Glenorchy and Kinloch Natural Hazards

Risk Analysis Report

Prepared for Otago Regional Council
Prepared by Beca Limited

26 August 2024

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Revision History

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Approved by	Hadley Wick		26 August 2024
on behalf of	Beca Limited		

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Executive Summary

Introduction

Otago Regional Council (ORC) is developing a natural hazard adaptation strategy for the area at the head of Lake Wakatipu (Whakatipu Waimāori). The area is known to be susceptible to natural hazards including flooding and the effects of earthquakes (seismic shaking, liquefaction and lateral spreading).

As part of this programme, Beca Limited (Beca) has been commissioned to conduct risk analyses of natural hazards impacting the townships of Glenorchy (Tāhuna) and Kinloch, based on natural hazards studies conducted by others.

The analyses considered the risk to life and property from the following natural hazards:

- River flooding from Rees River, Dart River and Buckler Burn.
- Lake Wakatipu flooding
- Seismic shaking.
- Liquefaction and lateral spreading in earthquakes (Glenorchy only).

The Rees and Dart Rivers were modelled together as the catchments sit alongside one another and are exposed to similar rainfall patterns (ORC, 2021).

Risk was initially assessed qualitatively (descriptively), and then quantitatively (providing a numeric risk value) for those hazards warranting further assessment.

This report details the findings of the natural hazards risk analysis in the townships of Glenorchy and Kinloch. The risk analysis has been peer reviewed by Tonkin + Taylor Ltd.

Study Area & Natural Hazards Overview

The Glenorchy township is located approximately 30km northwest of Queenstown at the head of Lake Wakatipu. The area is bounded by the Puahiri/Puahere (Rees River) and Te Awa Whakatipu (Dart River) to the north and Buckler Burn to the south. The existing township is sited on the low-lying alluvial fan deposited by Buckler Burn over the last 12,000 years. Bible Stream is located to the southeast of the township. Kinloch is located approximately 2.5km west of Glenorchy, and 25km by road, and is bounded to the east by the Dart River.

Both Glenorchy and Kinloch have experienced multiple river and lake flood events in recent decades. The most widely documented flood event was the 1999 flood which caused widespread damage in both communities including multiple road washouts, isolating Glenorchy and Kinloch. The area is subject to strong ground shaking during earthquakes with numerous mapped fault systems in the wider area, the most notable being the Alpine Fault some 55km away. Liquefaction and lateral spreading are expected to occur in Glenorchy during significant earthquakes.

A short list of natural hazards potentially impacting Glenorchy and Kinloch was developed and agreed with ORC following a high-level review of hazards and community exposure, as well as suitability of available data to conduct risk analyses.

Risk Analysis Process

Qualitative and quantitative risk analyses have been completed for the short-listed natural hazards in accordance with the requirements set out by the proposed Otago Regional Policy Statement (RPS) - Hearing Panel version (ORC, 2022). The RPS presents a framework for the assessment of natural hazards in Otago which considers the interaction between a hazard occurring (likelihood) and the effects on life and the built environment (consequence). The RPS requires three scenarios to be considered for each hazard representing median likelihood, high likelihood, and maximum credible event. The approach uses the following relationship:

$$Risk = Hazard\ (likelihood)\ x\ Consequence$$

Risk is assessed for the following elements in accordance with (and using the same terminology as) the RPS (ORC, 2022):

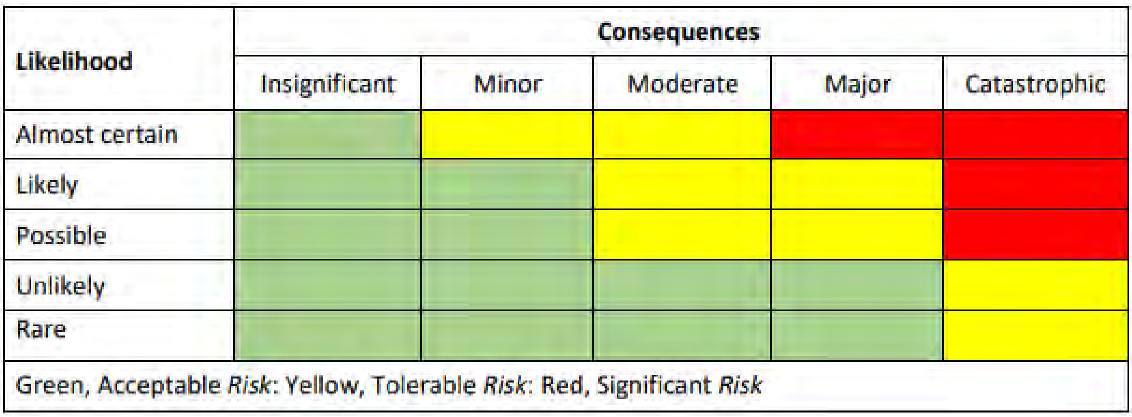
- Qualitative risk:
  - Health and safety (injuries and death)
  - Built environment
    - Buildings
    - Lifelines (essential infrastructure services e.g., water, transport, power, telecommunications)
- Quantitative risk:
  - Life
  - Property.

Qualitative Risk Analysis Process

Qualitative risk analysis uses professional judgement and qualitative observations to evaluate the potential risks of each hazard against a range of prescribed consequence criteria. It is typically used where there is insufficient data for quantitative analysis or as a preliminary screening tool to determine whether quantitative analysis is required.

Risk is determined based on the likelihood and consequences and described using the qualitative risk descriptors Acceptable, Tolerable and Significant, as shown in Table I below.

Table i: Qualitative risk table from proposed RPS (Table 8)



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

Quantitative Risk Analysis Process

Quantitative risk analyses allow for greater consideration of uncertainty and provides a numerical expression of risk for each hazard scenario. The output is risk presented as an annualised probability.

The quantitative assessment of life risk considers the probability that an individual most at risk is killed in any one year as a result of the hazards occurring. This is termed the Annual Individual Fatality Risk (AIFR).

The quantitative assessment of property risk considers the probability of total property (i.e., building) loss in any one year as a result of the hazards occurring, and is termed the Annual Property Risk (APR). Total property loss occurs when the cost of repair exceeds the value of the property.

Quantitative risk (AIFR and APR) is calculated from the following equation:

Quantitative Risk = Annual Probability x Spatial Probability x Temporal Probability x Vulnerability

Where:

- The annual probability is the risk of the hazard occurring in any one year.
- The spatial probability relates to impact by the hazard in a specific location occupied by the person most at risk, or occupied by property.
- The temporal probability for life risk incorporates the proportion of the time the person most at risk is present and allowing for the possibility that the person may be able to evade the hazard. The temporal probability for property risk is 1.0 (i.e., the house or building is always present).
- The vulnerability for life risk is the probability of death of the person most at risk, in the event of an interaction with the hazard. For property risk it is the vulnerability of the property to the damage, or the expected proportion of property value lost in the event of being impacted by the hazard (typically termed the damage ratio).

The assessment does not consider specific locations of people or buildings, and assumes they could be present anywhere across the study area, to allow for relative comparison of risk levels.

Quantitative Risk Categories

Qualitative risk levels are re-categorised in accordance with Table ii following quantitative analysis. The defined risk levels apply to both life (AIFR) and property (APR), for existing developments.

Table ii: Quantitative risk levels in accordance with the RPS (ORC, 2022)

Risk Category	Risk Value
Acceptable	Less than $1x10^{-5}$
Tolerable	$1x10^{-4}$ to $1x10^{-5}$
Significant	Greater than $1x10^{-4}$

Qualitative Risk Analyses Results

A summary showing the risk category for each hazard assessed qualitatively is shown in Table iii. The risk categories shown relate to the scenario with the highest risk assessed for each hazard, considering:

- All scenarios or scales of hazard,
- Any location within the study area, and
- All built environment sub-categories, where assessed (e.g., lifelines, buildings etc).

Table iii: Qualitative risk level summary

Hazard	Health and Safety Risk	Built Environment Risk
River flooding – Buckler Burn	Tolerable	Significant
River flooding – Rees/Dart	Significant	Significant
Lake Wakatipu flooding	Acceptable	Significant
Liquefaction and lateral spreading - Glenorchy	Acceptable	Significant
Seismic shaking	Acceptable	Tolerable

The risk levels shown are in accordance with Table ii above and were used to determine which hazards are Significant and therefore warrant further investigation through quantitative risk analysis.

On the basis of the above qualitative risk levels, the following hazards were carried forward to quantitative analysis as agreed with ORC:

- Buckler Burn flooding – life and property risk
- Rees/Dart flooding – life and property risk
- Joint flooding scenario – life and property risk
- Lake Wakatipu flooding – property risk
- Liquefaction and lateral spreading (Glenorchy) – property risk.

Note, the 'joint flood' event is a modelled scenario where Buckler Burn, Dart/Rees Rivers, Bible Stream, and two small Glenorchy catchments flood at the same time. This was assessed during the quantitative analysis only due to the availability of additional flood modelling data.

A description of the spatial distribution of risk, as assessed qualitatively, is included below. Comments relate to all scenarios assessed, unless stated otherwise.

River Flooding

Buckler Burn

- Built environment risk (lifelines and buildings) is overall Significant for a Buckler Burn flood event, with Glenorchy and Kinloch expected to be cut-off (out-of-service) due to flooding of Queenstown-Glenorchy Road in the large flood events that were used in the assessment. The flooding within the Glenorchy residential area is defined at a Tolerable risk level for buildings.
- The health and safety risk is assessed as Tolerable due to the marginal extent of the flooding within the residential area.

Rees/Dart Flooding

- Flood modelling shows that a Rees/Dart flood could lead to widespread flooding in the northern part of Glenorchy and along the Rees riverbank.
- Built environment risk is Significant for a Rees/Dart River flood event, with widespread flooding of the road north out of Glenorchy, and residential properties adjacent to the Rees River in northern Glenorchy and properties adjacent to the Dart River in Kinloch flooded.
- Health and Safety risk for the larger Rees/Dart River flood event is assessed as Significant.

Lake Flooding

- Flooding of Lake Wakatipu will impact areas adjacent to the lakefront and along the Rees and Dart Rivers.
- Built environment risk is Significant for properties in Glenorchy and Kinloch.
- Health and Safety risk is Acceptable for all areas due to the very low speed the lake levels rise and the prolonged warning times.

Seismic shaking

- Seismic shaking hazard at Kinloch and Glenorchy is expected to pose a Tolerable risk to the built environment due to structural damage of lifeline infrastructure. With Tolerable Risk assessed for water supply due to reliance on water supply wells which would be expected to take significant time to repair or replace.
- Predicted damage to buildings is considered to result in Acceptable levels of risk.
- The potential for collapse of the typical building in Glenorchy and Kinloch, being timber framed buildings, is relatively low and does not necessarily lead to fatality or serious injury therefore the risk to health and safety is considered Acceptable.

Liquefaction and Lateral Spreading

- The impacts of liquefaction in Kinloch were not assessed as there is insufficient data available to inform a risk assessment.

- The qualitative risk assessment for Glenorchy identified that widespread liquefaction is predicted, with lateral spread displacements up to 3m predicted along the shoreline.
- Lifeline risk is considered Significant due to the anticipated loss of water supply, wastewater, power, roading, and telecommunications.
- Building risk is considered Significant for the larger earthquake scenarios assessed.
- Public health and safety risk is considered to be Acceptable as liquefaction and lateral spreading generally does not cause death or injury.

Quantitative Risk Analysis Results

Quantitative assessments of life risk (AIFR) and property risk (APR) posed by the various natural hazards have been completed for all natural hazard scenarios assessed to be Significant, along with Buckler Burn flooding which was assessed as Tolerable.

A summary showing the risk level for each hazard assessed quantitatively is shown in Table iv, with discussion on the extents of risk levels shown below.

Table iv - Quantitative risk levels in accordance with the RPS (ORC, 2022)

Hazard	Life Risk	Property Risk
River flooding – Buckler Burn	Acceptable	Significant
River flooding – Rees/Dart	Acceptable	Significant
Joint flooding scenario	Acceptable	Significant
Lake Wakatipu flooding	-	Significant
Liquefaction and lateral spreading - Glenorchy	-	Significant

Annual Individual Fatality Risk

River Flooding

Results of the river flooding life risk (AIFR) analysis are shown in Figure i, based on Table ii above. Each map shows the combined risk, being the sum of risk from all three scenarios assessed for each hazard.

The risk to life (AIFR) from river flooding hazards has been assessed as Acceptable for developed areas in Glenorchy and Kinloch. The Significant effects of flooding are concentrated on the margins adjacent to the rivers and lake, and outside the developed areas. This lower level of risk is partly a function of the ability of people to evade slow rising floodwaters.

In Glenorchy, the primary river flooding risk come from flooding of the Rees/Dart Rivers. However, Buckler Burn also poses some risks within the township. The areas with the highest life risk (AIFR) are the Glenorchy lagoon, the lakefront (including Jetty Street and Benmore Place), and the Glenorchy golf course. Areas behind the floodbank, near the confluence of the Rees River and the lagoon, show the highest estimated AIFR values but are considered Acceptable.

The highest risks in Kinloch are also caused by Rees/Dart flooding. Existing buildings west of the Kinloch Road are in low flood risk areas. Areas east of the Kinloch Road have the highest life risk (AIFR) values but are still considered Acceptable.

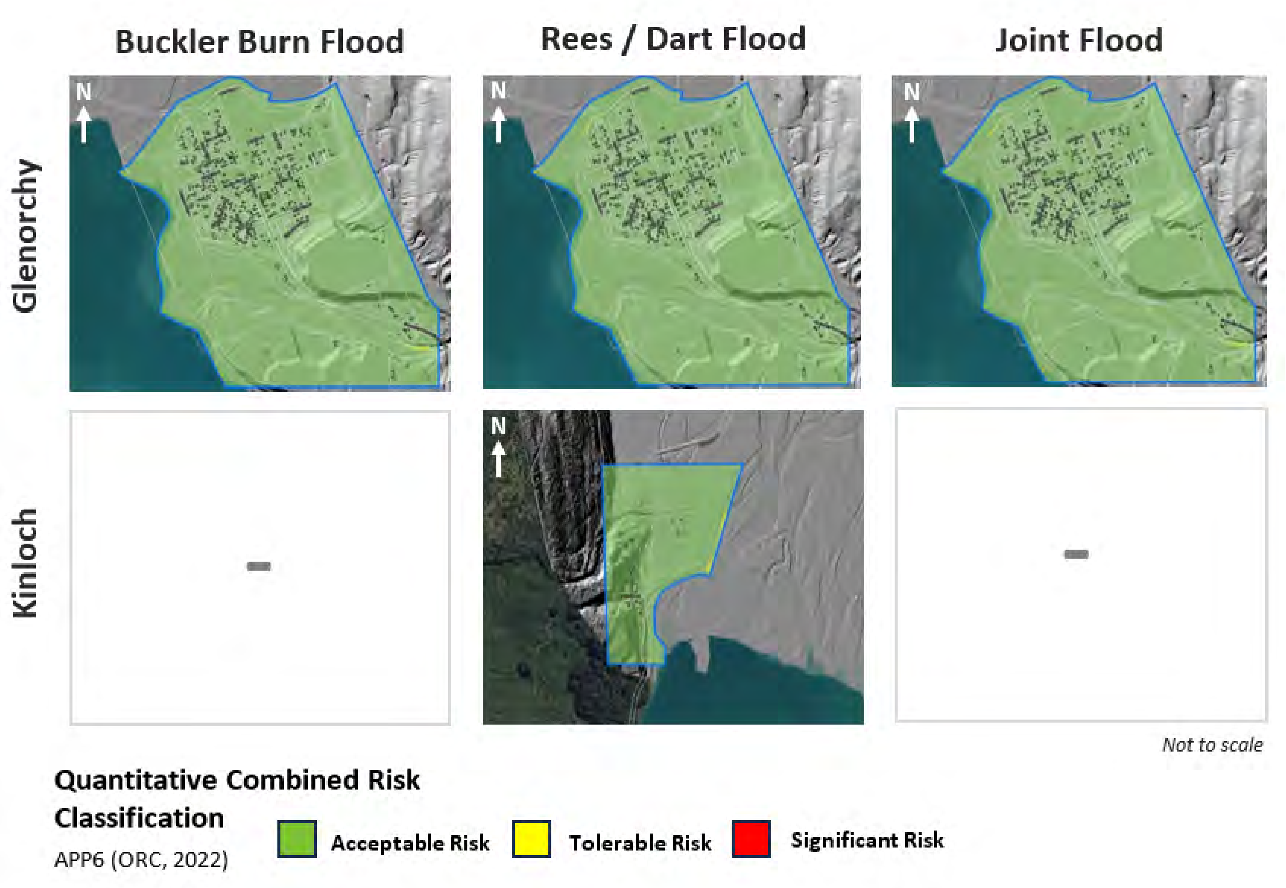


Figure i: River flooding life risk (AIFR) levels

Annual Property Risk

River Flooding

Results of the combined river flooding annual property risk (APR) analysis are shown in Figure ii, based on Table ii above.

Quantitative property risk levels vary spatially between hazards, with the risk to property being Significant along the river and lake margins, and Acceptable outside of these areas. A large proportion of the land area that is most prone to flooding and within the Significant risk categorisation is used for community recreation and does not house a permanent population (including recreation reserve/parks and the golf course).

A Dart/Rees River flood poses the highest risks to property, having the highest APR values and the greatest extent of potential damage to property. In Glenorchy, this leads to potential damage around the lagoon and the Rees River mouth, with the highest property risk (APR) values on the golf course, in areas of Significant risk. In Kinloch a Rees/Dart River flood could potentially damage areas to the east of Kinloch Rd with APR calculated to be Significant.

The potential damage caused by the Buckler Burn is limited to a few areas within its modelled overland flow path along the Glenorchy-Queenstown Road and Shield Street. Overall, the Buckler Burn has low property risk (APR values) and a small flood extent within the township area. Consequently, the additional damage caused by flooding from the Glenorchy catchments and the Buckler Burn in a joint flood scenario is minimal. The joint flooding scenario shows higher property risk (APR) values along Coll Street and the Glenorchy Cemetery, resulting in areas of Significant risk.

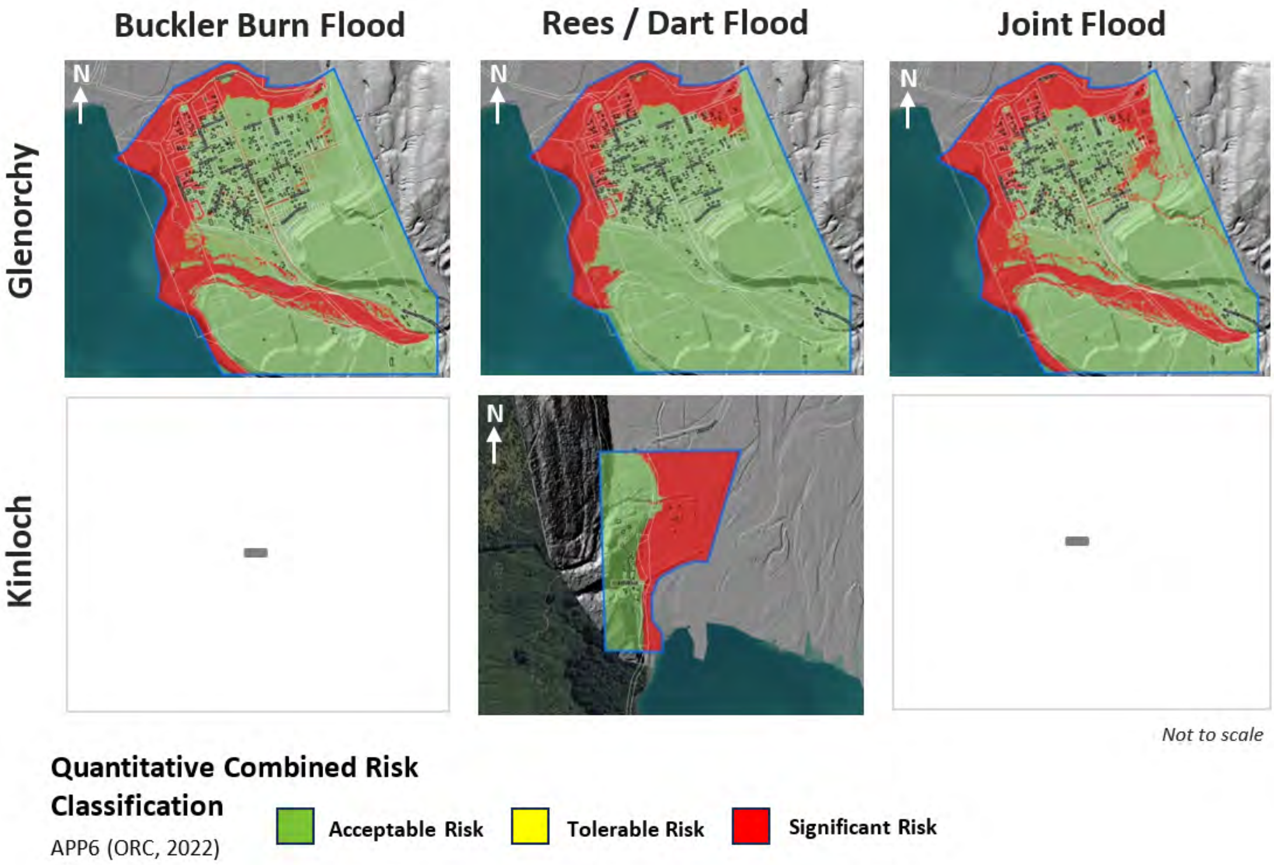


Figure ii: River flooding property risk (APR) levels

Lake Flooding

Results of the lake flooding property risk (APR) analysis are shown in Figure iii, based on the quantitative risk levels (Table ii).

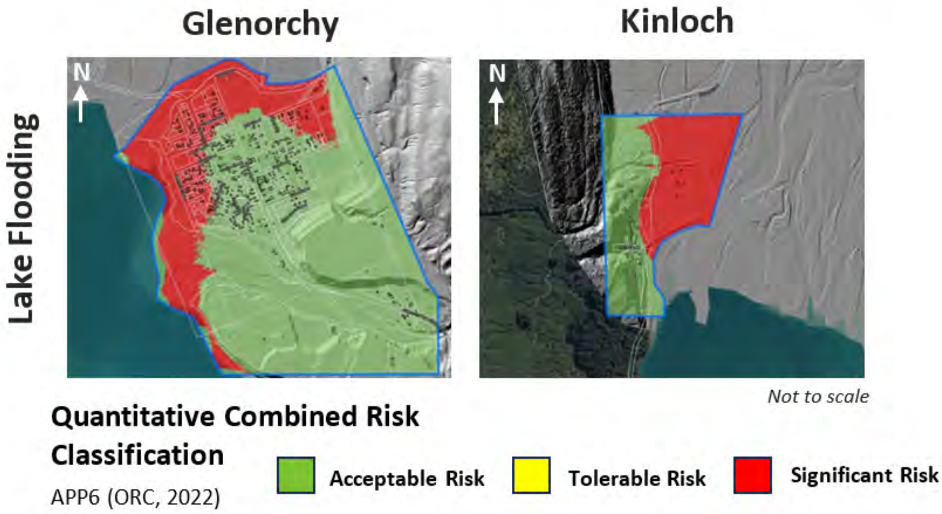


Figure iii: Lake flooding property risk (APR) levels

Quantitative property risk levels show areas of Significant risk along the lake front at both Glenorchy and Kinloch, and the Rees River margin in Glenorchy.

The level of damage caused by a lake flood follows the topography of Glenorchy and Kinloch. The low-lying areas along the Rees lagoon and the lake are the areas most affected (e.g. Jetty Street and Butement Street). In Kinloch, APR values on Kinloch Road equate to a Significant risk.

Liquefaction and Lateral Spread

Results of the liquefaction and lateral spread property risk (APR) analysis for Glenorchy are shown in Figure iv, based on Table ii above.

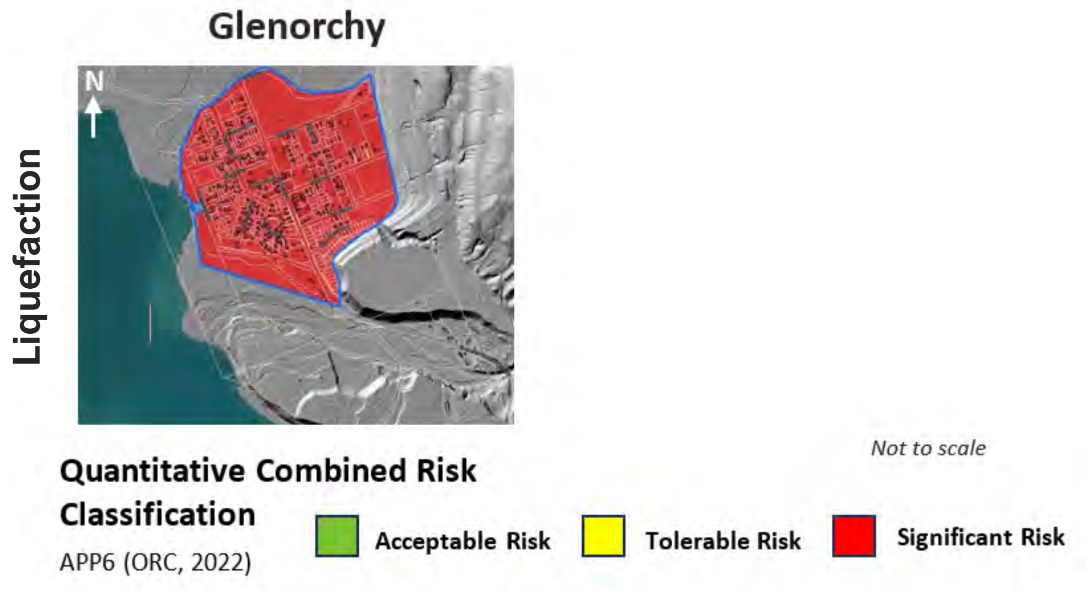


Figure iv: Liquefaction and lateral spread property risk (APR) levels

Quantitative property risk levels from liquefaction and lateral spread are Significant for the whole of Glenorchy township.

The hazards that affect the greatest area to the built environment in Glenorchy are liquefaction and lateral spread-inducing land damage affecting property. While damage associated with liquefaction is expected to be substantial, lateral spreading is anticipated to result in the most significant damage focused along the lake margins, due to an approximately 25m high free face (below lake level).

Risk Tolerability

Quantitative life risk (AIFR) was assessed for river flooding hazards. Life risk in Glenorchy and Kinloch is within the tolerable guidance in accordance with the RPS (ORC, 2022), outside of the active channels. Risk to property (APR) from flooding and liquefaction hazards exceeds the Tolerable threshold listed in the RPS (ORC, 2022) in parts of both settlements. It is noted in the RPS that it is ultimately the responsibility of local authorities to undertake a consultation process with communities, stakeholders and partners regarding risk level thresholds.

A comparison of common life risks and tolerability limits, along with the assessed range of AIFR for all assessed flooding scenarios is shown in Figure v below. The life risk to Glenorchy and Kinloch from river flooding shown below is for all areas modelled, including active channels and along the lakefront, which is conservative as values in the township area are lower.

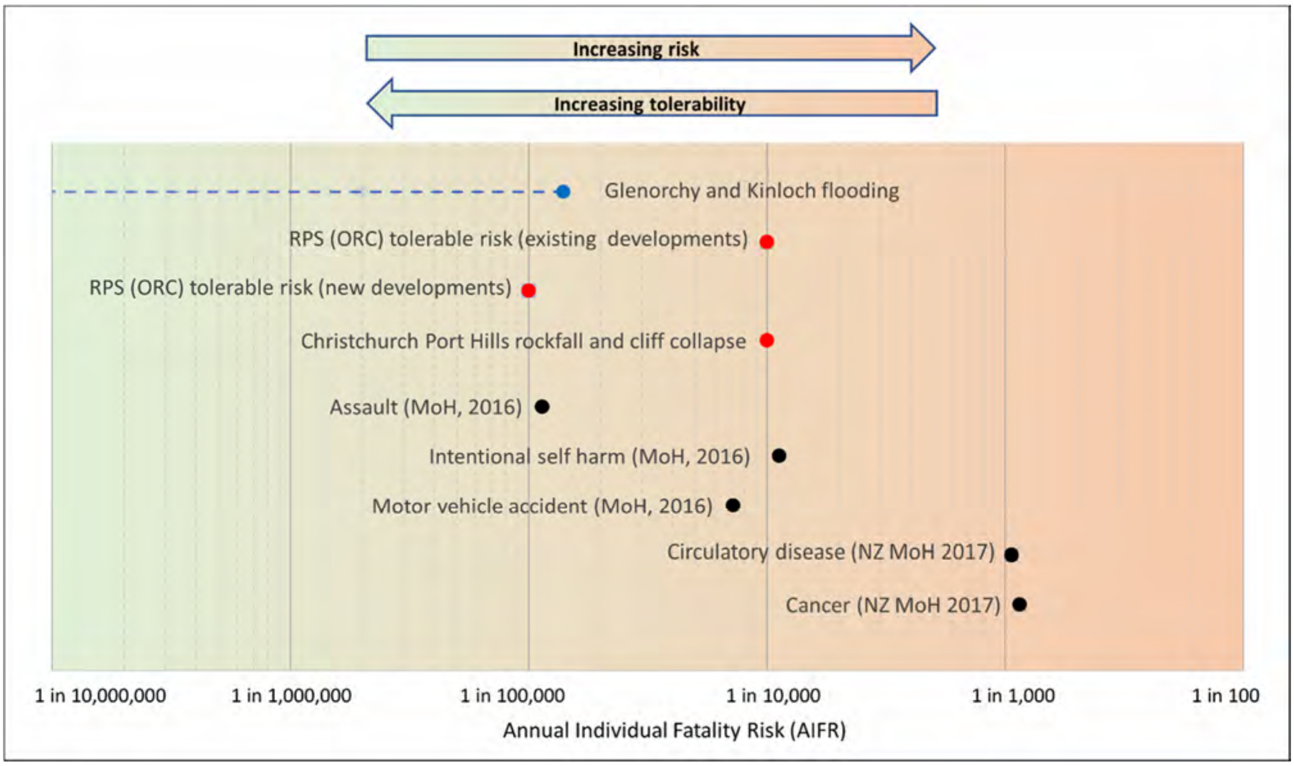


Figure v: Common risks and tolerability limits for life risk (AIFR)

1 Introduction

Beca Limited (Beca) has been engaged by Otago Regional Council (ORC) to conduct risk analyses of natural hazards in Tāhuna (Glenorchy) and Kinloch at the head of Lake Wakatipu. The study involves review and analysis of natural hazards characterisation work completed by ORC and others, and qualitative and quantitative risk analyses based on this information.

1.1 Project Objectives

The ORC objectives of this multi-hazard study are to systematically assess and describe risk for selected natural hazards affecting the Glenorchy and Kinloch built environment and communities. This risk analysis study feeds into a programme of work by ORC to develop a natural hazards adaption strategy to inform future risk management and adaptation activities for the area at the head of Lake Wakatipu (Whakatipu Waimāori). This work aligns with the Adaptation Pathways approach developed by the Ministry for the Environment (2017) which is being followed by ORC, where an understanding of natural hazards and risk is used to identify pathways that best manage, reduce or avoid risk.

1.2 Report Purpose

The purpose of this report is to present the findings of the risk analyses conducted by Beca. The findings will be used to inform future risk management and adaptation strategies for the area.

1.3 Study Extents

Glenorchy township is located at head of Lake Wakatipu approximately 30km northwest of Queenstown. The town is sited on low-lying land on the eastern margin of the lake, bounded by the Puahiri/Puahere (Rees River) and Te Awa Whakatipu (Dart River) to the north and Buckler Burn to the south. The extents of the study areas in Glenorchy and Kinloch, is shown in Figure 1-1.

The study area encompasses the current extents of the Glenorchy township that has a permanent population of approximately 380 (QLDC, 2022). Glenorchy is a popular tourist destination within the Queenstown area, with an associated transient population in the order of between 240 to 650 with seasonal variation (QLDC, 2022).

Kinloch is located approximately 2.5km west of Glenorchy, and 25km by road. Kinloch is bordered by the Dart River to the east, and in close proximity to Lake Wakatipu to the south. The wider Glenorchy area includes the settlement of Kinloch and has a permanent population of approximately 150, with smaller numbers of tourists ranging from 70 to 200 per day seasonally (QLDC, 2022).

Glenorchy township was originally developed through scheelite mining in the 19th century and has more recently become a base for farming and tourism activities in the wider region. The majority of the township comprises residential dwellings, as well as tourism operations and various community amenities.

Basemap source: Earthstar Geographics

Figure 1-1: Study areas and key features.
The study area outlines are shown in solid blue, with the Glenorchy liquefaction study extents outlined in dashed blue.

1.4 Scope

The scope of this study is to conduct risk analyses for various natural hazards that have the potential to affect communities and the built environment within the study areas. The study considers the risk from the following natural hazards, identified by ORC:

- River flooding
- Lake Wakatipu flooding
- Alluvial fan hazards - flooding and debris flows
- Seismic shaking affecting the built environment
- Liquefaction and lateral spreading
- Lake tsunami.

Risk analyses undertaken as part of this study are based on natural hazard characterisation and definition work conducted by others. Beca has not undertaken independent checking of the validity of data or studies on which the risk analyses were based. Details of these studies are included in the individual hazard sections of this report.

This study considers risk from selected natural hazards by way of assessing a range of hazard scenarios, first qualitatively and then quantitatively. The risk analysis process is detailed in Section 3 and is based on Appendix 6 of the Otago Regional Council Proposed Regional Policy Statement 2021 (ORC, 2022) – hearing panel version. The scope of the study comprises the following:

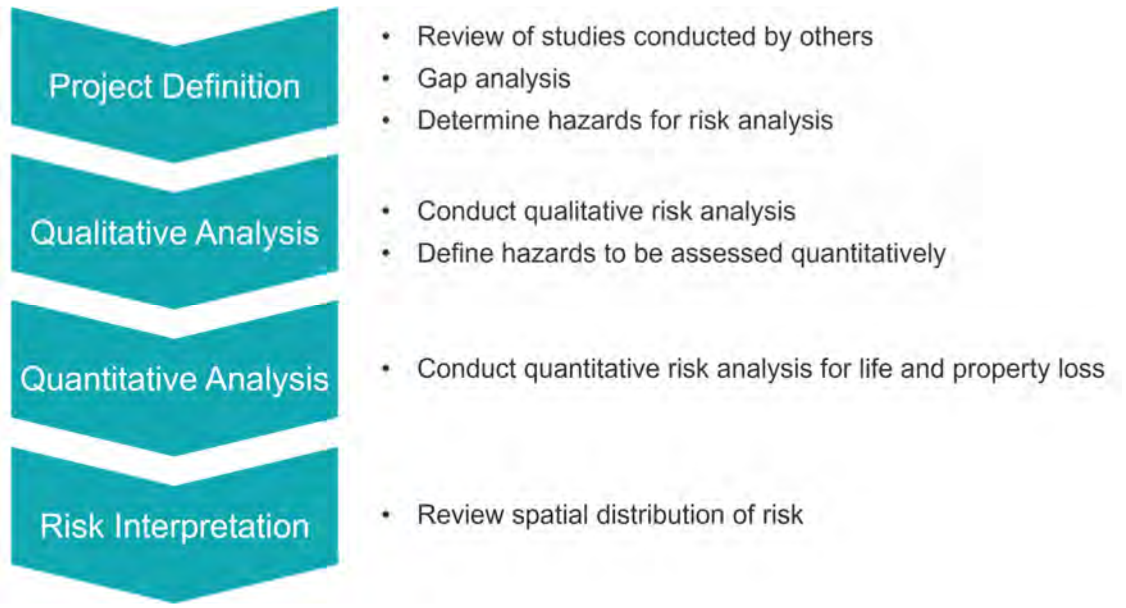


Figure 1-2: Study scope process

This report presents the outcomes of the qualitative and quantitative risk analysis. We have not sought to identify further hazards other than those identified by ORC as part of this study.

1.5 Other Studies

Other wide-ranging studies commissioned by ORC as part of the head of Lake Wakatipu adaptation programme include the following:

- Socio-economic Impact Assessment - Head of Lake Whakatipu Adaptation Strategy - Phase 1. Beca (2024).
- Floodplain management options. Damwatch (2024).

Further studies on specific hazards that informed this natural hazard risk analysis are included in the relevant hazard sections of this report.

1.6 Peer Review

This report has been peer reviewed on behalf of ORC by Tonkin + Taylor Limited (T+T), with review comments having been addressed in this final version of the report.

