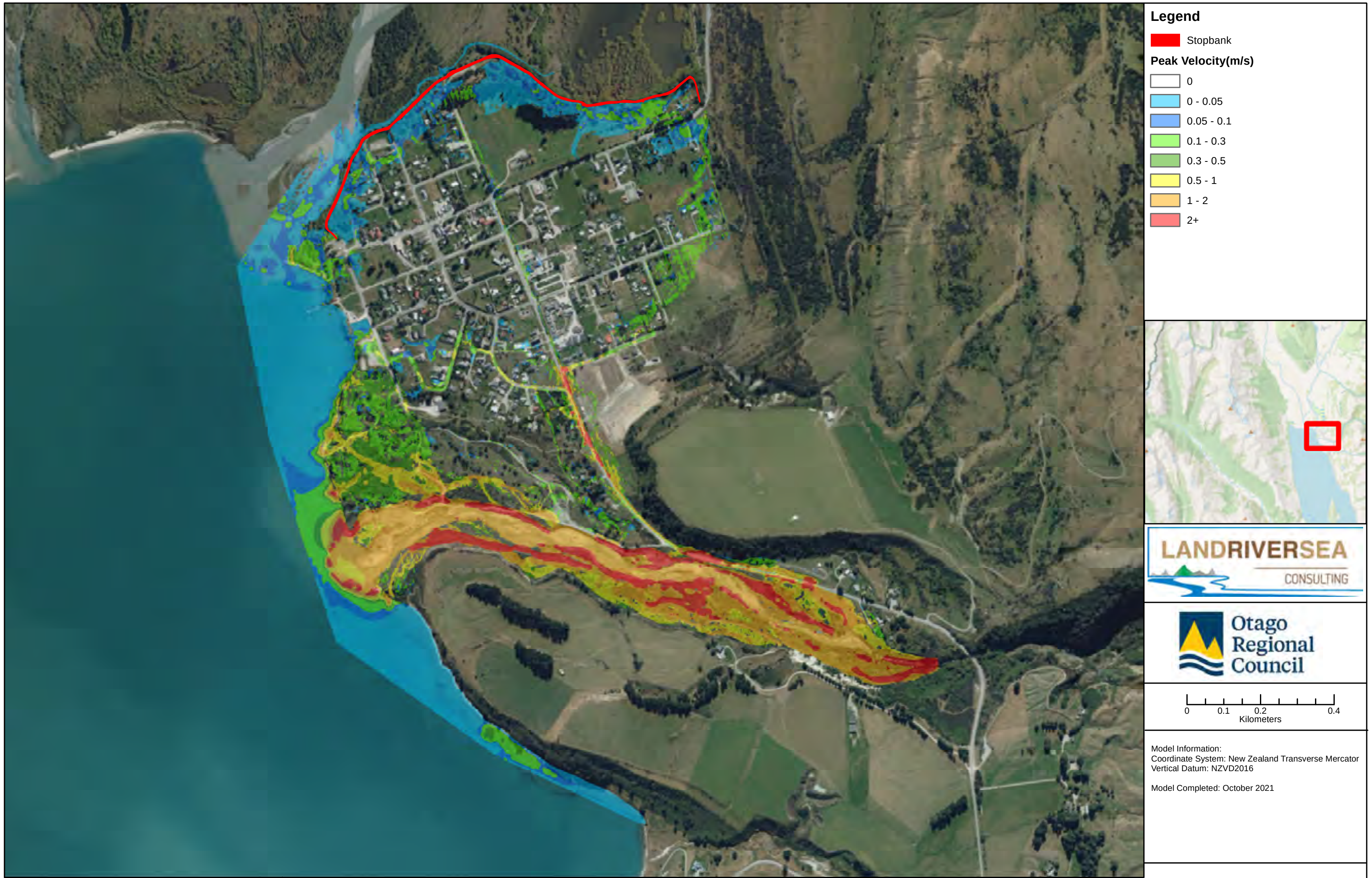
Otago Regional Council

0 0.1 0.2 0.4
Kilometers

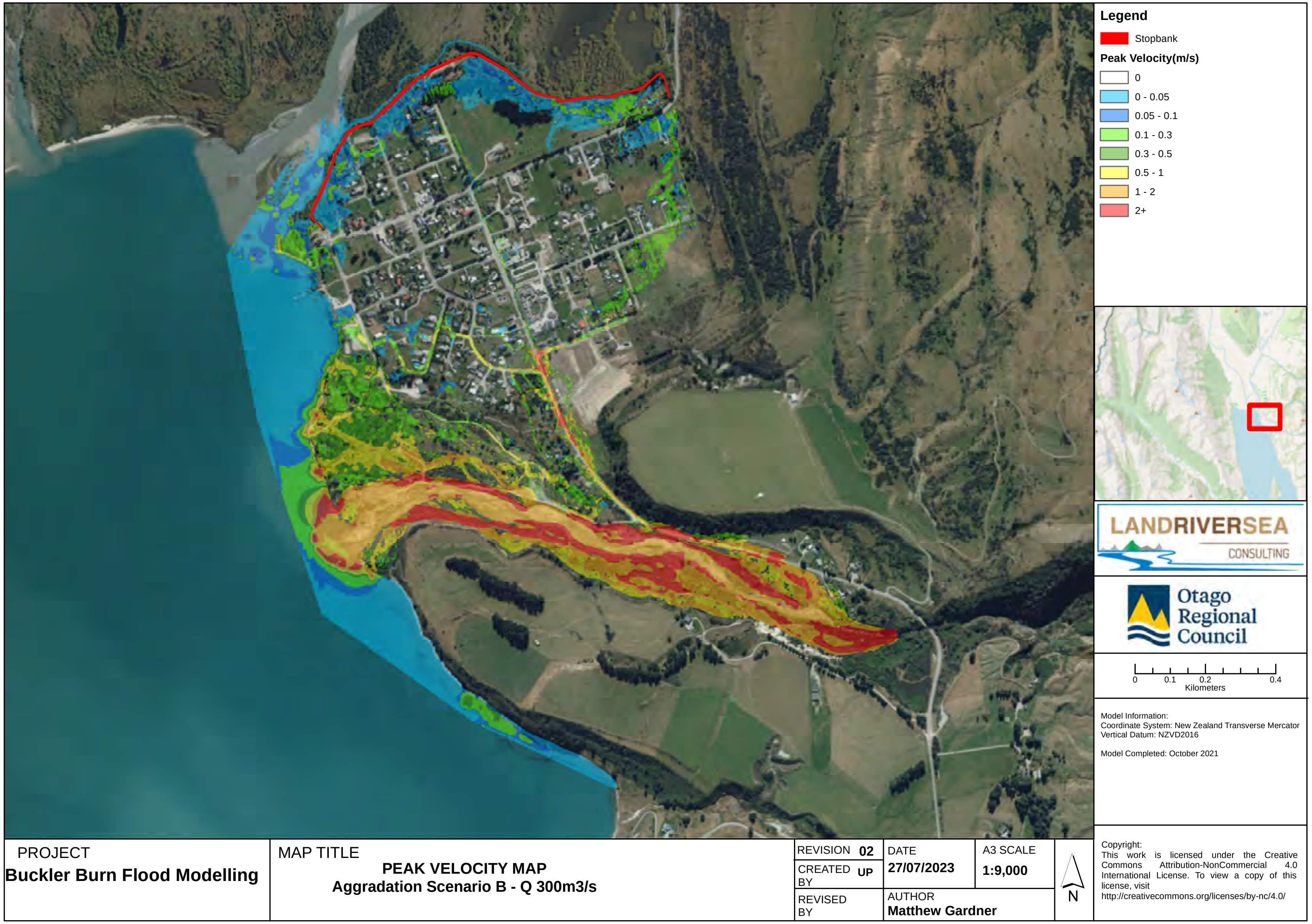
Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE	
Buckler Burn Flood Modelling	**PEAK VELOCITY MAP** **Aggradation Scenario B - Q 200m3/s**	CREATED BY UP	27/07/2023	1:9,000	N
		REVISED BY	AUTHOR **Matthew Gardner**		



PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE
Buckler Burn Flood Modelling	**PEAK VELOCITY MAP** **Aggradation Scenario B - Q 250m3/s**	CREATED BY UP	**27/07/2023**	**1:9,000**
		REVISED BY	AUTHOR **Matthew Gardner**	


Legend
Stopbank
Peak Velocity(m/s)
0
0 - 0.05
0.05 - 0.1
0.1 - 0.3
0.3 - 0.5
0.5 - 1
1 - 2
2+
LANDRIVERSEA
CONSULTING
Otago Regional Council
0 0.1 0.2 0.4
Kilometers
Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016
Model Completed: October 2021
PROJECT
Buckler Burn Flood Modelling
MAP TITLE
PEAK VELOCITY MAP
Aggradation Scenario B - Q 300m3/s
REVISION 02
CREATED BY UP
REVISED BY
DATE
27/07/2023
A3 SCALE
1:9,000
AUTHOR
Matthew Gardner
N
Copyright:
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Legend

- Stopbank

Peak Velocity(m/s)

- 0
- 0 - 0.05
- 0.05 - 0.1
- 0.1 - 0.3
- 0.3 - 0.5
- 0.5 - 1
- 1 - 2
- 2+

LANDRIVERSEA CONSULTING

Otago Regional Council

0 0.1 0.2 0.4
Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE	
Buckler Burn Flood Modelling	**PEAK VELOCITY MAP** **Aggradation Scenario C - Q 100m3/s**	CREATED BY **UP**	**27/07/2023**	**1:9,000**	N
		REVISED BY	AUTHOR **Matthew Gardner**		

Legend

Stopbank

Peak Velocity(m/s)

- 0
- 0 - 0.05
- 0.05 - 0.1
- 0.1 - 0.3
- 0.3 - 0.5
- 0.5 - 1
- 1 - 2
- 2+

LANDRIVERSEA CONSULTING

Otago Regional Council

0 0.1 0.2 0.4 Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE	
Buckler Burn Flood Modelling	**PEAK VELOCITY MAP** **Aggradation Scenario C - Q 150m3/s**	CREATED BY UP	**27/07/2023**	**1:9,000**	N
		REVISED BY	AUTHOR **Matthew Gardner**		

Legend

- Stopbank

Peak Velocity(m/s)

- 0
- 0 - 0.05
- 0.05 - 0.1
- 0.1 - 0.3
- 0.3 - 0.5
- 0.5 - 1
- 1 - 2
- 2+

LANDRIVERSEA CONSULTING

Otago Regional Council

0 0.1 0.2 0.4
Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE	
Buckler Burn Flood Modelling	**PEAK VELOCITY MAP** **Aggradation Scenario C - Q 180m3/s**	CREATED BY UP	**27/07/2023**	**1:9,000**	N
		REVISED BY	AUTHOR **Matthew Gardner**		

Legend

- Stopbank

Peak Velocity(m/s)