2 Natural Hazards Overview

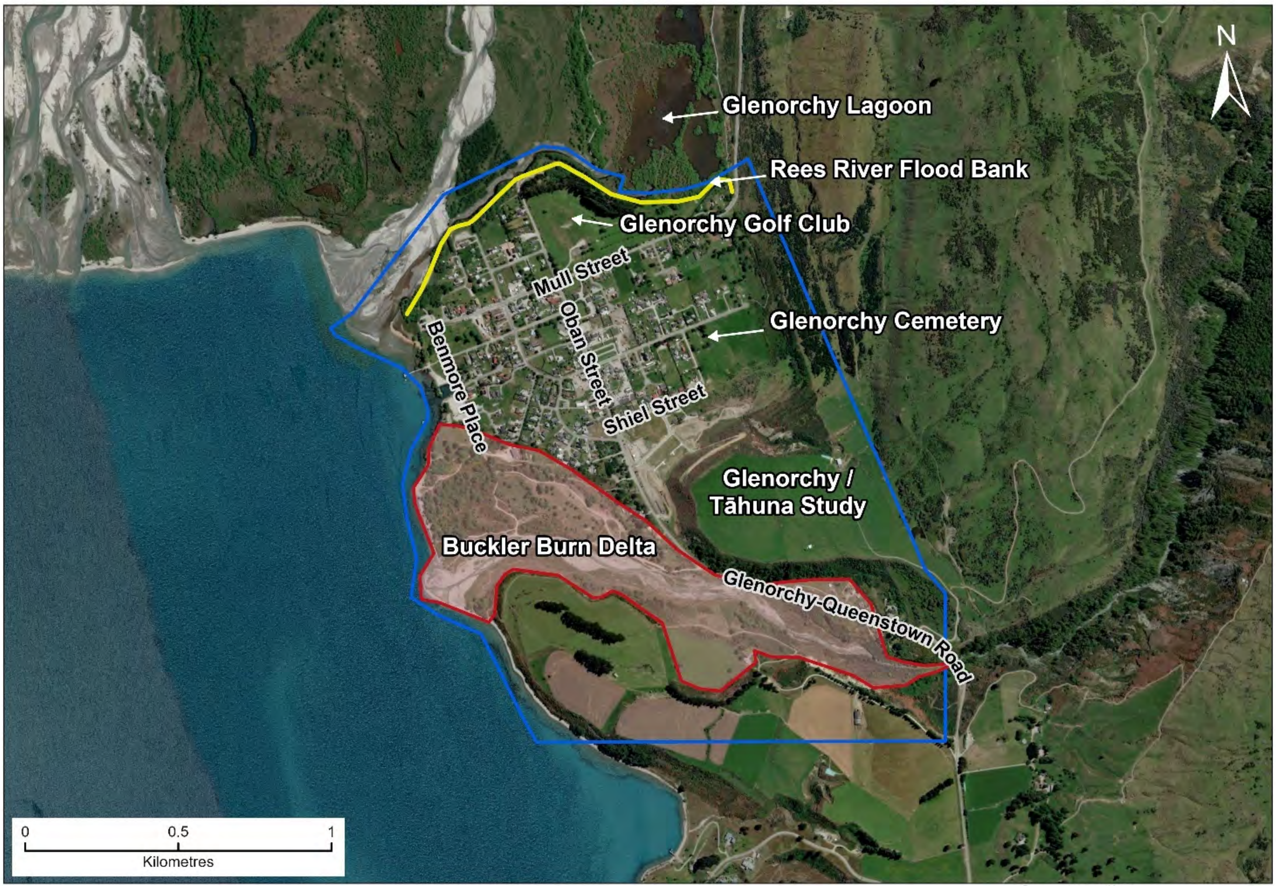
2.1 Study Area Setting

Glenorchy and Kinloch are located at the northern end of Lake Wakatipu and sit within a complex geomorphic setting as described in detail in 'Natural Hazards at Glenorchy' (ORC, 2010a) and summarised below.

Lake Wakatipu was carved by glaciers during the last ice age which ended approximately 12,000 years ago. The resulting valley is a typical U-shape with a relatively flat floor, gentle lower slopes and steep surrounding peaks. The surrounding mountains comprise Caples Terrane schist exhibiting varying degrees of metamorphism.

The Rees and Dart Rivers directly to the north of Glenorchy and Kinloch are braided systems which provide large quantities of sediment into the northern end of Lake Wakatipu adjacent to Glenorchy and Kinloch. This deposition has resulted in the formation of a combined delta which has advanced and avulsed during human settlement.

Bible Stream, southeast of Glenorchy, forms an erosional channel through a post-glacial terrace. Buckler Burn to the south of Glenorchy has developed an alluvial fan into Lake Wakatipu. Glenorchy township sits on this alluvial fan previously deposited by Buckler Burn over the last 12,000 years, as shown in Figure 2-1.



Basemap source: Maxar

Figure 2-1: Key geographical features within Glenorchy study area

Much of Kinloch settlement sits on Dart River terrace deposits, and alluvial fan deposits from Gorge Creek and other unnamed creeks to the west of the settlement.

2.2 Natural Hazard Identification

The study areas of Glenorchy and Kinloch were identified by ORC as potentially being exposed to a variety of natural hazards, including:

- River flooding (Rees River, Dart River, Buckler Burn, Bible Stream, Gorge Creek)
- Lake Wakatipu flooding
- Lake Wakatipu tsunami
- Debris flow (Buckler Burn, Gorge Creek)
- Seismic shaking affecting buildings
- Liquefaction and lateral spreading.

From this list of hazards, a short list was selected for risk analysis as detailed in this report. The short list was developed and agreed with ORC based on high level judgment-based review of hazards and community exposure, as well as suitability of available data to conduct risk analyses as identified during the gap filling stage of the study (summarised in Appendix A – Gap Analysis).

The following hazards were selected for risk analysis as part of this study:

- River flooding (Rees River, Dart River, Buckler Burn, Bible Stream, local Glenorchy catchments)
- Lake Wakatipu flooding
- Seismic shaking
- Liquefaction and lateral spreading in earthquakes (Glenorchy).

An overview of these hazards is provided in the following section.

In consultation with ORC, risk analysis has not been undertaken for the following natural hazards as part of this study. High level commentary on these hazards is included in Section 8:

- Flooding
  - Gorge Creek (Kinloch)
- Debris flows
  - Buckler Burn (Glenorchy)
  - Gorge Creek (Kinloch)
- Lake Wakatipu tsunami
- Liquefaction and lateral spreading – Kinloch.

Additionally, risk from cascading hazard scenarios, where one event triggers or affects the outcomes of another event, was not assessed as part of this study.

2.3 River Flooding

Flooding from the following rivers have been identified for risk analysis, as shown in Figure 2-2:

- Buckler Burn
- Rees and Dart River
- Bible Stream, and two small Glenorchy catchments ‘Glenorchy’ and ‘Glenorchy landfill’.

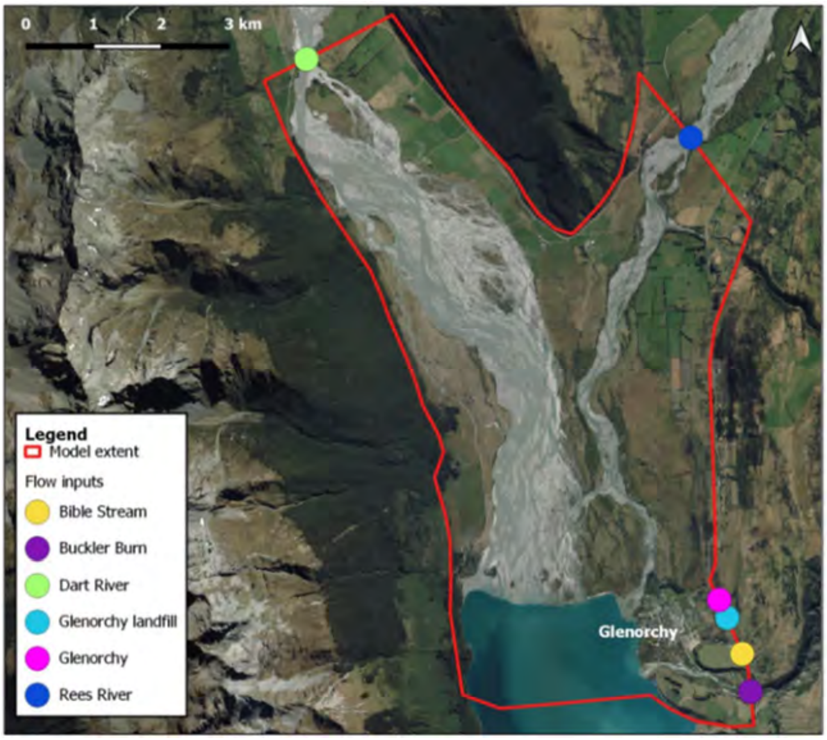


Figure 2-2: Catchments considered as part of the qualitative and quantitative flood risk assessment. Bible Stream and the Glenorchy and Glenorchy landfill catchments were only considered in the quantitative assessment in a joint source flooding scenario. Source: Land River Sea Consulting Limited, 2024.

Communities of Kinloch and Glenorchy have experienced multiple flood events in recent decades, the most widely documented being the 1999 flood that caused widespread damage in both communities, as shown in Figure 2-3 and Figure 2-4. The 1999 flood was caused by an estimated 100-year average recurrence interval (ARI) rainfall event in the catchments above Glenorchy (NIWA, 2018). The flood caused multiple road washouts, isolating Glenorchy and Kinloch (as shown in Figure 2-5). In the past, Kinloch has been cut-off multiple times because of road washouts or flooding.

Other significant flood events were the 1994 'Race-day floods', February 2020 (as shown in Figure 2-6) and September 2023 flood events. There have been no recorded deaths from past river flood events in Glenorchy.

Both the Dart and Rees rivers are undergoing constant riverbed changes due to river aggradation and erosion. There is a risk that increased gravel deposition within the current Rees River channel could result in an unpredictable and sudden river avulsion event, where the main Rees River flow could be diverted from the current channel (Tonkin + Taylor, 2021). An avulsion event could result in the Rees River flow changing its flow direction towards Glenorchy Lagoon and the Rees River stopbank. Such an event has the potential to overwhelm the Rees River floodbank and pose a serious flood risk to the Glenorchy township (Tonkin + Taylor, 2021). The risk of this avulsion event, involving severe breakout flooding and channel shifts along the left bank of the Rees River into the Glenorchy Lagoon, has significantly increased (Damwatch, 2022). Additionally, the Dart River is undergoing active westward channel belt migration, eroding the right bank along the Kinloch Road.

Figure 2-3: Flooding in Kinloch during the 1999 flood. Photo provided by ORC.

Figure 2-4: Flooding in the Glenorchy community during the 1999 flood. Source: glenorchycommunity.nz

Figure 2-5: Glenorchy - Queenstown Road is washed out by Buckler Burn during the 1999 flood event. Photo credit: Kelly Family.

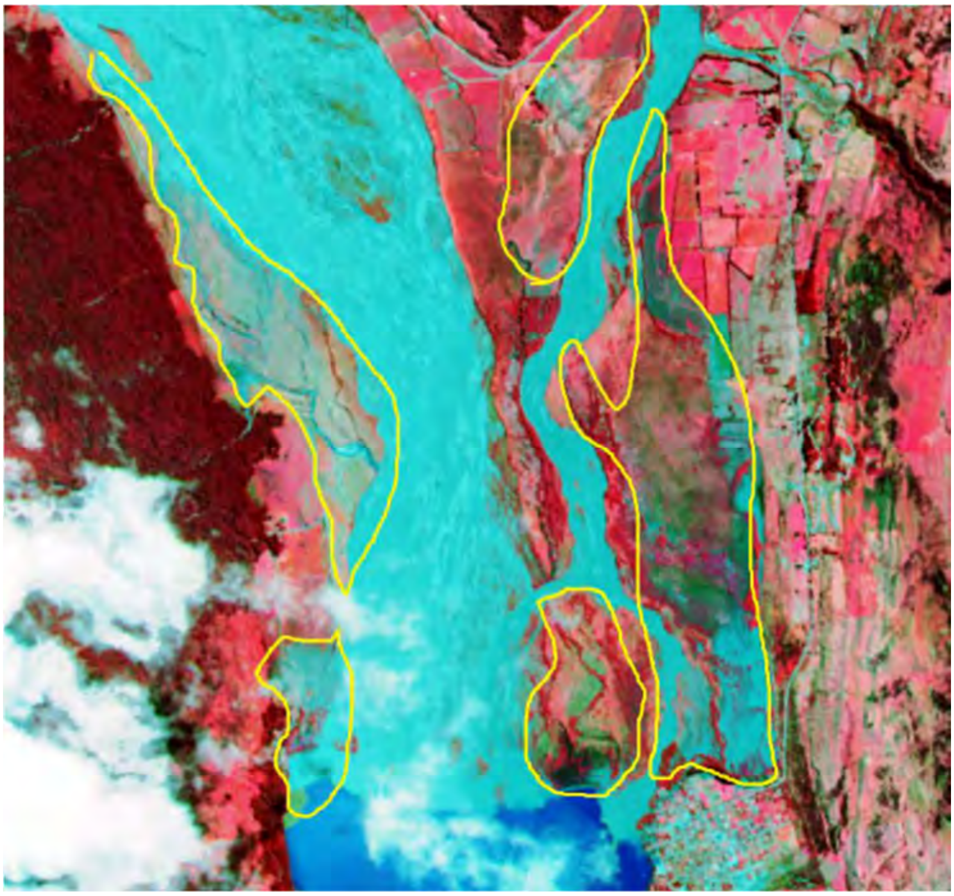


Figure 2-6: Flood extents from the 2020 flood from Sentinel 2 satellite (image taken on 4 February). Source: LRS, 2022. Red shows dry areas, with moist/wet areas in blue and green. Significant out of bank flows are outlined in yellow.

2.4 Lake Flooding

Since records began, Lake Wakatipu has flooded (with lake levels exceeding 311.3mRL Dunedin Vertical Datum 1958) multiple times, as shown in Figure 2-7. ORC conducts monitoring of the lake levels in multiple locations, including Glenorchy Boat Ramp within the study area. The median lake level is 309.8mRL at Glenorchy Boat Ramp (ORC, 2024b).

Typically, the lake starts flooding the lower areas of the Glenorchy Waterfront Reserve when it reaches 311mRL. This has happened 32 times since 1878 and there is a 29% chance the lake will rise above this level each year, and a 97% chance it will happen at least once in any 10-year period (ORC, 2013).

When the lake level reaches 311.4mRL, floodwaters reach the corner of Mull and Jetty Streets. There is a 10% chance the lake will rise to this level each year, and a 67% chance it will happen at least once in any 10-year period (ORC, 2013).

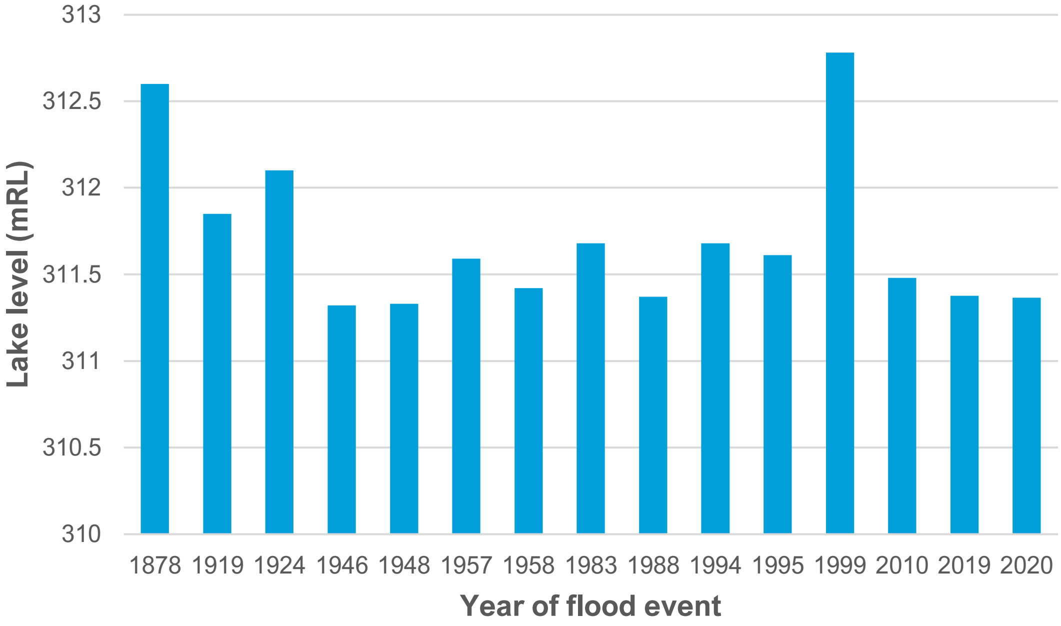


Figure 2-7: Peak recorded lake levels (≥ 311.3mRL) since 1878. The 1999 flood marks the highest recorded lake level to date. Lake levels from 1878-2000 were provided by ORC (2020); levels from 2000 onwards were obtained from ORC Environmental Data Portal with analysis undertaken by ORC.

The duration of Lake Wakatipu floods depends on weather conditions. Generally, a series of fronts bringing heavy rain to the headwater catchments can cause the lake levels to remain high for a prolonged period of time. In April 2010, the lake reached nearly 311.5mRL and stayed above 311mRL for over two weeks. In November 1999, Lake Wakatipu peaked at 312.78mRL (Figure 2-7) and remained above 311mRL for three weeks (ORC, 2013).

2.5 Seismic Shaking

New Zealand is seismically active, with a high frequency of earthquakes. Earthquakes induce strong ground motion (earthquake shaking) in response to rapid release of built-up strain along fault lines. The intensity of shaking depends on the severity of the earthquake, distance from the epicentre, specific ground characteristics and local topography. Numerous mapped fault systems are present in the wider area influence seismicity in Kinloch and Glenorchy. Adjacent possible active faults include the West Wakatipu Fault located approximately 2km west of Kinloch and the Moonlight Fault approximately 15km east of Glenorchy. The most notable fault in the area is the Alpine Fault some 55km to the nearest point from Glenorchy, due to the anticipated magnitude of earthquake and low recurrence interval. The probability of an earthquake triggering at some point along the 800km long Alpine Fault over the next 50 years is 75%, with an 80% chance that the earthquake event would exceed magnitude 8 (www.af8.org.nz).

Assessment of shaking hazard for this risk assessment considers a range of probabilistic earthquake scenarios rather than specific fault rupture scenarios.

2.6 Liquefaction and Lateral Spread

Liquefaction is a process where earthquake shaking, which varies with intensity and duration, leads to development of increased pore water pressure within saturated sands, silts and gravels, leading to temporal changes in soil characteristics. Common consequences of extensive liquefaction include damage to buildings, infrastructure and the land though vertical (differential) settlements and lateral ground deformation where the ground moves towards a “free face” such as a river, lake margin, slope (lateral spread). Figure 2-8 sets out the potential consequences of soil liquefaction.

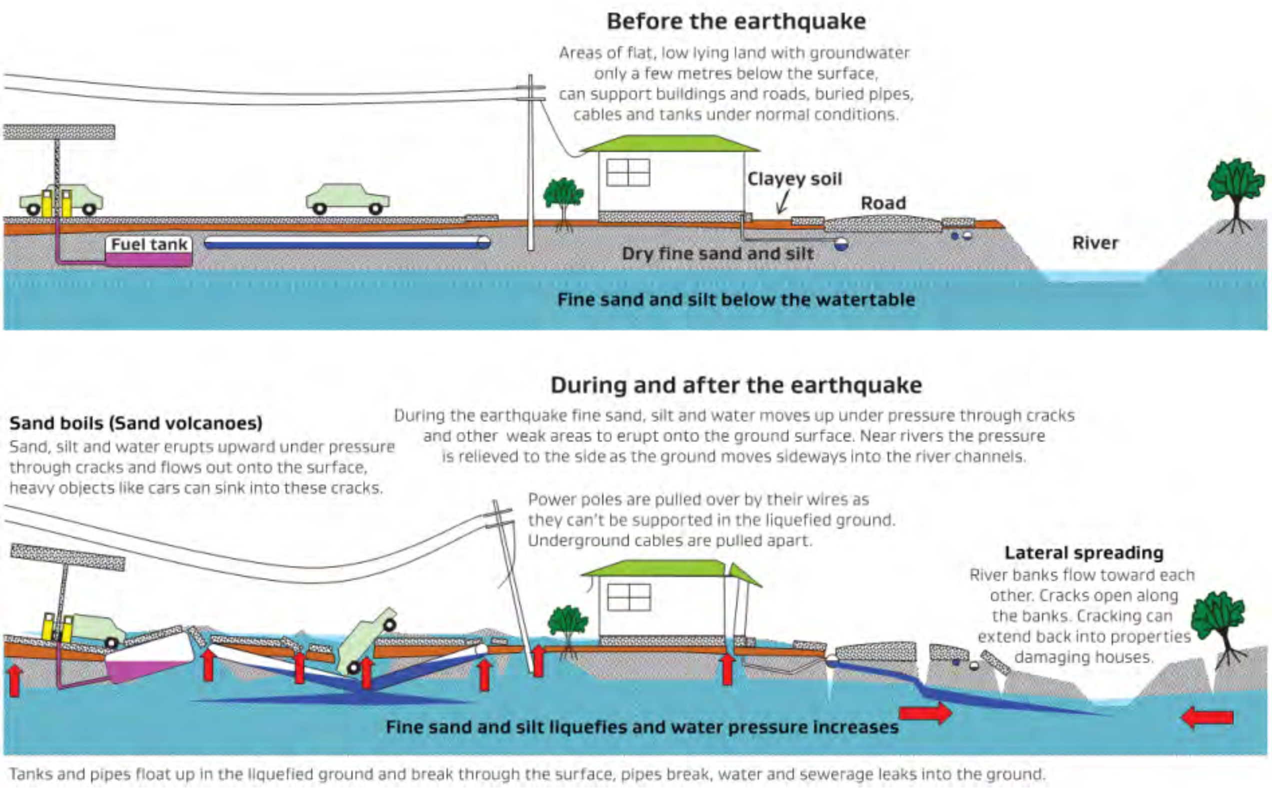


Figure 2-8: Liquefaction and its potential effect on ground surface. Source: Engineering NZ

Guidance from the Ministry of Business Innovation Employment and the Ministry for Environment (MBIE/MfE, 2017) recommends considering multiple different earthquake scenarios when assessing vulnerability to liquefaction. Larger earthquakes have the potential to cause more severe liquefaction damage than smaller ones, but smaller earthquakes typically occur more frequently.

A regional study of liquefaction hazard by GNS (2019) identified that Glenorchy and Kinloch are sited on the Rees/Dart River delta and low angle alluvial fans (Buckler Burn in the case of Glenorchy), and are vulnerable to liquefaction and associated land damage in response to earthquake shaking. ORC commissioned studies by Tonkin + Taylor (2022 and 2023) assessing liquefaction vulnerability within Glenorchy township. The 2022 study included geotechnical testing and analysis of liquefaction triggering potential, and potential land damage for various earthquake scenarios. The study identified that the land was highly vulnerable to liquefaction in response to low to moderate levels of shaking intensity, with extensive areas of Moderate to Severe liquefaction land damage. Further to this, the close proximity of Glenorchy to a 25m high free face at the Lake Wakatipu margin leads to high vulnerability to large magnitude lateral spread ground deformations. Liquefaction and lateral spread land damage is anticipated to have extensive and severe consequences to the built environment for Moderate to high frequency earthquake scenarios.

There are no records of liquefaction or lateral spread in the study area in recent history.

3 Risk Analysis Process

3.1 Otago Regulatory Context

The Hearing Panel version of the proposed RPS (ORC, 2022) sets out the requirements for conducting risk analysis in Otago. The hearing panel report recommendations were adopted by ORC on 27 March 2024. The RPS is still subject to appeal at the time of writing. Otago Regional Council (2024a) details the intent of how risk analyses conducted in accordance with the RPS will be used to inform regulatory processes, being:

- "It is a framework that will be used to inform future plan review processes where community input will ensure that the risk thresholds in district and regional plans are appropriate for those communities.
- Prior to that occurring, Appendix 6 (APP6) provides a framework for undertaking a risk assessment within resource consent processes."

The outputs of the risk analyses detailed in this report may be used to inform community consultation regarding any plan review changes and/or resource consent applications.

3.2 Risk Management

The risk-based assessment of natural hazards as detailed in the RPS (ORC, 2022) is aligned with the international standard for risk management (ISO 3100:2018). The key components of the risk management process are summarised in Figure 3-1. The outcomes of this report comprise the 'Risk Analysis' component of the process.

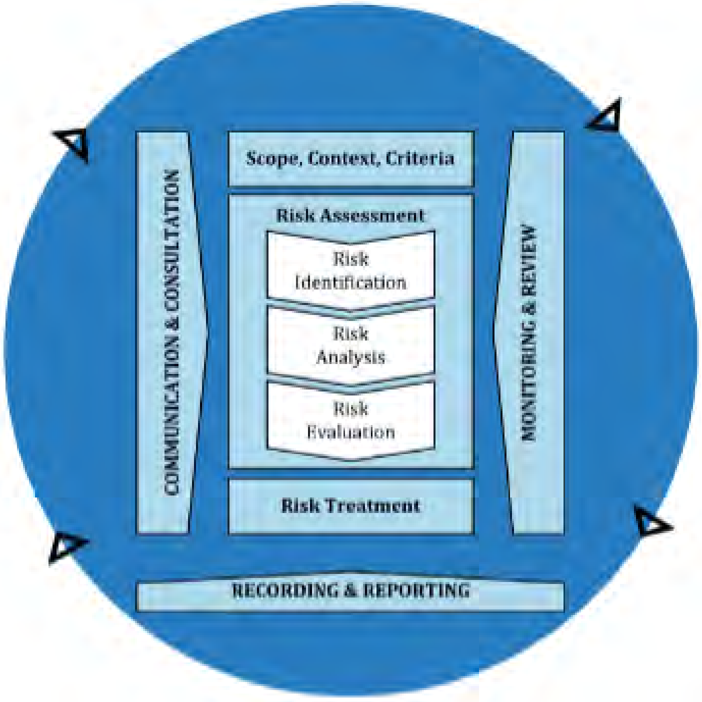
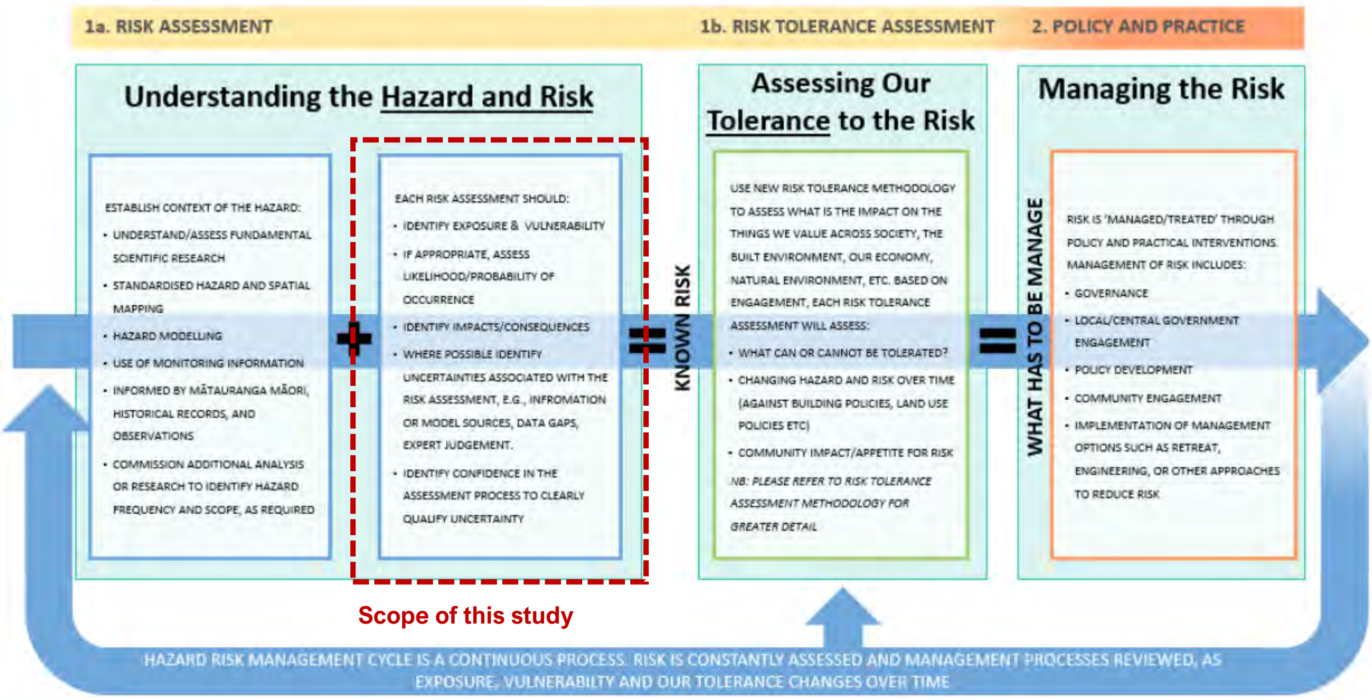


Figure 3-1: Risk management process (ISO 31000:2018)

The risk analysis process in Otago is detailed in Appendix 6 'APP6-Methodology for natural hazard risk assessment' of the Hearing Panel version of the proposed RPS (ORC, 2022), included in Appendix B – Otago Regional Policy Statement – Hearing Panel Version. The RPS methodology was developed in general accordance with the Australian Geomechanics Society (AGS, 2007) methodology for landslide risk management, and applied to wider natural hazards.

Further guidance documents aligned with the risk analysis process detailed in RPS (ORC, 2022) and AGS (2007) include:

- Toka Tū Ake EQC (2023) – Risk Tolerance Methodology, which provides guidance for regulators on risk management approach in New Zealand, incorporating risk analysis, risk tolerance and risk management (summarised in Figure 3-2).
- GNS Science (2013) - Risk-based land use planning for natural hazard risk reduction, which provides guidance to regulators to support risk-based land use policy decision making, and an overview of the risk analysis process.



ESTABLISH CONTEXT OF THE HAZARD:
- UNDERSTAND/ASSESS FUNDAMENTAL SCIENTIFIC RESEARCH
- STANDARDISED HAZARD AND SPATIAL MAPPING
- HAZARD MODELLING
- USE OF MONITORING INFORMATION
- INFORMED BY MĀTAURANGA MĀORI, HISTORICAL RECORDS, AND OBSERVATIONS
- COMMISSION ADDITIONAL ANALYSIS OR RESEARCH TO IDENTIFY HAZARD FREQUENCY AND SCOPE, AS REQUIRED

EACH RISK ASSESSMENT SHOULD:
- IDENTIFY EXPOSURE & VULNERABILITY
- IF APPROPRIATE, ASSESS LIKELIHOOD/PROBABILITY OF OCCURRENCE
- IDENTIFY IMPACTS/CONSEQUENCES
- WHERE POSSIBLE IDENTIFY UNCERTAINTIES ASSOCIATED WITH THE RISK ASSESSMENT, E.G., INFROMATION OR MODEL SOURCES, DATA GAPS, EXPERT JUDGEMENT.
- IDENTIFY CONFIDENCE IN THE ASSESSMENT PROCESS TO CLEARLY QUALIFY UNCERTAINTY

USE NEW RISK TOLERANCE METHODOLOGY TO ASSESS WHAT IS THE IMPACT ON THE THINGS WE VALUE ACROSS SOCIETY, THE BUILT ENVIRONMENT, OUR ECONOMY, NATURAL ENVIRONMENT, ETC. BASED ON ENGAGEMENT, EACH RISK TOLERANCE ASSESSMENT WILL ASSESS:
- WHAT CAN OR CANNOT BE TOLERATED?
- CHANGING HAZARD AND RISK OVER TIME (AGAINST BUILDING POLICIES, LAND USE POLICIES ETC)
- COMMUNITY IMPACT/APPETITE FOR RISK

NB: PLEASE REFER TO RISK TOLERANCE ASSESSMENT METHODOLOGY FOR GREATER DETAIL

RISK IS 'MANAGED/TREATED' THROUGH POLICY AND PRACTICAL INTERVENTIONS. MANAGEMENT OF RISK INCLUDES:
- GOVERNANCE
- LOCAL/CENTRAL GOVERNMENT ENGAGEMENT
- POLICY DEVELOPMENT
- COMMUNITY ENGAGEMENT
- IMPLEMENTATION OF MANAGEMENT OPTIONS SUCH AS RETREAT, ENGINEERING, OR OTHER APPROACHES TO REDUCE RISK

HAZARD RISK MANAGEMENT CYCLE IS A CONTINUOUS PROCESS. RISK IS CONSTANTLY ASSESSED AND MANAGEMENT PROCESSES REVIEWED, AS EXPOSURE, VULNERABILTY AND OUR TOLERANCE CHANGES OVER TIME

Figure 3-2: Approach to hazard risk management in Aotearoa NZ including the assessment of risk tolerance (Toka Tū Ake EQC, 2023). The scope of this Beca study is shown by the red dashed line.

The risk analysis phase is the focus of this report. The evaluation of risk mitigation measures and associated management of hazards is being conducted by others.

3.3 Risk Analysis Overview

The RPS (ORC, 2022) methodology examines the risk of interaction between a hazard occurring and the effect on life and the built environment considering natural hazard scenarios. The approach uses the following relationship:

$$Risk = Hazard\ (likelihood)\ x\ Consequence$$

The RPS (ORC, 2022) incorporates two stages of risk analysis, as included in this report:

- Qualitative assessment
- Quantitative assessment to estimate:
  - Annual Individual Fatality Risk (AIFR) and
  - Annual Property Risk (APR).

Qualitative risk analysis involves evaluating the potential risks associated with hazards against a range of criteria using judgement and qualitative observations. It is typically used where insufficient data exist for quantitative analysis or as a preliminary screening tool to determine whether quantitative analysis is required (NZGS, 2023). Outputs are typically displayed using a colour-coded risk matrix.

Quantitative risk analyses allow for greater consideration of uncertainty than qualitative analyses. Uncertainty surrounding some of the inputs to the assessments is accounted for by considering the likely range of values that could occur, which provides a risk range for each hazard scenario.

Quantitative risk is presented as a probability, which can be expressed in a number of different ways, as shown in Table 3-1.

Table 3-1: Ways of expressing annual risk probabilities

Return period (years)	Average recurrence interval (ARI) (years)	Scientific notation	Value	Percentage
1 in 100	100	1×10^{-2}	0.01	1%
1 in 1,000	1,000	1×10^{-3}	0.001	0.1%
1 in 10,000	10,000	1×10^{-4}	0.0001	0.01%
1 in 100,000	100,000	1×10^{-5}	0.00001	0.001%
1 in 1,000,000	1,000,000	1×10^{-6}	0.000001	0.0001%

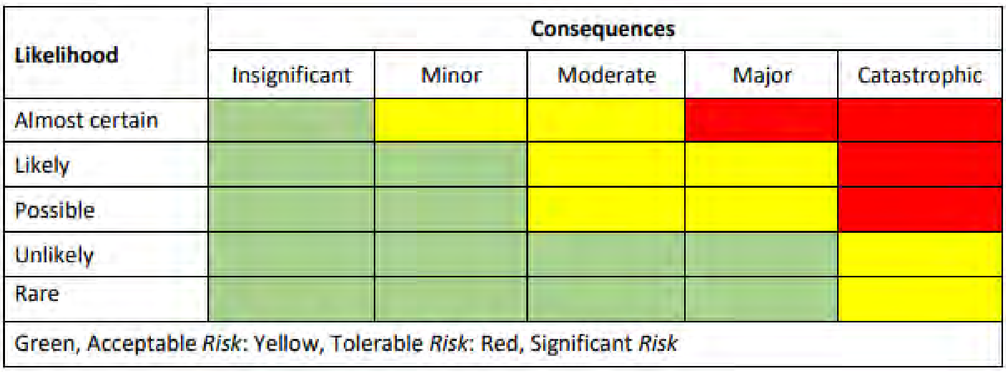
Details of the risk analysis results are included in the individual hazard sections of this report. The following subsections detail an overview of the qualitative and quantitative risk analysis processes. Risk terminology definitions are provided in Section 3.6.

3.4 Qualitative Risk Analysis Process

An overview of the qualitative risk assessment process from Appendix 6 of the RPS (ORC, 2022) is described below. This analysis has been undertaken for the hazards detailed in Section 2.2:

1. Determine **likelihood** of the hazards occurring, for three scales of event (high likelihood, median likelihood, and maximum credible event) that form hazard ‘scenarios’ for assessment. Definitions of likelihood are presented in Table 6 of APP6, RPS (ORC, 2022), included in Appendix B.
2. Assess anticipated **consequences** against the effects on life and injury (public health and safety) and the built environment, including buildings and lifelines. Assessment of consequence is broadly in accordance with the criteria of Table 7 APP6, RPS (ORC, 2022). The criteria provide descriptive guidance on severity of impact for various elements within the built environment and public health and safety. The assessment considers whether consequences will be short term or permanent.
3. Consider **spatial extents** of the hazards and use this information to inform the qualitative risk zone definition.
4. Determine the **qualitative risk level** for each hazard and scale of event in accordance with Table 8 of Appendix 6 within the proposed RPS (Figure 3-3). Three qualitative risk descriptors are defined:
    a. Acceptable risk (green)
    b. Tolerable risk (yellow)
    c. Significant risk (red)

    In accordance with the RPS guidance, any natural hazards with scenarios defined as Significant warrant further investigation through quantitative risk analysis.
5. Review risk levels and determine which hazards assessed as having Significant and (if relevant) Tolerable risk should proceed to quantitative analysis. Hazards with tolerable risk that may warrant quantitative analysis may include higher likelihood, lower consequence hazards such as liquefaction or flooding.



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

Figure 3-3: Qualitative risk table from proposed RPS (Table 8)

The results of the qualitative analysis were used to inform the scope of the quantitative analyses.

3.4.1 Departures from General Process

The two main departures from the qualitative process, as defined above, requested by ORC and adopted for this study are as follows:

- Qualitative analysis has been undertaken considering two likelihood scenarios for each hazard, where insufficient data is available for a third likelihood scenario to be assessed. This applies to all flooding hazards assessed.
- When assessing consequences, the analysis is conducted based on the current situation, with the intention of understanding the risk to communities at the present time. Future potential changes to the environment resulting from hazards (e.g., channel avulsion) have not been considered. Some such changes have the potential to increase the risk to Glenorchy and Kinloch.

3.5 Quantitative Risk Analysis Process

Quantitative assessment of life risk (AIFR) and property risk (APR) posed by the various hazards has been determined for all natural hazard scenarios assessed to be Significant through the qualitative assessment process, along with some hazards with risks assessed as Tolerable where the likelihood is considered high. An overview of the quantitative risk analysis process for each metric is provided below, with details and assumptions for each hazard included in the following sections of this report.