- 0
- 0 - 0.05
- 0.05 - 0.1
- 0.1 - 0.3
- 0.3 - 0.5
- 0.5 - 1
- 1 - 2
- 2+

LANDRIVERSEA CONSULTING

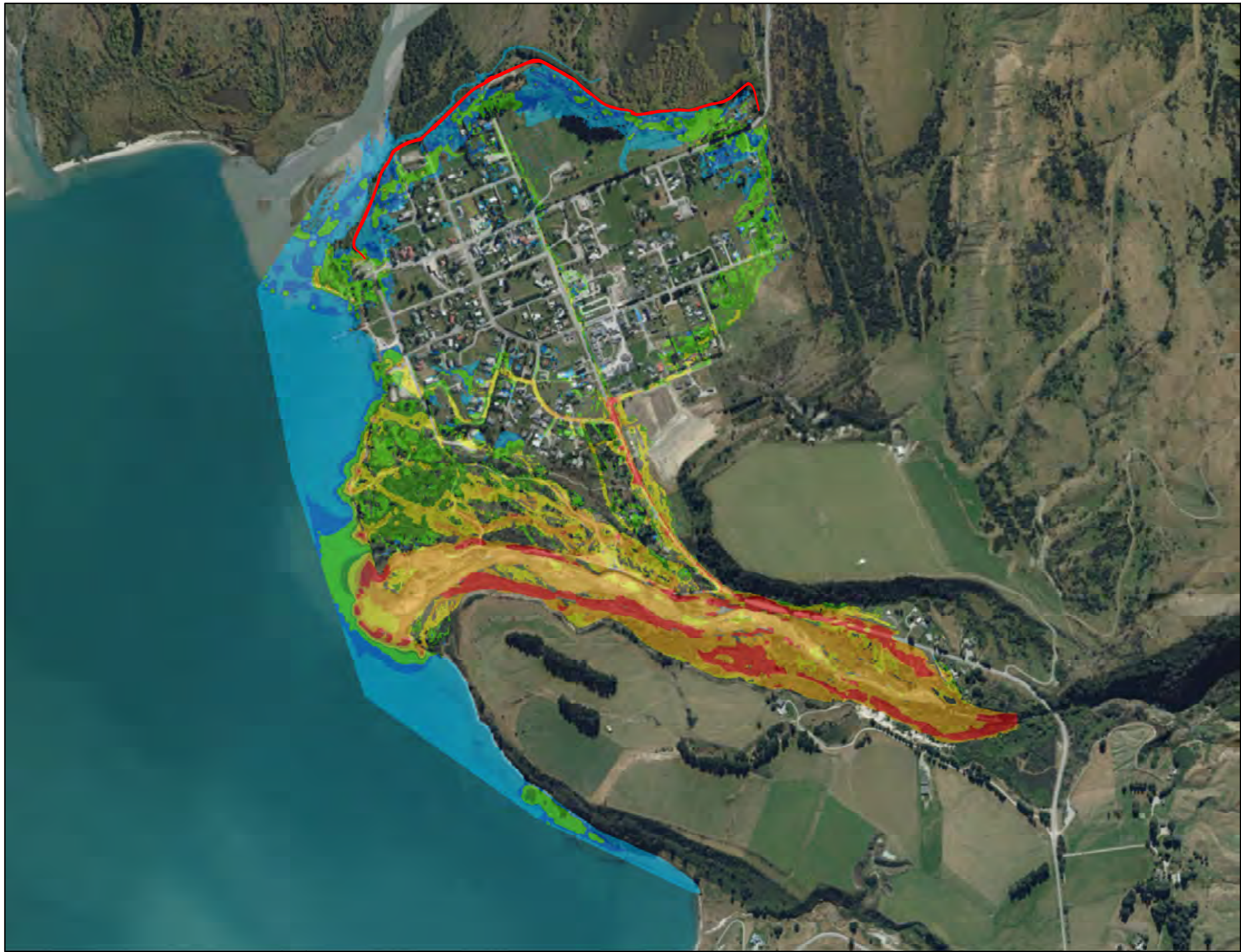
Otago Regional Council

0 0.1 0.2 0.4
Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT **Buckler Burn Flood Modelling**	MAP TITLE **PEAK VELOCITY MAP** **Aggradation Scenario C - Q 200m3/s**	REVISION **02** CREATED BY **UP** REVISED BY	DATE **27/07/2023** AUTHOR **Matthew Gardner**	A3 SCALE **1:9,000**	N



Legend

Stopbank

Peak Velocity(m/s)

- 0
- 0 - 0.05
- 0.05 - 0.1
- 0.1 - 0.3
- 0.3 - 0.5
- 0.5 - 1
- 1 - 2
- 2+

LANDRIVERSEA CONSULTING

Otago Regional Council

0 0.1 0.2 0.4 Kilometers

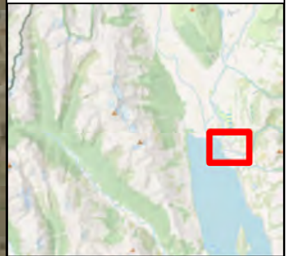
Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION	DATE	A3 SCALE
Buckler Burn Flood Modelling	**PEAK VELOCITY MAP** **Aggradation Scenario C - Q 250m3/s**	02	27/07/2023	1:9,000
		CREATED BY UP	AUTHOR	N
		REVISED BY	**Matthew Gardner**	

Legend

Stopbank	
Peak Veloity(m/s)	
0	
0 - 0.05	
0.05 - 0.1	
0.1 - 0.3	
0.3 - 0.5	
0.5 - 1	
1 - 2	
2+	



LANDRIVERSEA CONSULTING

Otago Regional Council

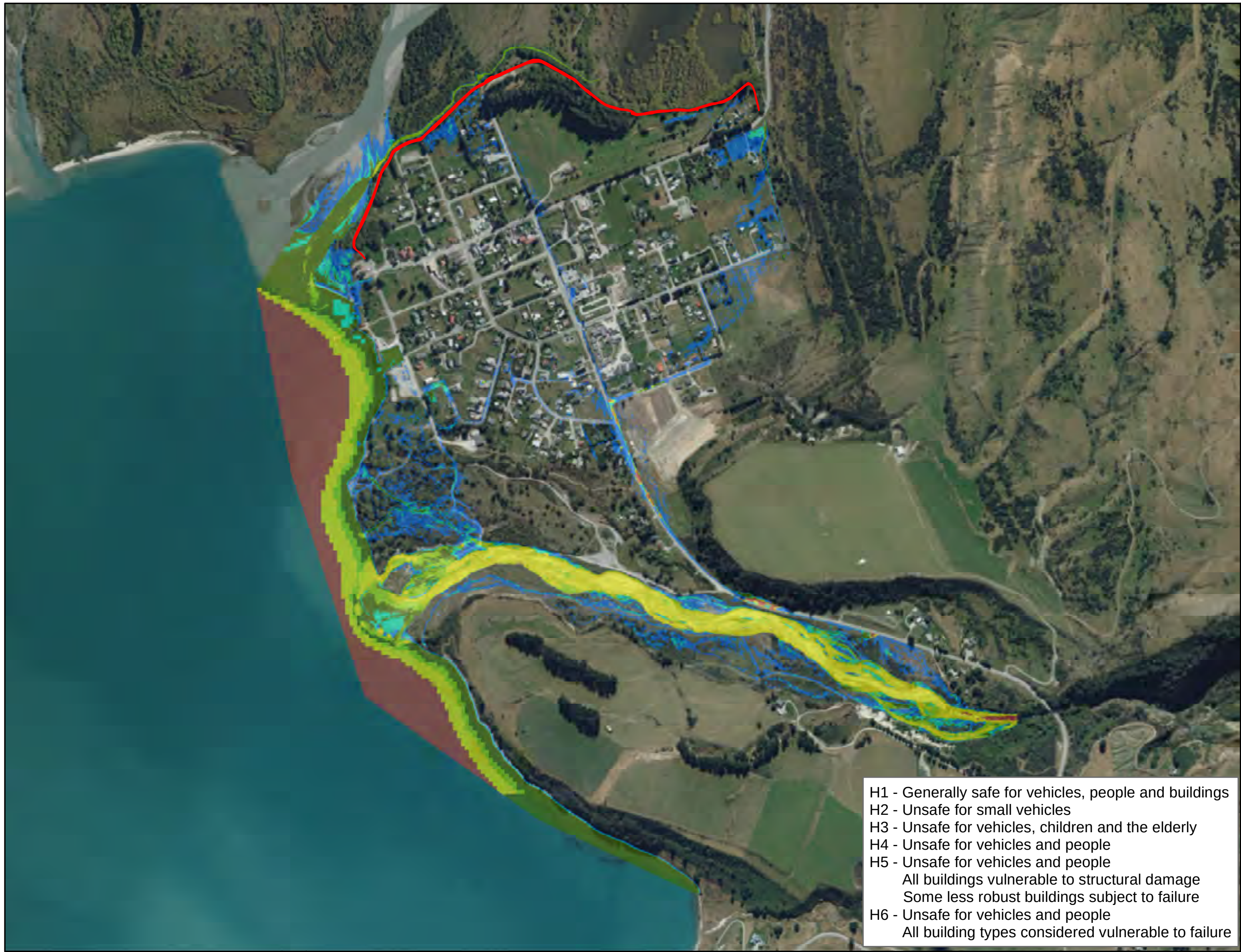
0 0.1 0.2 0.4
Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE	N
Buckler Burn Flood Modelling	**PEAK VELOCITY MAP** **Aggradation Scenario C - Q 300m3/s**	CREATED BY **UP**	**27/07/2023**	**1:9,000**	
		REVISED BY	AUTHOR **Matthew Gardner**		

APPENDIX F – AGGRADATION SCENARIOS – HAZARD MAPS



Legend

Stopbank

Hazard Category

- H6
- H5
- H4
- H3
- H2
- H1

LANDRIVERSEA CONSULTING

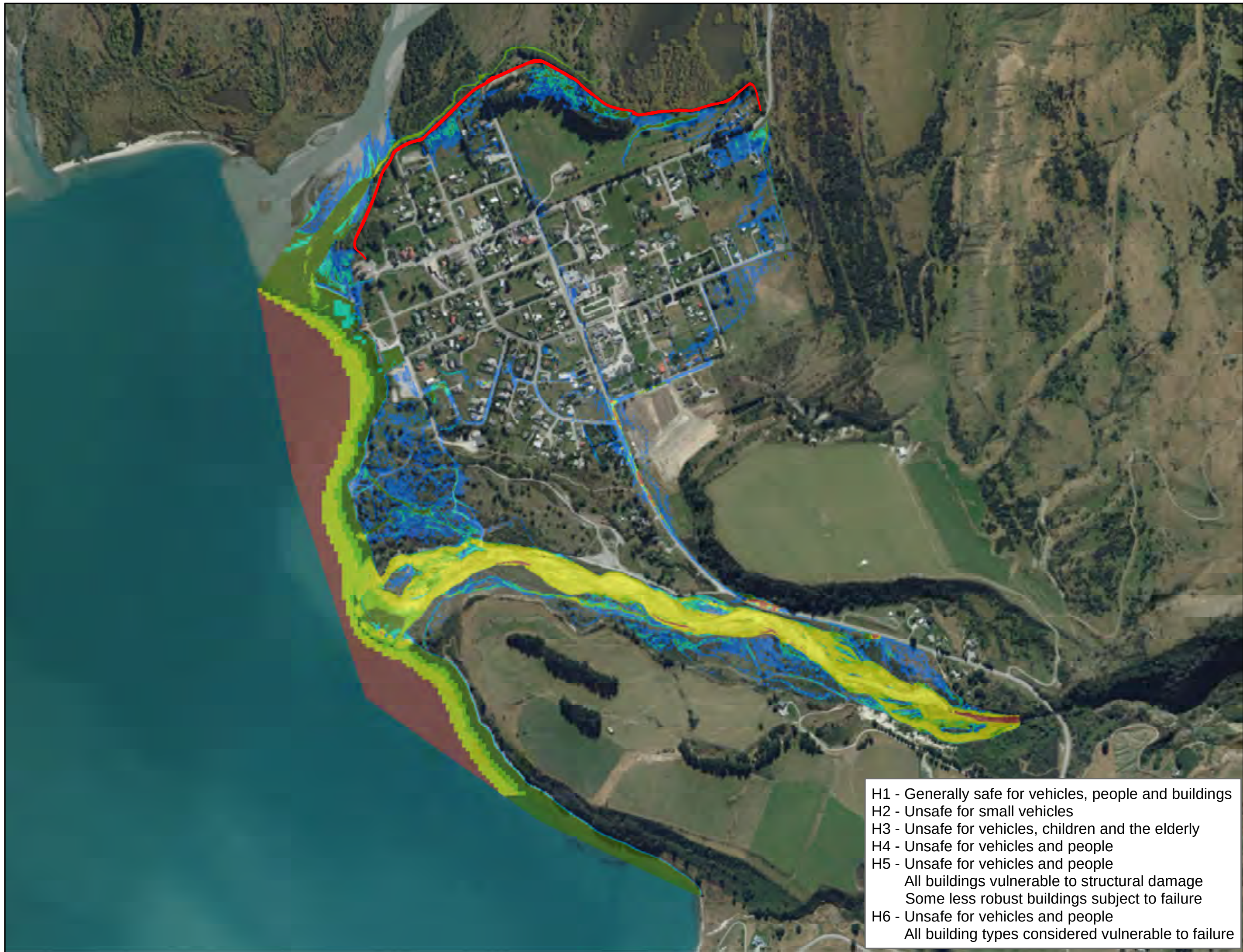
Otago Regional Council

0 0.1 0.2 0.4
Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE
Buckler Burn Flood Modelling	**HAZARD MAP** **Aggradation Scenario A - Q 100m3/s**	CREATED BY UP	**27/07/2023**	**1:9,000**
		REVISED BY	AUTHOR **Matthew Gardner**	N