3.5.1 Life Risk Analysis Process

The quantitative assessment of life risk (AIFR) considers the probability that an individual most at risk is killed in any one year as a result of the hazards occurring.

AIFR is calculated from the following equation (Australian Geomechanics Society, 2007):

$$\textbf{Annual Individual Fatality Risk} = P_{(H)} \times P_{(S:H)} \times P_{(T:S)} \times V_{(D:T)}$$

Where:

- $P_{(H)}$ is the annual probability of a hazard occurring.
- $P_{(S:H)}$ is the spatial probability of impact of the hazard in a specific location potentially occupied by the person most at risk.
- $P_{(T:S)}$ is the temporal spatial probability incorporating the proportion of the time the person most at risk is present and allowing for the possibility that the person may be able to evade the hazard.

- $V_{(D:T)}$ is the vulnerability, or probability of death of the person most at risk, in the event of an interaction with the hazard.

The assessment does not consider specific locations of residents, rather assesses spatial natural hazard consequence across the study area, with an individual assumed to be present in all locations.

3.5.2 Property Risk Analysis Process

The quantitative assessment of property risk (APR) considers the probability of total property loss in any one year as a result of the hazards occurring. Total property loss occurs when the cost of repair exceeds the value of the property.

APR is calculated form the following equation (Australian Geomechanics Society, 2007):

$$\boxed{\text{Annual Property Risk}} = \boxed{P_{(H)}} \times \boxed{P_{(S:H)}} \times \boxed{P_{(T:S)}} \times \boxed{V_{(D:T)}}$$

Where:

- $P_{(H)}$ is the annual probability of a hazard occurring.
- $P_{(S:H)}$ is the spatial probability of impact of the hazard in a specific location occupied by a property.
- $P_{(T:S)}$ is the temporal spatial probability. For houses and other buildings, $P_{(T:S)} = 1.0$ (i.e. the house or building is always present).
- $V_{(D:T)}$ is the vulnerability of the property to the spatial impact (or expected proportion of property value lost in the event of being impacted by the hazard), typically termed the damage ratio.

A key assumption of the APR analysis is that it does not consider specific locations or types of existing buildings, but considers the possibility for buildings to be present in any location within the study area. This allows for relative comparison of risk levels in the land use planning context, and means that the analysis is not tied to actual property construction which may change regularly. The analysis is based on a typical property definition, as detailed in Section 3.7.2.

3.5.3 Risk Contouring

The output of the quantitative risk analysis is risk maps, with risk values contoured to show areas of equivalent risk. Risk contours were created for the quantitative flood analysis only, as the quantitative liquefaction analysis outputs were discrete values, not continuous. The flood risk contours were created from the AIFR and APR combined scenario 1m raster analysis outputs using ArcGIS Contour List geoprocessing tool at order of magnitude intervals. In order to avoid a manual smoothing process to maintain visual accuracy, while also creating a clearly defined contour line, the contour line features were run through an FME (Feature Manipulation Engine) model and the following data transformers:

- Generaliser (Thinning) using the Thin algorithm with a Tolerance of 2
  - The Thin algorithm will remove vertices that are less than the Generalisation Tolerance distance away from an adjacent vertex. The begin and end points are never moved, unless the entire length of the feature being thinned is less than the tolerance, in which case the feature is replaced by a point feature holding the final coordinate.
- Generaliser (Smoothing) using the NURBfit (Smooth) Algorithm with a Degree of Basis Polynomial of 2
  - The NURBfit algorithm will fit lines using B-Spline curves of given polynomial degree. The resulting lines will follow these curves with given segment length. The higher the degree, the smoother the line. An example of usage is smoothing contour lines to remove spikes and simulate the work of a cartographic craftsman.

When displayed in the combined scenario maps Appendix G – Quantitative Risk Maps, contours with a length of less than 50m were removed.

3.5.4 Quantitative Risk Levels

In accordance with the RPS (ORC, 2022), qualitative risk levels are to be re-categorised in accordance with Table 3-2 following quantitative analysis. The defined risk levels for both life (AIFR) and property (APR) risk are the same in line with RPS guidance.

Table 3-2: Quantitative risk levels in accordance with the RPS (ORC, 2022)

Development	Risk Category	Risk Value
Existing Development	Acceptable	Less than 1×10^{-5}
	Tolerable	1×10^{-4} to 1×10^{-5}
	Significant	Greater than 1×10^{-4}
New Development	Acceptable	Less than 1×10^{-6}
	Tolerable	1×10^{-5} to 1×10^{-6}
	Significant	Greater than 1×10^{-5}

3.5.5 Departures from General Process

The only departure from the quantitative risk analysis process detailed in the RPS (ORC, 2022) is that the potential impacts of climate change have not been considered. The analysis has been conducted based on the current situation and climate, with the intention of understanding the risk to communities at the present time.

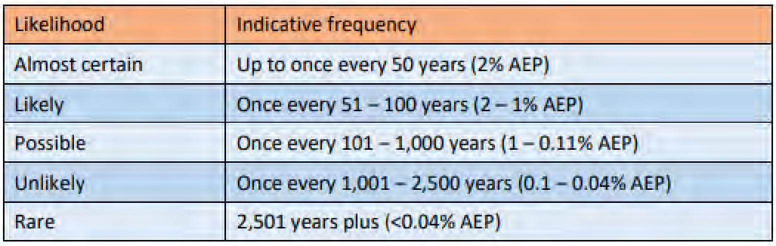
There is uncertainty associated with the effects of climate change, and by not considering these effects it could leave to under- or over-estimation of risk presented in this report. For example, the risk as presented in this report may show a minor underestimation of liquefaction and lateral spread consequences, as rising groundwater increases the liquefaction hazard, while conversely if lake levels fall in future due to rainfall pattern changes, the liquefaction consequences would be overestimated. The climate change induced changes to the flood hazard were not analysed, however the expected increase in peak flows is discussed in Section 4.5.

3.6 Risk Definitions

The following definitions for key terms within the qualitative and quantitative risk assessment are provided in Table 3-3. Further discussion of the risk level terminology including Acceptable, Tolerable and Significant risk is contained in EQC (2023).

Table 3-3: Definitions of key risk terms

Term	Definition
Acceptable Risk	• Level of risk which everyone affected is prepared to accept. Action to further reduce such risk is usually not required unless reasonably practicable measures are available at low cost in terms of money, time and effort (AGS, 2007). • Broadly acceptable. Activity can occur with limited controls or restrictions (EQC, 2023)
ALARP	• For a risk to be As Low As Reasonably Practicable (ALARP), it must be possible to demonstrate that the cost involved in reducing the risk further would be grossly disproportionate to the benefit gained (EQC, 2023)

Term	Definition
Annual Individual Fatality Risk (AIFR)	The probability that an individual of most risk within is killed in any given year as a result of the hazards occurring.
Annual Property Risk (APR)	The probability of total property loss in any given year as a result of the hazards occurring.
Annual Exceedance Probability (AEP)	The probability of an (rainfall/flow) event occurring or being exceeded in any given year. Refer to 'Likelihood' definition below.
Average Recurrence Interval (ARI)	The long-term average number of years between past occurrences of a certain size (rainfall/flow) event.
Buildings	Structures in the built environment. Buildings are categorised based on social/cultural importance and criticality within the community, as summarised in Section 3.7.2, comprising three criteria: • Social/Cultural Amenities – public buildings used for recreational purposes. • Buildings – for this study assumed to be a typical generalised residential building. • Critical Buildings – buildings critical to community and safety.
Consequence	The effects of a natural hazard on the built environment or public health and safety. For qualitative risk analysis, severity of consequence is defined in Table 7 of Appendix 6 of the RPS (ORC, 2022), with ratings of Insignificant, Minor, Moderate, Major and Catastrophic consequence. Ratings are defined depending on the percentage of buildings functionally compromised, effects on level of service provided by lifelines and proportion of community affected and the numbers of dead or injured people as a response of the natural hazard. For quantitative risk analysis, consequence focuses on fatalities and proportion of building value that is lost following the hazard event.
Functionality	For the purposes of this study a building is considered functionally compromised when it cannot continue to be used for its intended use immediately after an event. This may be due to the building being unable to provide its primary function of providing shelter. Also, the building may be in a temporary or permanent condition that poses a health and safety risk to occupants (physical or biological).
Likelihood	The probability of an event occurring. For the qualitative analysis this is assessed in line with Table 6 of Appendix 6 (RPS, 2022) 
Lifelines	Lifeline utilities are entities that provide essential infrastructure services to the community, e.g., water, wastewater, transport, energy and telecommunications. Severity of consequences on lifelines are assessed considering the post event duration that functionality is compromised and the proportion of the urban area/population that is affected by the service being out of service.

Likelihood	Indicative frequency
Almost certain	Up to once every 50 years (2% AEP)
Likely	Once every 51 – 100 years (2 – 1% AEP)
Possible	Once every 101 – 1,000 years (1 – 0.11% AEP)
Unlikely	Once every 1,001 – 2,500 years (0.1 – 0.04% AEP)
Rare	2,501 years plus (<0.04% AEP)

Term	Definition
Risk	The product of the probability of an event occurring along with consequence of the event.
Significant Risk	Risk that exceeds Tolerable bounds in accordance with the RPS (2022).
Tolerable Risk	Risks within a range that society can live with so as to secure certain benefits. It is a range of risk regarded as non-negligible and needing to be kept under review and reduced further if practicable (AGS, 2007) Risk is accepted only if the benefit gained is shown to outweigh the risk (using the 'ALARP' principle). Tolerable only if risk can be mitigated at a cost proportional to the benefit gained (EQC, 2023)

3.7 Characteristics of Glenorchy and Kinloch

While the consequence analysis does not consider the specific location of existing buildings or people across the study area, the population, general building typology and land use planning are considered. The following section includes a summary of assumptions adopted in the study relating to population density and building typology that are consistent across all hazards assessed.

3.7.1 Population

The projected populations of 'Glenorchy township' and 'Glenorchy other' as of 2021 are detailed in QLDC (2022) and summarised in Table 3-4. The following assumptions have been made regarding population in the risk analysis:

- 'Glenorchy other' includes settlements in the wider area including Kinloch and Paradise (to the north of Glenorchy and outside the scope of this study). For the purpose of our analysis, we have assumed the residents and visitors for Kinloch are a small proportion of those listed in 'Glenorchy other'.
- It is assumed that this population is distributed uniformly across the residential areas of Glenorchy and Kinloch.
- The permanent population was considered when assessing the effects on public health and safety (life and injury) for the qualitative analysis.
- Commentary is provided regarding the total population (average day) in the qualitative risk analysis for the individual hazards.

Table 3-4: Glenorchy and Kinloch population data (after QLDC, 2022)

	Glenorchy township	Glenorchy other
Residents	380	150
Visitors (average day)	240	70
Visitors (peak day)	650	200
Total population (average day)	**620**	**220**

3.7.2 Building Typology

Beca undertook a walkover in Glenorchy to review the existing building typology and construction, as shown in Figure 3-4. The following observations were made based on visual characteristics, supported by high level desktop review:

- The majority of buildings were typically residential dwellings constructed since the 1980s,
- The majority were of lightweight timber framed construction on a concrete slab, and
- A smaller proportion (approximately 30%) were elevated on piles.

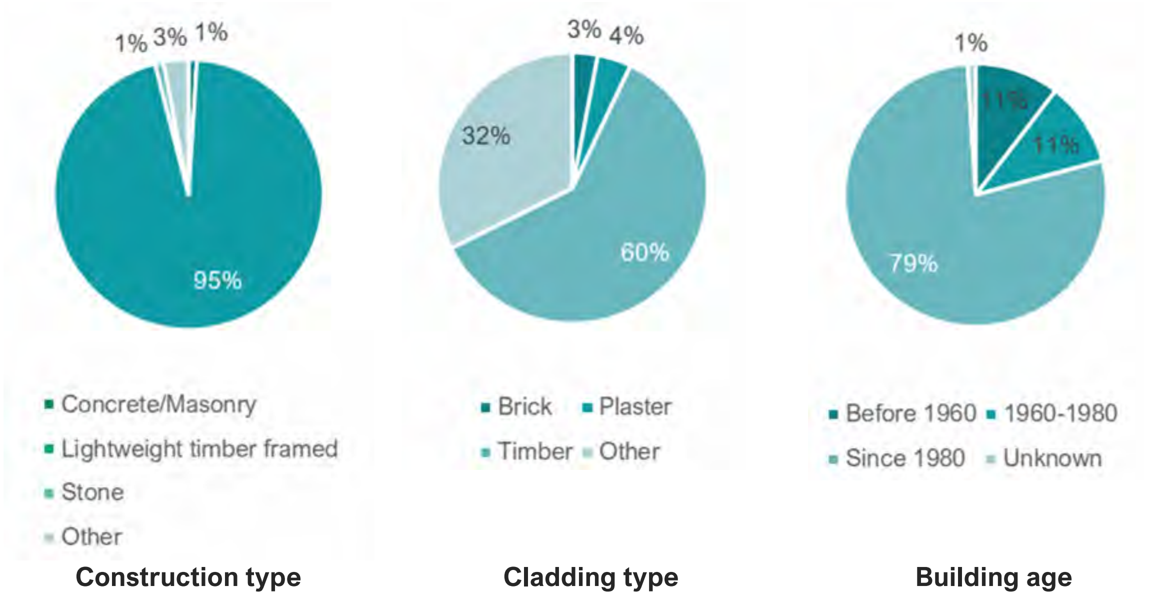


Figure 3-4: Typical building typology in Glenorchy

A list of social/cultural amenities and critical buildings used in the qualitative risk analysis is shown in Table 3-5, and a count of building numbers in Table 3-6.

Table 3-5: List of critical buildings and buildings of social and cultural importance

Social/Cultural Amenities	Critical Buildings
• Glenorchy Library • Glenorchy Marina • Glenorchy Museum • Glenorchy School Playground • Glenorchy Skatepark	• Community Early Childhood Education Centre • Glenorchy Fire Station • Glenorchy Hall • Glenorchy Petrol Station • Glenorchy Post Office • Glenorchy Primary School • St Johns Ambulance

Table 3-6: Count of building types in Glenorchy.

Building Type	Count
All Buildings [1]	347
Critical Buildings	7
Amenities of cultural and social importance	5

1. The count of "all buildings" includes critical buildings and amenities of cultural or social importance. Count of existing buildings is based LINZ data and on a review of aerial photography from the year 2022.

The above information has been used to inform the consequence analyses for all hazards, for both Glenorchy and Kinloch, as described in the individual sections.

3.7.3 Land Usage

Glenorchy sits in the 'Township Zone' under Queenstown Lakes District Council's (QLDC) Operative District Plan (QLDC, 2024), the purpose of which is to maintain low density residential character interspersed with non-residential activities.

Land use zoning from the Operative District Plan (QLDC, 2024) is shown as a proportion of the study area extents in Table 3-7. Spatial distribution of the various land use zones is presented in Figure 3-5 and Figure 3-6 for Glenorchy and Kinloch respectively. The remaining areas comprise water and roading zones.

Table 3-7: Operative District Plan land use zoning within the Glenorchy and Kinloch study areas

Land use zone	Specific usage	Proportion of Glenorchy Study Area	Proportion of Kinloch Study Area
Township	Township Zone	27%	45%
	Designation Area (e.g. parks, golf course)	8%	0%
	Visitor Accommodation Sub- Zone	5%	0%
Rural	Rural general usage	44%	26%

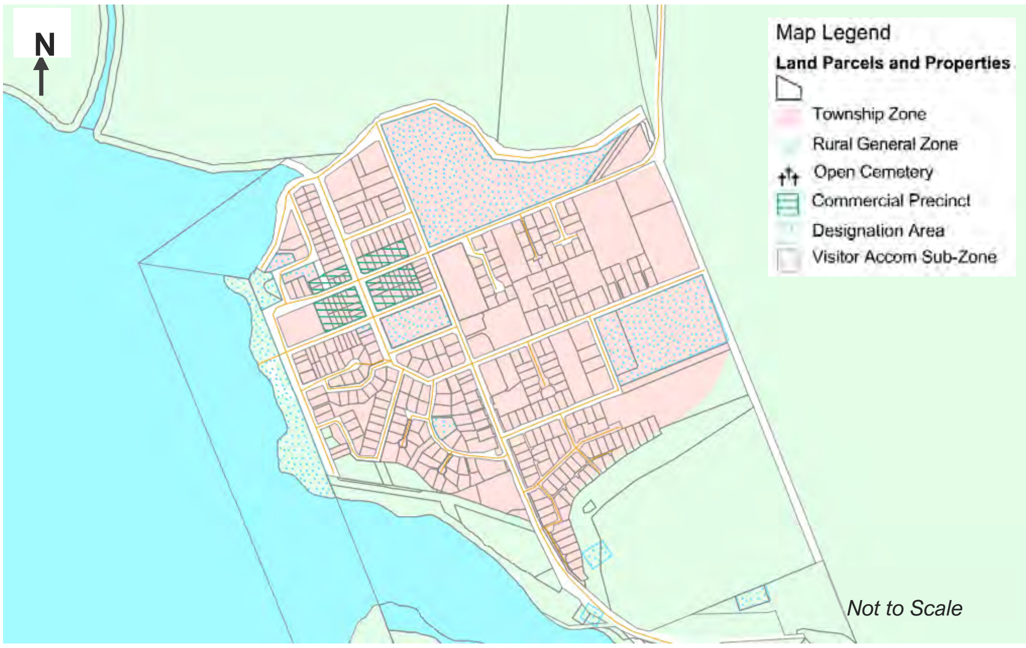


Figure 3-5: Operative District Plan land use zoning in Glenorchy (after QLDC, 2024)

It should be noted that undeveloped land parcels defined for Kinloch extend into the current Dart River flood plain as indicated in Figure 3-6. In the risk maps (included in Appendices F, G and H) these land parcels have been excluded for accuracy.

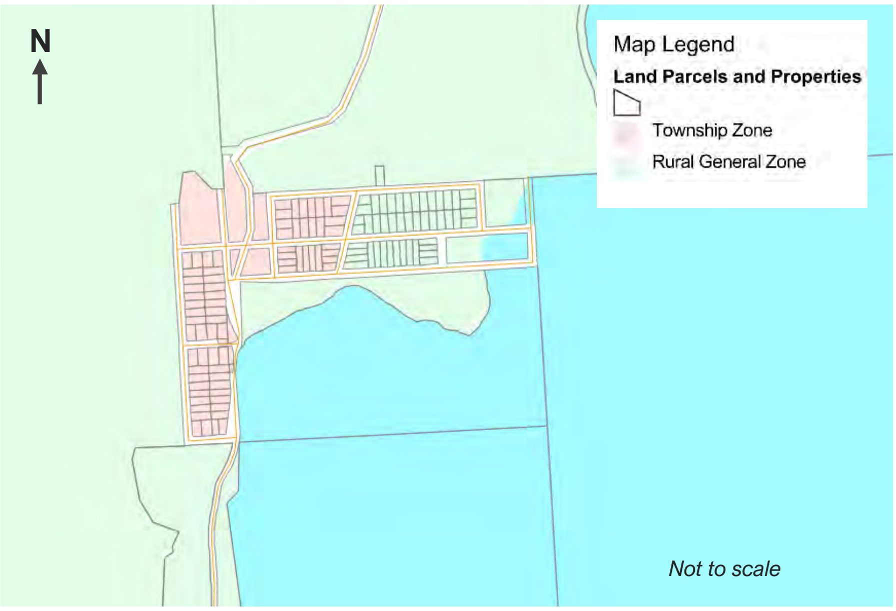


Figure 3-6: Operative District Plan land use zoning in Kinloch (after QLDC, 2024)

4 River Flooding Risk Analysis

4.1 Scope and Study Extents

To determine the risks posed by rivers, multiple flood model results and studies were assessed. The flood models used in the risk analysis are shown in Table 4-1, and the referenced studies are presented in Section 4.2. The extents of the river flood models considered are shown in Figure 2-2.

4.2 Sources of Information

The main sources of information used to inform the river flooding qualitative and quantitative risk analyses were flood model results provided by external consultants, as summarised in Table 4-1.

Table 4-1: Flood models used in the qualitative and quantitative river flood assessment

Catchment	Name	Year	Risk Assessment Type
Buckler Burn	Land River Sea: Buckler Burn Flood Hazard Modelling	2023	Qualitative
Dart/Rees	Land River Sea: Dart/Rees Rivers Flood Hazard Modelling	2022	Qualitative
Dart/Rees, Buckler Burn, Bible Stream and Tributaries	URS: Glenorchy Floodplain Flood Hazard Study	2007	Qualitative
Glenorchy Catchments Hydrology and Design Flows	HydroScience: Glenorchy Catchments Hydrology and Design Flows	2024	Quantitative
Buckler Burn, Dart/Rees and joint flood scenario (incl. Bible stream and both Glenorchy catchments)	Land River Sea: Glenorchy Flood Modelling – Flood Hazard Scenario	2024	Quantitative

Following the gap analysis and qualitative assessment, ORC commissioned two new studies in order to:

- Allocate likelihoods to the Buckler Burn events, and
- Assess the effect of a *joint flood scenario* which is when all rivers shown in Figure 2-2 flood at the same time.

While the hydrological inputs to the models changed, the basis of the models did not. The updated hydrology led to lower inflows in the models used in the quantitative assessment. The qualitative assessment is based on a simple hydrological assessment (Buckler Burn) or outdated hydrology (Rees/Dart) and in both models the flow is overestimated and therefore more conservative. The quantitative assessment uses the currently best available hydrologic data. Additionally, the updated hydrology enabled assessment of the effect of three different flood event Likelihoods (Almost Certain, Likely and Possible) as defined in RPS (ORC, 2022) as part of the quantitative assessment. In the qualitative assessment only two Likelihood scenarios were assessed: Likely and Possible as additional data was not yet available. Furthermore, the hydrologic assessment provided by HydroScience (2024) enabled the simulation of a joint flood scenario: all rivers flooding at the same time.

River flood scenarios used in the quantitative risk analysis are shown in the below table, based on model results provided by LandRiverSea (2024). Table 4-2 shows the estimated ARI for the input hydrograph and the lake level ARI as the downstream boundary. A frequency analysis of lake levels and Rees/Dart River flows suggests no correlation between high lake levels and a Rees/Dart River flood (HydroScience, 2024).

Therefore, lower lake level ARIs were used when simulating river floods. Table 4-2 also shows the Likelihood assigned to each model scenario, in alignment with Table 6, Appendix 6 of the RPS (ORC, 2022).

Table 4-2: Assessed scenarios used in the quantitative flood risk analysis from the 2023 LRS simulations.

Flood Source	Comment	DEM[1]	Likelihood (ORC, 2022)	Flow ARI[2] (years)	Lake Level ARI[2] (years)
Buckler Burn	Excl. Bible Stream and the two Glenorchy catchments	2019 with 1m aggregation	Almost Certain	50	10
			Likely	100	20
			Possible	500	100
Rees/Dart		2019, no avulsion scenario	Almost Certain	50	10
			Likely	100	20
			Possible	500	100
Joint-Scenario	Rees/Dart, Buckler Burn, Bible Stream and both Glenorchy catchments	2019 with 1m aggregation scenario for the Buckler Burn, no avulsion in Rees/Dart	Almost Certain	50	10
			Likely	100	20
			Possible	500	100

The provided flood extents, levels, velocities, and hazards were adopted to estimate the consequences for the built environment and public health and safety. Flood hazard refers to the potential risk posed by flooding, based on flood *depth* × *velocity*. The Flood Hazard Vulnerability Classification in this report follows the AIDR (2017) definition, as shown in Figure 4-1.

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[1] DEM = Digital Elevation Model. The ground surface which was applied to the flood model.

[2] ARI = Average Recurrence Interval. The long-term average number of years between past occurrences of a certain size event.

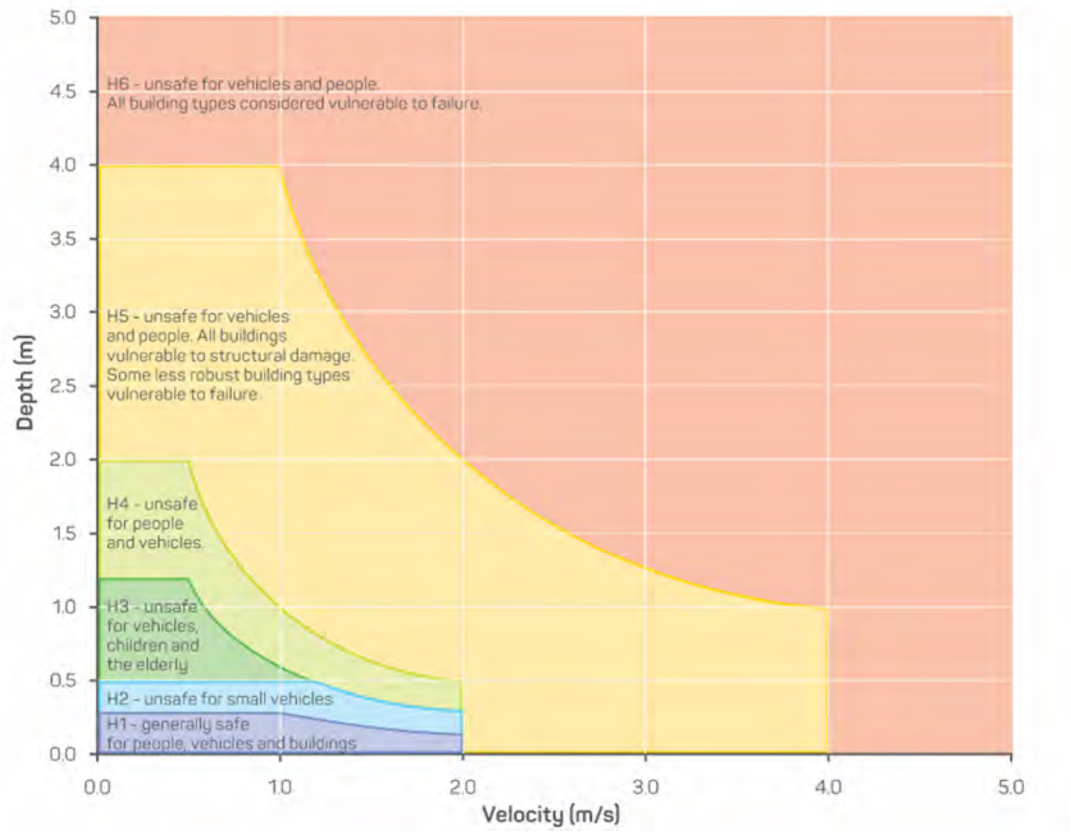


Figure 4-1: Flood Hazard Vulnerability Classification (AIDR, 2017).

4.3 River Flooding Qualitative Risk Analysis

4.3.1 Flood Hazard Consequence Thresholds

This section presents the criteria applied to the flood hazards to assess the risk to Public Health and Safety and the Built Environment. For all risk analyses, this study used the RPS guidance to define risk level thresholds by aligning the modelled flood hazard vulnerability with the severity of impact (RPS Appendix 6 Table 7 Consequences). These thresholds are shown in Table 4-3. The table also identifies the assessment criteria for each hazard subcategory. The content of Table 4-3 is further discussed in the next subchapters.

Table 4-3: Flood risk assessment thresholds applied following the RPS (ORC, 2022).

Category	Subcategory	Criteria in the RPS	Assessment	Unit of assessing consequences	Flood hazard threshold
Built Environment	Lifelines	*lifelines out of service*	Flood water blocking access via roads	The percentage of Glenorchy and Kinloch residential areas that are flooded or not accessible via road	Residential areas are 'out of service' if flooded by Flood Hazard Vulnerability Classification ≥H2, or if access roads are mainly blocked (>90% of width) by the Flood Hazard Vulnerability Classification ≥H2

Category	Subcategory	Criteria in the RPS	Assessment	Unit of assessing consequences	Flood hazard threshold
	- Buildings - Social/ Cultural Amenities - Critical Buildings	*buildings have their functionality compromised*	Flood hazard around and in buildings	Count of buildings per hazard impact area	Buildings (+2m buffer) that intersect with any Flood Hazard Vulnerability Classification
Public Health and Safety	Health and Safety	*deaths or injuries*	Affected population per flood hazard level	Sum of deaths and injured residents	Refer to Table 4-5

The individual scenarios and the equivalent ARI (Annual Recurrence Interval) used to assess the qualitative risk are shown Table 4-4.

Table 4-4: Scenarios used in the qualitative risk assessment showing the likelihoods bands as per RPS (ORC, 2022) definition.

Flood Source	Scenario			Likelihood	Indicative frequency
	Flow/ARI	Run	Lake Level		
Rees/Dart	100-year ARI	Current climate existing terrain	10-year	Likely	Once every 51 – 100 years (2 – 1% AEP)
Rees/Dart			100-year	Possible	Once every 101 – 1,000 years (1 – 0.11% AEP)
Buckler Burn	200m^3/s	Aggradation Scenario A (1m)	10-year	Likely	Once every 51 – 100 years (2 – 1% AEP)
Buckler Burn	250m^3/s		10-year	Possible	Once every 101 – 1,000 years (1 – 0.11% AEP)
Lake Wakatipu	100-year ARI – Lake level: 313.171mRL			Likely	Once every 51 – 100 years (2 – 1% AEP)
Lake Wakatipu	200-year ARI – Lake level: 313.725mRL			Possible	Once every 101 – 1,000 years (1 – 0.11% AEP)

4.3.2 Public Health and Safety Risk

The RPS (ORC, 2022) guidance uses the criteria of number of deaths and/or injured to assess the Public Health and Safety risk posed by a flood. Cox et al. (2010) analysed the stability (i.e., resilience) of people in floods and linked this to the Flood Hazard Vulnerability Classification (H1 – H6). Flood Hazard Vulnerability Classification is divided into separate vulnerability classifications for children and adults. Statistics NZ data from the 2018 census was used to estimate the percentage of children in Glenorchy as 11% of the total population.

Table 4-5: Adapted link between Flood Hazard Vulnerability Classification to injuries and deaths. Based on Cox et al. (2010).

Population	H1	H2	H3	H4	H5	H6
Adults	no risk	injured	injured	injured	death	death
Children	injured	death	death	death	death	death

The qualitative risk analysis involved summing up the number of deaths and injuries within each Flood Hazard Vulnerability Classification (Equation 5 in Appendix C – Flooding Risk Analysis Process). It was assumed that the population is uniformly distributed across the residential areas of Glenorchy and Kinloch.

4.3.3 Built Environment Risk

4.3.3.1 Lifelines

The following lifelines are present within the Glenorchy and Kinloch communities, and are relevant to flood risk:

- Roads
- Wastewater treatment plant, Lancaster Place (privately-owned)
- Wastewater septic tanks (privately owned, not considered in this assessment)
- Water supply borehole, Glenorchy-Queenstown Road.

Roads provide access to properties and critical services, evacuation routes, emergency services and general mobility for residents and visitors. According to the AIDR guidelines (AIDR, 2017) vehicles are safe to drive up to Flood Hazard Vulnerability Classification H1. From H2 onwards small vehicles are in danger and can no longer be moved safely. Analysis from Shand et al. (2011) illustrates that small vehicles lose stability in water as shallow as 0.2m depth at high velocities, and at 0.4m depth at low velocities, making them unsuitable for property access or evacuation under such conditions. All areas with flood hazard vulnerability classification >H1 are defined as cut-off and ‘out of service’ in this analysis. In this assessment, the ‘out-of-service’ criterion is based only on the depth and velocity of water, and does not consider expected damage e.g., road erosion.

To define the duration that lifelines are out-of-service for, as defined in Table 7, Appendix 6 (RPS, 2022), the provided flood model results, in the form of Flood Hazard Vulnerability Classification, do not include a temporal component and therefore could not be used to define the duration lifelines are out-of-service for. Instead, historical road closure data from QLDC was analysed, focusing on typical durations for such incidents in Glenorchy and Kinloch during flood events.

The qualitative risk analysis to the lifelines was estimated by calculating the percentage of the residential area that is either disconnected by road or flooded above the H1 classification (Equation 3 in Appendix C – Flooding Risk Analysis Process).

Note, the consequence of flood events on wastewater and water supply was not directly assessed due to difficulty in defining what severity of flood event would result in these lifelines being ‘out-of-service’ and the potential duration that these lifelines could be out-of-service for. For this assessment, the assumption was made that wastewater and water supply infrastructure would be out-of-service if disconnected by road, or if the area is flooded above the H1 classification.

4.3.3.2 Buildings

According to the RPS (ORC, 2022) guidance, the consequences for the built environment of a flood are assessed based on whether the functionality of buildings is compromised. The Flood Hazard Vulnerability Classification in and around the existing buildings (with 2m buffer) was evaluated to determine if in the modelled flood event, buildings would be subject to an Acceptable, Tolerable or Significant risk of damage from the flood. In this study, it is defined that a building has its functionality compromised as soon as the building footprint is flooded (any Flood Hazard Vulnerability Classification).

The building risk analysis was assessed by counting the number of properties (land parcels) that could be within each flood hazard impact area. The building flood risk has been defined based on the Flood Hazard Vulnerability Classifications in Table 4-6. This approach is applied to the social/cultural amenities, critical buildings and buildings separately. These thresholds are based on the damage floods can cause to buildings shown in the analysis of AIDR (2017).

Table 4-6: Definition of building flood risk based on the Flood Hazard Vulnerability Classifications.

Risk	Flood Hazard Vulnerability Classification	Reasoning from AIDR (2017)
Acceptable	<H1	Low risk of being affected by a flood.
Tolerable	H1 – H3	Buildings mostly still stable and flood depth <1.2m.
Significant	H4 – H6	Flood depth >1.2m or buildings, building stability is impaired up to risk of collapse.

4.3.4 Results

This section outlines the results of the qualitative assessment of the Likely and Possible scenarios. The outcome of each qualitative risk analysis is the severity of the hazard consequence denoted as Insignificant to Catastrophic as per RPS (ORC, 2022). The definition is outlined in Table 4-3 and the equations used are shown in Appendix C – Flooding Risk Analysis Process. The combination of the hazard consequence (e.g. Insignificant) and the considered likelihood (e.g. Possible) results in different risk levels (i.e. Tolerable, Acceptable, and Significant shown in Figure 3-3). The spatial extents of the qualitative risk levels are shown in each subsection.

4.3.4.1 Buckler Burn

The simulation results used in the qualitative analysis indicate that in the event of a flood, some water would overtop the true right riverbank of the Buckler Burn. The flooding would primarily impact Glenorchy-Queenstown Road and Shiel Street, concentrating flooding along these roads. Generally, flood velocities would be less than 0.75m/s. However, the Buckler Burn model results show some areas of Hazard Vulnerability Classification H3 along these roads with flood depths >0.5m, 'unsafe for vehicles, children, and the elderly'. The Buckler Burn River delta would experience significant flooding with higher water depths and velocities.

In the event of a Likely or Possible flood, the simulation results indicate that floodwater would accumulate on the golf course, along the Glenorchy floodbank, and possibly along Jetty Street. Except for these areas, and some spots along Glenorchy Queenstown Road, flooding of other areas are not expected to pose notable risks to Public Health and Safety. The spatial extent of the qualitative analysis results is shown in Figure 4-2 and Figure 4-3, with full risk maps included in Appendix F – Qualitative Risk Level Maps.

The consequences of a Buckler Burn flood event on the Glenorchy and Kinloch built environment and public health and safety is summarised below:

- Lifelines: The results show that the whole of Glenorchy (and therefore also Kinloch) is cut off (out-of-service) due to flooding of the Glenorchy-Queenstown Road (as occurred during the 1999 flood event). Both scenarios (Likely and Possible) are very similar in their flood extent and their Flood Hazard Vulnerability Classification in the residential part of Glenorchy. Therefore, the assumed out-of-service duration is the same for both scenarios.
- Buildings: Most of the flooding from the Buckler Burn with a Flood Hazard Vulnerability Classification >H1 is outside of the current residential area. The flooding within the residential area is ≤H3 and is therefore defined at a Tolerable risk level. The Tolerable risk level affects 40 properties under the Likely scenario and 43 properties under the Possible scenario. No identified critical or cultural/social amenities (for definition refer to Section 3.7) are within the flooded extent.
- Public Health and Safety: due to the marginal extent of the flooding within the residential area, very few (if any) deaths or injuries are anticipated in the Likely and Possible flood scenarios. However, the Proposed Regional Policy Statement (Hearing Panel Version, ORC, 2022*)* recommends that any deaths

within any hazard impact area trigger Major (or greater) consequences (ORC, 2022). Therefore, both the Likely and Possible Buckler Burn river flooding scenarios trigger Major consequences.

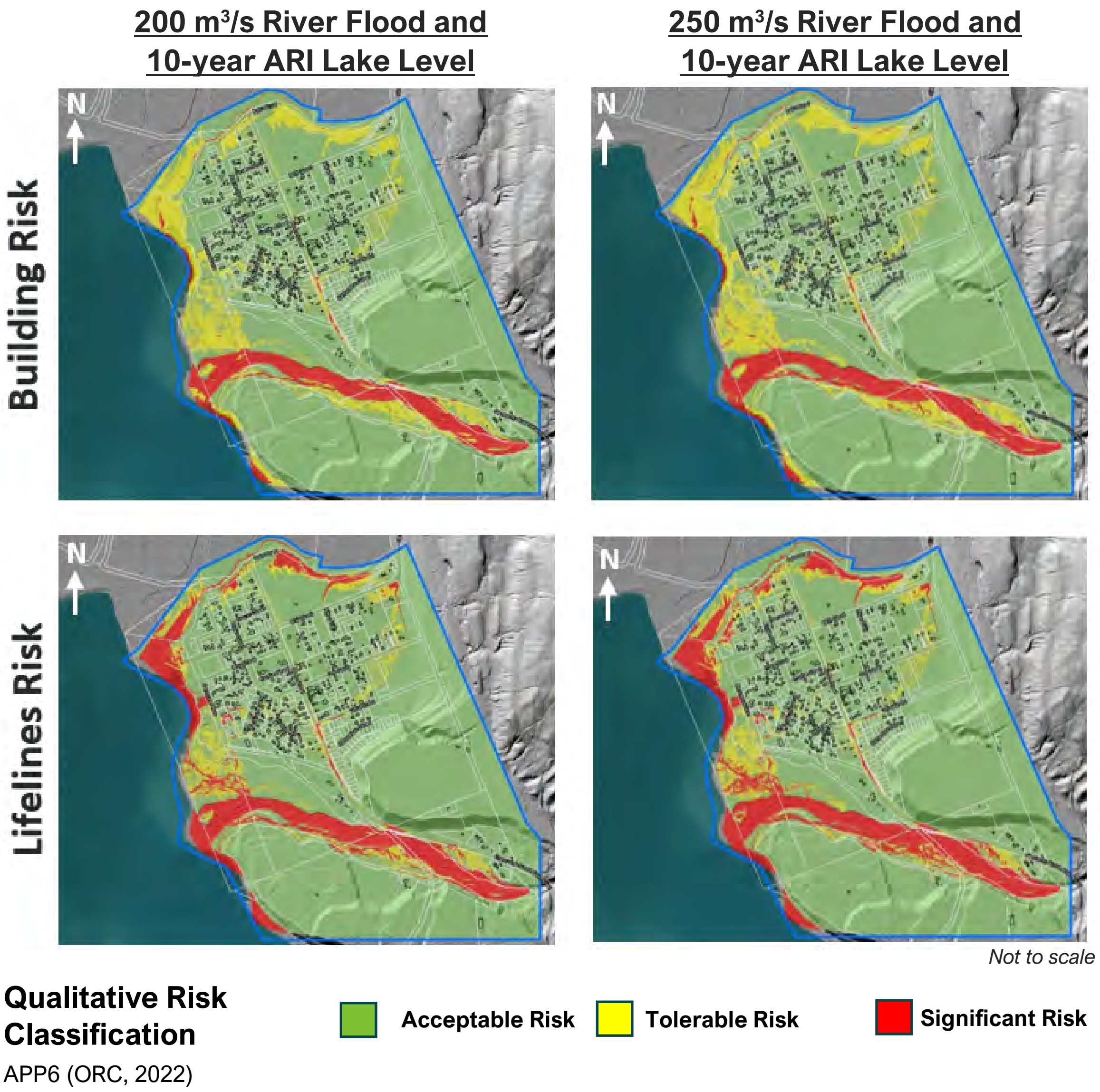


Figure 4-2: Buckler Burn qualitative risk classification results for Glenorchy built environment, for the Likely (200 m^3/s river flow, 10-year ARI lake level) and Possible (250 m^3/s river flow, 10-year ARI lake level) events.

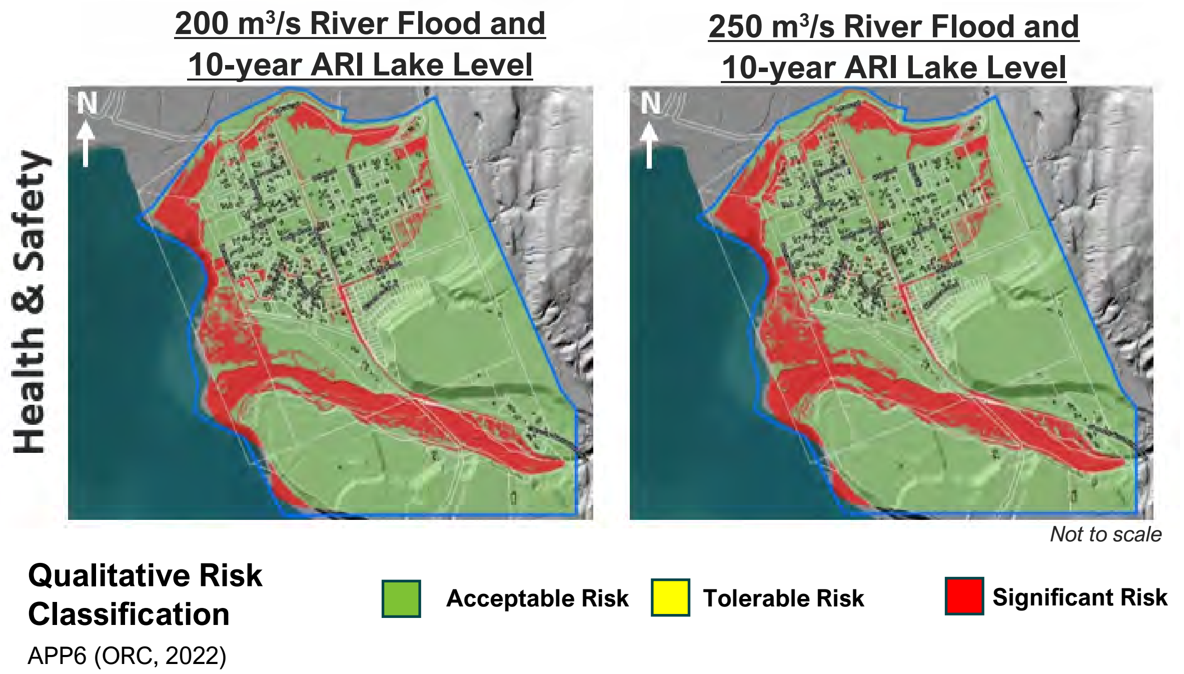


Figure 4-3: Buckler Burn qualitative risk classification results for Glenorchy public health and safety, for the Likely (200 m^3/s river flow, 10-year ARI lake level) and Possible (250 m^3/s river flow, 10-year ARI lake level) events.

4.3.4.2 Rees/Dart

Flood modelling shows that a Rees/Dart flood could lead to widespread flooding in the northern part of Glenorchy and along the Rees River bank. The Rees floodbank is expected to overtop in both the Likely and Possible Rees/Dart River flood likelihood scenarios.

Kinloch could become isolated due to flooding on multiple sections of the approach road (Glenorchy-Paradise Road, Priory Road, Glenorchy-Routeburn Road, Kinloch Road). Within Kinloch, most areas west of Kinloch Road could also experience flooding.

Simulated high lake levels in Lake Wakatipu, under the Possible likelihood scenario, have reduced velocities but significantly increase the flood extent and depth.

Figure 4-4 to Figure 4-6 show the spatial extents of the qualitative analysis results for Rees/Dart for Glenorchy and Kinloch for both scenarios, with full risk maps included in Appendix F – Qualitative Risk Level Maps.

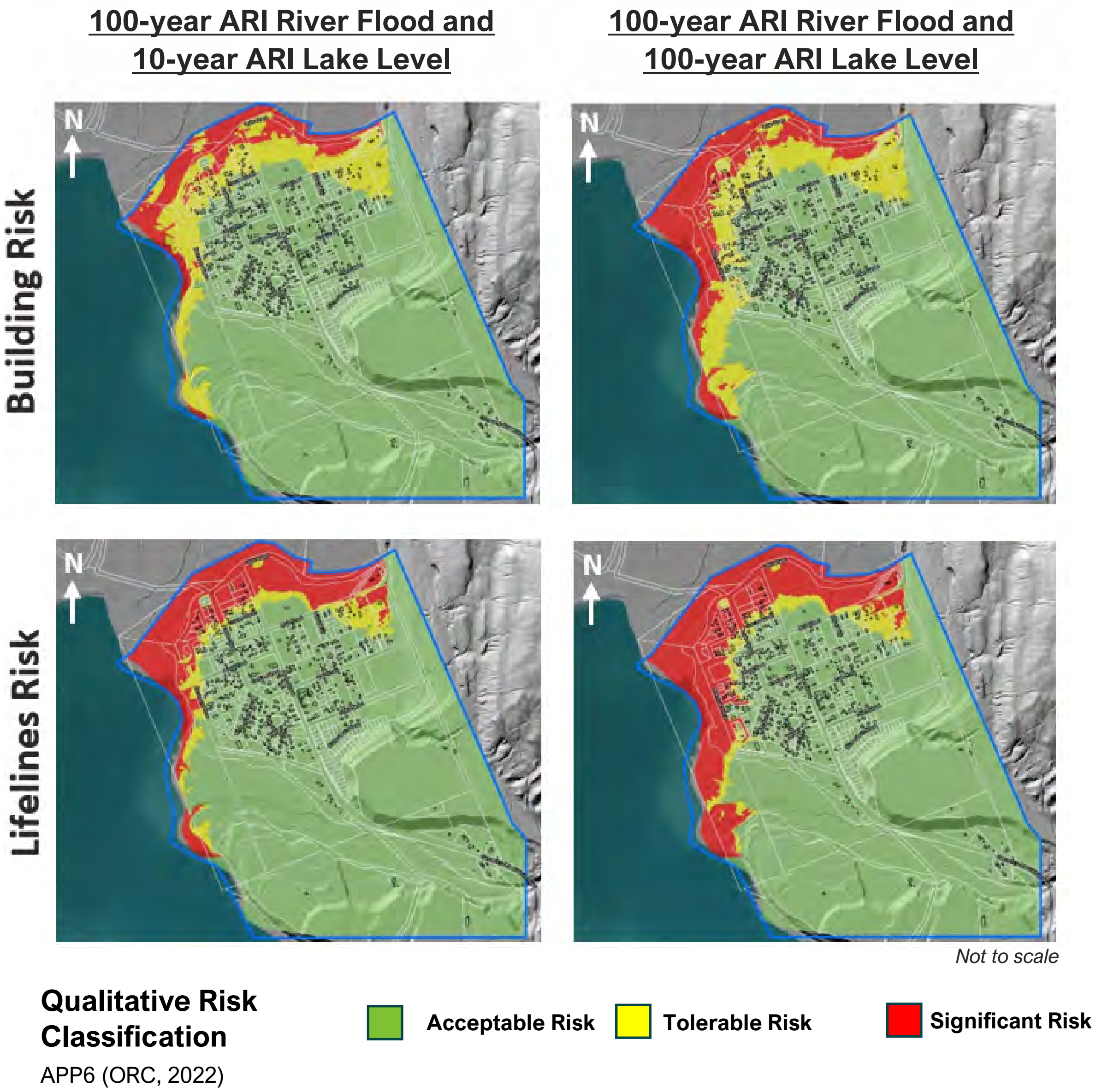


Figure 4-4: Rees/Dart River qualitative risk classification results for Glenorchy built environment, for the Likely (100-year ARI river flow, 10-year lake level) and Possible (100-year ARI river flow, 100-year ARI lake level) events.

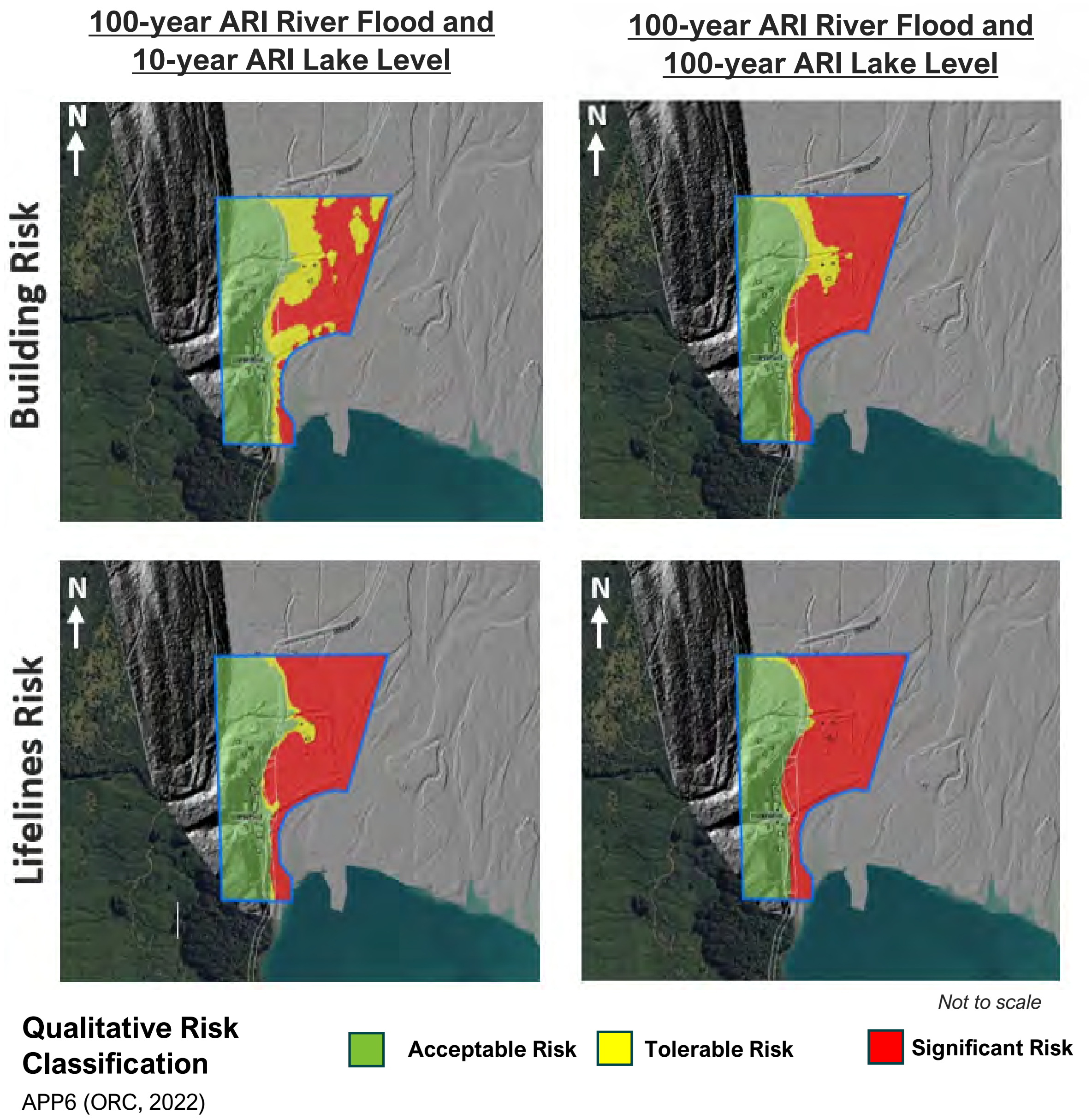


Figure 4-5: Rees/Dart River qualitative risk classification results for Kinloch built environment, for the Likely (100-year ARI river flow, 10-year lake level) and Possible (100-year ARI river flow, 100-year ARI lake level) events.

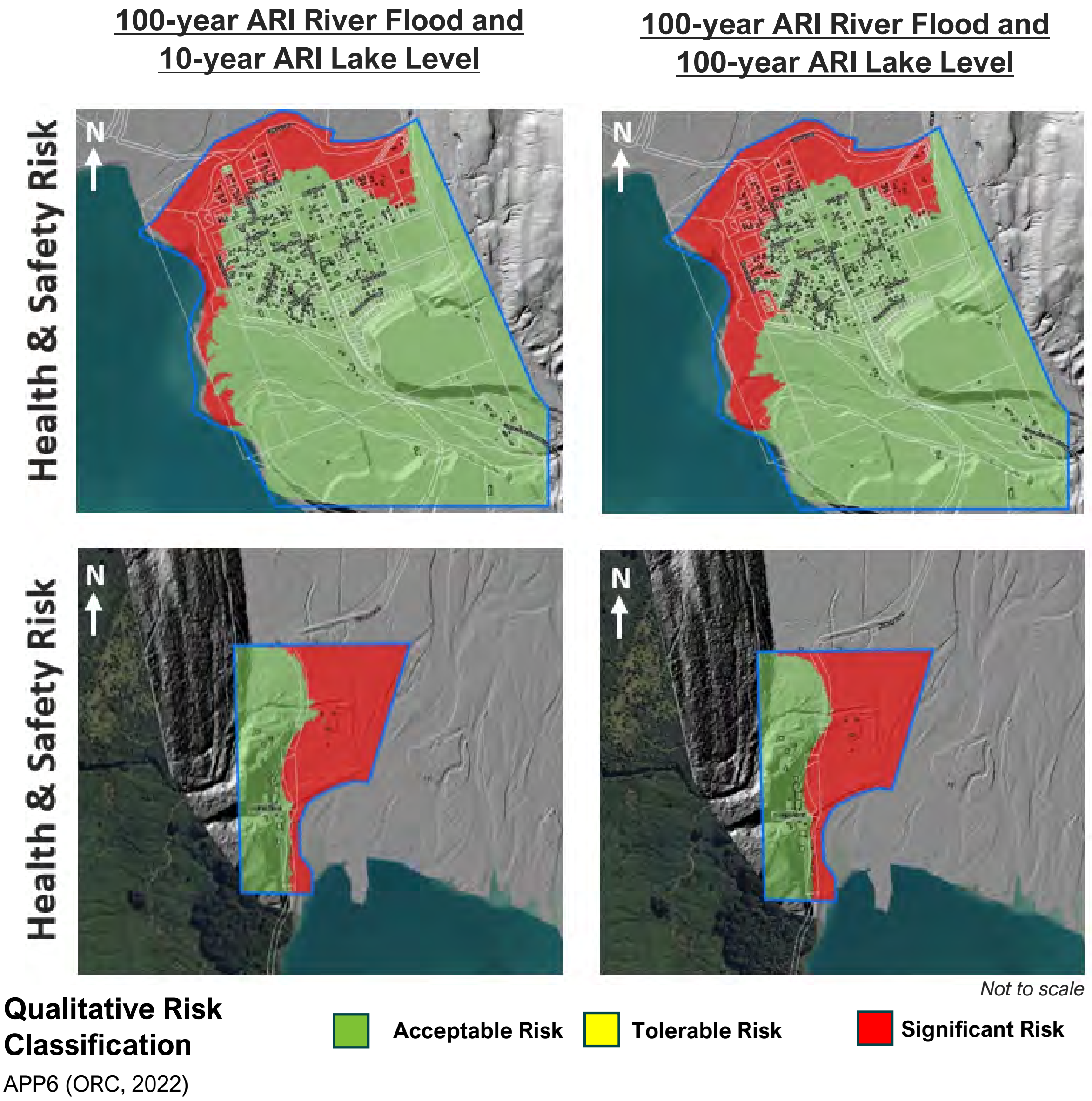


Figure 4-6: Rees/Dart River qualitative risk classification results for Glenorchy and Kinloch public health and safety, for the Likely (100-year ARI river flow, 10-year lake level) and Possible (100-year ARI river flow, 100-year ARI lake level) likelihood events.

The consequences of a Rees/Dart River flood event on the Glenorchy and Kinloch built environment and public health and safety is summarised below:

- Lifelines: The qualitative risk classification has shown that in the event of a Likely or Possible Rees/Dart River flood event, Kinloch would become inaccessible by road. Kinloch has experienced being cut-off on a relatively regular basis during significant flood events over 1-2 days. Being cut-off triggers up to Major consequences in the Possible likelihood scenario (refer to Table 7, Appendix 6 of the RPS, 2022).
- Buildings: A Rees/Dart will flood up to 66 properties in the Possible scenario, affecting residential buildings, critical buildings and cultural/social amenities. For all three building categories, Catastrophic consequences are triggered.
- Public Health and Safety: Due to the simulated widespread extent of flooding within the Glenorchy and Kinloch residential areas, consequences up to Catastrophic are triggered in the Possible Rees-Dart flood scenario, as per the Proposed Regional Policy Statement 2021 (Hearing Panel Version) (ORC, 2022).

4.3.4.3 Summary of River Flooding Qualitative Assessment

The river flooding qualitative risk is summarised in Table 4-7, for Public Health and Safety and the Built Environment. The qualitative risk applies to both the Glenorchy and Kinloch study areas.

From the qualitative risk assessment, flooding from the Rees/Dart and Buckler Burn rivers poses a Significant risk to the Built Environment in Glenorchy and Kinloch, including residential buildings, critical buildings and amenities of cultural/social significance. The Public Health and Safety risk is Tolerable for flooding from Buckler Burn and Significant for flooding of Rees/Dart Rivers.

The privately owned wastewater treatment plant (Lancaster Place) is outside of the flooded area of the Buckler Burn and the 100-year lake flood. The water supply wells along the Glenorchy-Queenstown Road is outside of the simulated flood zone of any of the Buckler Burn flooding scenarios. However, a Buckler Burn breach could happen anywhere along the Buckler Burn riverbank, which could possibly affect the water supply from the borehole. To mitigate this risk, Glenorchy has water tanks outside of the flood extents that could act as limited buffer storage in the case the water supply is affected at the borehole.

Figure 4-4 shows the qualitative risk classification of the built environment for the Rees/Dart River flood Likely and Possible scenarios. For a Rees/Dart River flood event, the areas subject to Significant risk of the built environment are restricted to along the Rees lagoon. In Kinloch, a Significant risk is posed to the built environment east of the Kinloch Road. The potential risk posed by Buckler Burn is much lower than the potential risk posed by a Rees/Dart River flood. For a Buckler Burn flood event, Significant risk to the built environment is mostly restricted to outside of the residential area, and there is Tolerable risk to the built environment along the Queenstown – Glenorchy Road, Shiel Street and Invincible Drive (Figure 4-2). However, it is important to note that Buckler Burn flooding has the potential to cut off Glenorchy and Kinloch by flooding the Glenorchy Queenstown Road.

In accordance with the RPS (ORC, 2022) guidance, any Significant risk warrants further assessment through a quantitative risk analysis. Whilst the Public Health and Safety risk has been assessed qualitatively as Tolerable for Buckler Burn flooding, it will also be assessed quantitatively as detailed in Section 9.1.1.

Table 4-7 : Qualitative river flooding risk assessment results

Hazard	Public Health and Safety Risk	Built Environment Risk
River flooding – Buckler Burn	Tolerable	Significant
River flooding – Rees/Dart	Significant	Significant
	Definition of risks within Appendix 6 of the RPS (ORC, 2022)	

Section 4.4 presents the river flooding quantitative risk analysis, including Built Environment and Public Health and Safety risk.

4.4 River Flooding Quantitative Risk Analysis

4.4.1 Life Risk Analysis

As detailed in Section 3.5.1, the equation for determining the annual individual fatality risk (AIFR) is (Australian Geomechanics Society, 2007):

$$AIFR = P_{(H)} \times P_{(S:H)} \times P_{(T:S)} \times V_{(D:T)} \quad (1)$$

Details of how the probabilities have been determined for each hazard are included in in this section:

- The probability of flood hazard ($P_{(H)}$) is the frequency of the model scenario, i.e. for a 50-year ARI event this would be $2x10^{-2}$.
- The spatial probability ($P_{(S:H)}$) is a function of the spatial extent of the hazard, determined by the extent of the Flood Hazard Vulnerability Classification taken from the flood model results.
- The probability of exposure ($P_{(T:S)}$) for the individual most at risk, is based on two studies that describe the spatial distribution of New Zealanders on an average day (Ministry of Transport, 2018 and Khajehzadeh & Vale, 2016). These studies indicate that a resident spends 70% of their time at home and 15% travelling. To consider people driving within Glenorchy, between Glenorchy and Kinloch and to areas close by we assume that a resident is 85% of the time present in Glenorchy. Therefore, $P_{(T)}$ = 0.85.
- The vulnerability ($V_{(D:T)}$) is based on two studies (AIDR, 2017 and Feinberg et al., 2016) that describe the fatality rate when exposed to different flood severities. Refer to Figure C-2 and Figure C-5. Flood severity measures the impact of a flood based on the flood velocity and depth. In this study, the vulnerability represents the estimated fatality rate for a given Flood Hazard Vulnerability Classification.

Feinberg et al. (2016) factored in the effect of warning time on reducing fatality rates (Figure C-5). This study assumes ‘sufficient warning’, as the large catchments considered do not typically result in flash floods. Additionally, Glenorchy and Kinloch are expected to be easily evacuated (in comparison to the historical events analysed by Feinberg et al.) because of their low population density and open landscape.

The probabilities applied to river flooding AIFR are shown in Table 4-8. The median values have been used to calculate the AIFR outputs. In order to account for uncertainty in the values adopted, lower and upper bounds have been considered for the temporal and vulnerability parameters. These results of the AIFR analysis with the lower and upper bound are discussed in Section 4.5. The upper and lower bound are based on the variation of fatality rates of past events. We follow the suggested fatality rate limits shown in Feinberg et al. (*‘suggested limit’* in Figure C-5:).

Table 4-8: Probabilities used to estimate AIFR.
The median is the value to calculate the AIFR in this study. Values based on Feinberg et al. (2016) using the fatality rates with adequate warning time. Flood hazard classification is defined by AIDR (2017).

Uncertainty	Annual probability of hazard occurring ($P_{(H)}$)	Probability of exposure ($P_{(T:S)}$)	Vulnerability: Estimated fatality rate (H = Flood Hazard Vulnerability Classification)					
			H1	H2	H3	H4	H5	H6
Upper Bound	Scenario dependent: 0.02 – 0.002 (50-year to 500-year ARI	0.7	0	0	0	$1x10^{-5}$	$1x10^{-5}$	$4x10^{-5}$
Median		**0.85**	**$5x10^{-6}$**	**$5x10^{-6}$**	**$5x10^{-5}$**	**$1.1x10^{-4}$**	**$3x10^{-4}$**	**$5x10^{-4}$**
Lower Bound		1	$1x10^{-5}$	$1x10^{-5}$	$1x10^{-4}$	$2x10^{-4}$	0.03	0.15

4.4.2 Property Risk Analysis

The APR is based on the estimated damage a flood can cause to a building. As detailed in Section 3.5.1, the equation for determining the annual property risk (APR) is (Australian Geomechanics Society, 2007):

$$APR = P_{(H)} \times \, P_{(T)} \times V_{(D:T)} \qquad (2)$$

Where:

$P_{(H)}$ is the annual probability of a hazard occurring. This based on the likelihood of the considered scenario.

$P_{(T)}$ is the temporal spatial probability. As buildings do not move in time or space this is set to 1.

$V_{(D:T)}$ is the vulnerability of the property to damage from a hazard and is based on the damage ratio. The damage ratio describes the expected building damage at a given flood depth. Its values can range between 0 – 1 (1 being total damage).

To inform the flooding analysis, the damage ratio developed by NIWA (2010) was adopted (shown in Figure 4-7). NIWA proposes different damage ratio curves for different housing types, age and the number of storeys. As detailed in Section 3.7.2, most of the houses in Glenorchy and Kinloch are classified as lightweight timber framed buildings built after 1980. In order to estimate the theoretical APR distribution within Glenorchy, the appropriate damage ratio of the most common housing type and age within Glenorchy/Kinloch was adopted (refer to Section 3.7.2).

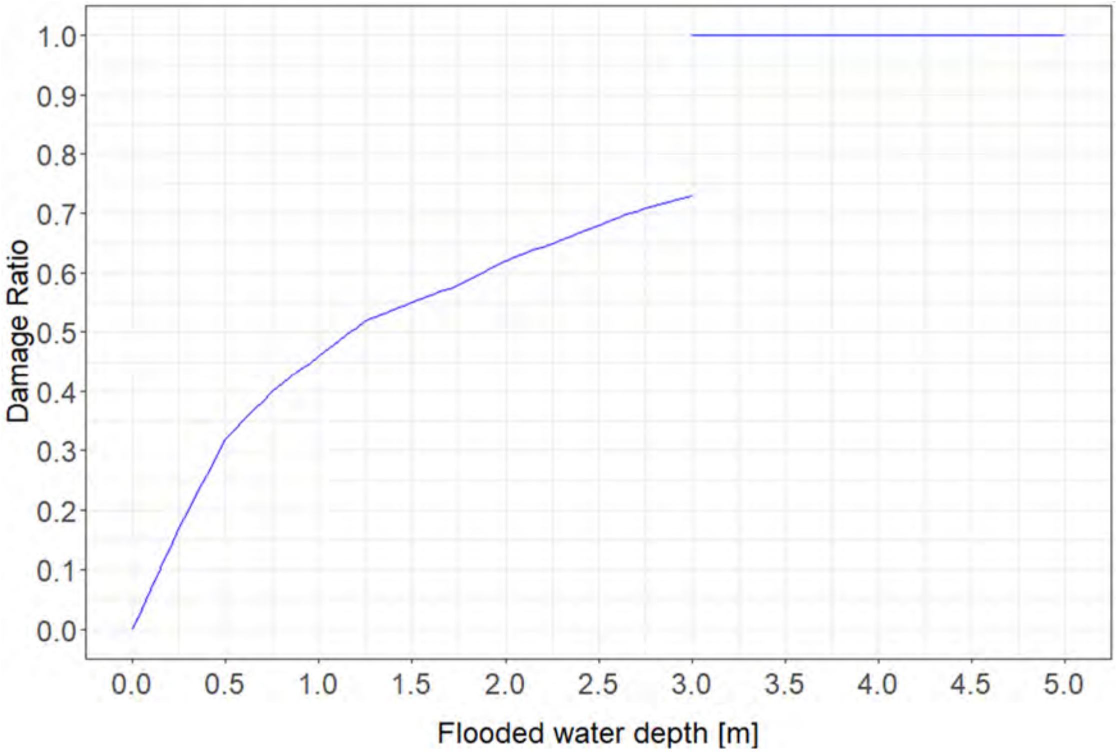


Figure 4-7: Applied flood fragility curve.
Applicable to timber buildings with one storey that are built before 1960 or post 1980. Only 10.5% of the houses are built between 1960 – 1980. The original curve is shown in Figure C-6 in Appendix C. Based on NIWA, 2010.

In this quantitative assessment, both the AIFR and the APR have been calculated for river flooding of Buckler Burn and Rees/Dart River, for the Almost Certain, Likely and Possible likelihoods. Additionally, a 'combined' AIFR and APR has been calculated for the Buckler Burn flood event, and separately for the Rees/Dart flood event. The 'combined' AIFR/APR is the annual risk of having three flood events with different likelihoods occur in the same year, for the same flood source (e.g., Buckler Burn). The three flood events represent the three likelihood bands: Almost Certain, Likely and Possible and are based on the recommendation outlined in the RPS (ORC, 2022).

4.4.3 Results

4.4.3.1 Life Risk

As defined in the RPS (ORC, 2022), the life risk for areas with existing development is Acceptable if the AIFR is less than $1x10^{-5}$. The life risk is Tolerable for areas with existing development if the AIFR is between $1x10^{-5}$ and $1x10^{-4}$. The life risk is Significant for areas with existing development if the AIFR is higher than $1x10^{-4}$. The flood risk posed to any potential new development areas within Glenorchy or Kinloch has not been considered in this assessment. The results of the quantitative risk analysis are shown in the figures below, with full risk maps included in .

The quantitative AIFR assessment indicates that higher frequency events pose the highest and most widespread risk to individuals. These river flood events happen more frequently, and over time their impact per year is greater than rarer events like the 500-year ARI event. Figure 4-8 shows the mean AIFR of the 50-year ARI joint flood scenario is approximately $8x10^{-6}$ (Acceptable risk) within Glenorchy township area, a scenario where the Rees/Dart, Buckler Burn, Bible Stream and both Glenorchy catchments flood simultaneously. The same joint flood scenario has a AIFR of $2x10^{-7}$ (Acceptable risk) in a 500-year ARI event.

In Glenorchy, the areas with the highest individual risks are the Glenorchy lagoon, the lakefront (including Jetty Street and Benmore Place), and the Glenorchy Golf Course. Properties behind the floodbank, near the confluence of the Rees River and the lagoon, show the highest estimated AIFR at $5x10^{-6}$ (Acceptable risk). These risks stem from flooding of the Rees/Dart rivers. The AIFR in these areas does not increase in a joint flood scenario, where all rivers flood simultaneously.

Within the Glenorchy township, impacts associated with flooding of the buckler burn vary, with AIFR values ranging from $9x10^{-8}$ to $5x10^{-6}$ along Shiel Street, the end of Coll Street, and on the Glenorchy-Queenstown Road (Acceptable risk).

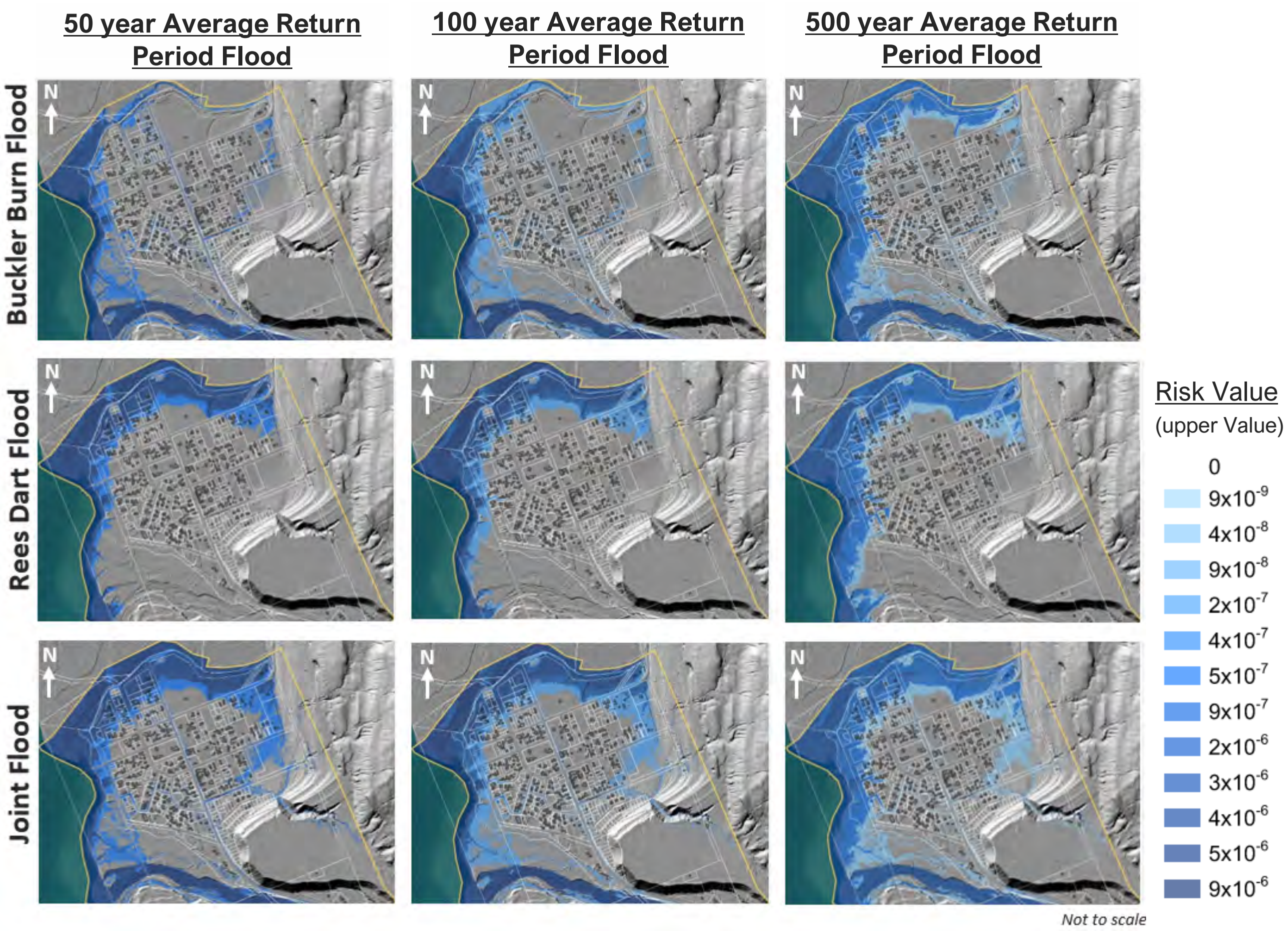


Figure 4-8: AIFR results for Glenorchy from all river flooding scenarios.

In Kinloch, some areas zoned as township area show an estimated AIFR of $5x10^{-6}$ during a 50-year and $5x10^{-7}$ during a 500-year ARI Rees/Dart event (Acceptable risk). These areas are currently undeveloped. Existing buildings west of the Kinloch Road are in low flood risk areas (AIFR $<8x10^{-7}$, Acceptable risk). Some properties east of the Kinloch Road have AIFR values of up to $5x10^{-6}$, Acceptable risk. The results are shown in Figure 4-9. The highest risks in Kinloch are caused by a 50-year ARI event of the Rees/Dart.

In Glenorchy, similar to Kinloch, the primary risks come from flooding of the Rees/Dart Rivers. However, within the township, Buckler Burn also poses some risks, albeit lower. When considering flooding from all catchments at the same time as a ‘joint flood’ scenario (Rees River, Dart River, Glenorchy catchments, Bible Stream, and Buckler Burn) compared to from only Buckler Burn, certain areas in eastern Glenorchy face slightly higher risks ($1x10^{-6}$ versus $8x10^{-8}$). The AIFR values for the Rees/Dart rivers and the joint flood scenario are very similar. This is because the fatality risk from Buckler Burn and the smaller Glenorchy catchments is too low to have a significant additional impact.