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- Stopbank

Hazard Category

- H6
- H5
- H4
- H3
- H2
- H1

LANDRIVERSEA CONSULTING

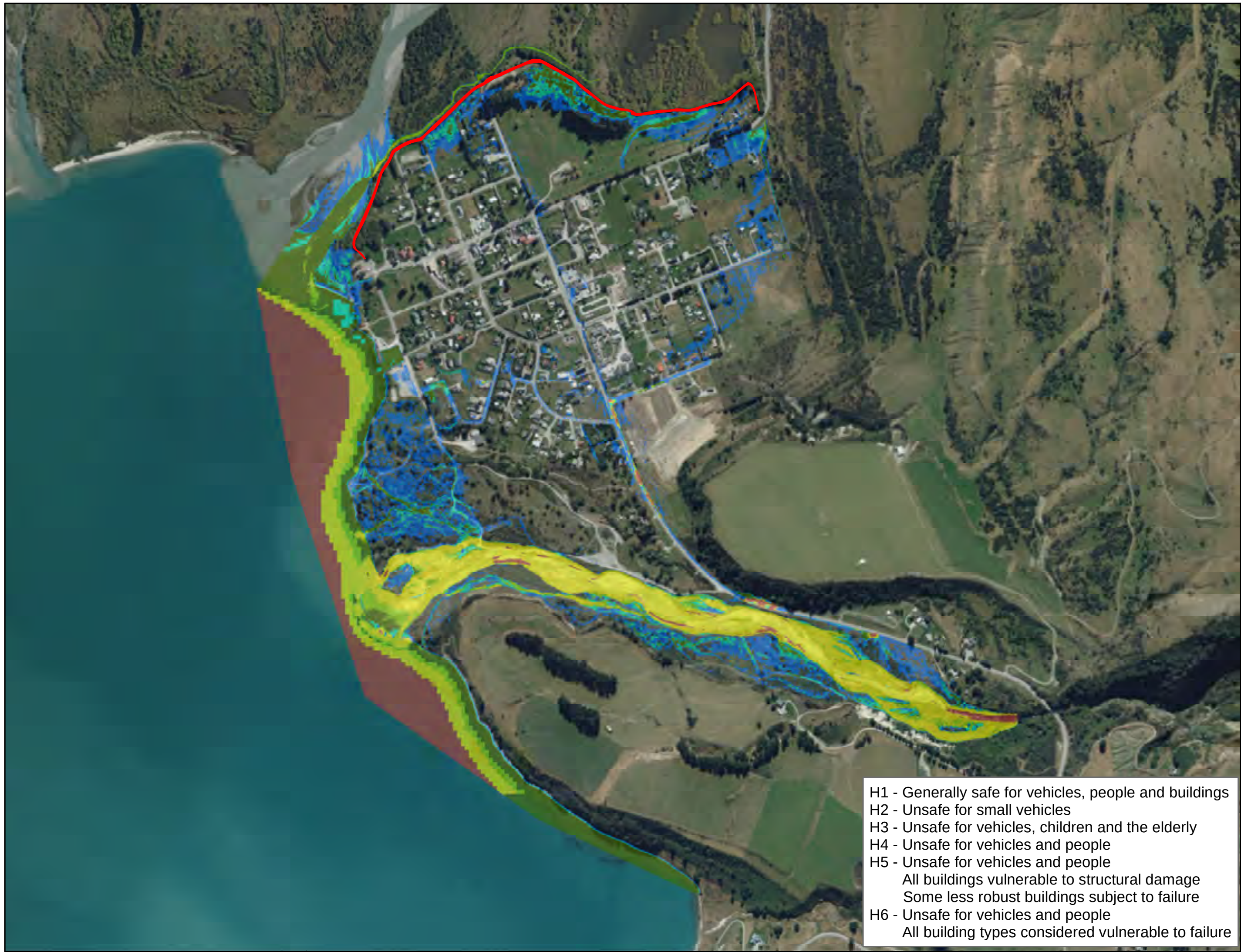
Otago Regional Council

0 0.1 0.2 0.4 Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE
Buckler Burn Flood Modelling	**HAZARD MAP** **Aggradation Scenario A - Q 150m3/s**	CREATED BY UP	**27/07/2023**	**1:9,000**
		REVISED BY	AUTHOR **Matthew Gardner**	N



Legend

- Stopbank

Hazard Category

- H6
- H5
- H4
- H3
- H2
- H1

LANDRIVERSEA CONSULTING

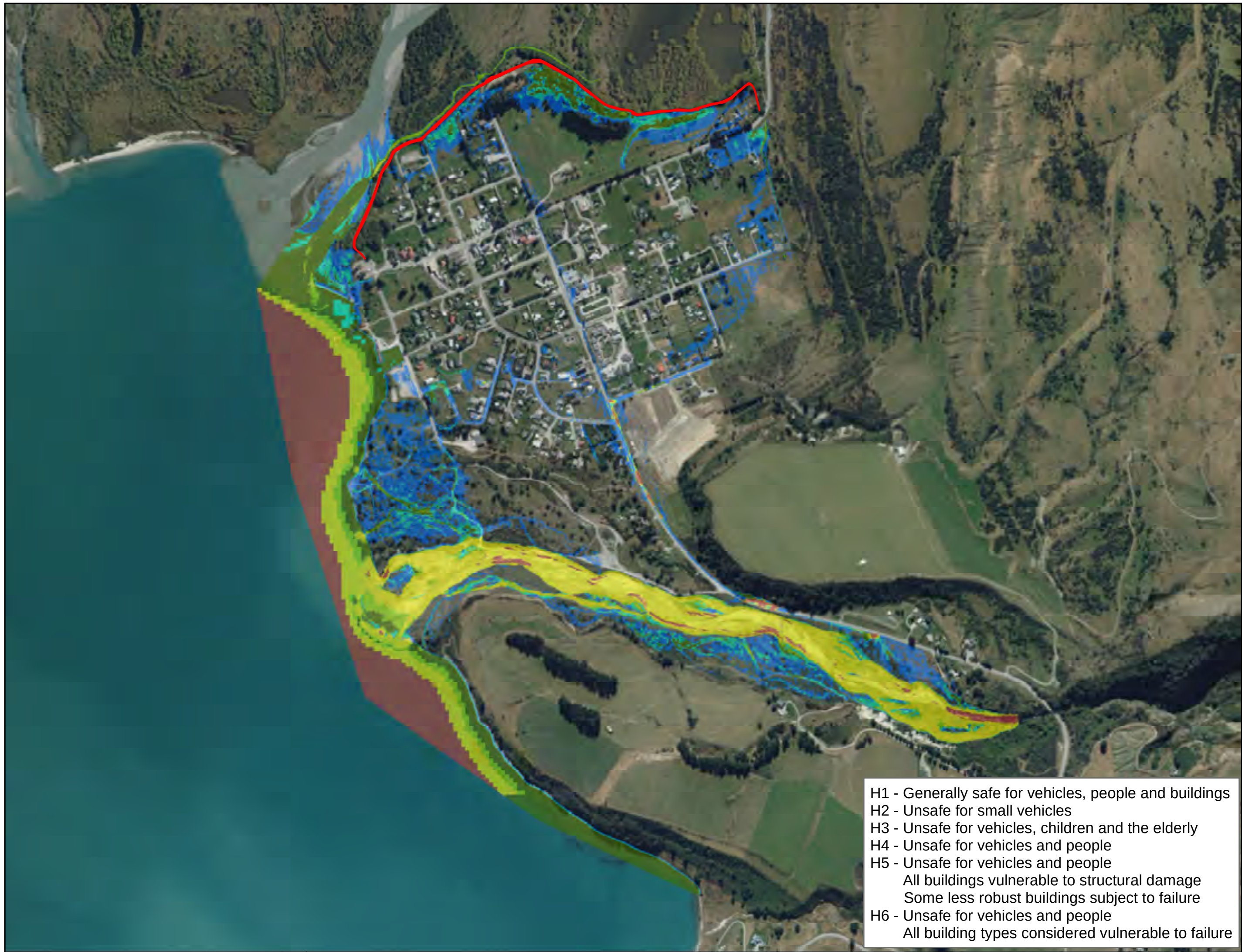
Otago Regional Council

0 0.1 0.2 0.4 Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE	
Buckler Burn Flood Modelling	**HAZARD MAP** **Aggradation Scenario A - Q 180m3/s**	CREATED BY **UP**	**27/07/2023**	**1:9,000**	N
		REVISED BY	AUTHOR **Matthew Gardner**		



Legend

- Stopbank

Hazard_Q200_Gleno...

Hazard Category

- H6
- H5
- H4
- H3
- H2
- H1

LANDRIVERSEA CONSULTING

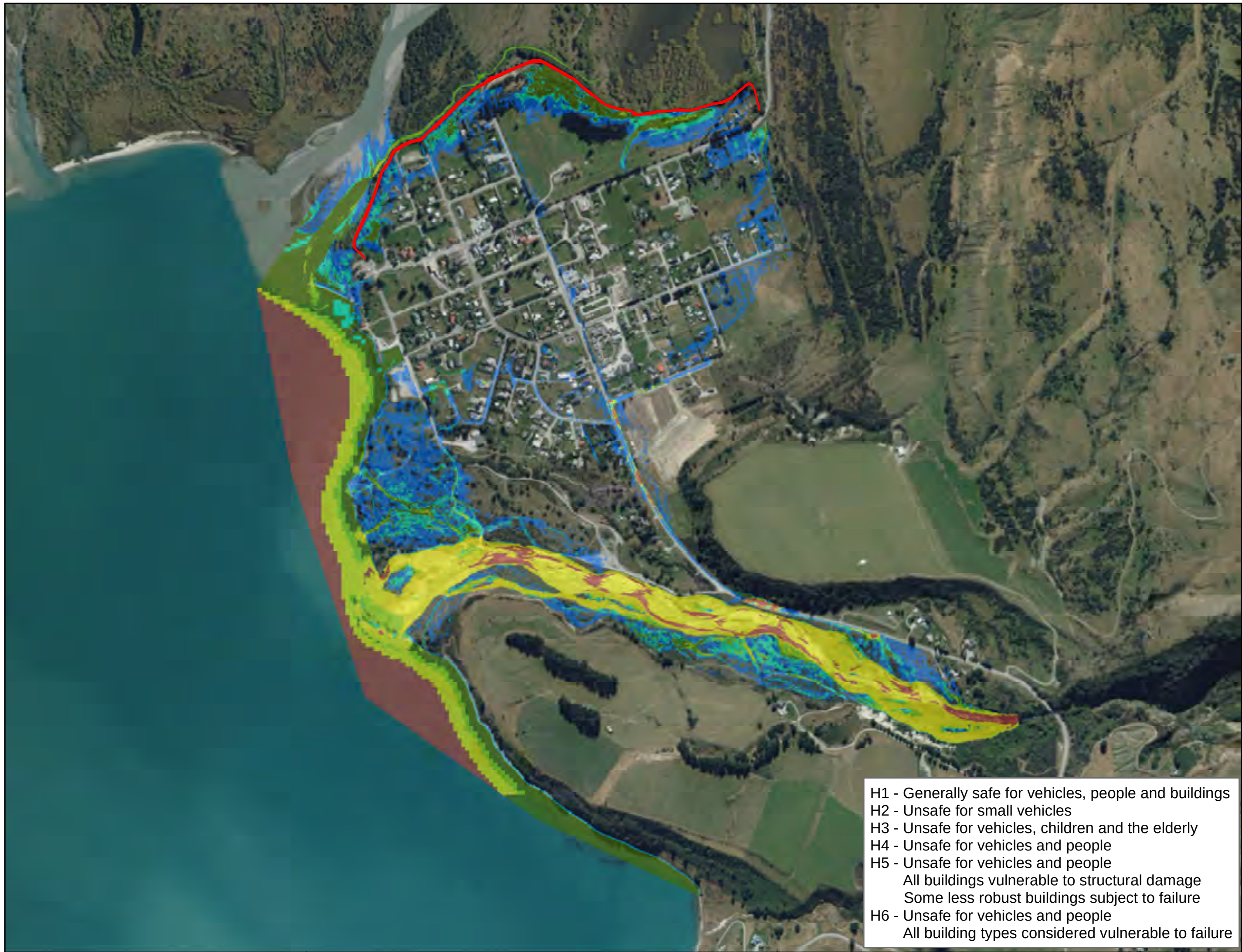
Otago Regional Council

0 0.1 0.2 0.4 Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE	
Buckler Burn Flood Modelling	**HAZARD MAP** **Aggradation Scenario A - Q 200m3/s**	CREATED BY UP	**27/07/2023**	**1:9,000**	N
		REVISED BY	AUTHOR **Matthew Gardner**		