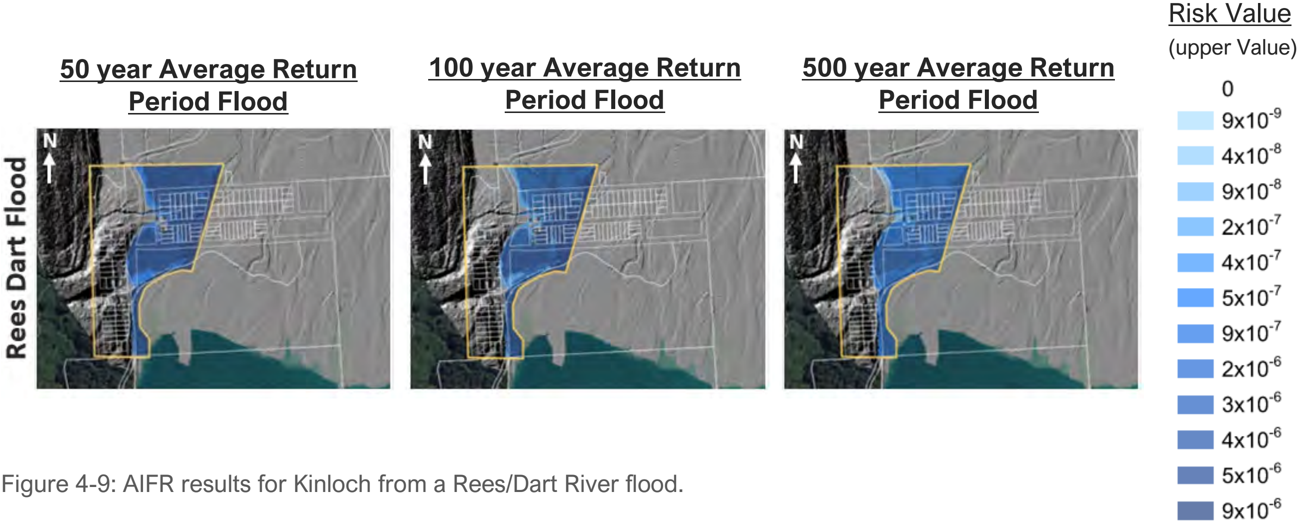


Figure 4-9: AIFR results for Kinloch from a Rees/Dart River flood.

In both Glenorchy and Kinloch, the AIFR values are below the Tolerable risk threshold for existing development defined in the RPS of $1x10^{-5}$ (ORC, 2022), as shown in Figure 4-8 and Figure 4-9. Therefore, the life risk is re-categorised as acceptable for Glenorchy and Kinloch. When considering the combined AIFR results (Figure 4-10), which is the addition of each annual individual risk (50-year + 100-year + 500-year ARI), the AIFR is still lower than the threshold for Tolerable risk, except for areas in the riverbeds.

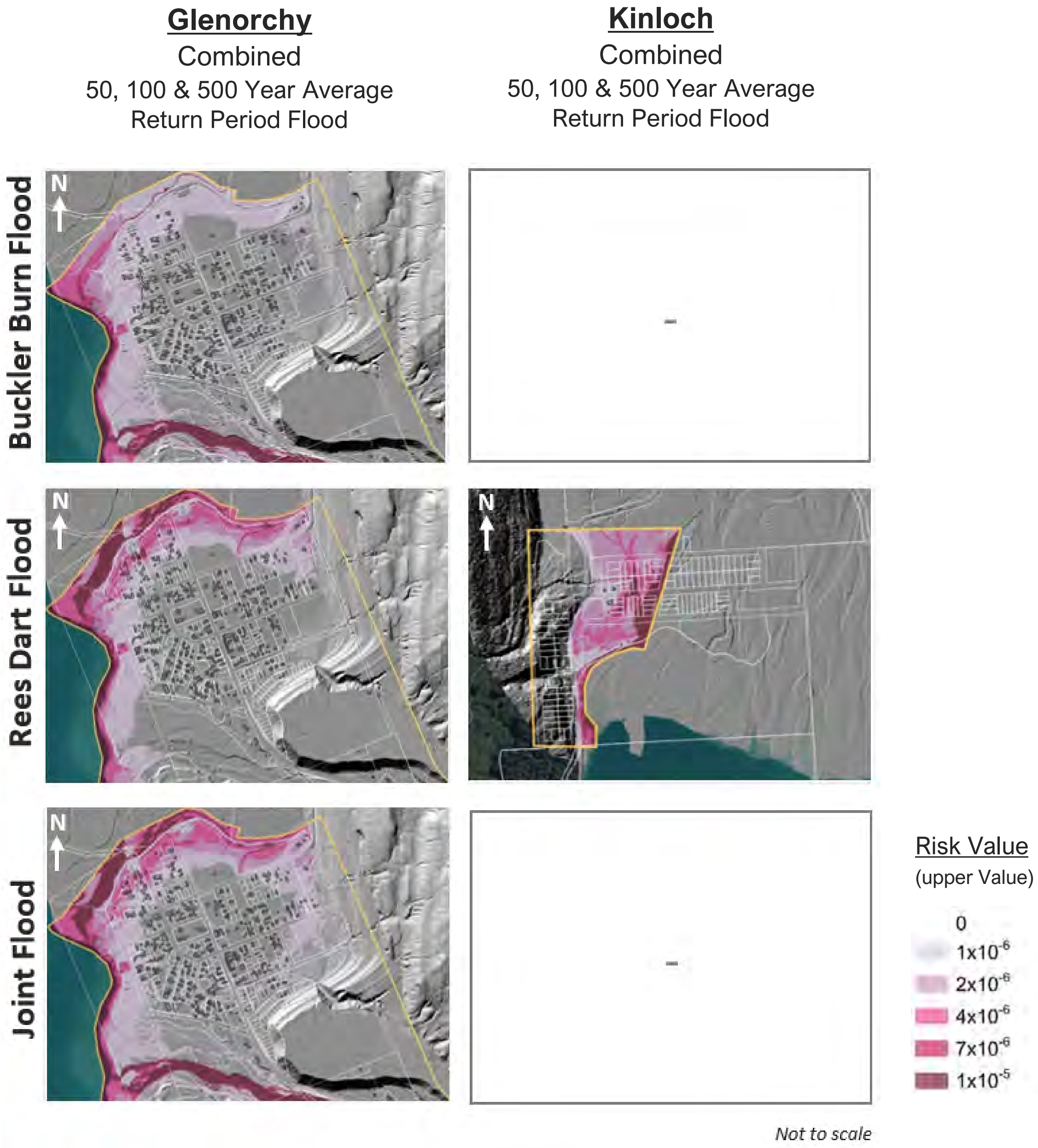


Figure 4-10: Combined AIFR flood results for Glenorchy and Kinloch, adding the AIFR values of all scenarios per flood source together.

Figure 4-11 shows the outcomes of the above combined risk analysis spatially in relation to the risk levels of Acceptable, Tolerable and Significant in accordance with the RPS guidance (Table 3-2) for *existing developments.* The quantitative life risk levels are Acceptable for river flooding hazards for all developed areas (outside of the river channels). Full quantitative risk level maps are shown in Appendix H – Quantitative Risk Level Maps.

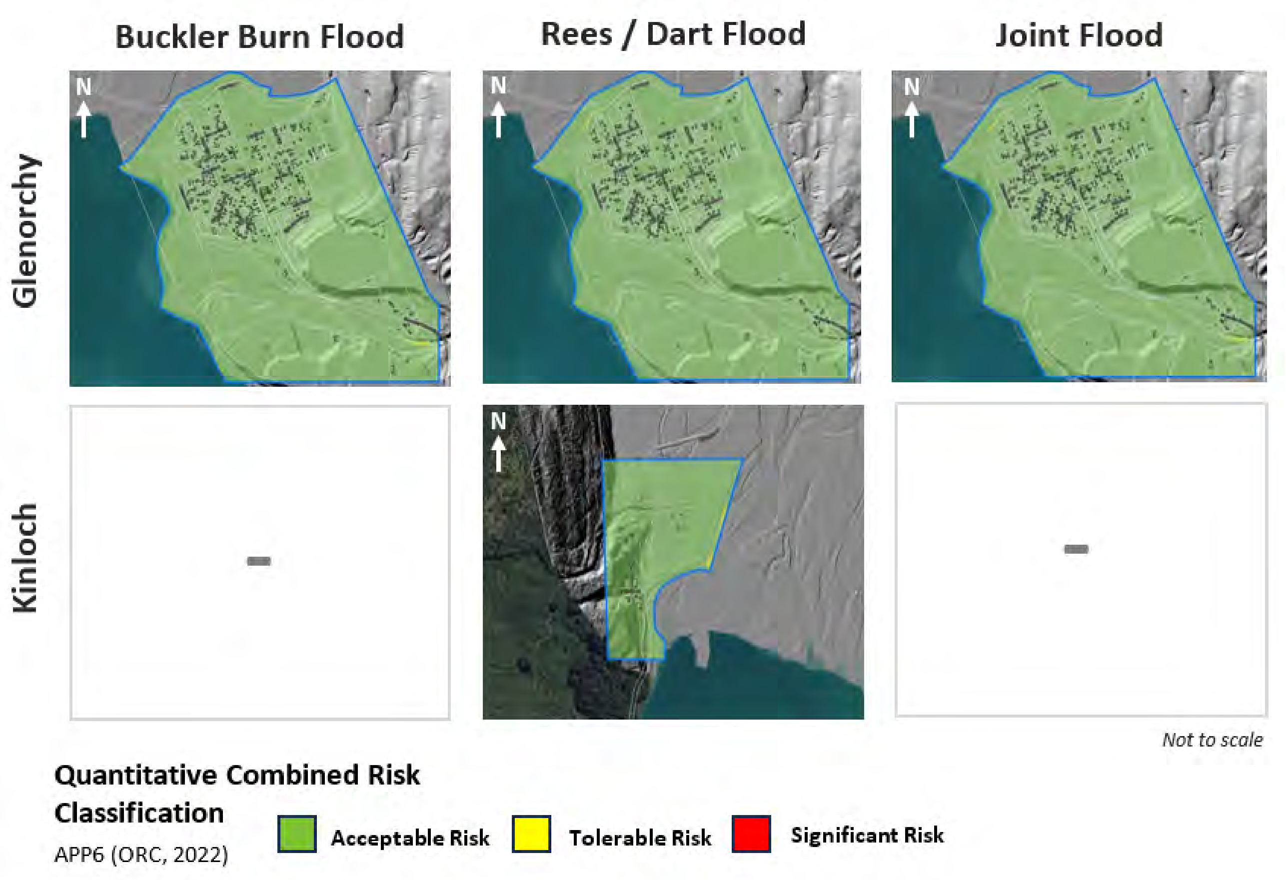


Figure 4-11: River flooding life risk (AIFR) levels

4.4.3.2 Property Risk

As defined in the RPS (ORC, 2022), the property risk for areas with existing development is Acceptable if the APR is less than $1\text{x}10^{-5}$. The property risk is Tolerable for areas with existing development if the APR is between $1\text{x}10^{-5}$ and $1\text{x}10^{-4}$. The property risk is Significant for areas with existing development if the APR is higher than $1\text{x}10^{-4}$. The flood risk posed to any potential new development areas within Glenorchy or Kinloch has not been considered in this assessment. The results of the quantitative risk analysis are shown in the figures below, with full risk maps included in .

A Dart/Rees River flood event poses the highest risks to property, exhibiting the highest APR values and the greatest extent of potential damage (Figure 4-12 and Figure 4-13). In Glenorchy this leads to potential damage along the lagoon and the Rees River mouth, with APR values reaching up to $1.3\text{x}10^{-2}$ on the golf course (Significant property risk). In Kinloch, a Rees/Dart River flood can potentially damage areas to the east of the Kinloch Rd with APR values reaching up to $1.1\text{x}10^{-2}$ within the township zone, a Significant property risk.

The potential damage caused by the Buckler Burn is limited to very few areas along its potential overland flow path along the Glenorchy-Queenstown Road and Shiel Street (Figure 4-12). Overall, the Buckler Burn has lower APR values and a small flood extent within the township area. Consequently, the additional damage caused by flooding from the Glenorchy catchments and the Buckler Burn in a joint flood scenario is minimal. In a joint scenario the additional effect of Bible Stream, the Glenorchy catchments and the Buckler Burn result in higher APR values of up to $8\text{x}10^{-3}$ along Coll Street and the Glenorchy Cemetery, a Significant property risk. The Rees/Dart flood has the highest damage potential.

The combined APR is shown in Figure 4-14, showing the risk of multiple floods happening in the same year.

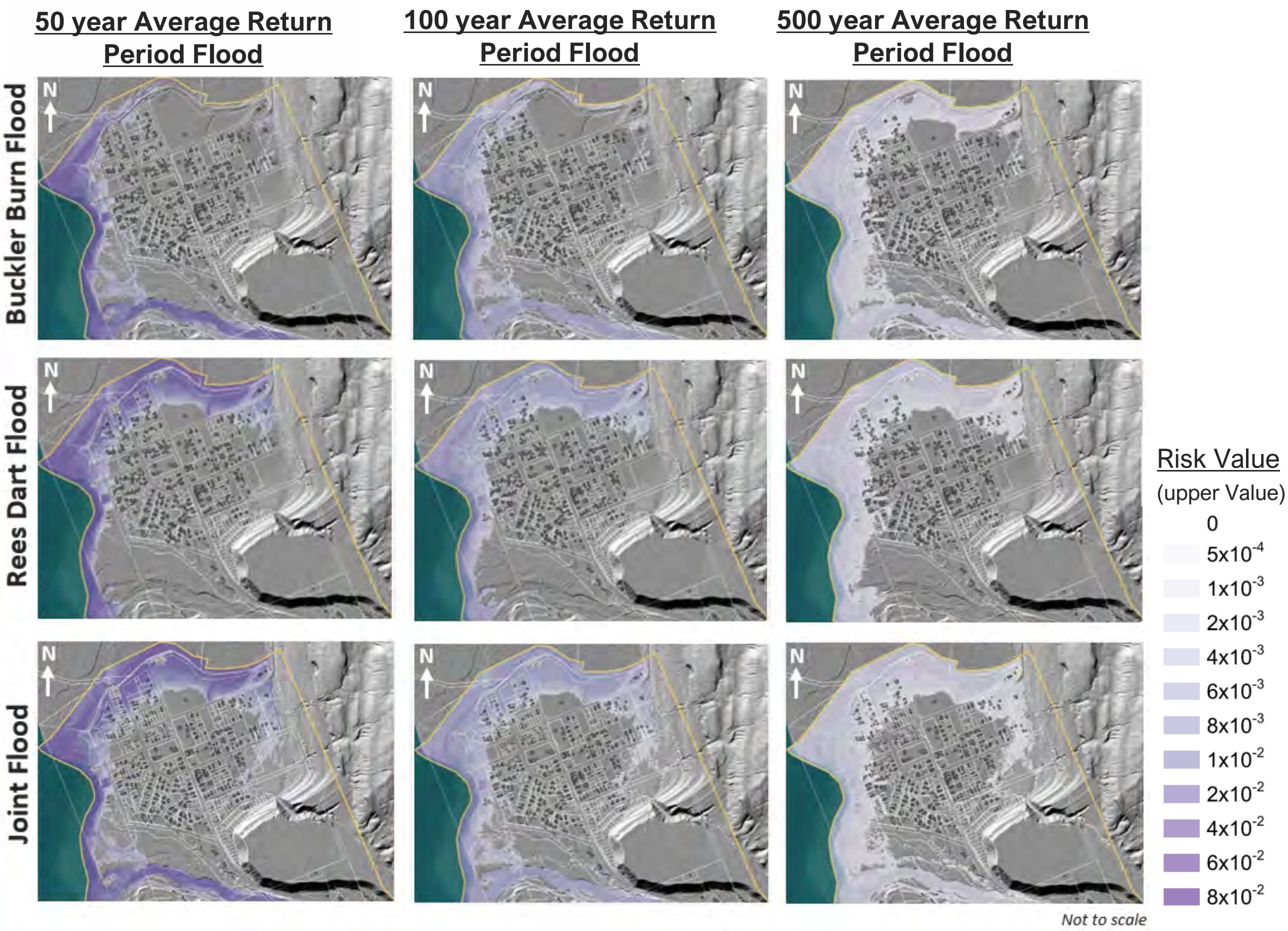


Figure 4-12: APR results for Glenorchy from all river flooding scenarios.

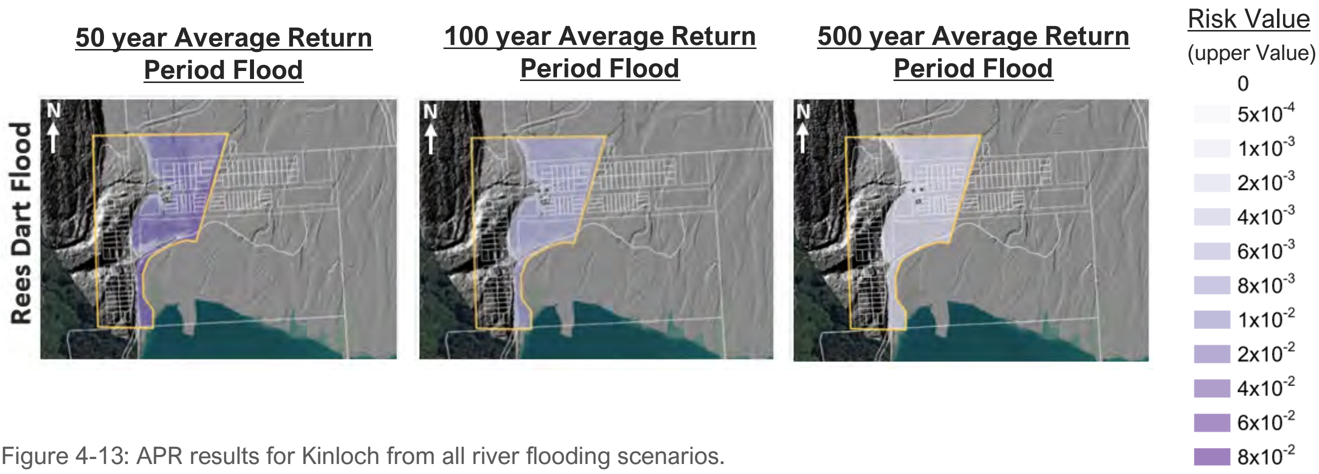
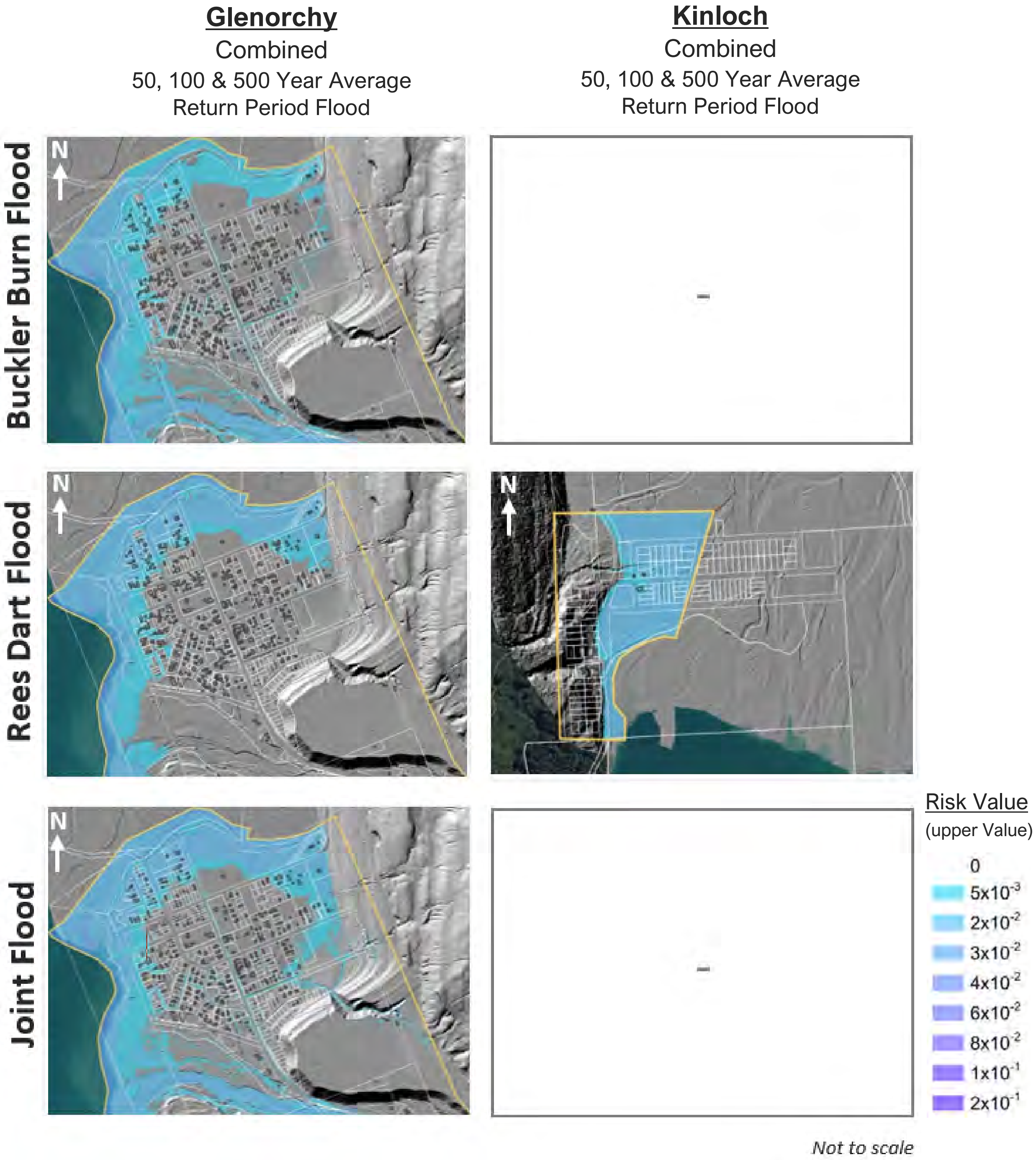


Figure 4-13: APR results for Kinloch from all river flooding scenarios.



Glenorchy
Combined
50, 100 & 500 Year Average
Return Period Flood

Kinloch
Combined
50, 100 & 500 Year Average
Return Period Flood

Figure 4-14: Combined APR flood results, adding the APR values of all scenarios per flood source together.

Quantitative property risk levels in accordance with the ORC guidance (Table 3-2) are shown in Figure 4-15, and included as full risk maps in Appendix H – Quantitative Risk Level Maps. This shows that risk level extents vary spatially between hazards, with the risk to property being *Significant* along the river and lake margins.

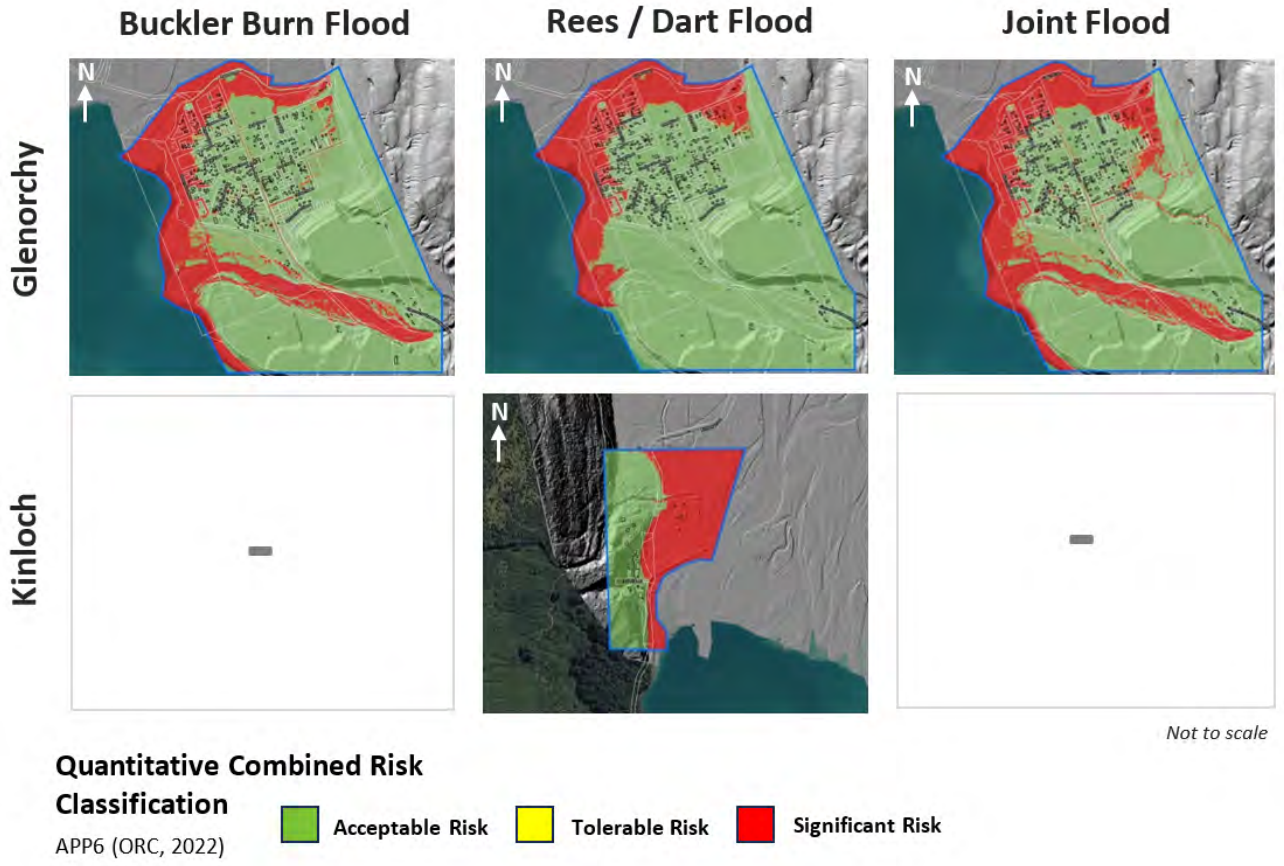


Figure 4-15: River flooding property risk (APR) levels

4.5 Discussion

The highest AIFR occurs during the 50-year ARI event. Properties and individuals along the Rees and Dart River mouth and in Glenorchy along the floodbank face higher risks than properties further away from these feature as they are generally at a higher elevation. In general, the risks follow the land profile of both areas (i.e. the higher the elevation the lower the risk). However, this becomes more complex when taking multiple flood hazards into account. Buckler Burn increases the risks within the township of Glenorchy (along Shiel Street and at the end of Coll Street).

The quantitative results confirm the assessment of the qualitative assessment, that the risk to property is Significant in areas affected by flooding. The quantification of the risk to life reduced the risk level from Tolerable (in the qualitative assessment) to Acceptable for the entire study area in the quantitative assessment (compare Table 9-1 and Table 9-2).

The uncertainty of a person to the vulnerabilities to flood hazards presented in Table 4-8 result in a large range of final AIFR values. The consequences of this for the classification according to the RPS (ORC, 2022) is shown in Figure 4-16. It is important to consider this uncertainty of the AIFR when using these risk values.

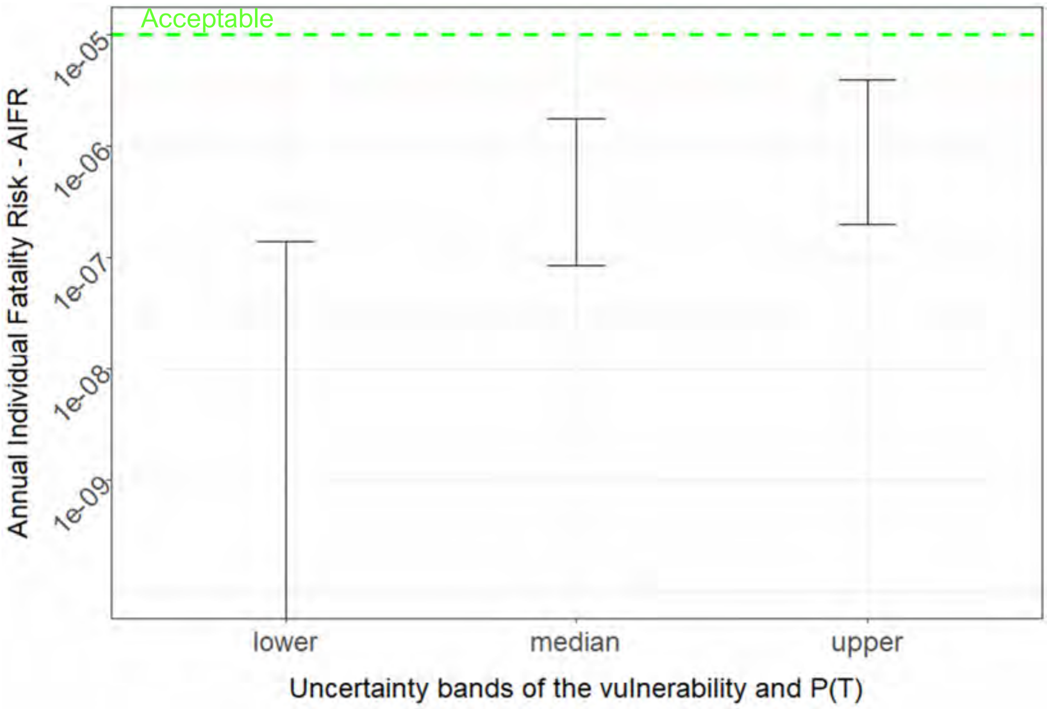


Figure 4-16: AIFR results considering the lower, median and upper bound shown in Table 4-8.
The AIFR values of a 50-year ARI joint scenario are shown. The horizontal line shows the threshold as defined by RPS (ORC, 2022) for existing developments.

Based on QLDC Demand Projections (QLDC, 2022), the number of day visitors is usually around 190 but can reach up to 1,000 on peak days. Assuming an average of 190 visitors and a similar flood evacuation behaviour to the residents, the potential number of deaths and injuries in all flood scenarios could increase by a factor of 1.8. For the Rees/Dart River, the consequences would remain Catastrophic. For Buckler Burn, the consequences would remain Major. This has no effect on the AIFR calculation as the AIFR estimates the risk for an individual.

All of the big three catchments (Rees, Dart, and Buckler Burn) are subject to a changing riverbed. The Rees and Dart riverbeds are dynamic and localised degradation and aggradation can occur. This is evident in the fact that Kinloch Road is being eroded by a lateral migration of the Dart River and the higher bed levels in Rees River increase the hydrostatic pressure on the existing floodbank in Glenorchy. Furthermore, the Rees River is subject to avulsion events, where floodwater flows along the steeper flood route further east of the existing riverbed. This could lead to higher flood hazards within the Glenorchy community.

Extreme, rare rainfall events are expected to become more intense with climate change. For example, NIWA's model show that by the end of the century, rainfall totals for 100-year events could increase by 22-33% at the *Dart at Paradise*. NIWA projects a 20-50% increase in mean discharge and a 50-100% increase in the mean annual flood under the RCP8.5 scenario by the end of the century for all Lake Wakatipu catchments (NIWA, 2019). Increased flow has only been considered in the Rees/Dart River model used in the qualitative analysis (LRS, 2022). However, these results could not be used in this study as there is no equivalent *Possible* scenario with the effect of climate change. This would have led to a *Possible* scenario with no climate change and *Likely* scenario with climate change, making the results incomparable.

The Glenorchy community has a floodbank along the lagoon, however the flood results show that it was not constructed to protect the community from the simulated events. The floodbank is overtopped and merely delays the flooding of the area behind the floodbank.

Massey University (2021) noted an inadequate floodbank/levee at the base of the Bible Stream gully, which is more likely to act as a dam than a diversion structure. A dry channel runs through the former landfill area to the northwest, which could be a preferential path for flood discharges if the floodbank was to breach or if the existing Bible Stream flood bund were to be overtopped. Several buildings at the end of Shiel Street could potentially be in an overland flow path if the floodbank was to breach. The results from the joint flood scenario show that water from the Bible Stream flows towards the Glenorchy lagoon via the eastern part of Glenorchy (end of Coll Street).

4.6 Limitations

- At the time of the qualitative assessment no hydrologic estimates existed for Buckler Burn. Therefore, the highest estimates of the NIWA (2018) and URS (2007) estimates were taken. For the quantitative assessment hydrologic estimates were available. This showed that the qualitative assessment slightly overestimated the flows (200m³/s vs 166m³/s in the quantitative assessment for a 100-year ARI event).
- The Bucker Burn model was validated with the 1999 flood event, where the Glenorchy-Queenstown Road was flooded. In the 1999 flood, the flooding on the road originated from the river immediately adjacent to the road. In all simulations this could not be reproduced, the flooding of the road rather originated from further upstream (adjacent to Campbelltown).
- Aspects related to the dynamic nature of the Buckler Burn riverbed (river bifurcation, ongoing riverbed aggradation/erosion, debris flow) were not assessed within this river flooding risk analysis.
- In this report, vulnerability refers to the average vulnerability of a resident in Glenorchy. The estimated vulnerabilities are based on the fatality rates from Feinberg et al. (2016) which are derived from numerous historical events primarily in North America. Differences such as different demographics, flood behaviour, the flood pattern itself, the timing (day vs night), the seasonality (summer vs. winter) are not accounted for as this data is not available from past events. Future floods could occur under various conditions, making the total average from past events the best estimate for potential future events. Feinberg et al. (2016) used a total of 80 historical flood events to describe typical vulnerability curves (Figure C-15). This variance is illustrated in Figure 4-16.
- The uncertainty of the risk levels as defined in AIDR (2017) were not incorporated in the qualitative assessment. However, the categorisation is grouping variable that covers a range of depth and velocity values and therefore allows for a given uncertainty in the results itself.
- The idea that the rivers can affect each other's flooding because of their proximity is called Spatial Autocorrelation, a concept explained by Odland (1988). To accurately predict how often the rivers flood together, we would need to analyse data taking into account their spatial connection. Unfortunately, we do not have ongoing flow records for the Buckler Burn, which makes this challenging, but it is still an important factor to consider for understanding flood risks. HydroScience (2024) conducted an extensive time series analysis to develop flood hydrographs for a joint scenario. This data is the best currently available. However, uncertainties will remain until the Buckler Burn flow has been monitored over an extended period of time.
- Building damage is estimated from the given flood depth. In a scenario where all buildings have a raised floor level of 50cm, 40% fewer houses will experience floodwater entry. However, it's important to consider that floodwaters can still cause structural damage to the areas underneath the floors (Table 4-9).

Table 4-9: The number of houses in Glenorchy and Kinloch that would be flooded with at least 5cm of water depth in a 50-year joint scenario in the normal scenario (no raised floor levels i.e. ground level = floor level) and in the raised floor level scenario of 50cm.

Normal	Raised floor levels
79	20

- The damage ratio from NIWA only uses flood depth as an indication to estimate flood damage and does not incorporate the effect of flood velocities nor the uncertainty of the depth-damage function. High velocities can exacerbate structural damage to buildings, this effect has not been quantified yet and can therefore not be incorporated. Nonetheless, flood depth is a reliable estimator of flood damage and is widely used in the scientific community (Flood Depth-Damage Function) e.g. Pistrika et al. (2014) and Rahim et al. (2024).

- A flood risk categorisation of ex-tropical Cyclone Gabrielle (PDP, 2023) showed that factors other than flood velocity and depth played a vital role in defining the risk to life. In the special case of Hawkes Bay and the weather event of Cyclone Gabrielle the following criteria played an important role:
  - Rate of rise
  - Entrained silt
  - Debris loads (solid loads e.g. branches, trees, rocks)
- The effect of the above on the flood related risk was not assessed. The Rees/Dart Rivers have shown a fast rate of rise in the past, e.g. >1000m³/s rise within 12 hours during the Dart River flood event in January 2024. The smaller Glenorchy catchments might show a faster rate of rise, but their limited catchment size means that the risk posed to people and property from rate of rise is likely lower than that posed by Rees/Dart Rivers. The hazard caused by debris is discussed in Section 8.3.
- The simulations do not account for a sudden rise event caused by severe outbreak of the Rees River, known as an avulsion event. These events are very hard to predict and there are few studies on past occurrences. However, in such a rare event, water could flow through the Glenorchy community at higher speeds than simulated, increasing the flood hazard and risk to life (Brasington, 2021). LRS (2022) simulated an avulsion event, their result showed more water around the lagoon and increase in flood depth and in the extent of flooding at the upstream end of the floodbanks. The flood extent closer to the lake remains largely unchanged.

5 Lake Wakatipu Flooding Risk Analysis

5.1 Scope and Study Extents

In this section the potential risk posed by a Lake Wakatipu flood on Glenorchy and Kinloch are presented. This section only discusses the risk caused by 'static' lake floods. Lake seiche and tsunamis are discussed in Section 8.4.

5.2 Sources of Information

In order to assess the risk posed by a lake flood, past events and lake flood levels were assessed. Unlike the river flood models discussed in the previous section, lake floods can be simplified as constant flood level with very low flood velocities. Therefore, the lake flood depth can be estimated from the digital elevation model and estimated return periods of lake flood levels.

Lake levels and their corresponding return periods (referred to as ARI) were derived from a frequency analysis provided by ORC. The fitted generalised extreme value (GEV) distribution was used to derive the following lake levels at given ARIs.

Table 5-1: Lake levels in DUN58 vertical datum used in this study of Lake Wakatipu at given ARI intervals (provided by ORC based on update from March 2024).

Lake level ARI [years]	Water level [mRL]
10	311.39
20	311.69
100	312.60
200	313.10

5.3 Lake Flooding Qualitative Risk Analysis

The methodology of the qualitative risk analysis is the same as for the river flood assessment (refer to section 4.3). The only difference is that lake flood exhibit very low speeds (ORC, 2013), therefore the hazard definition of a lake flood only uses the hazard definition for flow velocities <0.5m/s. The hazard classification based on water level is shown in Table 5-2 and the accompanying hazard impact area definition is shown in Table 5-3.

For the qualitative assessment two scenarios were analysed: a 100-year and a 200-year ARI flood event which are within the Possible and Likely likelihoods definition from the RPS (ORC, 2022).

Due to the very low speed the lake levels rise and the prolonged warning times (Forsyth et al., 2000) there is negligible risk to health and safety from a lake flood. ORC provides early warning of high lake levels using a flood forecasting model which estimates high lake levels for Lake Wakatipu based on forecast or recorded rainfall totals. Therefore, no health and safety risk analysis has been undertaken for the lake flood scenarios.

Table 5-2: Converting Lake Wakatipu flooding depth into Flood Hazard Vulnerability Classification. Based on Flood Hazard Vulnerability Classification presented in AIDR (2017) shown in Figure 4-1.

Hazard Vulnerability Classification	Water depth [m]
H1	0 – 0.4
H2	0.4 – 0.5
H3	0.5 – 1.2
H4	1.2 – 2
H5	2 – 4
H6	4 – 6

Table 5-3: Definition of flood risk for Lake Wakatipu flooding.

Risk	Threshold
Acceptable	No flooding
Tolerable	0 - 1.2m
Significant	>1.2m

5.3.1 Results

Figure 5-1 and Figure 5-2 show the qualitative results of the two lake flood scenarios (Likely and Possible). Full qualitative risk maps are included in Appendix F – Qualitative Risk Level Maps.

- Lifelines: The 100-year ARI lake levels will lead to the road closure towards Kinloch (Mull Street and Kinloch Road will be flooded). The consequence of the lake flooding is classified as Moderate in this area according to the RPS (ORC, 2022).
- Buildings: The high lake levels would flood the properties along the Glenorchy lake front and lagoon. In Kinloch, the campground and parts of Kinloch Road would be flooded in both lake flooding scenarios (Likely and Possible). The consequence of this flooding is considered Catastrophic in these areas, according to the RPS (ORC, 2022).
- Health and Safety: Not directly assessed, due to the very low speed the lake levels rise and the prolonged warning times (Forsyth et al., 2000). There is negligible risk to health and safety from a lake flood event, and the Public Health and Safety Risk has been assumed to be Acceptable.

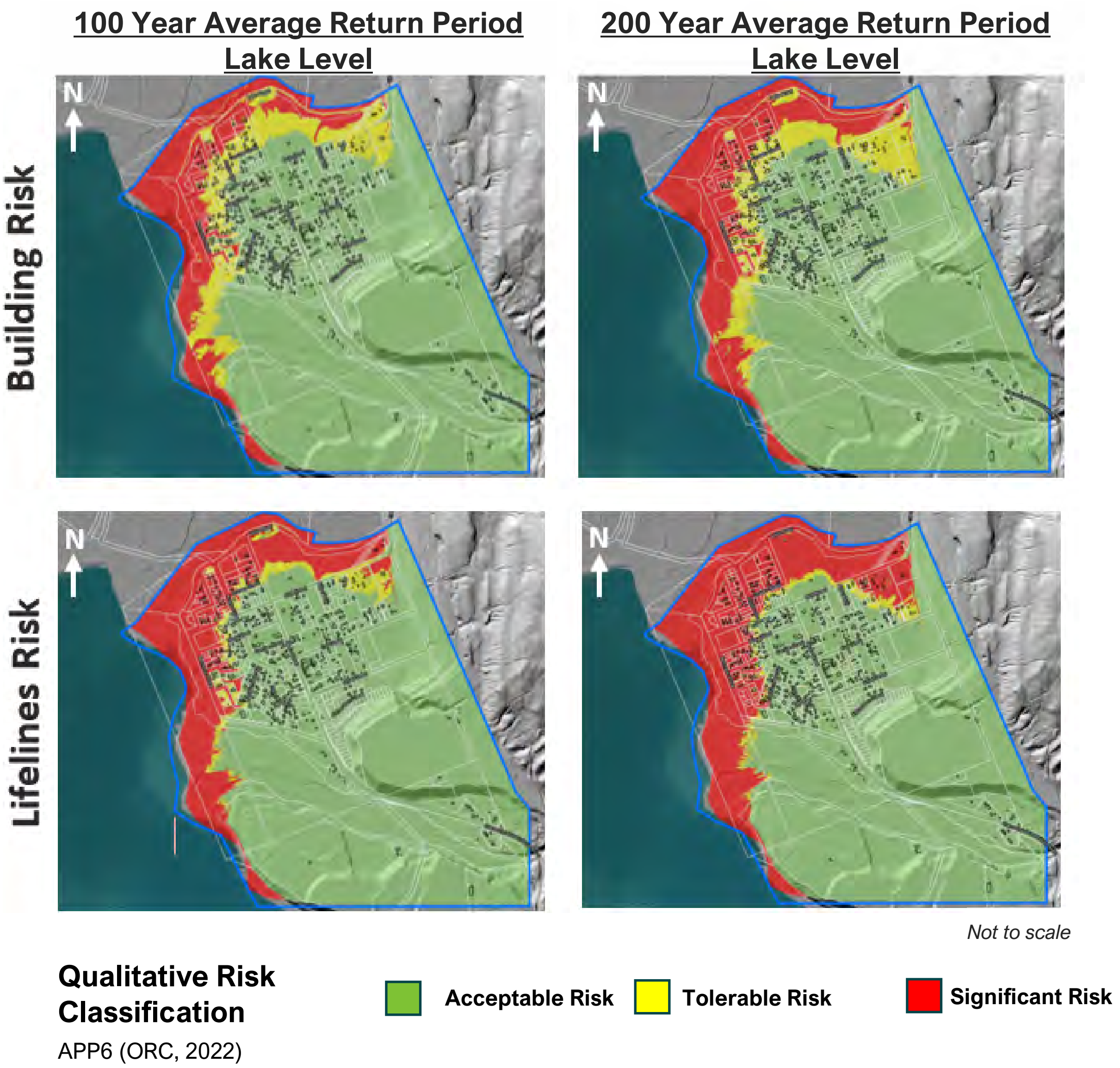


Figure 5-1: Lake flooding qualitative analysis results for Glenorchy. Showing the Likely (100-year ARI lake level) and Possible (200-year ARI lake level) scenarios for the built environment assessment.

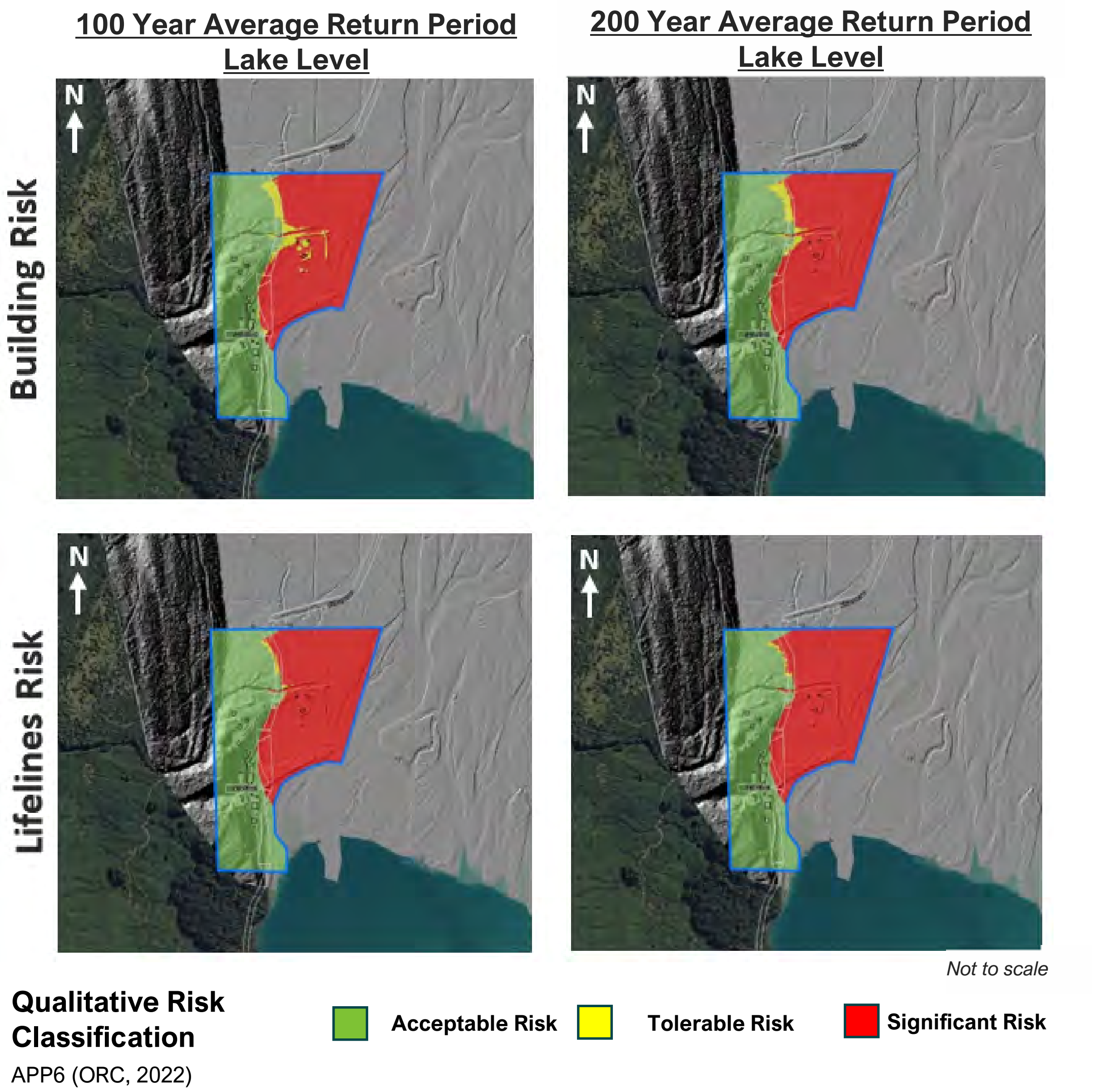


Figure 5-2: Lake flooding qualitative analysis results for Kinloch. Showing the Likely (100-year ARI lake level) and Possible (200-year ARI lake level) scenarios for the built environment assessment.

5.3.2 Summary of Lake Flooding Qualitative Assessment

The lake flooding qualitative risk is summarised in Table 5-4, for Public Health and Safety and the Built Environment. The qualitative risk applies to both the Glenorchy and Kinloch study areas.

From the qualitative risk assessment, lake flooding poses a Significant risk to the Built Environment in Glenorchy and Kinloch, including to lifelines, residential buildings, critical buildings and amenities of cultural/social significance. The Public Health and Safety risk is Acceptable for lake flooding, assumed based on the low rate of lake level rise and the prolonged warning time that would be expected.

Table 5-4: Qualitative lake flooding risk assessment results

Hazard	Public Health and Safety Risk	Built Environment Risk
Lake flooding	Acceptable	Significant

5.4 Lake Flooding Quantitative Risk Analysis

5.4.1 Property Risk Analysis

The Property Risk Analysis follows the same approach as for a river flood as the damage is only based on flood depth and therefore the same property vulnerabilities can be used.

5.4.2 Results

In comparison to a river flood, a lake flood poses similar potential damage to properties. The high APR values shown in Figure 5-3, are merely a reflection of the considered high recurrence interval and therefore a low exposure component in the APR calculation ($P_{(H)}$). Full quantitative risk maps are included in Appendix G – Quantitative Risk Maps.

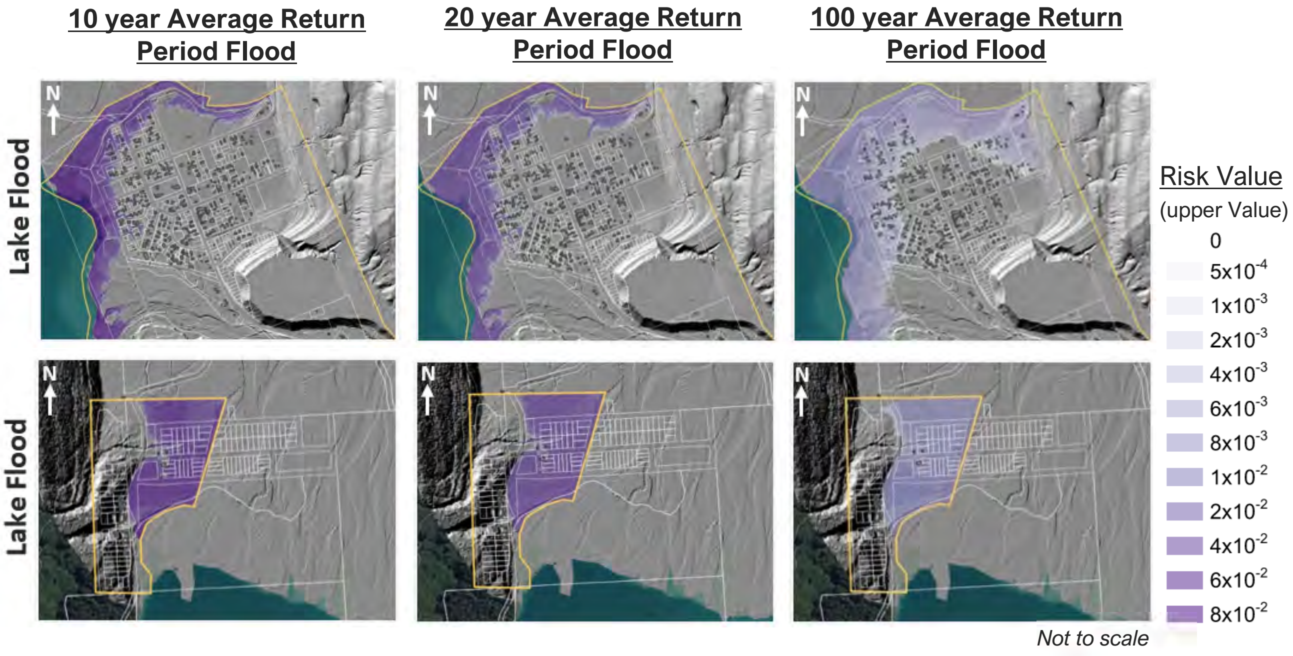


Figure 5-3: APR results of the three lake flood scenarios in Glenorchy and Kinloch.

The level of damage caused by a lake flood follows the topography of Glenorchy and Kinloch. The low-lying areas along the Rees lagoon and the lake are the areas more affected (e.g. Jetty Street and Butement Street). In Kinloch the Kinloch Road will be flooded in all three considered scenarios with APR values less than $1x10^{-2}$, as shown in Figure 5-3.

The combined risk is the sum of all scenarios per flood source i.e. the 10-year, the 20-year and the 100-year ARI scenario combined (shown in Figure 5-4 and Appendix G – Quantitative Risk Maps).

Property combined risk levels in accordance with the RPS guidance (Table 3-2) are shown in Figure 5-5, with areas of Significant risk along the lake front for both Glenorchy and Kinloch, and the Rees River margin in Glenorchy. Full quantitative risk level maps are included in Appendix H – Quantitative Risk Level Maps.

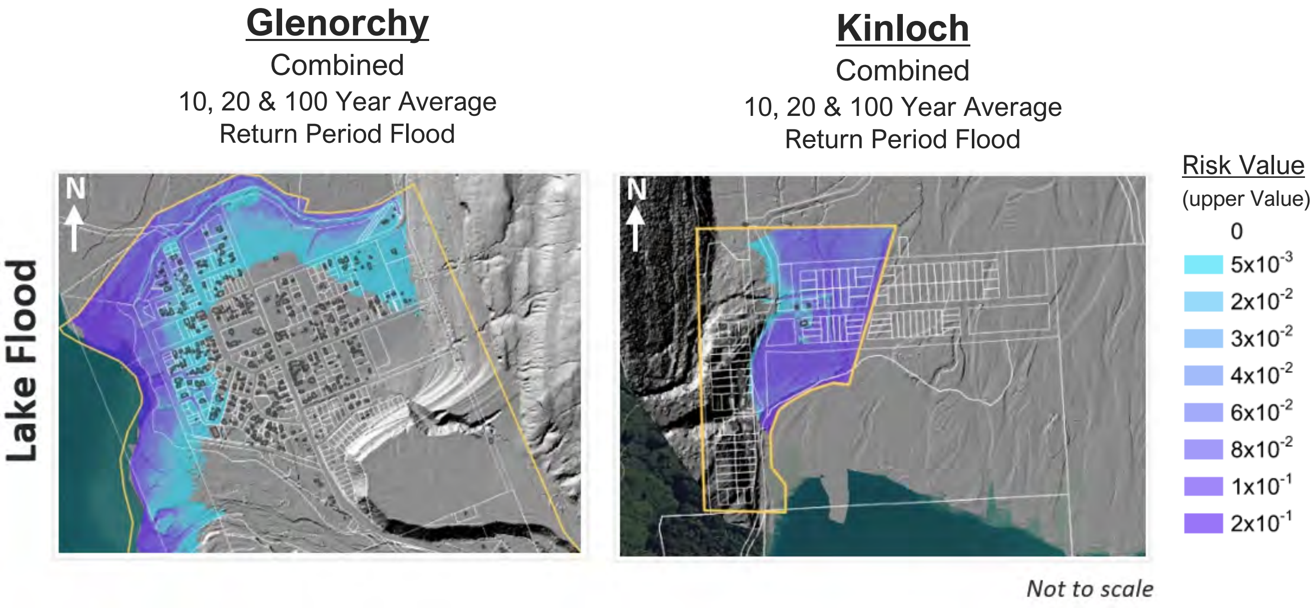


Figure 5-4: APR results of the combined APR of all lake flood scenarios (10 + 20 + 100 average return period).

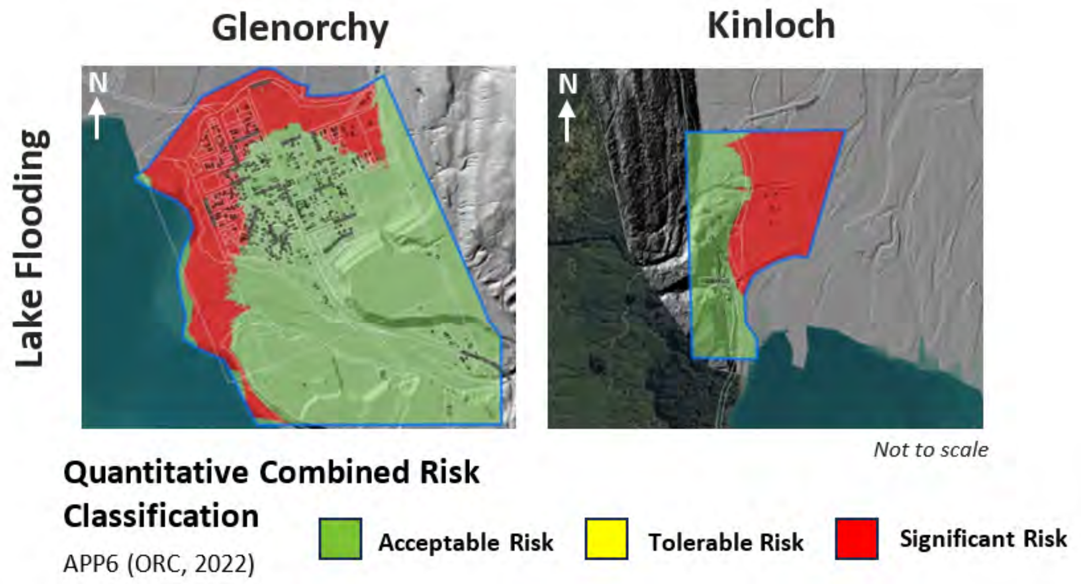


Figure 5-5: Lake flooding property risk (APR) levels.

5.5 Discussion

The biggest risk posed by Lake Wakatipu flooding is the potential to cut-off Kinloch and the damage it can cause to lake front properties. Results indicate that a high lake level combined with a river flood has a relatively minor impact on flood extent, increasing flood levels by less than 0.1m. The most significant effect is that the high lake level dampens the flow, reducing water velocities near the lake compared to an event with a low lake level. Results reveal that a high lake level scenario leads to significant flooding in the lower end of Glenorchy, especially near Benmore Place, Jetty Steet and Butement Steet and the surrounding areas. The land levels in this region range between 311mRL to 312mRL, indicating that these areas will experience flooding during an event with a less than a 10-year return period lake level (LRS, 2022).

Lake floods are a slow process with sufficient warning time that allow for planning/response to the event. There have been no recorded deaths caused directly by Lake Wakatipu flooding in Glenorchy or Kinloch.

ORC provides early warning of high lake levels using a flood forecasting model which estimates high lake levels for Lake Wakatipu based on forecast or recorded rainfall totals. Therefore, a lake flood has a very low potential to cause deaths or injuries within Glenorchy.

5.6 Limitations

The flooding extent and depth is based on the digital elevation model. Therefore, flooding is assumed to spread freely through the landscape rather than be held back by features that may not be represented by the terrain modelled terrain e.g., stopbanks, buildings, fences.

6 Seismic Shaking Risk Analysis

6.1 Scope and Study Extents

The study extents for assessment of seismic shaking effects are presented in Section 1.3.

6.2 Sources of Information

The following sources of information have been referenced in this assessment:

- GNS Science. National Seismic Hazard Model. Retrieved from: https://nshm.gns.cri.nz
- Lumantarna E., Wilson J., Lam N., (2010). Peak Seismic Displacement Demand and Second Corner Period Australian Earthquake Engineering Society 2010 Conference, Perth, Western Australia.
- FEMA, 2022. Hazus Earthquake Model Technical Manual, Hazus 5.1, Federal Emergency Management Agency.
- New Zealand Standard 1170.5 (2004). Structural design actions - Part 5: Earthquake actions - New Zealand
- New Zealand Standard 3604. Timber-framed buildings. Wellington, New Zealand: Standards New Zealand.
- Uma, S. R., Bothara, J., Jury, R., & King, A. (2008, April). Performance assessment of existing buildings in New Zealand. In *Proc. of the New Zealand Society for Earthquake Engineering Conference, Wairakei, New Zealand*.
- Ma, Z, Liu, A, Wang, J, Zhou, L & Wenchen, D. (2022). Seismic performance of single-storey light timber-framed buildings braced by gypsum plasterboards considering rigidity of ceiling diaphragms.

6.3 Seismic Shaking Qualitative Risk Analysis

Seismic shaking has been assessed against the impact on buildings, and lifelines infrastructure which is considered to have the highest risk in accordance with the RPS methodology (Table 7 in Appendix 6 from ORC, 2022). Consideration of the shaking hazard to natural features or structures other than buildings and lifelines infrastructure is excluded from this assessment. Appendix 6 of the RPS (ORC, 2022) defines the consequences of a hazard to buildings in terms of the percentage of buildings within the impact area that have “functionality compromised” and for lifelines the duration of loss of service.

Seismic shaking hazard at Kinloch and Glenorchy is expected to pose the greatest risk to buildings and lifelines infrastructure through structural damage, compared to relatively few injuries or deaths. During the 2010/2011 Canterbury earthquakes no deaths were attributed to structural failure of light weight timber frame buildings (being the typical building form within Glenorchy, refer Section 3.7.2). However, one fatality occurred associated with collapse of a chimney induced by strong ground motion (Canterbury Earthquakes Royal Commission, 2012).

The three hazard scenarios considered for seismic shaking are summarised Table 6-1. The scenarios align with the RPS guidance (ORC, 2022) and are based on the New Zealand Standard 1170.5 which is the current standard adopted for seismic design criteria for structures in New Zealand. Given the close proximity and similar position on the lake margins, the same shaking hazard has been assessed at Glenorchy and Kinloch.

The *Median Likelihood* scenario with an annual exceedance probability of 1/500 aligns with the standard design criteria for Importance Level 2 structures having a design life of 50 years (NZS1170.5), being the seismic design criteria for the typical buildings that are found within the study area.

The New Zealand Seismic Hazard Model was updated in 2022 (www.nshm.gns.cri.nz). This probabilistic seismic hazard has not yet been incorporated into NZS1170.5 seismic criteria. Review of the change of seismic criteria suggests that at Kinloch and Glenorchy the change is minor. With the spectral acceleration criteria incorporated within TS1170.5 (currently in consultation, not an active document) being within the ranges presented within Table 6-1 considered in this risk assessment (refer 6.3.3 for further discussion).

The strong ground motion from an Alpine Fault rupture varies depending on the characteristics and location of the rupture. However, the effects of an Alpine Fault rupture event in the southern portion of the South Island are anticipated to be within the range between "*High Likelihood*" earthquake and "*Median Likelihood*" earthquake as presented in Table 6-1.

Table 6-1: Earthquake hazard scenario for seismic shaking at Glenorchy and Kinloch

Earthquake Return Period	Return Period Factor A	Spectral Shape Factor B	Hazard Factor C	Spectral Acceleration, Sa D	Earthquake Magnitude M_w
25 year	0.25	2.36 (Subsoil class C, shallow soil sites)	0.42	0.25g to 0.32g	7.5
500 year	1.00	3.00 (Subsoil class D, deep soil sites)		0.99g to 1.26g	7.5
1500 year	1.50			1.49g to 1.89g	7.5

[A] Table 3.5, NZS1170.5

[B] Table 3.1, NZS1170.5 – considered a range of subsoil class.

[C] Figure 3.4, NZS1170.5

[D] Acceleration for single storey lightweight timber structure with assumed period (T) of 0.4 seconds

6.3.1 Public Health and Safety Risk

The qualitative assessment of property risk (refer Section 6.3.2, and Appendix D – Seismic Shaking Risk Analysis Process) assessed the probability of exceedance for various building damage states for NZ timber houses (being the typical building type in the study area). Hazus (FEMA, 2022) Complete Structural Damage of building (historically categorised as Damage State 4 [DS4]) comprises "large permanent lateral displacement or may be in imminent danger of collapse", from which typically 3% of total building area is anticipated to collapse (Complete Structural Damage/DS4). Timber building collapse does not necessarily lead to fatality, as health and safety consequences relate to habitation at the time of the event and the specific nature of structural collapse. Table 6-2 provides a summary of the high-level qualitative assessment of building collapse risk that could lead to Health and Safety risk.

Table 6-2: Summary of qualitative review of Public Health and Safety Risk in Kinloch and Glenorchy associated with earthquake shaking building damage

Earthquake Return Period	Estimated proportion of buildings collapsing [1]	Life risk consequence [2]	Qualitative Public Health and Safety Risk [3]
25 year	0%	Insignificant	Acceptable
500 year	~0.2%	Insignificant to Minor	Acceptable
1500 year	0.3%	Minor	Acceptable

[1] Considers probability of exceedance of DS4 and 3% of DS4 buildings collapsing, Hazus (FEMA, 2022)

[2] Consequence qualitatively assessed adopting guidance in Table 7 Appendix 6 RPS (ORC, 2022).

[3] Risk qualitatively assessed in accordance with Table 8 APP6 RPS.

Masonry and stone buildings are more prone to collapse and typically the nature of collapse is more severe and poses greater health and safety consequence than lightweight timber framed buildings. The Beca walkover of buildings in Glenorchy (refer Section 3.7.2) identified that approximately 4% of the existing buildings were of masonry or stone construction. Sensitivity review indicates that the consideration of these more vulnerable building typologies existing in Glenorchy and Kinloch does not change the overall risk assessment outcome for Public Health and Safety for shaking from the assessed Acceptable level for the three earthquake scenarios.

6.3.2 Built Environment Risk

6.3.2.1 Buildings

Qualitative assessment of consequences of earthquake damage on buildings has been assessed considering damage states for NZ timber houses (being the typical building type in the study area). Appendix D – Seismic Shaking Risk Analysis Process describes the process of assessment that is based on the Uma et al (2008) study that assessed the vulnerability of New Zealand structures to damage for different levels of shaking. For assessment of shaking risk, Extensive Structural Damage as defined by Hazus (historically termed Damage State 3 [DS3]) is conservatively assessed as functionally compromised, the effects are described in Hazus (FEMA, 2022) as "*permanent lateral movement of floors and roof and slippage of structure over foundations*".

Table 6-3 provides a summary of the high-level qualitative assessment of building risk.

Table 6-3: Summary of qualitative review of Building Risk in Kinloch and Glenorchy associated with earthquake shaking building damage

Earthquake Return Period	**Estimated proportion of buildings assessed as functionally compromised** [1]	**Consequence** [2]			**Building Risk** [3]
		Buildings	Social/Cultural Amenities	Critical buildings	
25 year	~0%	Insignificant	Insignificant	Insignificant	Acceptable
500 year	5%	Minor	Minor	Minor	Acceptable
1500 year	15%	Moderate	Major	Major	Acceptable

[1] Considers probability of exceedance of DS3, Hazus (FEMA, 2022)

[2] Consequence qualitatively assessed adopting guidance in Table 7 APP6 RPS.

[3] Risk qualitatively assessed in accordance with Table 8 APP6 RPS, with the most critical risk adopted from social/cultural amenities, buildings, and critical buildings.

6.3.2.2 Lifelines

Review of lifelines within Glenorchy and Kinloch identified that the critical lifelines vulnerable to shaking damage to be:

- Water supply system – water bores and treatment facility, and pipe network.
- Wastewater system – the wastewater system is dominated by private septic tanks and private effluent treatment schemes (typically associated with recent developments).
- Power supply network – overhead supply lines and local distribution dominated by overhead powerlines with exception of new developments.
- Flood defences/stopbanks.

Review of the Queenstown Lakes District Council (QLDC) GIS has identified that the water supply network is dominated by PVC and PE pipe materials. These pipe materials typically exhibit good levels of performance during earthquake shaking (Beca, 2019), with damage typically associated with the smaller diameter mechanical pipe connectors and fittings, and with damage associated with shaking dominated by pipe leaks rather than breaks (FEMA, 2022), leading to only minor effects on level of service. Repair of water supply pipelines is relatively simple due to shallow depth and the repair of the dominate leak defects can frequently be completed as programmed maintenance during the recovery period.

The more challenging and time-consuming components of the water supply network to remediate damage are the bores, reservoirs and associated treatment facilities. Glenorchy has two recently installed steel reservoir tanks, which were part of a QLDC project to improve the seismic resilience of the water supply. The water supply is sourced from two water supply wells adjacent to the Buckler Burn. The water supply wells are anticipated to be the critical component of the water supply network that if damaged would result in the longest loss of service. In the event of extensive damage to these wells, an alternative temporary water supply would be required to be established until the bore is remediated or a new bore constructed which is likely over a period of weeks to months (Hazus damage restoration curves, FEMA 2022). However, observations of performance of water supply wells in Christchurch during the Canterbury Earthquake identified that well damage was not a significant challenge post-earthquake for reinstating water supply, however damage did occur which was dominated by differential settlement of structures/concrete masses connected to the wells, or shaking damage due to inertia of these concrete masses. Assessment of risk in Table 6-4 is dominated by the wells, and has considered fragility guidance and restoration curves provided by Hazus (FEMA, 2022). Water supply in Kinloch comprises private water bores, and as such effects of damage to individual assets are limited due to then small proportion of community reliant on individual assets.

As Glenorchy and Kinloch do not have a community wastewater system, the dominant treatment is private septic tanks. These are simple devices that are anticipated to provide a level of functionality if damaged structurally by shaking.

The seismic performance of wastewater, and water supply systems is expected be significantly dominated by damage associated with liquefaction and lateral spread, refer Section 7.4.2.

The power supply to Glenorchy and Kinloch and though the communities is dominated by above ground powerlines. Overhead powerlines typically provide a good level of seismic resilience to earthquakes compared to buried services that are more vulnerable to damage associated with ground movement due to shaking, liquefaction and lateral spread. If the power lines are damaged remediation within the study area is anticipated to be within a short period of time (assuming no wider region outage).

Existing flood defences comprise earth embankments. Strong ground motion from the earthquake scenarios is likely to induce some cracking of the embankments, however the risk of a breach from piping failure is elevated until remedial is completed. The severity of damage to the flood defences from strong ground motion and non-liquefied ground conditions is insignificant compared to the damage sustained upon triggering of liquefaction and lateral spreading (refer Section 7).

The roads within the Glenorchy and Kinloch study areas have low susceptibility to damage affecting their functionality. Risk is largely associated with damage to bridge or culverts, or failure of services. The greatest risk to roads due to earthquake shaking is anticipated to be beyond the study areas and associated with rockfall and landslide damage on the connecting routes to Queenstown. Table 6-4 provides a summary of high-level judgement based qualitative assessment of infrastructure risk.

Table 6-4: Summary of qualitative review of Lifelines Risk in Kinloch and Glenorchy associated with earthquake shaking

Earthquake Return Period	**Consequence** [1]					**Lifelines Risk** [2]
	Water Supply	Wastewater	Power & Communications Networks	Roads	Flood Defences	
25 year	Insignificant to Minor	Insignificant to Minor	Insignificant	Insignificant	Insignificant	Tolerable
500 year	*Glenorchy* Moderate to Major [3] *Kinloch* Moderate [3]	Moderate	Minor	Minor	Minor	Tolerable
1500 year	Major	Major	Moderate	Moderate	Moderate	Acceptable

[1] Consequence qualitatively assessed adopting guidance in Table 7 APP6 (ORC, 2022).

[2] Risk qualitatively assessed in accordance with Table 8 APP6 (ORC, 2022).

[3] Consequence rating dominated by duration to repair or construct new water supply wells, if damaged.

6.3.3 Results

The qualitative assessment identified the risk associated with earthquake shaking to be Acceptable Risk for the three hazard scenarios, for Public Health and Safety and for the Buildings. For infrastructure the risk was assessed to be typically of Acceptable risk due to reliance of the water supply network on two water supply wells, however considering the durations to undertake repair or replacement the risk is assessed to be elevated for water supply lifelines and has been conservatively assessed as of Tolerable Risk.

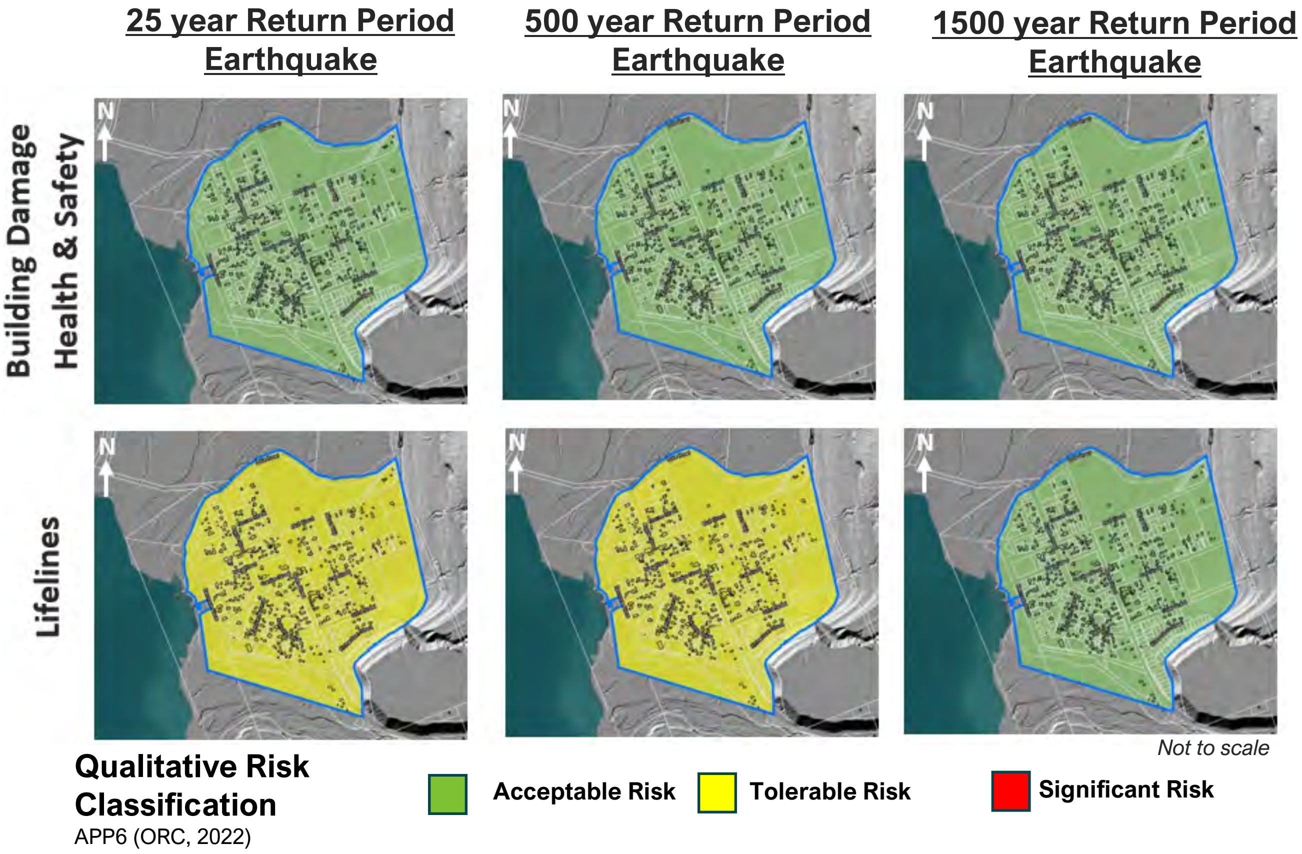


Figure 6-1: Qualitative seismic shaking risk at Glenorchy for three earthquake hazard scenarios.

Table 6-2, Table 6-3 and Table 6-4 provide a summary of the qualitatively assessed risk associated with earthquake shaking. Figure 6-1 and Figure 6-2 spatially present an overall combined qualitative risk assessment for Glenorchy and Kinloch. Full qualitative risk maps are included in Appendix F.