Legend

- Stopbank

Hazard Category

- H6
- H5
- H4
- H3
- H2
- H1

LANDRIVERSEA CONSULTING

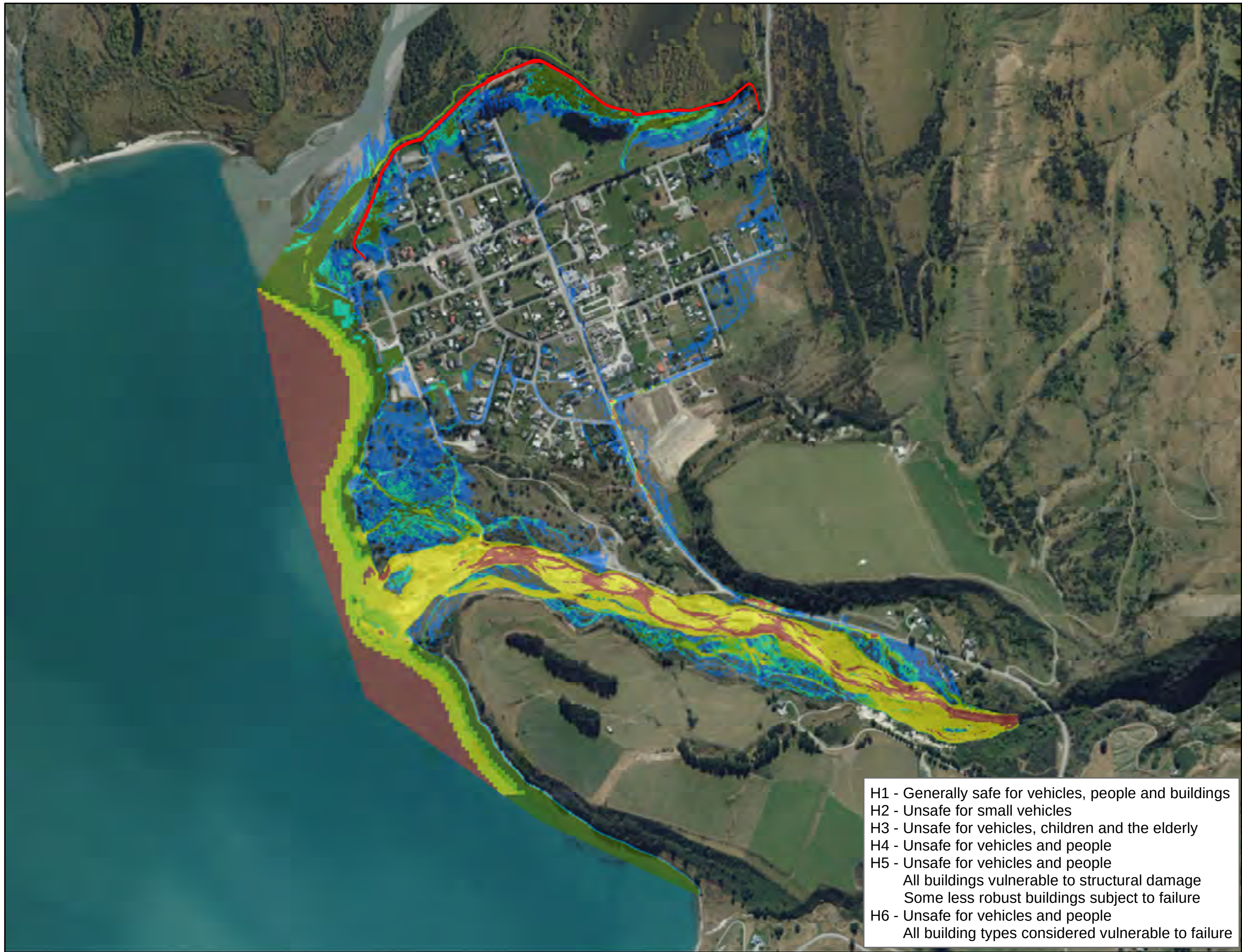
Otago Regional Council

0 0.1 0.2 0.4 Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT **Buckler Burn Flood Modelling**	MAP TITLE **HAZARD MAP Aggradation Scenario A - Q 250m3/s**	REVISION **02**	DATE	A3 SCALE
		CREATED BY **UP**	**27/07/2023**	**1:9,000**
		REVISED BY	AUTHOR **Matthew Gardner**	N

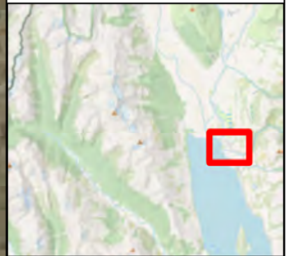


Legend

Stopbank

Hazard Category

- H6
- H5
- H4
- H3
- H2
- H1



LANDRIVERSEA CONSULTING

Otago Regional Council

0 0.1 0.2 0.4 Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE
Buckler Burn Flood Modelling	**HAZARD MAP** **Aggradation Scenario A - Q 300m3/s**	CREATED BY UP	**27/07/2023**	**1:9,000**
		REVISED BY	AUTHOR **Matthew Gardner**	

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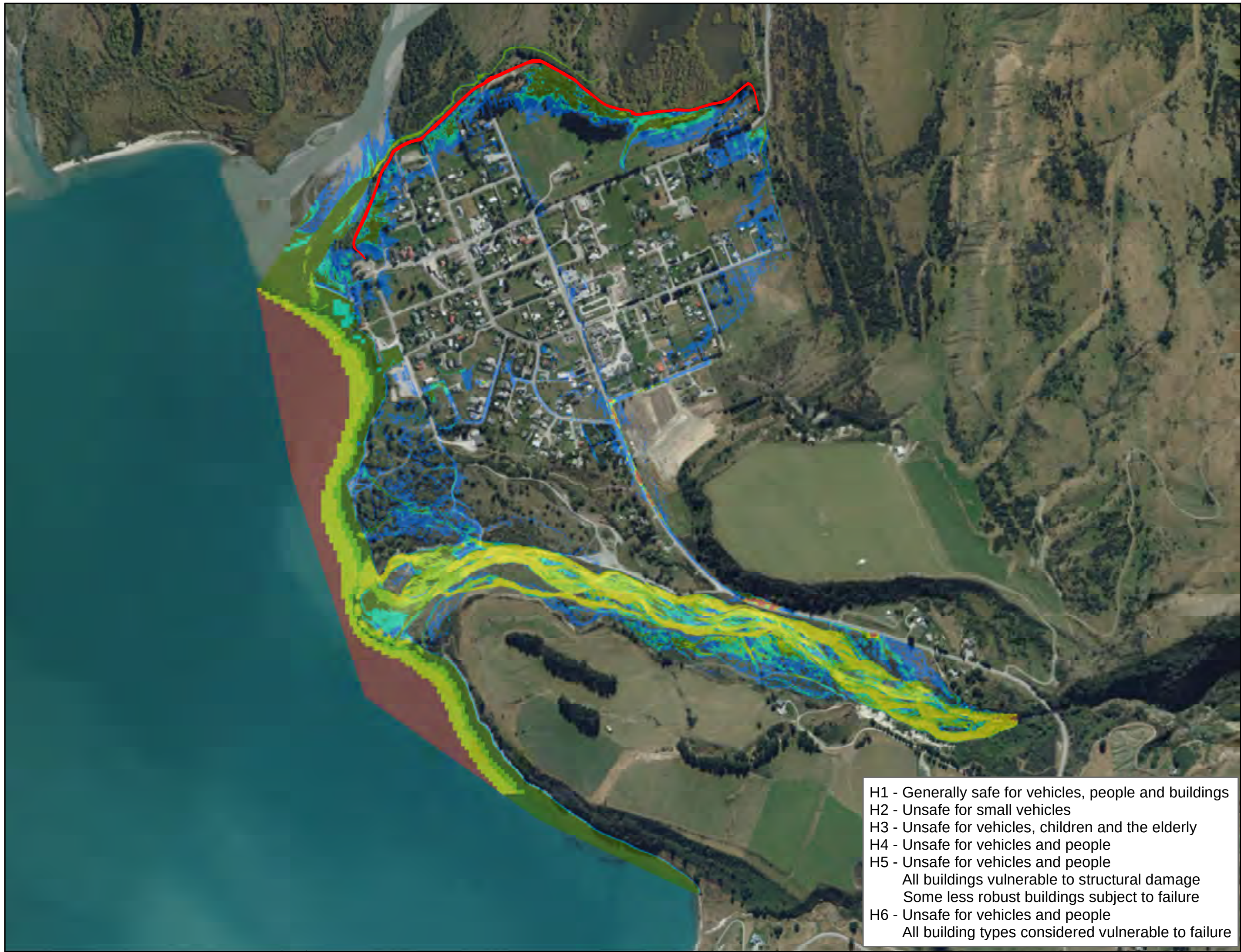


Legend

Stopbank

Hazard Category

- H6
- H5
- H4
- H3
- H2
- H1

LANDRIVERSEA CONSULTING

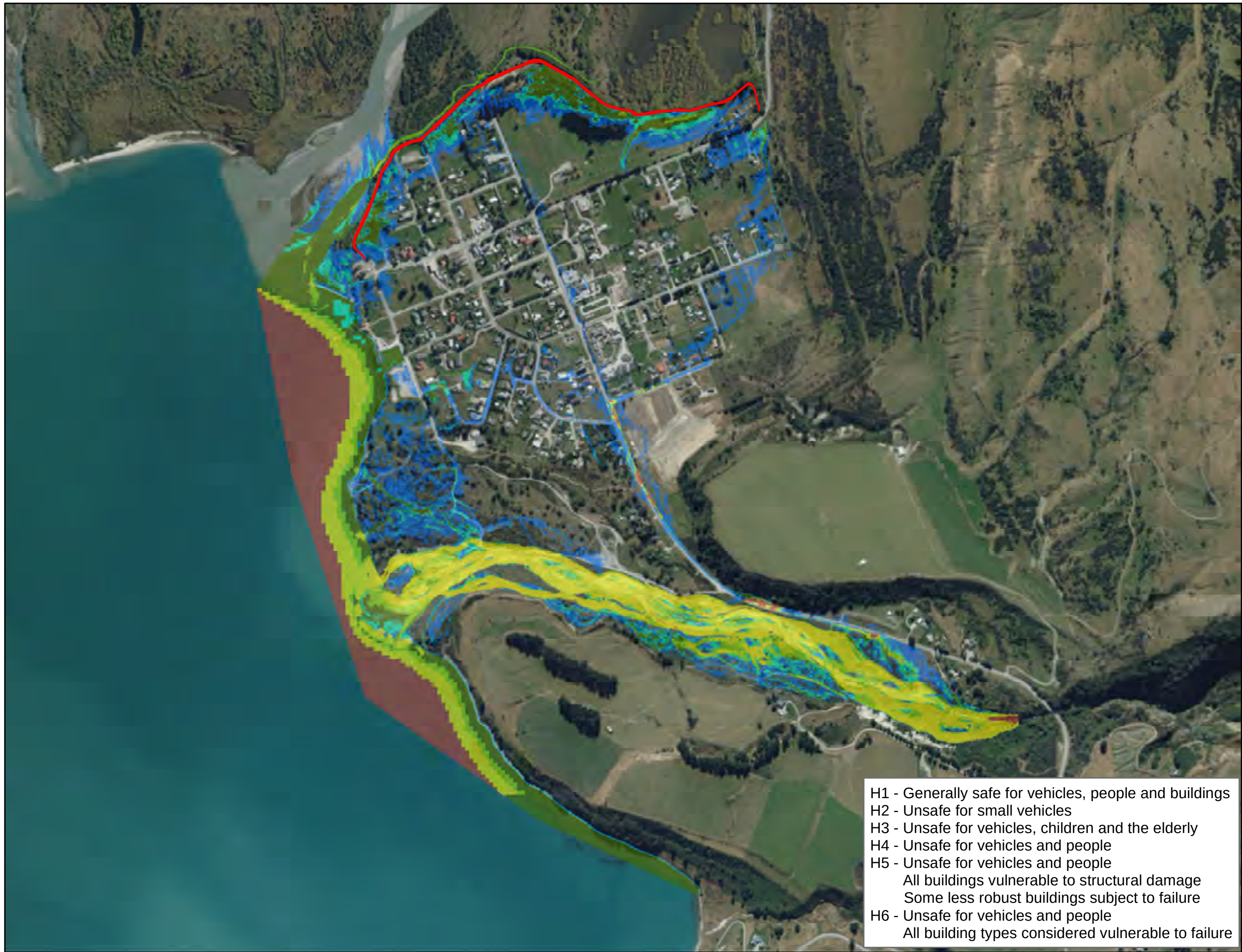
Otago Regional Council

0 0.1 0.2 0.4
Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT **Buckler Burn Flood Modelling**	MAP TITLE **HAZARD MAP** **Aggradation Scenario B - Q 100m3/s**	REVISION **02** / CREATED BY **UP** / REVISED BY	DATE **27/07/2023** / AUTHOR **Matthew Gardner**	A3 SCALE **1:9,000**	N



Legend

Stopbank

Hazard Category

- H6
- H5
- H4
- H3
- H2
- H1

LANDRIVERSEA CONSULTING

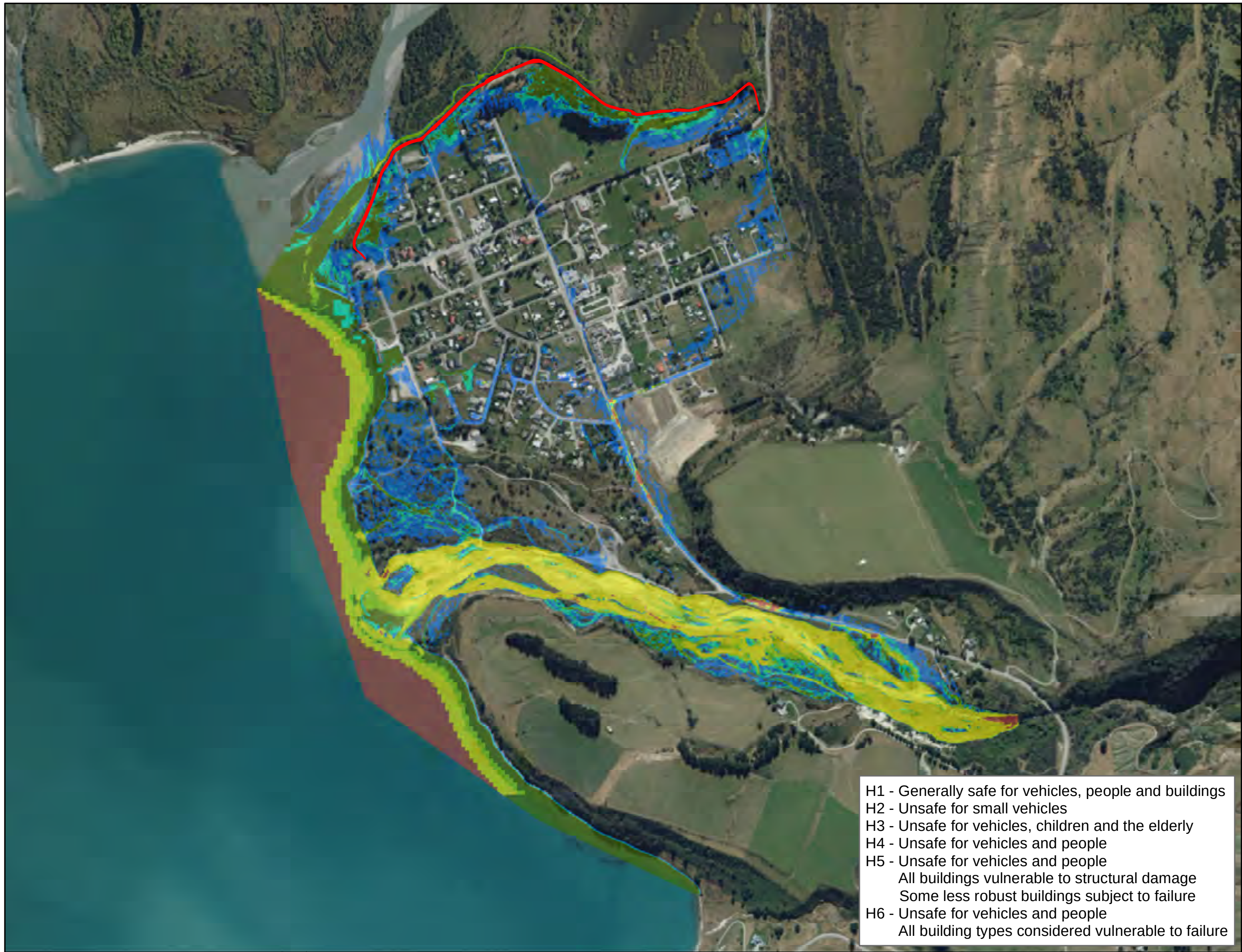
Otago Regional Council

0 0.1 0.2 0.4
Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT **Buckler Burn Flood Modelling**	MAP TITLE **HAZARD MAP** **Aggradation Scenario B - Q 150m3/s**	REVISION **02** CREATED BY **UP** REVISED BY	DATE **27/07/2023** AUTHOR **Matthew Gardner**	A3 SCALE **1:9,000**	N



Legend

Stopbank

Hazard Category

- H6
- H5
- H4
- H3
- H2
- H1

LANDRIVERSEA CONSULTING

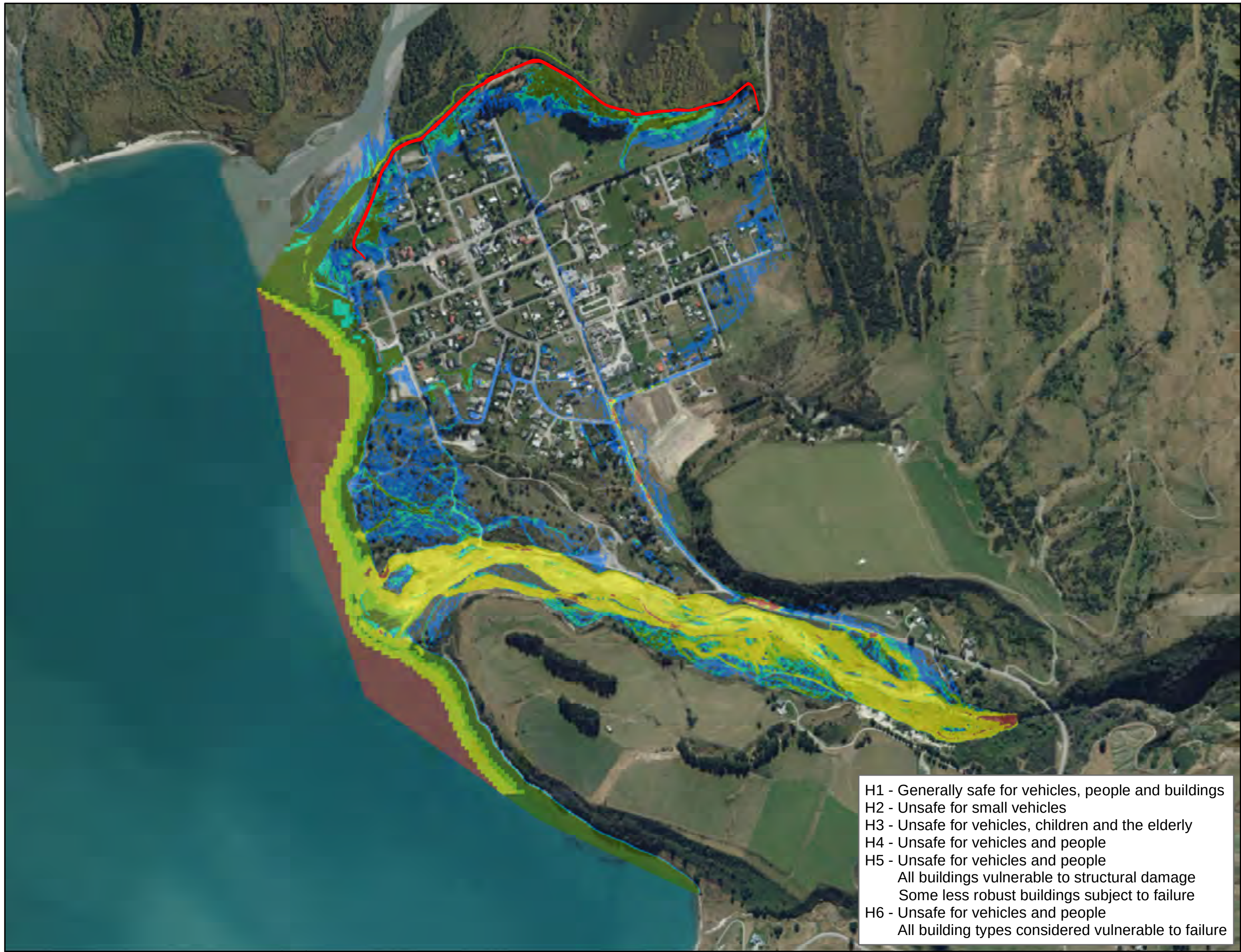
Otago Regional Council

0 0.1 0.2 0.4
Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION **02**	DATE	A3 SCALE
Buckler Burn Flood Modelling	**HAZARD MAP** **Aggradation Scenario B - Q 180m3/s**	CREATED BY **UP**	**27/07/2023**	**1:9,000**
		REVISED BY	AUTHOR **Matthew Gardner**	N



Legend

Stopbank

Hazard Category

- H6
- H5
- H4
- H3
- H2
- H1

LANDRIVERSEA CONSULTING

Otago Regional Council

0 0.1 0.2 0.4 Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION	DATE	A3 SCALE	
Buckler Burn Flood Modelling	**HAZARD MAP** **Aggradation Scenario B - Q 200m3/s**	02	27/07/2023	1:9,000	N
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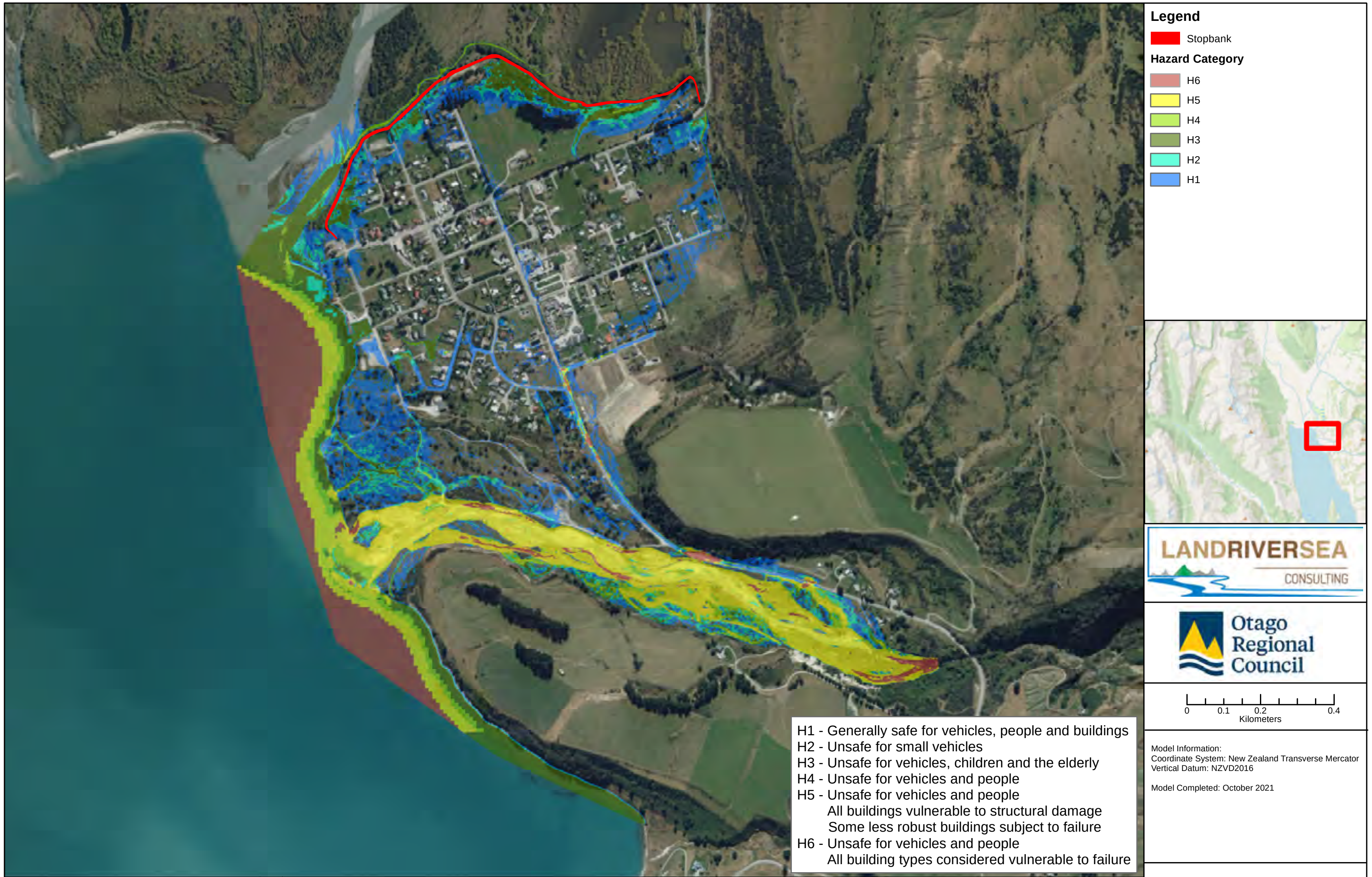
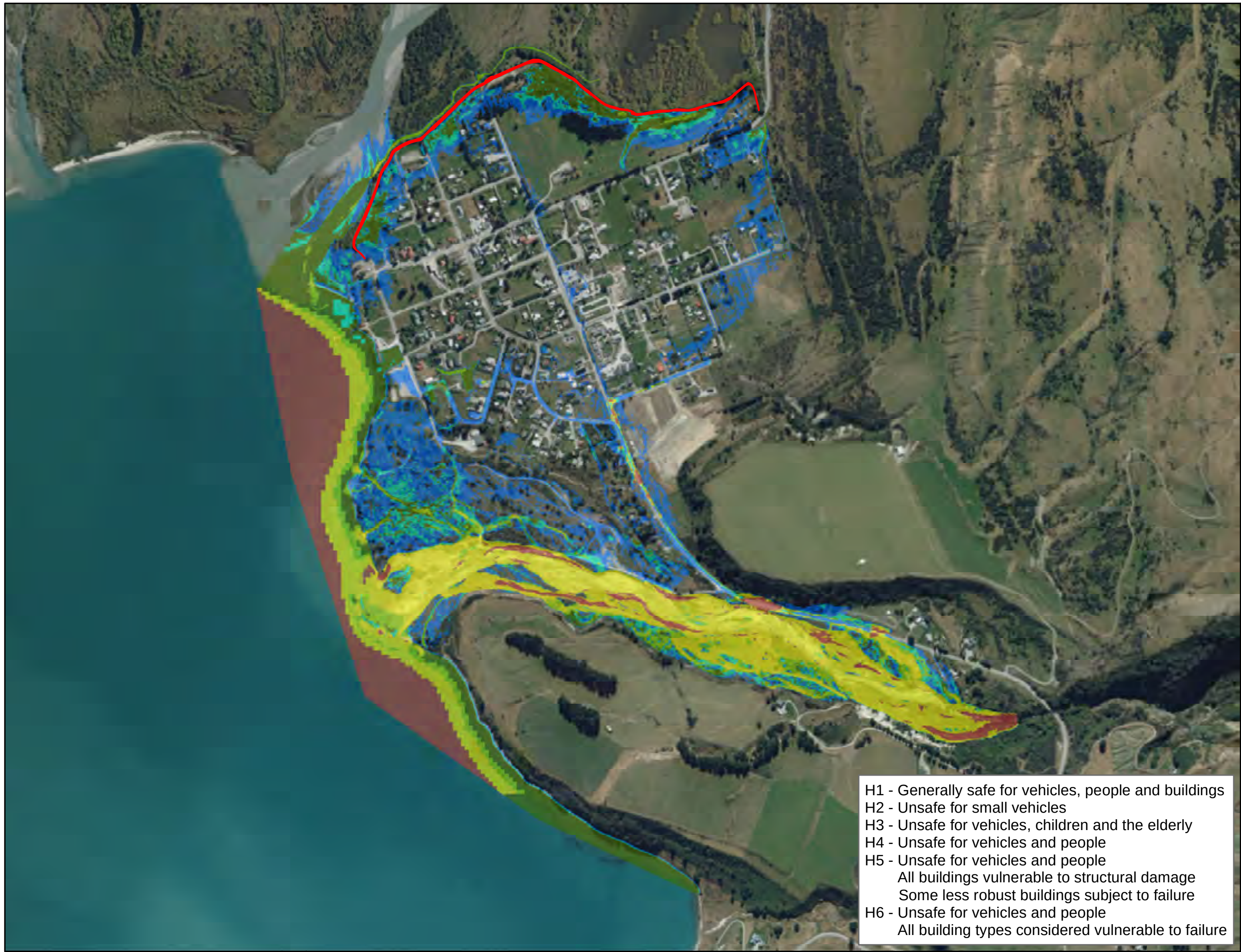
		REVISED BY	AUTHOR: **Matthew Gardner**		