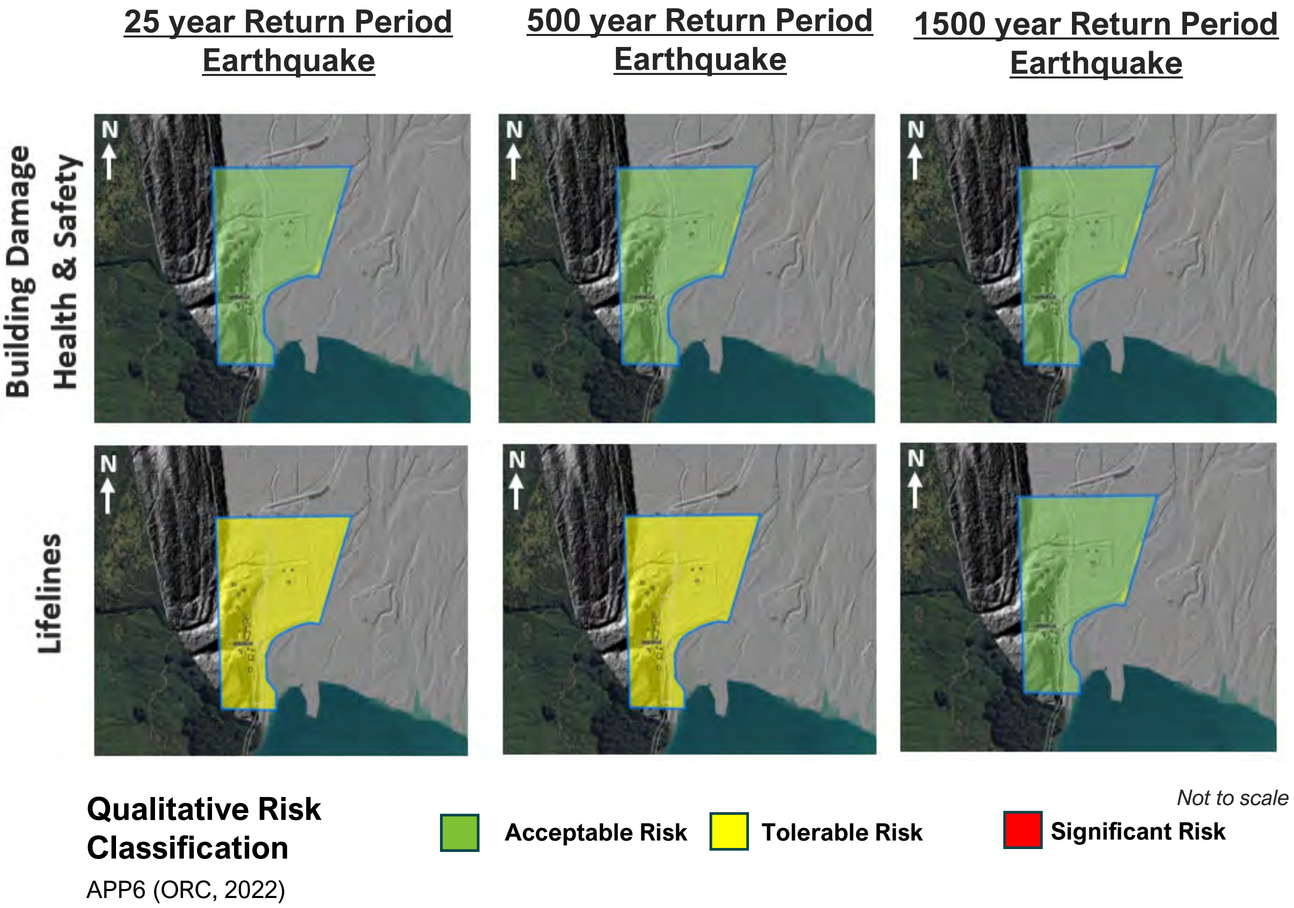


Figure 6-2: Qualitative seismic shaking risk at Kinloch for three earthquake hazard scenarios.

6.4 Discussion

An assessment of anticipated damage to buildings and infrastructure and consequence on the community has been undertaken. The qualitative seismic shaking risk has been completed in accordance with Table 8 of Appendix 6 of the RPS (ORC, 2022). The assessment identified the risk associated with earthquake shaking to be Acceptable risk for the three hazard scenarios, for Public Health and Safety and for Buildings. For infrastructure the risk was assessed to be typically *Acceptable Risk*. However, Glenorchy having relance of the water supply network on two water supply wells, and considering the likely durations to undertake repair or replacement - the risk is assessed to be elevated for water supply lifelines and has been assessed as Tolerable Risk for Glenorchy.

For building damage assessment, there is possibility that a proportion of the building stock have defects that compromise their seismic performance and could accentuate damage. In addition, the risk assessment focuses on lightweight timber framed buildings as these are the typical building typology. A sensitivity review of the influence of the stone or masonry buildings that exhibit greater susceptibility to damage from earthquake shaking and more severe potential to influence health and safety, was undertaken. This review concluded that due to the small number of these more vulnerable buildings the overall consequence was not shifted sufficiently to adjust the qualitative risk assessment outcomes to the community.

Assessment for the built environment buildings considers the elevated importance of social/cultural amenities and critical buildings as identified in Section 3.7.2, though the variable thresholds, RPS (ORC, 2022, APP6 Table 7) defines for severity of impact for these different building types.

Variation in ground conditions can influence the specific shaking characteristics experienced. These factors are expected to result in only minor variance in results across the study areas due to depositional environments and relatively consistent topography.

The land at Glenorchy and Kinloch is highly vulnerable to land damage associated with liquefaction and lateral spread (refer Section 2.6 and Section 7). Damage associated with shaking is expected to be overshadowed by the significantly more severe damage induced to buildings and infrastructure associated with liquefaction and lateral spread.

As the qualitative assessment identified the shaking risk to be acceptable (with exception of water supply risk for Glenorchy) and considering that land damage associated with liquefaction and lateral spread would dominate risk, assessment did not progress into quantitative assessment.

6.5 Limitations

The following limitations have been noted for the qualitative assessment of seismic shaking:

- There is limited site investigation data to assess the subsoil site class, which informs the strength and duration of the earthquake shaking at a particular site. On the basis of the geology and the existing investigation data, the site was assumed to be either Class C (shallow soil site) or Class D (deep soil site) in accordance with New Zealand seismic standards. We have undertaken a sensitivity check with both site classes and site investigations would be required at each town to determine the actual site class.
- GNS Science (GNS) has led a revision of the New Zealand National Seismic Hazard Model (NSHM) that was released in 2022. Design spectra from the updated model is now accessible from a website and gives more accurate parameters for a design earthquake at a specific points in New Zealand. While the guidance in the New Zealand standards and codes are still being revised to reference the new model, in the interim the data provides a useful reference on the future seismic demands. The new model requires assessment of the shear wave velocity in the top 30m of the ground profile, and this is obtained by specialist site testing. In the absence of shear wave test data, we have undertaken sensitivity checks adopting a shear wave velocity range of 175 to 275m/s. The spectral accelerations (refer to Table 6-5) are of similar magnitude to those calculated using the current building code.

Table 6-5 National Seismic Hazard Model Scenario Sensitivity Check

Earthquake Return Period	Spectral Acceleration, Sa [A]
25 year	0.26 to 0.33
500 year	1.25 to 1.26
1,500 year	1.80 to 1.83

[A] Acceleration for lightweight timber structure with assumed period (T) of 0.4 seconds

- The fragility equation linking building damage to seismic shaking assumes lightweight single storey timber framed buildings. This building type is most commonly observed in residential construction in New Zealand and was the main building type noted during our site walkover, refer to section 3.4.1. Buildings constructed from different material (concrete) or multi-storey buildings would be expected to have a different tolerances to seismic shaking and their performance would require assessment using a different fragility equation.

- The assessment does not consider the age of the buildings. Older buildings would have been constructed to a less rigorous seismic loading code and in general are more likely to be in a poorer condition. Following an earthquake, older buildings are more likely to be damaged.
- The seismic shaking assessment only considers the movement of the structure from shaking. Vertical settlement and lateral displacement of the ground from liquefaction and lateral spreading are considered separately.
- The assessment of building “functionality comprised” to fragility equation has some uncertainty and which has been linked using a single study.
- Performance of lifelines has been undertaken qualitatively based on engineering judgment considering both literature review and practitioner experience in Christchurch during the Canterbury Earthquake sequence of 2010/2011.

7 Liquefaction and Lateral Spread Risk Analysis

7.1 Scope and Study Extents

The study extents for assessment of liquefaction and lateral spread effects are presented in Section 1.3.

7.1.1 Kinloch

GNS Science (2019) undertook a desktop assessment of the liquefaction hazards in Otago and produced maps of the liquefaction susceptibility which covers the settlement of Kinloch. The study is classified as a "Level A" (basic desktop assessment) in accordance with MBIE/MfE planning and engineering guidance for liquefaction prone land (2017). It is based on the form and origin of the ground (geomorphology) and does not consider site specific investigations and numerical liquefaction assessment. GNS Science mapped land east of Kinloch Road as "damaging liquefaction possible (Minor to Moderate severity)" and land west of Kinloch Road as "damaging liquefaction unlikely".

A qualitative risk assessment has not been undertaken for Kinloch as there is insufficient site investigation data and numerical liquefaction assessment available to inform the risk assessment.

7.1.2 Glenorchy

Tonkin + Taylor (T+T) undertook a more detailed "Level C" (detailed area-wide assessment) liquefaction and lateral spreading assessment in 2022 for Glenorchy in accordance with MBIE/MfE guidance (2017). The assessment covered the Glenorchy township and was bounded by the Rees River to the north and the Buckler Burn to the south. Geotechnical site investigations were undertaken as part of this study, and subsequent analysis for a range of design earthquakes showed the township is susceptible to liquefaction and lateral spreading following small to moderate earthquakes. This study has formed the basis of our qualitative liquefaction and lateral spreading assessment for Glenorchy and as such our qualitative assessment has adopted the same study extents.

7.2 Sources of Information

The following sources of information have been referenced in this assessment:

- FEMA, 2022. Hazus Earthquake Model Technical Manual, Hazus 5.1, Federal Emergency Management Agency.
- GNS Science (2019). Assessment of liquefaction hazards in the Queenstown Lakes, Central Otago, Clutha & Waitaki districts of the Otago Region. Report No. 2018/67.
- Ministry of Business Innovation Employment (MBIE) & Ministry for Environment (MfE) (2017). Planning and engineering guidance for potentially liquefaction-prone land.
- Ministry of Business Innovation Employment & New Zealand Geological Society (November 2021). Module 3, Identification, assessment and mitigation of liquefaction hazards. Earthquake geotechnical engineering practice. Rev 1.
- Rogers, N., S. van Ballegooy, K. Williams, and L. Johnson. (2015). Considering Post-Disaster Damage to Residential Building Construction - Is Our Modern Building Construction Resilient? 6th International Conference of Earthquake Geotechnical Engineering, Christchurch, New Zealand
- Tonkin + Taylor (2021). Head of Lake Wakatipu. Natural Hazards Assessment.
- Tonkin + Taylor (2022). Glenorchy Liquefaction Vulnerability Assessment. Reference 1017916.
- Tonkin + Taylor (2023). Head of Lake Wakatipu Natural Hazards Adaptation – Engineering Approaches for Managing Liquefaction-Related Risk. Reference 1017916 v1.

- Tonkin + Taylor (2015). Canterbury Earthquake Sequence: Increased Liquefaction Vulnerability Assessment Methodology, report prepared by Tonkin + Taylor for the Earthquake Commission, http://www.eqc.govt.nz/ILv-engineering-assessment-methodology

7.3 Earthquake Scenarios

The three probabilistic earthquake hazard scenarios considered for liquefaction and lateral spreading are summarised in Table 7-1. The scenarios align with the guidance in APP6 (ORC, 2022) and the liquefaction severity number (LSN) assessment approach from the T+T (2022) study.

The 2022 T+T study assessed that the onset of liquefaction at Glenorchy begins at the 25 to 50 year return period earthquake and that liquefaction is “fully developed” at the 50 to 100 year return period earthquake. The extent of liquefaction at Glenorchy was assessed to “not significantly increase” beyond the 250 year return period earthquake and for this reason the LSN plots for less frequent (higher intensity) earthquake events are not provided by T+T and as such are not considered in the assessment.

While the extent and severity of liquefaction may not show a meaningful increase for higher intensity events, more widespread and damaging lateral spreading would be expected for earthquakes with a higher return period due to a longer duration earthquake shaking and stronger shaking. T+T (2022) completed further assessment quantifying lateral spreading and concluded that lateral spreading displacements “increases with large return period earthquake shaking”. With T+T undertaking assessment for lateral spread for a most severe earthquake scenario being a 500 year return period earthquake. The lateral spread assessment only assessed lateral spread within a distance of 300m, focusing on the large magnitude lateral spread deformations of many metres of lateral displacement, excluding assessment of lesser ground deformation beyond the 300m offset. Assessed lateral spread ground deformation for 500 year return period, this was only marginally greater than for the 250 year return period earthquake within the 300m of the lake shore. Negligible change in outcomes of land damage consequence is indicated between the 250 and 500 year return period earthquakes for risk assessment in accordance with APP6 (ORC, 2022).

An actual MCE earthquake, typically selected to have ground accelerations of 1.5 times the ultimate limit state design earthquake, would have a larger return period and greater land damage movement from lateral spreading. Residential buildings, that are typically Importance Level 2 structures and with a design life of 50 years (NZS1170.0:2002), predominate at Glenorchy. An MCE design earthquake would have an annual exceedance probability of approximately 1/1500. The effects of the more severe lateral spreading would be more pronounced closer to riverbanks and the lake front where a free face is present. For the MCE earthquake, these areas have been assessed at the highest qualitative risk category (Significant) using the T+T (2022) LSN plots and the higher return period 250 year earthquake and therefore this limitation is not expected to significantly affect the outcomes of the qualitative risk assessment.

A mid-level earthquake scenario has been selected aligning with an anticipated Alpine Fault scenario as defined and assessed by T+T (2022).

To provide compatibility between the liquefaction and lateral spread land damage assessment within the risk review, assessment has been limited to an earthquake with return period of 250 years.

Table 7-1: Earthquake hazard scenarios for liquefaction & lateral spreading

Earthquake Return Period	Annual Exceedance Probability	Peak Ground Acceleration (PGA) ^{A}	Earthquake Magnitude, M_w
25 year	4.0%	0.10g to 0.16g	6.1 to 6.5
30 year (conditional) [Alpine Fault Event]	3.0%	0.11g to 0.32g	8.1
250 year	0.4%	0.31g to 0.48g	6.1 to 6.5

^{A} Upper and lower bound values from Tonkin + Taylor (2022)

It is acknowledged that the seismic criteria adopted for risk assessment for liquefaction and lateral spreading (refer Table 7-1) is less severe than seismic criteria adopted for seismic shaking risk assessment (refer Table 6-1). Reasons for not aligning these seismic criteria are as follow:

- The severity of shaking damage continues to increase with severity of the probabilistic earthquake scenario, but to a progressively lesser degree as event severity continues to increase.
- Limitations on existing hazard data availability for liquefaction and lateral spread limit ability to reliably assess consequences for an appropriate maximum credible earthquake (annual exceedance probability in the order of 1/500).

7.4 Liquefaction and Lateral Spread Qualitative Risk Analysis

The qualitative risk of liquefaction and lateral spreading as a combined natural hazard at Glenorchy has been assessed against the impact on buildings and lifeline infrastructure. The basis for this approach is due to lateral spread being induced by liquefaction triggering, and both hazards lead to permanent deformation of the land. Lateral spread is associated with ground sloping toward a free face, which for Glenorchy is dominated by the approximately 25m free face along the lake edge. Lateral spread damage is focused around this free face with lateral deformations and associated ground settlement reducing when moving away from the free face, transitioning to liquefaction dominated land damage leading to settlements and changes in soil properties affecting foundation performance. Constraints on the hazard data reviewed leads to lateral spread only been considered within approximately 300m of the lake edge. While the majority of lateral spread damage is likely to be within this zone, due to the significant height of the free face there is a high potential that land damage beyond 300m could still be dominated by lateral spread rather than liquefaction. A sensitivity review has been undertaken within the qualitative assessment considering the effects of potentially conservative or unconservative assumptions for liquefaction and lateral spread land damage on overall risk assessment.

The consequences of liquefaction on buildings have been assessed using the available existing studies and we have adopted the linkages between Liquefaction Severity Number (LSN) and estimates of liquefaction land damage on the built environment. The process and assumptions of this assessment process are discussed in Appendix E. Damage associated with lateral spread has been estimated by engineering judgement considering the large magnitude of land damage, and likely lateral stretch.

As identified by T+T (2022), there is relativity similar levels of land damage across the study area for the different earthquake scenarios in Table 7-1, refer to Figure 7-1: below. The exception being the land to the southwest edge of the study area adjacent to the Buckler Burn that exhibits lower susceptibility to liquefaction triggering than the rest of Glenorchy.

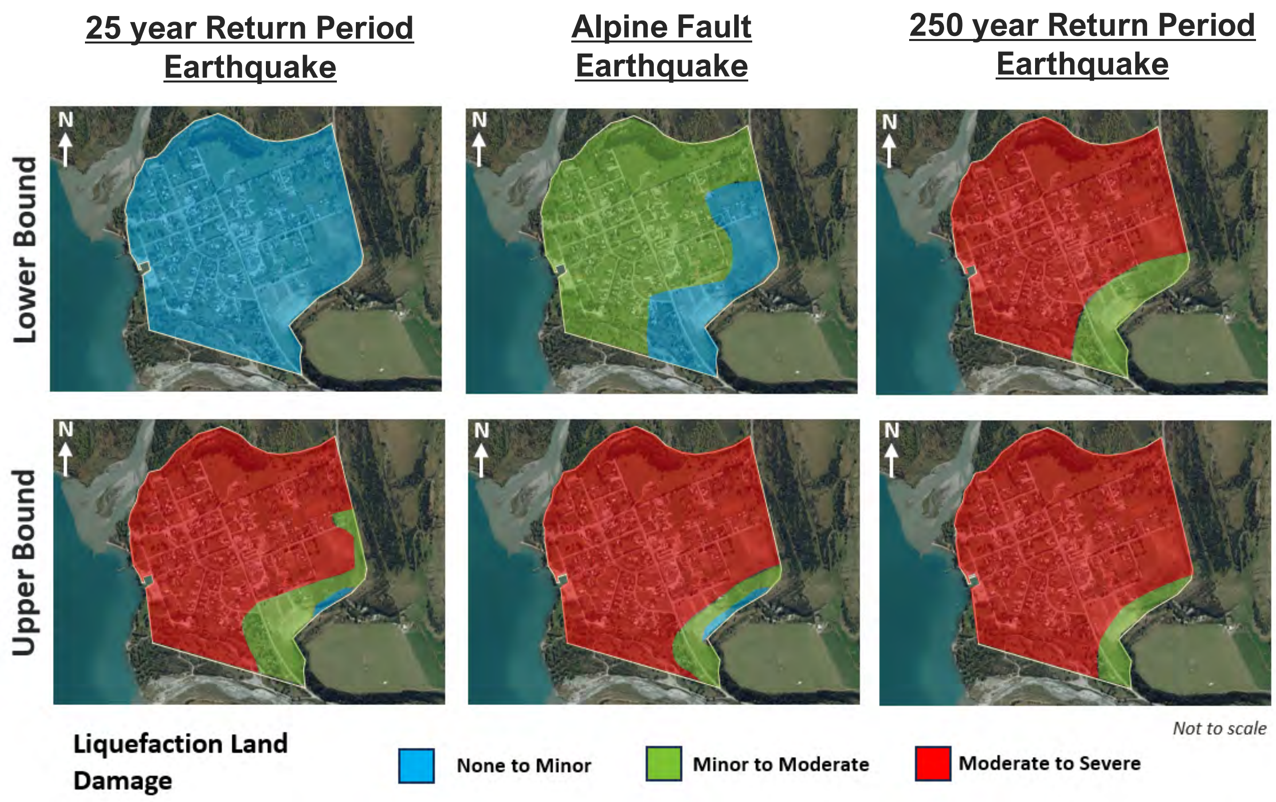


Figure 7-1: Upper and lower bound liquefaction land damage classification risk at Glenorchy for three earthquake hazard scenarios. Refer to Appendix E for basis for classification, based on T+T (2022) LSN assessment.

7.4.1 Public Health and Safety Risk

Liquefaction and lateral spreading can result in permanent vertical and horizontal ground movements that are expected to be most damaging to the built environment and less frequently causes injuries and/or deaths. A study considering earthquake case histories in Japan identified that over the past 60 years there have been six casualties associated with liquefaction and lateral spreading, with the total number of earthquake related casualties in excess of 10,000 (Hakuno, 2004), with deaths dominated by land damage leading to bridge collapse. This is consistent with observations from recent earthquakes in New Zealand, such as Canterbury earthquakes (2010-2011) and Kaikoura earthquakes (2016) where buildings and infrastructure suffered the greatest damage from liquefaction and lateral spreading and there were relatively few (if any) injuries and/or deaths directly attributed to liquefaction and lateral spreading induced ground movement.

Public Health and Safety risk associated with liquefaction has been assessed qualitatively using engineering judgement considering the level of building damage anticipated as described in Appendix E, based on relationships with LSN. Assessed qualitative risk associated with liquefaction is presented in Table 7-2.

Large lateral spread displacements are anticipated in Glenorchy in the order of 3m or more along the lake shore. Such large displacements would lead to the development of both wide and frequent cracking of the ground sub-parallel to the lake edge and lateral stretch across buildings. Such ground displacements would lead to significant structural damage and potential for building collapse.

Table 7-2: Summary of qualitative review of Public Health and Safety Risk in Glenorchy associated with earthquake shaking building damage

Earthquake Return Period	Life risk consequence Liquefaction [2]	Life risk consequence Lateral Spread [2]	Qualitative Public Health and Safety Risk [3]
25 year	Insignificant	Insignificant	Acceptable
30 year (conditional) [Alpine Fault Event]	Insignificant	Insignificant to Minor	Acceptable [4]
250 year	Insignificant	Minor	Acceptable

1. Considers probability of exceedance of DS4 and 3% of DS4 buildings collapsing ,Hazus (FEMA, 2022)
2. Consequence qualitatively assessed adopting guidance in Table 7 APP6 (ORC, 2022).
3. Risk qualitatively assessed in accordance with Table 8 APP6 (ORC, 2022).
4. Potentially *Tolerable* for the 85th percentile lateral spread assessment as injury possible due to risk of collapse for 'almost certain' likelihood earthquake

7.4.2 Built Environment Risk

7.4.2.1 Buildings

The consequence of liquefaction on buildings has been assessed qualitatively using engineering judgement considering the level of building damage estimated using relationships with LSN, by the process as described in Appendix E. Table 7-3 provides a summary of high-level qualitative assessment of building risk in response to liquefaction hazard.

Table 7-3: Summary of qualitative review of Building Risk in Kinloch and Glenorchy associated with Liquefaction

Earthquake Return Period	Estimated typical proportion of buildings assessed as functionally compromised [1]	Consequence [1]			Building Risk [2]
		Buildings	Social/Cultural Amenities	Critical buildings	
25 year	<20%	Minor to Moderate	Moderate	Moderate	Tolerable [3]
30 year (conditional) [Alpine Fault Event]	<20%	Moderate	Moderate to Major	Moderate to Major	Significant [4]
250 year	>50%	Catastrophic	Catastrophic	Catastrophic	Significant

1. Consequence qualitatively assessed adopting guidance in Table 7 APP6 (ORC, 2022).
2. Risk qualitatively assessed in accordance with Table 8 APP6 (ORC, 2022), with the most critical risk adopted from social/cultural amenities, buildings, and critical buildings.
3. Presents risk assessment considering the 25 year average earthquake return period upper bound estimate of liquefaction land damage (refer Figure 7-1). Assessed risk for lower bound estimates of land damage is Acceptable.
4. Presents risk assessment considering the Alpine Fault Scenario for 50th and 84th shaking percentile for liquefaction and lateral spread (T+T, 2022). Assessed risk for 16th shaking percentile estimates of land damage is Acceptable to Tolerable.

Damage to buildings associated with liquefaction has been estimated using engineering judgment. As there is high uncertainty associated with estimates, review has considered the sensitivity of lateral spreading. Table 7-4 provides a summary of high-level qualitative assessment of building risk in response to lateral spread hazard.

Table 7-4: Summary of qualitative review of Building Risk in Kinloch and Glenorchy associated with lateral spreading

Earthquake Return Period	**Estimated typical proportion of buildings assessed as functionally compromised 1**	**Consequence [1]**			**Building Risk [2]**
		Buildings	Social/Cultural Amenities	Critical buildings	
25 year	>20%	Major	Catastrophic	Catastrophic	Significant [3]
30 year (conditional) [Alpine Fault Event]	>50%	Catastrophic	Catastrophic	Catastrophic	Significant [4]
250 year	>70%	Catastrophic	Catastrophic	Catastrophic	Significant

1. Consequence qualitatively assessed adopting guidance in Table 7 APP6 (ORC,2022).
2. Risk qualitatively assessed in accordance with Table 8 APP6 RPS, with the most critical risk adopted from social/cultural amenities, buildings, and critical buildings.
3. Presents risk assessment considering the 25 year average earthquake return period upper bound estimate of lateral spread land damage (T+T, 2022). The risk is anticipated to transition from Significant though to Acceptable when moving beyond 300m setback from the dominate lake edge free face. Assessed risk for lower bound estimates of lateral spread land damage is Acceptable.
4. Presents risk assessment considering the Alpine Fault Scenario for 50th to 84th shaking percentile for liquefaction and lateral spread (T+T, 2022). The risk is anticipated to transition from Significant though to Acceptable when moving beyond 300m setback from the dominate lake edge free face. Assessed risk for 16th percentile to be acceptable for lateral spread land damage is Acceptable.

Reviewing the above building risk to liquefaction and lateral spread, Glenorchy is exposed to a Significant risk when assessed in accordance with the APP6 (ORC, 2022). The identified social/Cultural amenities (refer Section 3.7.2) are located within the zone of anticipated lateral spread, with three of the critical buildings (Hall, Post Office and Petrol Station) located within the lateral spread zone with significant damage likely for a significant earthquake.

7.4.2.2 Lifelines

Section 6.3.2.2 provides a high-level outline of the water supply, wastewater and power supply lifelines vulnerable to earthquake shaking damage. These lifelines along with roads and telecommunications are highly vulnerable to extensive damage from liquefaction and lateral spread. Such lifelines were severely affected during the 2010 / 2011 Canterbury earthquakes leading to extensive periods of loss of service and a long period for response and recovery (still continuing more than 10 years following the earthquake). A high level summary of anticipated infrastructure damage and community consequence is summarised below:

- Water supply network: Extensive loss of the water supply network is expected within the zone of lateral spread (defined by T+T (2022) to be within approximately 300m of the lake edge). Segmented PVC pipes will separate and/or develop structural defects and more resilient PE pipelines will suffer damage at mechanical connections especially on the smaller diameter pipelines. Remedial work to reinstate water supply pipeline service in the zone of lateral spread is anticipated to take months to complete. Pipelines beyond the zone of lateral spread, subject to liquefaction differential settlements, are likely to exhibit moderate level of defects, however, these are anticipated to be repaired within a period of weeks. The water supply wells and treatment facilities are likely to be vulnerable to damage, with significant loss of functionality anticipated, requiring rebuild and/or temporary water supply to be established.

- Power supply network: Overhead power lines are relatively tolerant of ground deformations, where slack within the cables is not exceeded. Damage to a proportion of overhead powerlines is possible due to lateral stretch in the areas of lateral spread, and temporary change in soil properties and ground deformation could lead to foundation failure for some power poles requiring reinstatement. Buried cables are vulnerable to damage where insufficient slack is provided to accommodate the ground deformation. Overall damage to the power supply network is anticipated requiring repair, however with a dominance of overhead power lines the timeframe for loss of service will be largely controlled by the performance of the ground-based transformers/distribution network.
- Wastewater: The wastewater is dominantly local private septic tanks or localised private wastewater treatment schemes. Septic tanks are anticipated to be severely damaged through lateral stretch within lateral spread zones and ingress of liquefaction ejecta material into the septic tank and effluent drainage field. With a larger proposition of the wastewater treatment infrastructure likely requiring extensive repair or replacement for a moderate level of earthquake across the majority of Glenorchy, with near complete loss of infrastructure within the lateral spread zones.
- Road network: The road network will sustain extensive damage within the zone of lateral spread requiring full rebuild, however, temporary reinstatement to allow access across Glenorchy is likely to be able to be implemented within a period of days to weeks. In areas of liquefaction beyond the lateral spread zones, extensive pavement repairs will be required over time, for shape correction and for remediation localized pavement/subgrade failures due to the effects of liquefaction and/or liquefaction ejecta.
- Telecommunications: Buried cables will be vulnerable to damage especially in areas of lateral spread, requiring repair. Cell phone tower foundations may be compromised by the effects of liquefaction and ground deformation.
- Flood protection: The flood protection infrastructure is located adjacent to free faces associated with the lake shore and rivers. The land beneath these typical earth embankment flood protection structures is anticipated to experience significant lateral spread and land settlement during earthquake scenarios, which will severely crack the stopbank and lower the crest level. With the exception of the 25 year lower bound land damage assessment, the flood defences are not anticipated to provide the minimum level of flood protection post-earthquake without significant repair/rebuild. Temporary restoration of this damage to provide minimum level of service would take weeks to implement, and restoration to achieve a desired long term level of service taking months.

Table 7-5 provides a summary of high-level judgement based qualitative assessment of infrastructure risk.

Table 7-5: Summary of qualitative review of Lifelines Risk in Glenorchy associated with liquefaction and lateral spread

Earthquake Return Period	**Consequence [1]**						**Lifelines Risk [2]**
	Water Supply Network	Wastewater	Power Network	Road Network	Telecommunications Network	Flood Protection Stopbanks	
25 year	Moderate to Major	Major	Minor to Moderate	Minor to Moderate	Minor to Moderate	Moderate to Major	Significant [3]
30 year (conditional) [Alpine Fault Event]	Major	Major to Catastrophic	Moderate	Minor to Moderate	Moderate	Moderate to Major	Significant [4]
250 year	Catastrophic	Catastrophic	Major	Moderate	Major	Major	Significant

1. Consequence qualitatively assessed adopting guidance in Table 7 APP6 (ORC, 2022).
2. Risk qualitatively assessed in accordance with Table 8 APP6 (ORC, 2022), with the most critical risk adopted from social/cultural amenities, buildings, and critical buildings.
3. Presents risk assessment considering the 25 year average earthquake return period upper bound estimate of lateral spread and liquefaction land damage (T+T, 2022). The risk is anticipated to transition from Significant though to Acceptable when moving beyond 300m setback from the dominate lake edge free face. Assessed risk for lower bound estimates of lateral spread and liquefaction land damage is Acceptable.
4. Presents risk assessment considering the Alpine Fault Scenario for 50th and 84th shaking percentile for liquefaction and lateral spread (T+T, 2022). The risk is anticipated to transition from Significant though to Acceptable when moving beyond 300m setback from the dominate lake edge free face. Assessed risk for 16th percentile estimates of lateral spread and liquefaction land damage is Acceptable.

7.4.3 Results

The qualitative assessment identified the risk associated with liquefaction and lateral spreading to be Acceptable for Public Health and Safety. However, in areas of lateral spread there is potential for this risk to elevate to Tolerable Risk if upper bound lateral spread displacements are realised or if there are any partially vulnerable buildings within the lateral spread zone (e.g. masonry or stone buildings, or buildings with structural defects elevating vulnerability). Assessment of qualitative risk for the built environment has indicated that the risk is Significant for the majority of the study area, with the exception of a zone of Tolerable Risk at the southeastern periphery of the study area adjacent to Buckler Burn. Where the ground is outside the main lateral spread zone along the lake edge and the soils exhibit lower potential for liquefaction triggering.

A summary of the qualitatively assessed risk associated with earthquake shaking is provided in the previous section. Figure 7-2 below spatially presents an overall combined qualitative risk assessment for Glenorchy for upper and lower bound estimates of lateral spread and liquefaction potential as assessed by Tonkin + Taylor (2022). Full qualitative risk maps are included in Appendix F – Qualitative Risk Level Maps.

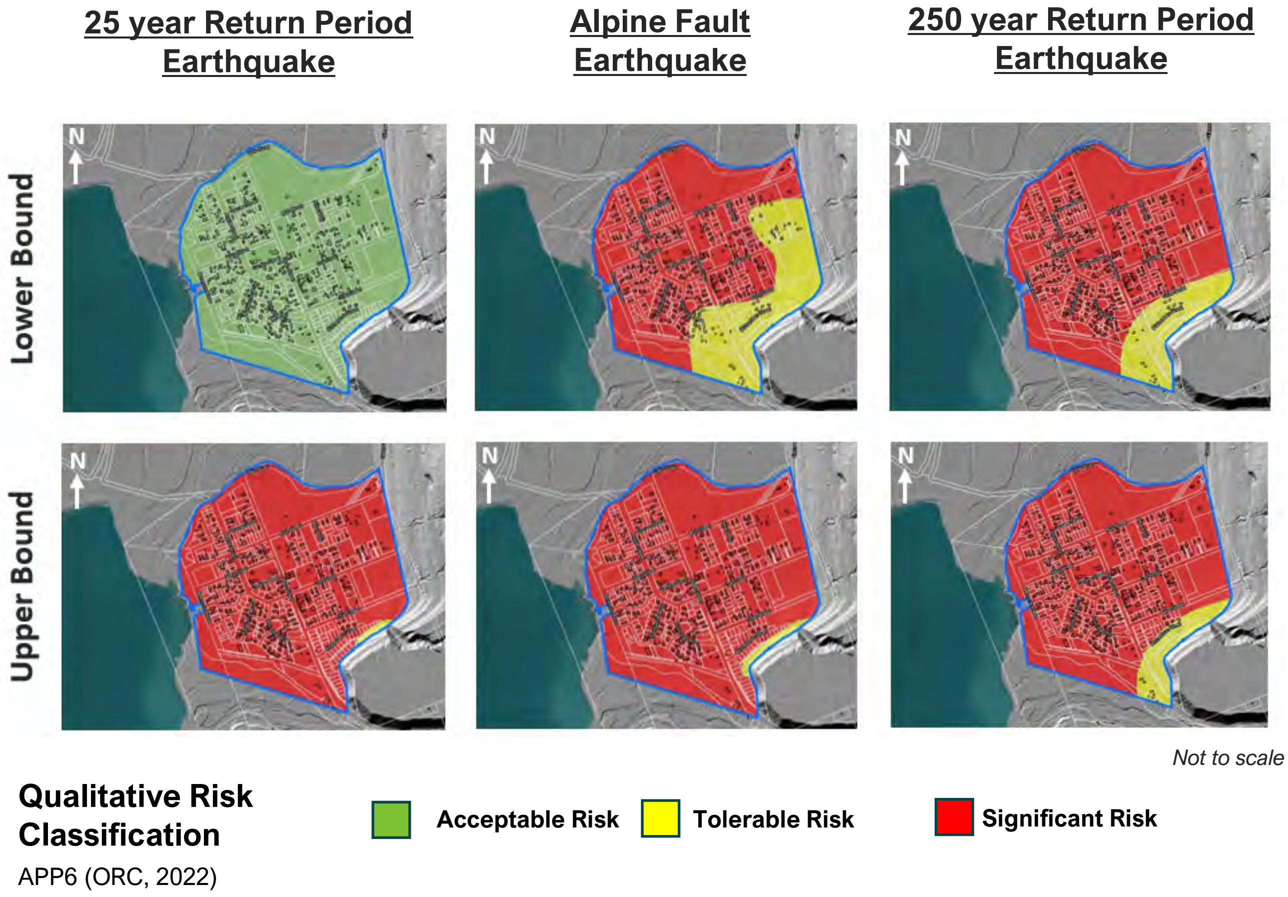


Figure 7-2: Upper and lower bound qualitative liquefaction and lateral spreading risk at Glenorchy for three earthquake hazard scenarios. Risk assessed in accordance with Table 8 of APP6 (ORC, 2022).

7.5 Liquefaction and Lateral Spread Quantitative Risk Analysis

7.5.1 Life Risk Analysis

Quantitative life risk analysis has not been undertaken as the qualitative assessment assessed the public health and safety risk as Acceptable Risk.

7.5.2 Property Risk Analysis

Quantitative Assessment has not been undertaken in Kinloch as there is insufficient hazard data available to support quantitative analysis.

Quantitative assessment of Annual Property Risk has been assessed for Glenorchy, and this has focused on building damage for the typical light weight timber framed building as described in Section 3.7.2. For this study quantitative assessment has not extended to assessment of damage to lifeline infrastructure due to the high complexity of considering both damage on specific components of the infrastructure and considering the effects of damage on the network. Extensive detailed network damage and network consequence modelling is required to accurately complete a quantitative analysis for infrastructure. Also, different infrastructure types exhibit high variance in both vulnerability to damage, and duration and cost for remedial/rebuild works following an earthquake.

Assessment of annual property risk (APR) relies heavily on the estimation of the building vulnerability to damage ($V_{(D:T)}$). As described in Appendix E, estimation of $V_{(D:T)}$ has utilised Building Damage Ratio (BDR) data developed from building damage in Christchurch from the 2010/2011 Canterbury earthquakes, as presented in Rogers et al 2015. This data has been used to estimate typical BDR for liquefaction induced land damage categories considered within qualitative risk assessment (refer Table 7-6 for adopted BDR for varying degrees of liquefaction induced ground damage). This relationship is considered appropriate for the buildings within Glenorchy as lightweight timber frame buildings of 1-2 stories is also the dominate building typology in Christchurch. Refer Appendix E for further discussion on the development of BDR estimates for application in the quantitative assessment.

Table 7-6 provides a summary of the estimated annual property risk (APR) for the three earthquake scenarios assessed for liquefaction land damage.