PROJECT
Buckler Burn Flood Modelling

MAP TITLE
HAZARD MAP
Aggradation Scenario B - Q 250m3/s

REVISION **02**	DATE **27/07/2023**	A3 SCALE **1:9,000**	N
CREATED BY **UP**			
REVISED BY	AUTHOR **Matthew Gardner**		



Legend

Stopbank

Hazard Category

- H6
- H5
- H4
- H3
- H2
- H1

LANDRIVERSEA CONSULTING

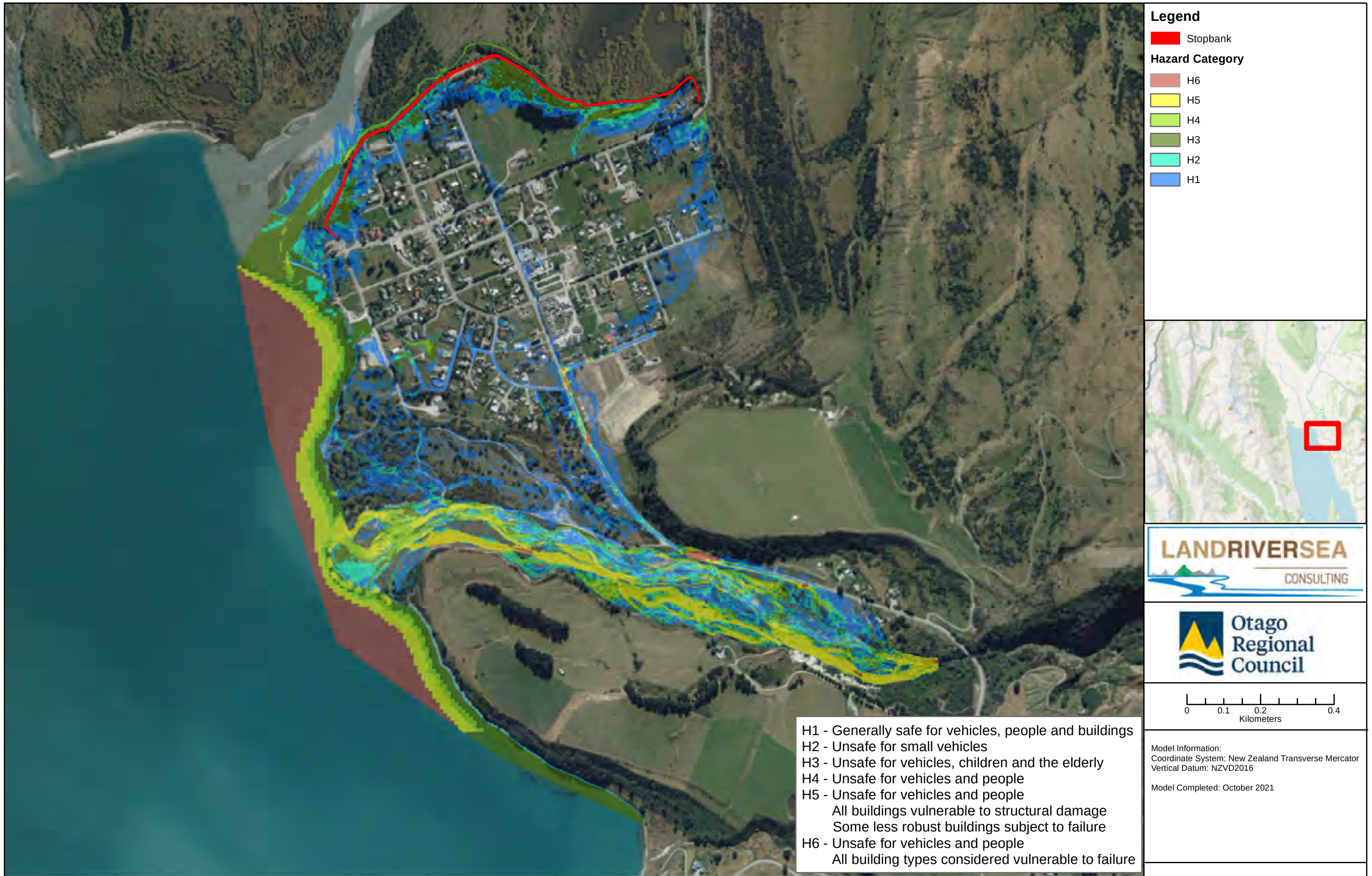
Otago Regional Council

0 0.1 0.2 0.4 Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

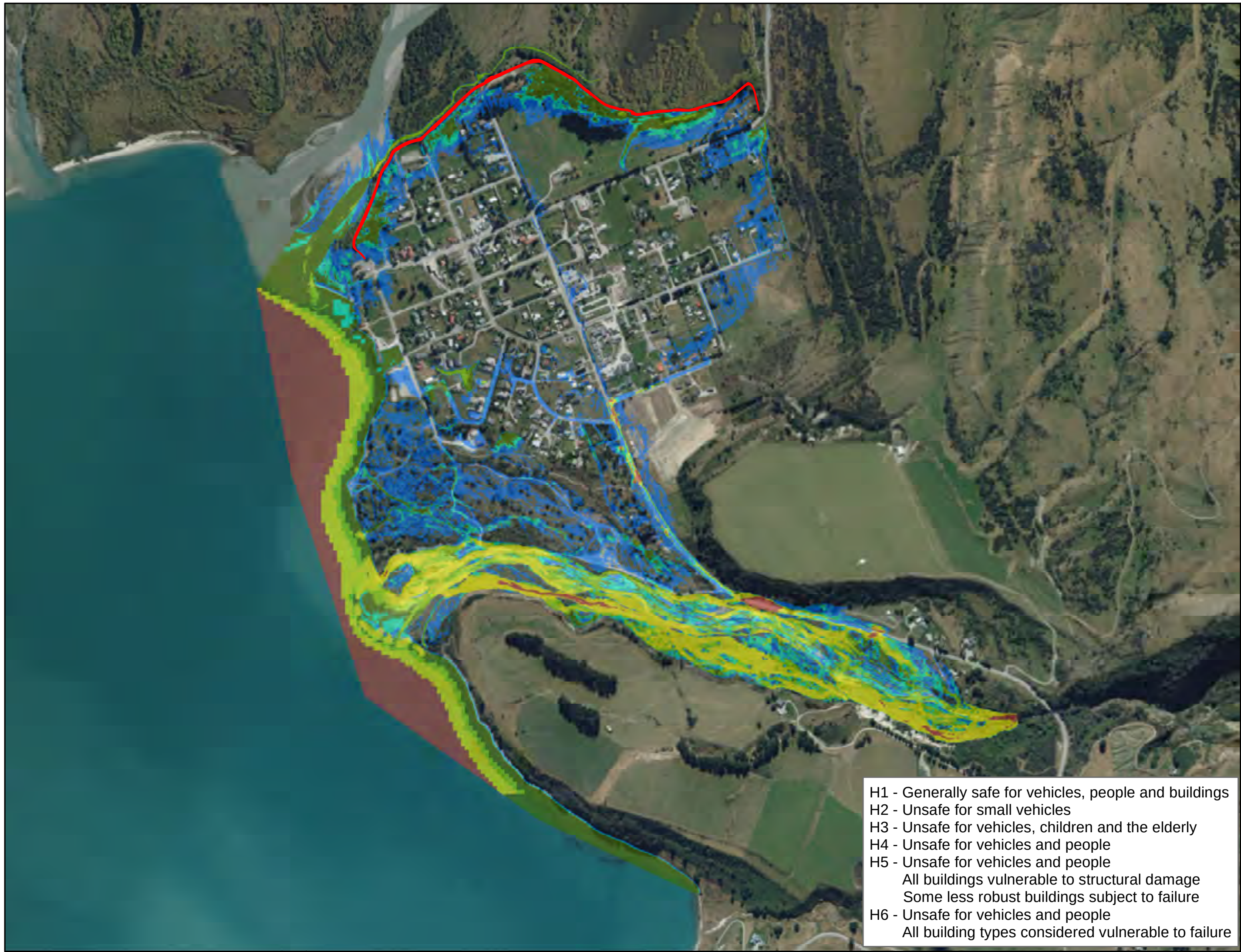
PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE
Buckler Burn Flood Modelling	**HAZARD MAP** **Aggradation Scenario B - Q 300m3/s**	CREATED BY UP	**27/07/2023**	**1:9,000**
		REVISED BY	AUTHOR **Matthew Gardner**	N



PROJECT
Buckler Burn Flood Modelling

MAP TITLE
HAZARD MAP
Aggradation Scenario C - Q 100m3/s

REVISION **02**
CREATED BY **UP**
REVISED BY
DATE **27/07/2023**
A3 SCALE **1:9,000**
AUTHOR **Matthew Gardner**
N



Legend

Stopbank

Hazard Category

H6

H5

H4

H3

H2

H1

LANDRIVERSEA CONSULTING

Otago Regional Council

0 0.1 0.2 0.4
Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE
Buckler Burn Flood Modelling	**HAZARD MAP** **Aggradation Scenario C - Q 150m3/s**	CREATED BY UP	**27/07/2023**	**1:9,000**
		REVISED BY	AUTHOR **Matthew Gardner**	

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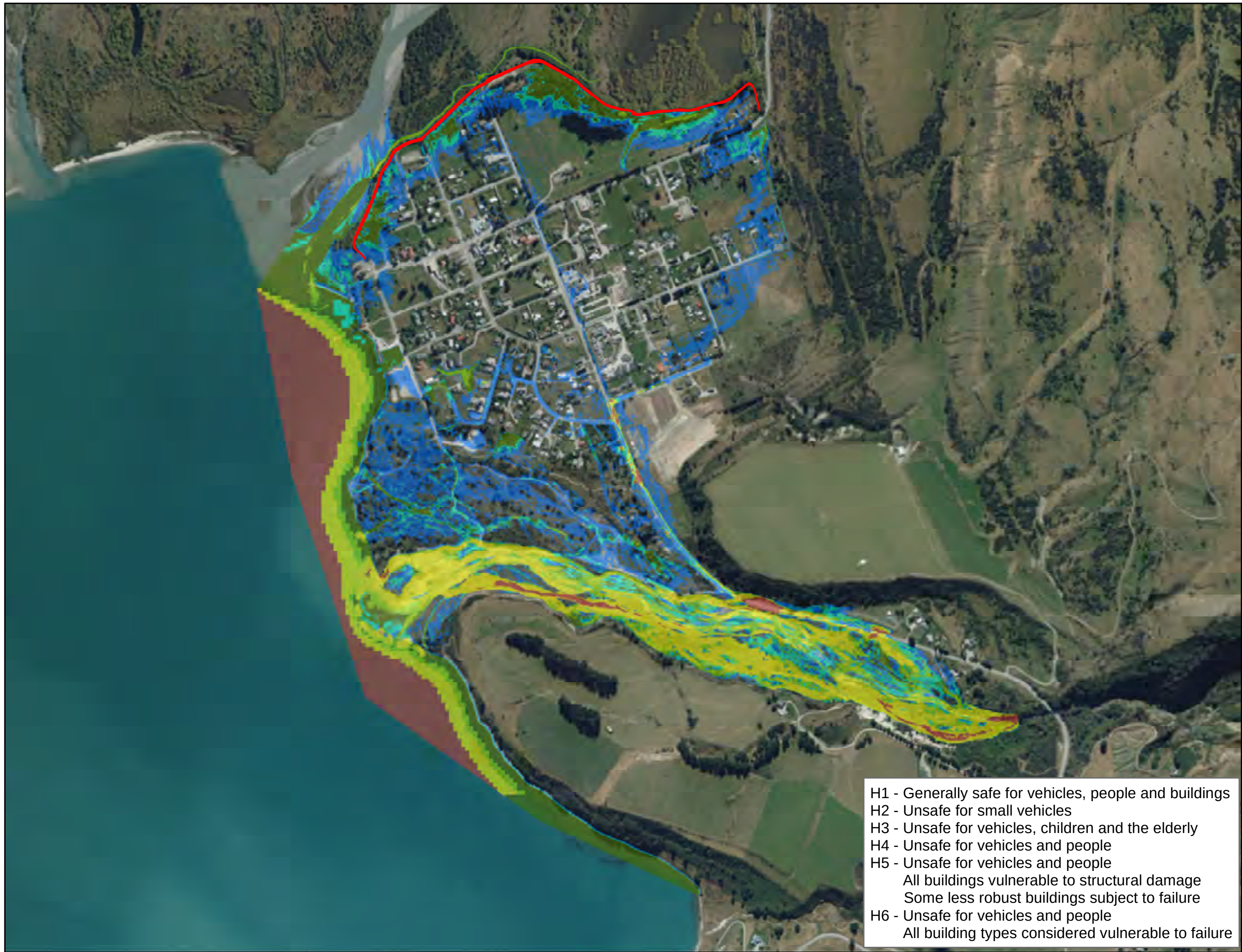

Legend

Stopbank

Hazard Category

H6
H5
H4
H3
H2
H1

LANDRIVERSEA CONSULTING

Otago Regional Council

0 0.1 0.2 0.4 Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT
Buckler Burn Flood Modelling

MAP TITLE
HAZARD MAP
Aggradation Scenario C - Q 180m3/s

REVISION **02**	DATE **27/07/2023**	A3 SCALE **1:9,000**
CREATED BY **UP**		
REVISED BY	AUTHOR **Matthew Gardner**	

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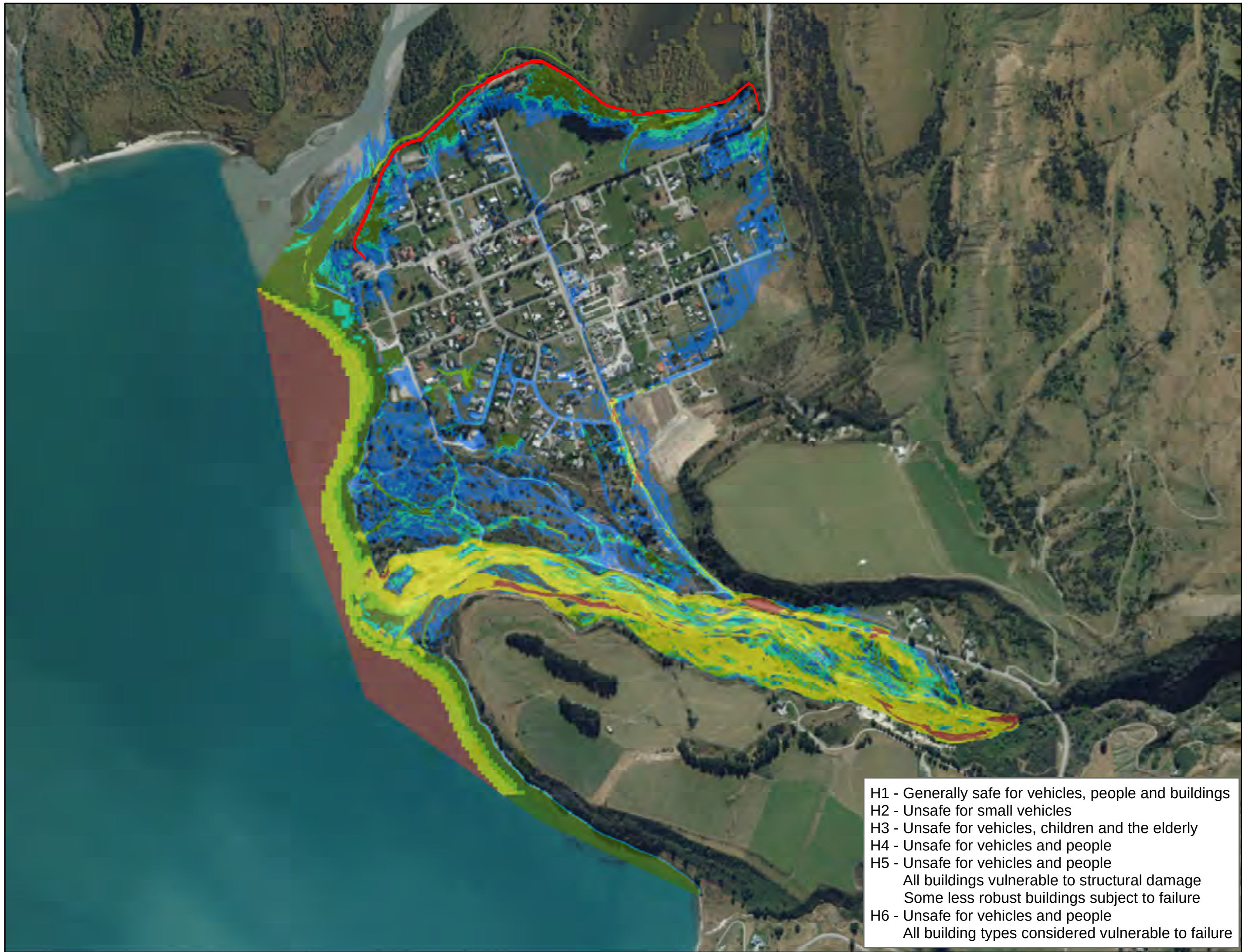


Legend

Stopbank

Hazard Category

- H6
- H5
- H4
- H3
- H2
- H1

LANDRIVERSEA CONSULTING

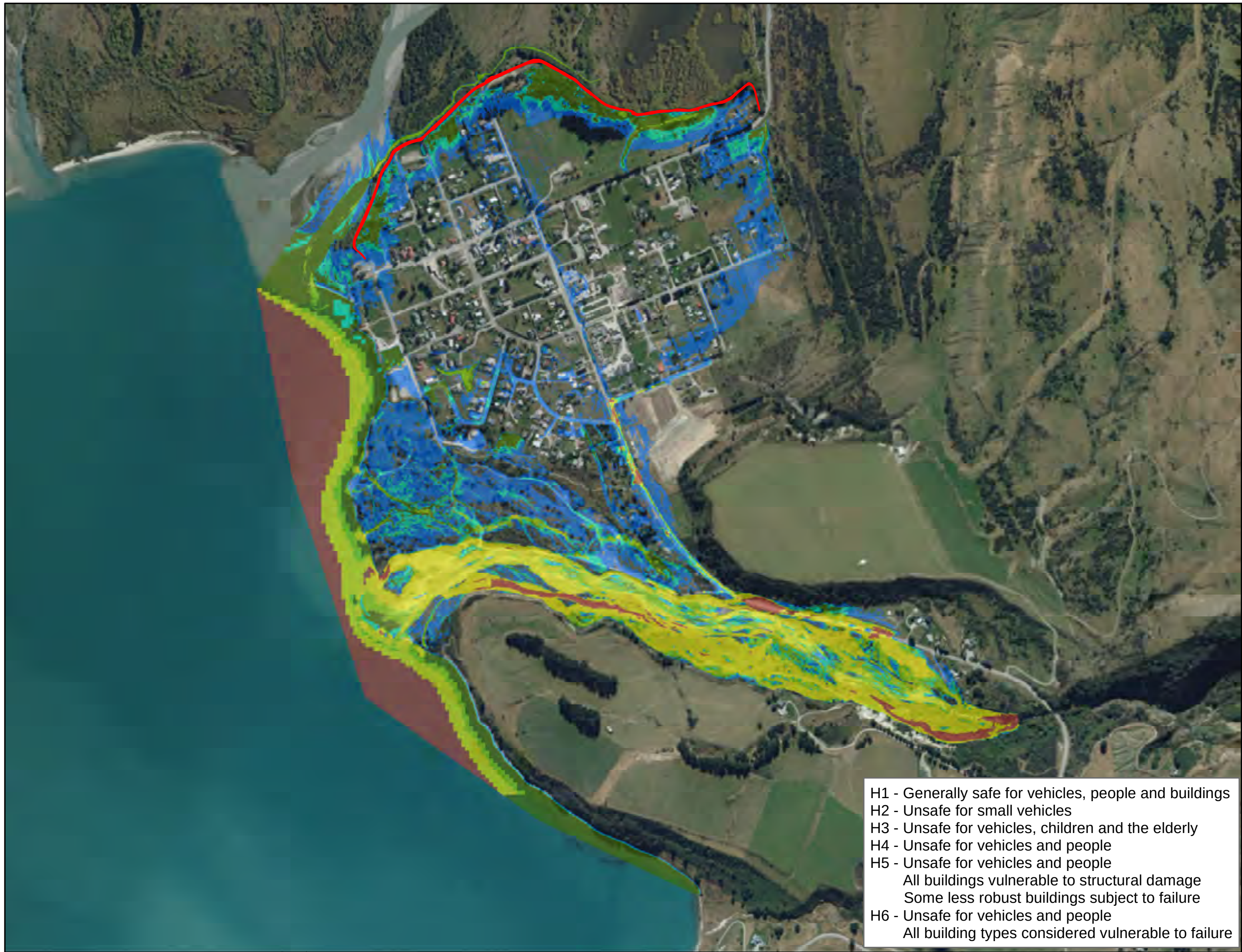
Otago Regional Council

0 0.1 0.2 0.4
Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE	N
Buckler Burn Flood Modelling	**HAZARD MAP** **Aggradation Scenario C - Q 200m3/s**	CREATED BY **UP**	**27/07/2023**	**1:9,000**	
		REVISED BY	AUTHOR **Matthew Gardner**		



Legend

Stopbank

Hazard Category

- H6
- H5
- H4
- H3
- H2
- H1

LANDRIVERSEA CONSULTING

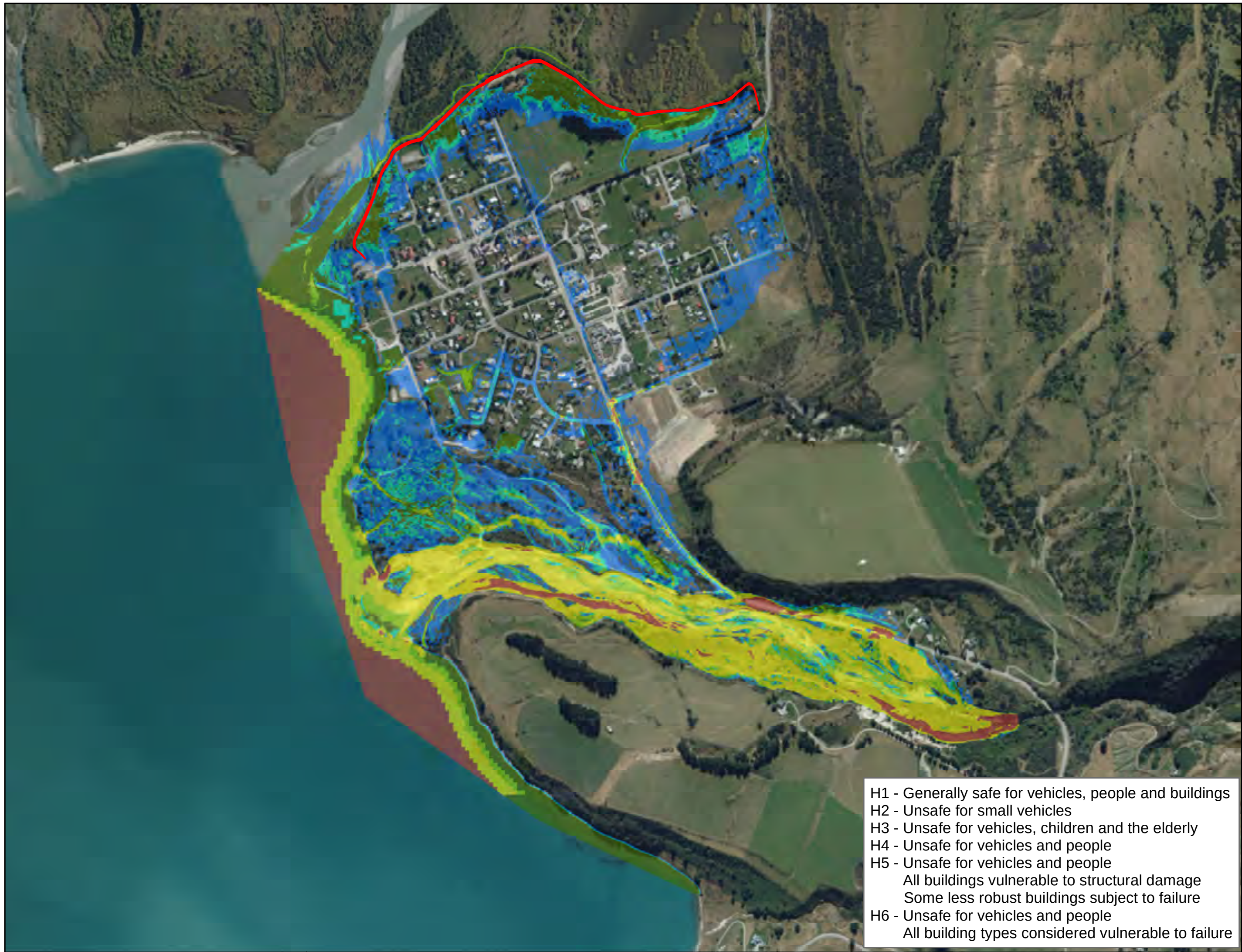
Otago Regional Council

0 0.1 0.2 0.4
Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION	DATE	A3 SCALE
Buckler Burn Flood Modelling	**HAZARD MAP** **Aggradation Scenario C - Q 250m3/s**	02	27/07/2023	1:9,000
		CREATED BY UP	AUTHOR **Matthew Gardner**	N
		REVISED BY		



Legend

Stopbank

Hazard Category

- H6
- H5
- H4
- H3
- H2
- H1

LANDRIVERSEA CONSULTING

Otago Regional Council

0 0.1 0.2 0.4 Kilometers

Model Information:
Coordinate System: New Zealand Transverse Mercator
Vertical Datum: NZVD2016

Model Completed: October 2021

PROJECT	MAP TITLE	REVISION 02	DATE	A3 SCALE	N
Buckler Burn Flood Modelling	**HAZARD MAP** **Aggradation Scenario C - Q 300m3/s**	CREATED BY **UP**	**27/07/2023**	**1:9,000**	
		REVISED BY	AUTHOR **Matthew Gardner**		

8 September 2023
Job No: 1015117.0160

Otago Regional Council
70 Stafford Street
Private Bag 1954
Dunedin 9054

Attention: Mr T van Woerden

Dear Tim

Buckler Burn flood hazard – Technical Review

In accordance with our Short Form Agreement for Consultant Engagement dated 17 July 2023, we are pleased to report on our review of the reporting for the Buckler Burn flood hazard project.

Land River Sea Consulting Ltd (LRS) has developed a computational hydraulic model of the Buckler Burn system as it flows into Lake Wakatipu to the south of Glenorchy. The model has been used to investigate various modelling scenarios and outcomes as they may affect the flooding in Buckler Burn and other locations within Glenorchy township. The modelling scenarios principally relate to assumed peak flows from the catchment and various aggradation scenarios in the bed of Buckler Burn.

We received by email (van Woerden/Bassett) on 27 June 2023, a link to a soft copy of the draft report prepared by LRS. We provided comments on the review, primarily annotated in the report document, to LRS on 13 July 2023. Our technical specialist, Tom Bassett, discussed this review with Matt Gardner and Rose Beagley of LRS by phone on 25 July. LRS subsequently issued its final report on 7 August 2023.

Our essential scope from ORC was a review of the draft modelling report and whether the completed work has met the objectives set out for it, including:

- The validity of the assumptions
- The validity of the conclusions
- The validity of the recommendations.

LRS states in its report that the purpose of the model is to:

- Inform landowners and residents of the potential hazards posed by the Buckler Burn
- Provide input into the ongoing Head of Lake Wakatipu Hazards Adaption project, providing a better understanding of hazard and risk characteristics of the Buckler Burn flooding threat.

The scope of the project identified by LRS was:

- Upgrading the LRS 'Dart/Rees Rivers MIKE21FM model' by converting it to HECRAS, and then extending the mesh to include the entire Buckler Burn fan, creating a new roughness layer, and recalibrating it to the February 2020 flood event

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PO Box 5271, Victoria Street West, Auckland 1142 P +64-9-355 6000 F +64-9-307 0265 E akl@tonkintaylor.co.nz

- Simulating a range of design flow scenarios on the fan
- Simulating a range of simplified aggradation scenarios on the fan
- Generating peak depth, floodwater elevation, velocity, hazard, and extent maps for the above scenarios.

The scope of the LRS assessment does not include for modelling of debris flow events.

We set out our observations and review comment for each of the three objectives (plus "Modelling scenarios") in the sections below (i.e. four sub-sections). Our observations and review comments are based on the final 160-page report, Buckler Burn, Flood Hazard Modelling, by Matthew Gardner and Rose Beagley, Land River Sea Consulting for Otago Regional Council, dated 7 August 2023.

Modelling Assumptions

The model for the Buckler Burn stream system has been developed using HECRAS two dimensional software. This has been converted from an existing model of the wider Dart-Rees river system (developed by LRS using MIKE21FM software) and extended to cover the entire Buckler Burn floodplain. As noted in earlier review of the Dart-Rees model (T+T, 2022) the LRS approach to developing the computational flood model was conventional, based on widely used software.

The Buckler Burn model uses 2019 LiDAR survey data of the terrain as the base digital elevation model (DEM). It also considers more recent (2022) LiDAR data to model the effect of recent changes in the alluvial fan. The DEM is represented in the model as a 10 m by 10 m rectangular mesh.

Hydraulic resistance in the model domain has been modelled by assigned roughness coefficients based on land use and, in the active channel of Buckler Burn, research for steep, active bed load dominated gravel river systems.

There are few observed data detailed and prolific enough to have enabled a robust calibration of the model. However, the converted HECRAS model output has been validated by comparing model output from the February 2020 flood event with the MIKE21FM modelling results. The two models generated very similar flood extents in and around Glenorchy.

Review comment:

> The modelling approach, and parameters selected in development of the model, are soundly based, and reflect conventional practice. The model results for the February 2020 flood event from the HECRAS model platform in comparison to the MIKE21FM platform provide validation of the model as a tool to investigate flooding processes in Buckler Burn.

Modelling Scenarios

For the Buckler Burn investigation other model input data for the scenarios to be modelled included:

- Hydrology input hydrographs for the Buckler Burn catchment, with profiles based on Dart Rees recorded events, and scaled for six assumed peak flows
- Channel aggradation scenarios provided by ORC.

Hydrology

Inflow hydrographs to Buckler Burn are based on the flood response profile of the February 2020 event in the Rees River. These have been scaled for six peak flows between 100 m^3/s and 300 m^3/s.

In terms of peak flows, LRS notes flood frequency data from URS (2007) and NIWA NZ River Flood Statistics which estimated peak 100 year flows of 170 m^3/s and 82 m^3/s respectively. In comparison to these estimates the 300 m^3/s peak flow modelled is very significant. However, given there has been no recent hydrology study of the Buckler Burn catchment specifically, the frequency of flows in Buckler Burn is uncertain. The future flood frequency will also change based on expected temperature increases due to climate change.

The hydrology scenarios also do not consider the possibility of high flows generated by the failure of a debris dam in the upper catchment.

Aggradation of Buckler Burn

To model the sensitivity of the Glenorchy flood hazard to aggradation of the Buckler Burn channel, the six design hydrographs were simulated with the three aggradation scenarios provided to LRS by ORC. The channel belt of the Buckler Burn in the upper fan (represented by 2019 LiDAR DEM) was aggraded by 1 m, 2 m and 3 m to create three DEM scenarios. It is noted that these are simplifications likely to represent longer-term aggradation processes. As noted by LRS, in an event the thickness of sediment deposited could vary due to the unpredictable and erratic pulse-like nature of material and debris transported in a significant flood.

These aggradation scenarios have not been scrutinised as part of this review, noting a separate informal review provided to ORC by Professor Ian Fuller of Massey University (June 2023).

Review comment:

> Notwithstanding the limitations of the hydrological and aggradation assumptions noted above, we consider that the modelling results do provide useful information regarding the potential flood hazard to Glenorchy for the specific scenarios modelled in Buckler Burn.
>
> However, to extend this to inform a risk assessment for instance it is recommended that:
>
> – the hydrology of the Buckler Burn catchment is studied to determine more accurately the flood frequency of flood flows
> – the possible consequences of event-based debris flows on channel capacity are investigated, including debris dams in the upper catchment.
>
> These are also noted by LRS in its recommendations.

Modelling Conclusions

Based on the modelling of the six hydrological events and three aggradation scenarios LRS concluded:

- *Flood flows have the potential to overtop the active Buckler Burn channel belt, spill out across the fan surface and inundate Glenorchy township.*
- *Aggradation across the fan surface and infilling of the active channel belt, leads to a reduction in the flow required to spill out onto the fan surface.*
- *Flood behaviour is therefore sensitive to aggradation on the fan and the exact nature of a flood will change based on that.*
- *Simplification of the aggradation profiles may have resulted in an underestimation of the inundation extents to the north, and warrant further study with greater detail.*
- *Subtle changes in the fan morphology between the 2019 and 2022 results in differences in the extent and depth of inundation, and the size of flow required to fill the active channel belt and spillover onto rest of fan surface. This shows that the modelling cannot capture the full range of such a dynamic system, but rather provide only a generalised prediction of behaviour and resulting inundation for these design and aggradation scenarios.*
- *Given the steep nature of the fan, flood flows across the fan surface are classed as hazard category 5, 6 or a mixture of both, whilst the floodwaters which enter the township, are for the*

most part given the lowest hazard category of 1, with localised spots there and along the Glenorchy-Queenstown Rd and Oban St as high as 6, rendering these roads impassable and likely damaged during an extreme event.

- *High velocities along the true right in the vicinity of the Glenorchy-Queenstown Rd also suggest that rates of erosion would be significant and there is the risk of avulsion to the north.*
- *Imagery, cross sections, and past behaviour of the fan, suggest that its surface is actively changing with resulting effect on flood risk. For example, the active channel belt is currently aligned at the most southern limit of the fan; therefore northwards migration should be anticipated.*
- *To better understand the relationship between the fan surface morphology and flood risk, the fan would benefit from ongoing monitoring.*

Review comment:

> Despite considerable uncertainty in likelihood and timeframes that the scenarios represent we consider that the modelling results for the various combination scenarios provide useful guidance to the Glenorchy community regarding the flood hazard to the township if the Buckler Burn channel capacity is reduced by sediment deposition. This will inform landowners and residents of the potential hazard, and assist the ongoing Head of Lake Wakatipu Hazards Adaption project.

Modelling and Monitoring Recommendations

LRS recommended the following with regard to further modelling investigations and monitoring of the Buckler Burn fan:

- *More detailed aggradation scenarios that have a more realistic distribution of sediment across the entire fan surface could be simulated. As could a scenario where the spillover onto the inactive fan surface between the 0.25 and 0.5km is prevented.*
- *Delft 3D could be used to model sediment transport and channel morphology within the Buckler Burn.*
- *Rapid Mass Movement Simulation (RAMMS) could be used to assess the potential magnitude of near-instantaneous bed aggradation in response to mass flows (debris flows/floods) by investigating the risks posed by slope failures in delivering large volumes of sediment.*
- *To better determine the risk of flooding to the Glenorchy township, a detailed catchment hydrology review could be completed to determine best-estimate flood frequency flows (annual return intervals) and provide an estimation on future flows under the climate change projection scenarios.*
- *Annual/biannual cross section monitoring to better understand flood risk from the burn, by keeping track of the change in channel capacity, fan surface elevation, and gradient over time.*
- *Annual or significant event-based monitoring using LiDAR or drone survey to capture high resolution detail of the fan surface, will allow for analysis to show change in the fan surface and channel topography over time.*
- *These successive DEMs should then be incorporated into future model runs to better understand changes in risk of inundation as the channel morphology adjusts.*
- *Document behaviour of the fan (main and subsidiary channels and delta) during and immediately after flood events.*

Review comment:

> We concur further investigation of hydrological and debris flow processes will provide information required to clarify the risk to Glenorchy from the Buckler Burn flood hazard.

Monitoring of the fan system will also provide useful information firstly to refine modelling assumptions, and secondly to inform present-day risk from for instance reduced Buckler Burn system flow capacity.

We trust that this meets your requirements. Please contact Tom Bassett at tbassett@tonkintaylor.co.nz if you require clarification or elaboration of this review report.

This T+T review was a form of peer review, undertaken on a level-of-effort basis, to provide additional assurance to Otago Regional Council as to the quality of the modelling. The responsibility for the modelling remains fully with the Principal Consultant (LRS), and T+T's review does not constitute a means by which that modelling responsibility can be passed on to T+T. This report has been prepared on behalf of, and for the exclusive use of ORC, and is subject to, and issued in accordance with, the provisions of the contract between T+T and ORC. T+T accepts no liability or responsibility whatsoever for, or in respect of, any use of, or reliance upon, this report by any third party.

Yours sincerely

Jon Rix
PROJECT DIRECTOR

8-Sep-23
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