Table 7-6 : Summary of liquefaction and lateral spreading land damage annual property risk and quantitative reassessment of risk category

Earthquake Return Period	Liquefaction Land Damage	$P_{(H)}$	$P_{(S:H)}$	$P_{(T:S)}$	$V_{(D:T)}$	Annual Property Risk, APR	Quantitative Reassessment of Risk Category
25 year	None to Minor	0.040	1	1	0.15	$6x10^{-3}$	Significant
	Minor to Moderate	0.040	1	1	0.5	$2x10^{-2}$	Significant
	Moderate to Severe	0.040	1	1	0.7	**$3x10^{-2}$**	Significant
30 year (conditional) [Alpine Fault Event]	None to Minor	0.033	1	1	0.15	$5x10^{-3}$	Significant
	Minor to Moderate	0.033	1	1	0.5	$2x10^{-2}$	Significant
	Moderate to Severe	0.033	1	1	0.7	**$3x10^{-2}$**	Significant
250 year	None to Minor	0.004	1	1	0.15	$6x10^{-4}$	Significant
	Minor to Moderate	0.004	1	1	0.5	$2x10^{-3}$	Significant
	Moderate to Severe	0.004	1	1	0.7	**$3x10^{-3}$**	Significant

1. Refer to Section 3.5.2 for description of parameters feeding into the determination and APR
2. Quantitative reassessment of Risk Category assessed as significant as APR is greater than $1x10^{-4}$ for existing development

7.5.3 Results

Quantitative risk assessment for liquefaction land damage was only considered for property damage to buildings, which includes damage to critical, social and cultural amenities. As summarised in Table 7-6 and Figure 7-3, the risk assessed in accordance with the APP6 (ORC, 2022) methodology is Significant based on annual property risk for the entire Glenorchy study area considering all three earthquake scenarios (criteria defined within APP6 (ORC, 2022), as APR exceeds 1x10^{-4} for existing developments (as shown in Figure 7-5 for combined risk). The dominant liquefaction land damage for the earthquakes is Moderate to Severe damage, leading to the critical annual property risk being associated with the higher likelihood earthquakes.

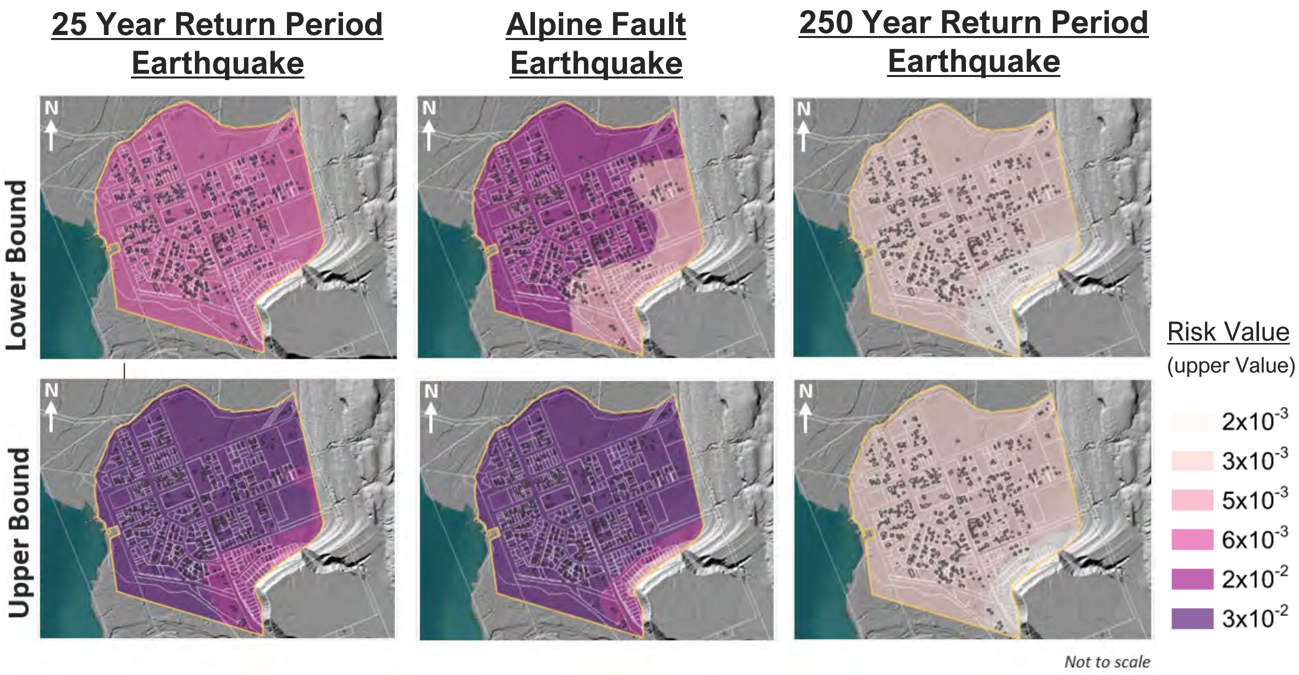


Figure 7-3: Upper and lower bound quantitative liquefaction APR risk at Glenorchy for three earthquake hazard scenarios. Risk assessed in accordance with APP6 (ORC, 2022).

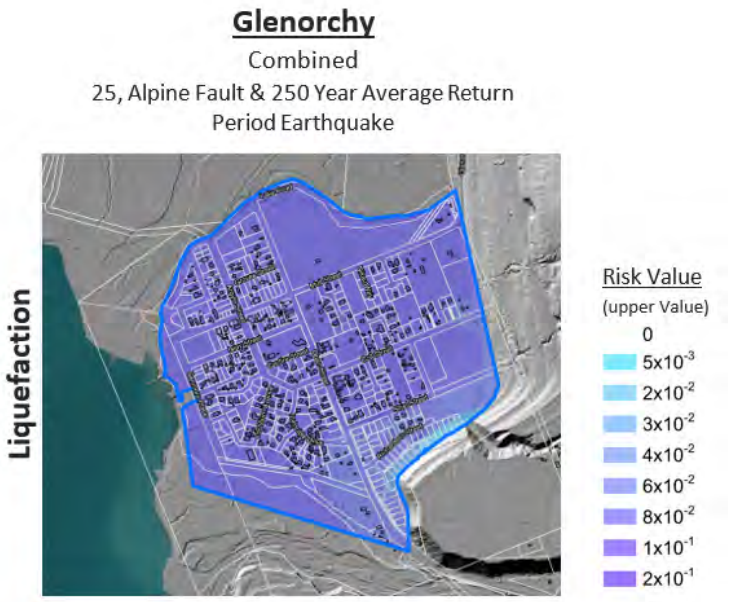


Figure 7-4: APR results of the combined APR of all earthquake liquefaction scenarios (25 + Alpine Fault + 250 year average return period).

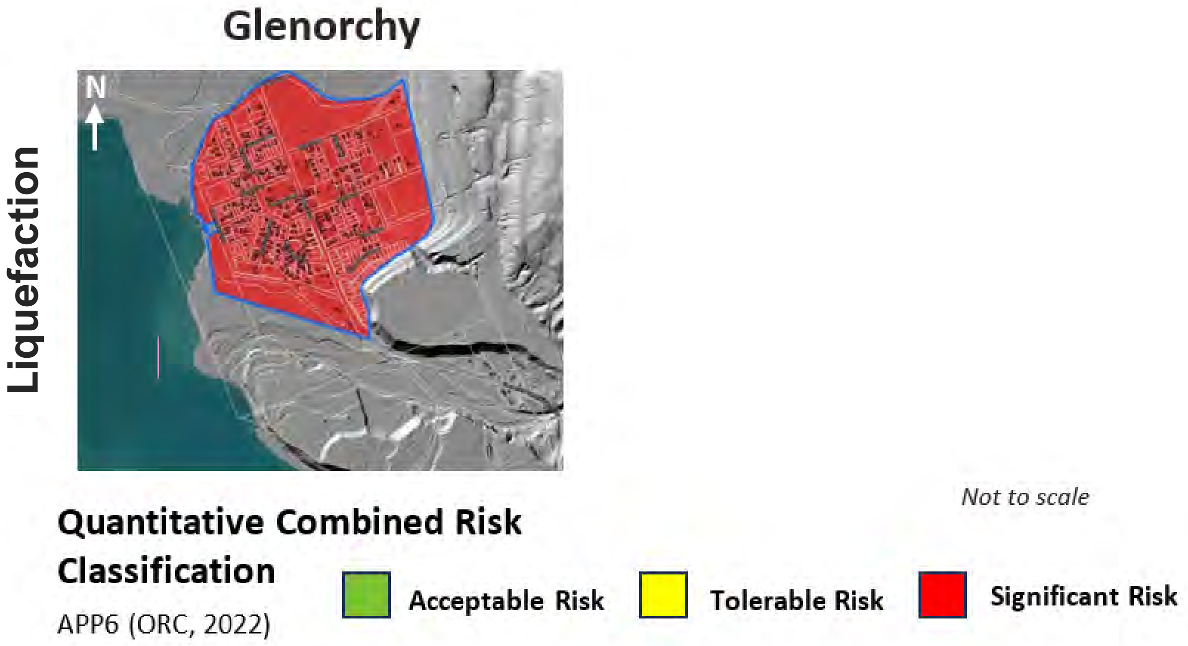


Figure 7-5: Glenorchy quantitative property risk (APR) levels assessed for liquefaction in accordance with the RPS (ORC, 2022)

7.6 Discussion

Assessment of APR has not specifically incorporated lateral spread land damage in the assessment due to insufficient definition of extents and gaps in data for all earthquake scenarios. This leads to an unconservative assessment of APR moving towards the lake edge where lateral spread will dominate damage to buildings. The vulnerability of buildings within this lateral spread zone will increase from 0.7 associated with moderate to severe liquefaction land damage, to around 0.9 to 1.0 near the lake edge where large magnitude ground deformation is anticipated. However, as the APR quantitative risk assessment already classifies the risk category across the study area as Significant for existing development, this simplification for assessment does not lead to underestimation of the risk category. It should be noted that, considering the effects of lateral spread, the presented APR could increase by up to 40% within 200-400m of the lake edge.

Tonkin + Taylor (2022, 2023) completed assessments of liquefaction and lateral spread vulnerability, consequence of land damage and potential opportunities to help improve outcomes following a significant earthquake. The soils beneath Glenorchy are susceptible to liquefaction under Likely earthquake scenarios with land damage expected to impact on the post disaster functionality of buildings and infrastructure and lead to significant rebuild costs. Comparison of land damage and effects anticipated in Glenorchy has indicated that this is anticipated to be similar or more severe than land within and bordering the Christchurch residential red zone. Following the 2010/2011 Canterbury Earthquakes, land damage was categorised into categories of 'None to Minor', 'Minor to Moderate' and 'Moderate to severe'. For this risk assessment a similar categorisation of anticipated land damage was developed to categorise land performance impacts on the built environment, but to also assist with drawing comparisons against performance observations in Christchurch following the recent earthquakes. Rogers et al (2015) provides a summary of performance of the land and buildings in Christchurch, the study notes that 90% of property damage within Christchurch was associated with liquefaction alone, lateral spread damage was focused adjacent to waterways and coastal margins. Assessment in Glenorchy for the liquefaction and lateral spread hazard scenarios indicates that it is likely that in excess of 30-40% of the damage to the built environment will be associated with lateral spread with this land damage being more severe than induced by liquefaction alone. The 2010/2011 Canterbury earthquakes resulted in 77% of houses in Christchurch having a building damage ratio (ratio of cost of damage to building vs replacement cost) of 0.3 or less, with only 17% having a building damage ratio of greater than 0.5, and 10% having a building damage ratio exceeding 0.75. The severity and extent of damage to the built environment is expected to be more severe for Glenorchy. For example, for an Alpine Fault event, being a highly probable earthquake scenario, it is anticipated that in the order of 70% to 100% of the Glenorchy township to have a building damage ratio of greater than 0.5, with areas exposed to lateral spread damage likely to exhibit building damage ratio in excess of 0.7.

7.7 Limitations

The following limitations have been noted for the qualitative and quantitative risk assessment of liquefaction and lateral spreading:

- The assessment is based on the LSN plots (T+T, 2022), which are provided up to the 250 year return period earthquake. The 250 year return period earthquake has been adopted as the MCE earthquake hazard scenario APP6 (ORC, 2022). An actual MCE earthquake, typically selected to have an intensity of 1.5 times the design ultimate limit state design earthquake, would have a larger return period and greater land damage movement from lateral spreading as discussed in Section 4.3. The effects of the more severe lateral spreading would be more pronounced closer to river banks and the lake front where a free face is present. For the MCE earthquake, these areas have been assessed at the highest qualitative risk category (Significant) using the higher return period 250 year earthquake and therefore this limitation is not expected to significantly affect the output of the qualitative risk assessment.
- The resolution of the existing studies (based on LSN) cannot distinguish between Moderate, Minor and Insignificant consequences (Table 7, APP6 ORC (2022)) where the LSN is less than 8. The assessment has assumed the most adverse consequence (Moderate), but there is a possibility that these areas could have a lower consequence and the corresponding risk rating may be lower than that reported.
- The T+T (2022) report notes other limitations with the liquefaction and lateral spreading assessment used to derive the LSN plots and the full report should be referred to for further details.
- It should be noted that the damage component of this study was quite simplified, as only one summarised data set of building damage ratio from Canterbury earthquakes is published to support analysis.
- Lateral spread assessment T+T (2022) has not been undertaken for all of the earthquake scenarios assessed, and when undertaken there is lack of clarity in the anticipated displacement beyond 300m form

the lake edge. Lateral spread is expected to dominate land damage outcomes where present. Building Damage ratios in calculation of APR could exceed 0.9 in areas of lateral spread exceeding 1m lateral displacement.

- The severity of the liquefaction related land damage is primarily influenced by the earthquake magnitude, peak ground accelerations, subsurface soil conditions, and seasonal groundwater levels. Topography, proximity to rivers and streams and land use also played a big part in the distribution of liquefaction related land damage. The performance of specific property will depend on the building types, foundation types, age of construction, construction methodology, founding soil layer etc.

8 Other Hazards

During the project definition phase of this study the following hazards were identified as not warranting risk analysis, as agreed with ORC. This decision was informed by judgment-based review of hazards and community exposure, or suitability of available data to conduct risk analyses:

- Flooding - Gorge Creek (Kinloch)
- Liquefaction and lateral spread - Kinloch
- Debris flows
  - Buckler Burn (Glenorchy)
  - Gorge Creek (Kinloch)
- Lake Wakatipu tsunami
- Cascading hazard scenarios

Commentary on the geomorphic environment and evidence (or absence of) of past events for the above hazards is included in this section. Where sufficient information is available, high-level comments on risk are provided.

8.1 Flooding - Gorge Creek (Kinloch)

There is no flood assessment available for Gorge Creek catchment in Kinloch. Anecdotal knowledge received during a site visit mentioned that there has been no known flood damage.

8.2 Liquefaction and Lateral Spreading (Kinloch)

As noted in Section 7.1.1, there is insufficient data to inform a qualitative or quantitative risk analysis for Kinloch.

8.3 Debris Flows

Glenorchy and Kinloch townships are situated on alluvial fans. These are cone shaped landforms comprising alluvial sediments which typically form where streams emerge from hill country onto valley floors (GNS, 2009). The fans form when debris comprising rock, soil and vegetation from the upper catchment areas is entrained during periods of high flow and deposited on the fan at the mouth of the catchment. Deposition may occur as pulses of saturated material of varying magnitude known as debris flows. Debris flows can pose a risk to people and property located within the depositional area.

Debris flows require a supply of loose sediment which will primarily depend on the geology, existing or potential slope instability, the catchment area, and the steepness of the catchment and stream channels. Debris flows are typically triggered by short duration, high intensity rainfall. Where debris flows exceed the capacity of a drainage channel, material will escape the channel and affect surrounding areas.

Reference should be made to the studies by GNS (2009) and ORC (2011) for detailed analyses on the characteristics, nature and classification of alluvial fans in the wider Otago region.

8.3.1 Buckler Burn

8.3.1.1 Available information

A number of studies have been conducted characterising and assessing the debris flow hazard from Buckler Burn, the most relevant being:

- GNS Science (2009). Otago Alluvial Fans Project: Supplementary maps and information on fans in selected areas of Otago.

- GNS Science (2010). Assessment of debris flow potential on alluvial fans in Otago, New Zealand, using morphometry.
- Massey University (2021). Key notes and observations from preliminary assessment of debris flood and flow hazard potential at Glenorchy, Otago, for Otago Regional Council.
- Geosolve (2021). Factual Report – Debris Flow Modelling Results Buckler Burn, Glenorchy.
- Faulkner and Rogers (2021). Joint witness statement (JWS). ENV-2021-CHC-70: Otago Regional Council (Appellant) and Queenstown Lakes District Council (Respondent) and Blackthorn Lodge Glenorchy Ltd (Applicant).
- Tonkin + Taylor (2021). Head of Lake Wakatipu - Natural Hazards Assessment.

8.3.1.2 Background information

A summary of the debris flow potential of the Buckler Burn catchment is as follows:

- The GNS Science (2009) study identified the predominant fan processes as being flooding and associated sedimentation (i.e., not debris flows).
- The GNS Science (2010) report included a morphometric analysis of the Buckler Burn catchment. The report found:
  - A review of historic debris flows indicated that none are known to have occurred affecting the township in recent years.
  - Melton Ratio of 0.28. This indicates a ‘flood’ classification, with a sediment concentration of <20% by volume.
  - Reference to fluvial flooding events indicated that fans including Buckler Burn would be ‘subject only to fluvial processes on the basis of geomorphic data’.
- The Massey University (2021) study for ORC included:
  - A review of borehole core found some evidence of possible debris *flood* deposits within the top 5m of one borehole.
  - Furthermore, the study concluded that ‘It is unlikely that any debris flows routed down Buckler Burn pose a threat to Glenorchy at this point in time. Morphometric assessment by GNS (2010) did not suggest debris flows were capable of reaching the fan on which Glenorchy is built, supported by our own independent morphometric analyses and observations’.

8.3.1.3 Debris flows modelling

A Geosolve (2021) report and Faulkner and Rogers (2021) joint witness statement were prepared in support of the resource consent application for the Grand Earnslaw Hotel development at 1 Benmore Place, Glenorchy. The Geosolve study included RAMMS software modelling of multiple debris flow scenarios to determine whether the development site could potentially be affected, and the report notes that ‘the modelled events do not necessarily reflect feasible or likely debris flow scenarios’. Review of the study identified gaps with the potential use of the RAMMS models for qualitative or quantitative risk analysis for Glenorchy, including:

- Absence of morphometric analysis, ground investigation data, identification of potential debris flow sources, or a historic event for model calibration.
- Limited correlation between modelled scenarios and return periods, although some attempt was made to relate hydrograph (dam) failures to rainfall events and associated ARIs.
- Extremely large release volumes modelled – in the order of 1 to 50 million m^3 material for block release (landslide) scenarios, and 0.4 to 4 million m^3 for hydrograph.
- Low resolution of 20m for the larger models, which typically results in larger modelled runout areas.
- Only one magnitude of failure (approximate 100 year ARI) modelled – a minimum of three are required in accordance with the RPS (ORC, 2022).

It should be highlighted that this study was not undertaken with the intent of informing a large-scale risk analysis. It was therefore determined that without further detailed analysis, there is insufficient information to conducted qualitative or quantitative analysis on the debris flow risk from Buckler Burn.

8.3.1.4 Other Hazards Studies

Review of the analyses conducted by GNS Science (2009, 2010) and Massey University (2021) shows that debris flows originating from Buckler Burn would be unlikely to pose a threat to Glenorchy township at this time.

8.3.2 Gorge Creek

The only available study referring to the risk from debris flows from Gorge Creek in Kinloch is the GNS Science (2009) alluvial fans project. The study noted the following:

- An aggradational type fan, the predominant processes being flooding and sedimentation, with debris flows in the channels near the heads of the fans.
- Mapped as ‘fan active bed/fan recently active’.

There are no records of recent debris flows or debris floods occurring in Gorge Creek.

8.4 Lake Wakatipu Tsunami

8.4.1 Background

Lake Wakatipu is subject to the hazard of lake tsunamis and waves caused by seismic seiche.

A lake tsunami is a large wave or series of waves caused by sudden ground movements under the water. Earthquakes and landslides are the most typical trigger for these waves, which can cause significant flooding and damage to areas around the lake.

A seismic seiche is a standing wave in a closed or partially closed body of water. Earthquakes typically generate these waves. They can cause the water in lakes, reservoirs, or even swimming pools to oscillate, leading to potential flooding and structural damage along the shorelines.

Both events are very rare and to date, lake waves have caused minimal property damage or personal injury (Benn, 2023). The research and case history are very limited globally and specifically in New Zealand. Benn (2023) reviewed 74 known lake wave events (lake tsunami, seismic seiches and undermined wave events) and reported that there have been four waves on Lake Wakatipu since 1846, three from seismic seiche and one tsunami.

In April 1871 it has been reported that a sailor nearly capsized because of the seismic seiche caused by a severe earthquake in Queenstown. In April 1915 several large ripples were reported as created a high wave against the shore following an earthquake.

A prehistoric assessment by Ruddenklau and Davies (2000) estimated that landslides that have fallen into Lake Wakatipu could have generated waves with a height between 0.4 and 80m. These waves could have run up the shoreline between 5m to 400m.

8.4.2 Risk commentary

Lake tsunamis have a very low probability of occurrence. Despite their low probability, lake tsunamis could cause high numbers of casualties due to their short or non-existent warning times. One study done by Ruddenklau and Davies (2000), estimated the annual probability ($P_{(H)}$ in Equation 1) of a 4m high wave to impact Glenorchy and Kinloch to be 6x10-4. However, the level of uncertainty and lack of data available means a quantitative risk analysis could not be conducted. Since landslides entering Lake Wakatipu and impulse waves propagating across and along the lake cannot be prevented, protection measures would be required to reduce risk. Furthermore, if a large earthquake occurs, it is possible to be followed by an impulse wave event. This scenario could mean that structures might already be compromised and more vulnerable to damage by the lake tsunami.

Future lake side development can exacerbate the consequences as more infrastructure and residents will be within the destructive zone of Lake tsunamis.

8.5 Cascading Hazards

Cascading hazards are a sequence of natural hazards where one hazard event triggers or affects the outcome of another hazard. For Glenorchy and Kinloch, this includes seismic shaking (earthquake) followed by flooding (from any source). Liquefaction and lateral spreading associated with seismic shaking can cause land settlement, particularly in the lower areas near the lake, leading to new flow paths, increased flood velocities and depths, a higher permanent groundwater level and possible permanent ponding, and therefore potentially a higher flood hazard.

Further analysis was not conducted as this would require Rees/Dart River model run results based on the post-earthquake DEM adjusted to account for liquefaction and lateral spreading induced land settlement.

Another potential cascading hazard is the breaching of floodbanks due to seismic shaking or associated liquefaction/lateral spreading/global instability leading to loss of crest height from and/or development piping failure mechanisms through embankments. Simulations in the Rees/Dart model demonstrated that the floodbanks are overtopped in both Likely and Potential scenarios. The results from the simulated floodbank breach (Land River Sea, 2022) showed an earlier onset of flooding in residential areas, impacting potential warning times. However, there is no increase to flood hazard at the considered likelihoods in the Rees/Dart River flood model that includes floodbank breach, compared to results from the Rees/Dart River flood model that does not include floodbank breach.

9 Summary and Risk Management

9.1 Risk Analysis Outcomes

Risk to life and the built environment from a range of natural hazards in the Glenorchy and Kinloch areas has been assessed as part of this study. A summary of the outcomes of this assessment is included in this section.

The hazards assessed in this report include:

- River flooding (Rees River, Dart River, Buckler Burn)
- Lake Wakatipu flooding
- Flooding from multiple sources.
- Seismic shaking affecting buildings
- Liquefaction and lateral spreading in earthquakes (Glenorchy).

9.1.1 Qualitative Risk Analysis Summary

A simplified summary showing the highest risk level for each hazard assessed qualitatively is shown in Table 9-1. The risk levels shown relate to the scenario with the highest risk assessed for each hazard, considering:

- All scenarios or scales of hazard,
- Any location within the study area, and
- All built environment sub-categories, where assessed (e.g., lifelines, buildings etc).

The risk levels shown are in accordance with the proposed RPS (ORC, 2022), and were used to determine which hazards are Significant in accordance with the qualitative process and therefore warrant further investigation through quantitative risk analysis. The spatial extents of the various qualitative risk zones are included in the relevant sections of this report and Appendix F – Qualitative Risk Level Maps.

Table 9-1: Qualitative risk level summary

Hazard	Health and Safety Risk	Built Environment Risk
River flooding – Buckler Burn	Tolerable	Significant
River flooding – Rees/Dart	Significant	Significant
Lake Wakatipu flooding	Acceptable	Significant
Liquefaction and lateral spreading - Glenorchy	Acceptable	Significant
Seismic shaking	Acceptable	Tolerable

Buckler Burn flooding was assessed as being of Tolerable risk to health and safety. Following discussion with ORC, it was determined that this hazard warranted further investigation through quantitative analysis to allow for more detailed review of parameters that are not considered in the qualitative stage.

Furthermore, following completion of the qualitative analysis, ORC commissioned additional modelling by others to evaluate the effects of a joint flooding scenario (as detailed in 4.4), to inform how the risks may change if flooding occurs from multiple sources at the same time.

On the basis of the qualitative findings and the above comments, the following hazards were carried forward to quantitative analysis as agreed with ORC:

- Buckler Burn flooding – life and property risk
- Rees/Dart flooding – life and property risk
- Joint flooding scenario – life and property risk
- Lake Wakatipu flooding – property risk

- Liquefaction and lateral spreading (Glenorchy) – property risk.

The risk levels shown Table 9-1should be considered alongside the assumptions and limitations detailed in the individual hazard sections of this report.

9.1.2 Quantitative Risk Analysis Summary

In accordance with the RPS, the qualitative risk levels have been re-categorised following the quantitative analysis, in line with the risk levels detailed in Table 3-2 for *existing developments.* The RPS risk level thresholds are an order of magnitude lower for *new developments*. A simplified summary table showing the risk level for each hazard assessed quantitatively is shown in Table 9-2. The risk levels shown are in accordance with the *existing development* categorisation from the RPS (ORC, 2022). The table shows the highest risk level for any scenario assessed for each hazard, and the highest risk level spatially for each hazard. The spatial extents of the different risk levels are shown in the individual hazard sections of the report, which should be referred to when considering the results shown in the table.

Table 9-2: Quantitative risk levels in accordance with the RPS (ORC, 2022)

Hazard	Life Risk	Property Risk
River flooding – Buckler Burn	Acceptable	Significant
River flooding – Rees/Dart	Acceptable	Significant
Joint flooding scenario	Acceptable	Significant
Lake Wakatipu flooding	-	Significant
Liquefaction and lateral spreading - Glenorchy	-	Significant

Furthermore, cumulative APR has been assessed quantitively considering the effects of liquefaction and flooding (joint flooding scenario). The cumulative risk from these hazards fell into the Significant category for the whole of Glenorchy.

The quantitative analysis outcomes include:

- Life risk was classified as Acceptable in all developed areas, for all hazards assessed quantitatively.
- There are areas of Significant risk to property from river and lake flooding along the river and lake margins of Glenorchy and Kinloch (east of Kinloch Road).
- All of Glenorchy is classified as being of Significant risk for liquefaction and lateral spread land damage. Note that severity of risk varies spatially across Glenorchy with greatest risk along the lake and river margins.

9.1.3 Cumulative Risk

Cumulative risk is the sum of the individual risk scenarios for all hazards considered, which in accordance with AGS (2007) guidance should be undertaken for comparison with risk tolerability criteria. A cumulative property risk map has been developed by summing the combined risk for the hazards considered in this study quantitatively, specifically liquefaction and flooding. The 'flood joint scenario' was used in place of the individual flood hazards (Rees/Dart, Buckler Burn and Lake Wakatipu), to avoid the effect of considering the risk from the same hazard more than once.

The cumulative property risk from the liquefaction and flooding hazards for Glenorchy ranges from 0.013 to 0.86 (1×10^{-2} to 9×10^{-2}). The highest risk areas are located along the Rees River and lakefront margins, with the lowest risk area in the southeast of the township, adjacent to Bible Terrace. The cumulative risk map is shown in Appendix G – Quantitative Risk Maps.

The entire Glenorchy township was assessed as being at Significant risk from liquefaction and lateral spreading, and correspondingly the risk level for cumulative risk is also Significant.

A cumulative life risk map was not developed, as AIFR analysis was not undertaken for multiple hazards; and correspondingly a cumulative risk map was not developed for Kinloch as only flooding hazards were assessed quantitatively.

9.2 Risk Tolerability

Property risk from flooding and liquefaction hazards assessed through this study exceed the ORC Regional Policy Statement (ORC, 2022) published guidance on risk tolerability for both new and existing developments for the whole of Glenorchy, and part of Kinloch (east of Kinloch Road).

Detailed commentary on Tolerable risk levels is outside the scope of this study. It is noted in Appendix 6 of the RPS (ORC, 2022), that it is ultimately the responsibility of local authorities to undertake a consultation process with communities, stakeholders and partners regarding risk level thresholds.

A comparison of common life risks and tolerability limits, along with the range of AIFR values for all flooding scenarios from this study, is shown in Figure 9-1. The flooding values shown include those in the active channels and along the lakefront, which is conservative as values in the township zone are lower. The risk levels are within the Tolerable guidance for existing developments in accordance with the RPS (ORC, 2022).

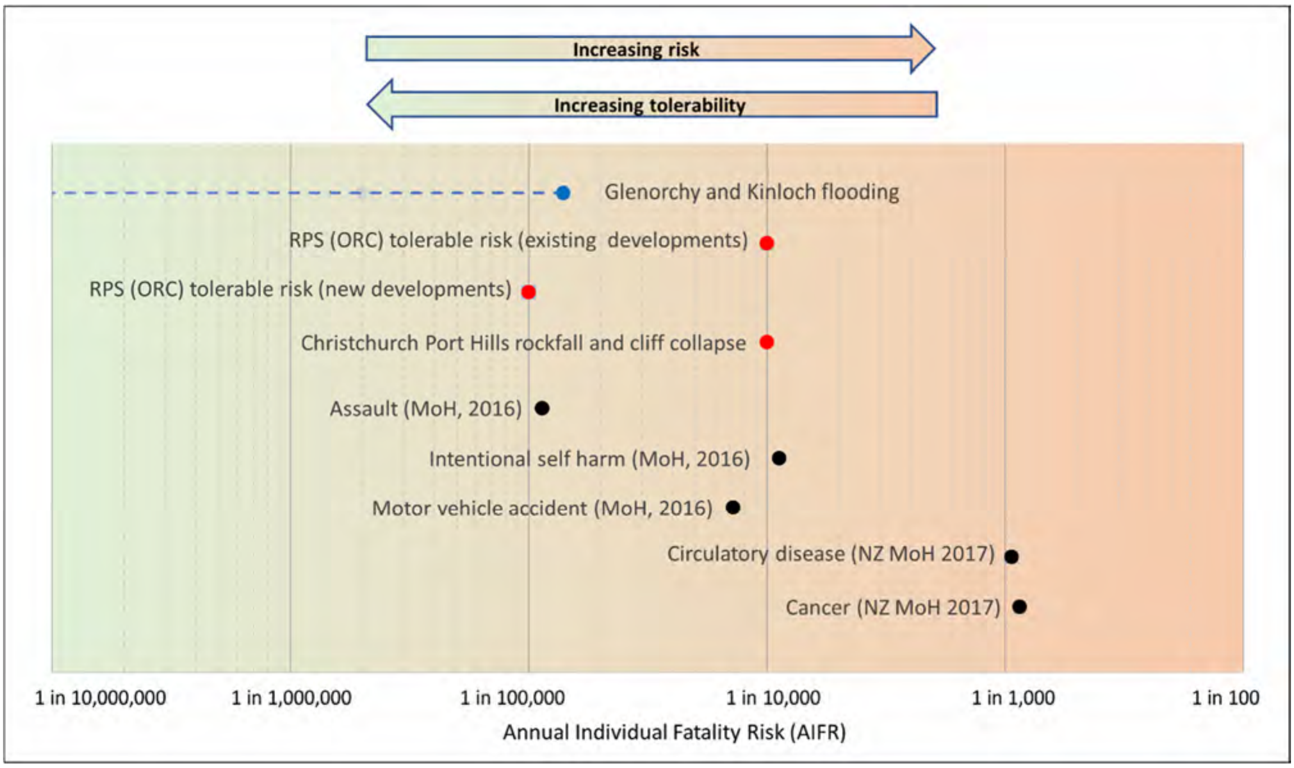


Figure 9-1: Common risks and tolerability limits for life risk (AIFR)

Quantitative assessment of property risk has not been widely adopted in New Zealand to date. This may be due to a lower community tolerance of life risk than property risk. Comparing the calculated property risks for Glenorchy and Kinloch to other New Zealand communities proves challenging, as each catchment and residential area has unique risk exposures and vulnerabilities.

Recent flood events in New Zealand have caused significant damage - Cyclone Gabrielle left 287 houses unsafe to live in a year after the event (RNZ, 2024). These figures serve as a reminder of the potential damage that can occur during flood events, though they are not directly comparable to Glenorchy.

9.3 Risk Commentary

The key outcomes from this study are as follows:

Flooding

- The hazard that poses the greatest risk to public health and safety is flooding, however the significant effects of flooding are concentrated on the margins adjacent to the rivers and lake, and outside the built areas. The relatively lower level of life risk (in relation to property risk) is partly a function of the ability of people to evade slow rising floodwaters, which has been considered in the analysis.
- Flooding poses significant risk to the built environment at both Glenorchy and Kinloch, with the highest risk areas concentrated along the lake and river margins. Modelled flood extents don't coincide with the critical buildings (as detailed in Section 3.7.2), although some social/cultural amenities would be affected. A significant proportion of the land area that is most prone to flooding and within the Significant risk categorisation is used for community recreation and does not house a permanent population (including recreation reserves/parks and the golf course). Approximately 5-30% of the township area within Glenorchy that could potentially accommodate a permanent population is assessed as Significant risk category for property, varying with the flood scenario and the return period considered.
- The property risk analysis is based on a theoretical spatial housing distribution with no raised floors (i.e. houses are at ground level). Raising floor levels by 50cm or greater can reduce the number of buildings directly affected by floods, as shown in Section 6.7. Implementing raised floor levels in new development sites could reduce property risk to flooding.

Liquefaction and lateral spread

- The hazards that pose the most spatially extensive risk to the built environment in Glenorchy are liquefaction and lateral spread inducing land damage. While damage associated with liquefaction is expected to be substantial, lateral spreading is anticipated to result in the most significant damage, with lateral spread focused along the lake margins, due to an approximately 25m high free face (below lake level). The land damage and consequential property damage is anticipated for a moderate to significant earthquake to be more severe and extensive across the majority of the township than observed in the most affected parts of Christchurch during the 2010/2011 Canterbury earthquakes. Analysis was not conducted for Kinloch due to insufficient data available.
- The effects of liquefaction and lateral spread on lifelines are expected to be Significant. Lifeline networks are vulnerable as functionality can be compromised over a wider area from discrete defects.
  - The water supply is likely to be the most vulnerable service due to reliance on a small number of water wells. Water supply pipelines appear to be constructed of materials that have higher levels of resilience such as PVC and PE, however socketed PVC may dislocate with lateral spread.
  - The flood defences along lake and river margins are anticipated to be damaged requiring remedial work for modelled levels of liquefaction and lateral spread. Temporary restoration is expected to provide for minimum acceptable levels of service, with subsequent restoration improvements to make stopbank breach risk to acceptable levels of long term risk.
  - There is no wastewater network, with a dominance of private septic tanks and small private schemes which will assist with ability to recover.
  - An overhead power supply, such as that in Glenorchy and Kinloch, reduces the risk of loss of service and assists with speed of recovery.
- The quantitative assessment for liquefaction and lateral spread land damage considers annual property risk (APR), with this risk metric essentially focusing on the financial consequence of an earthquake .The APR does not provide a direct representation of building functionality following an event, which is often what has the most effect on welfare of a community, especially for areas where land damage categorisation is within the bands of 'none' to 'Moderate'. It is recommended that for assessment of liquefaction and lateral spread hazard risk, more reliance be placed on the qualitative assessment, as this

focuses on the effects of land damage on the community welfare and disruption following an earthquake. The qualitative assessment considers a wider range of effects on the built environment, including lifelines, and buildings and facilities of importance to the community, and also considers to a degree the resilience of a community and its ability to adapt to or accommodate the effects of the hazard.

Seismic shaking

- Life and property risk from seismic shaking was assessed qualitatively as being of Acceptable risk. The greatest vulnerability from seismic events is likely associated with collapse of vulnerable structures such as stone and masonry structures, which are only a small proportion of the built environment in Glenorchy and Kinloch. While shaking will damage properties, the severity of damage will be dominated by onset of liquefaction and lateral spread, which is anticipated for relatively low levels of strong ground motion.

Risk analysis process

- Cumulative property risk has been determined for a combination of flooding (joint flooding scenario) and liquefaction, for Glenorchy. Property risk from the individual hazards was assessed as Significant and remains so when considered together. While adding the risk from multiple scenarios and hazards is aligned with the process detailed in AGS (2007) and as referred to in the RPS (ORC, 2022), caution should be applied when summing risks as the value could theoretically be greater than 1.
- Cascading hazard scenarios have not been considered in this study. The most likely cascading hazard would be liquefaction and lateral spread resulting in land settlement (in the order of 1m in many areas), which could result in:
  - Increase in the extent and severity of flooding risk.
  - Rising groundwater levels relative to the ground surface, which could lead to areas being permanently submerged. In other areas there could be an increase public health risks associated with shallow groundwater and building habitation.

9.4 Risk Management

The risks to life and property have been assessed as part of this study. The next stage of ORC's broader study includes consideration of how various controls may be implemented to manage risks identified in this report. Options to manage the risks from flooding hazards include a study underway by Damwatch (2024) to review soft and engineering controls along the Glenorchy floodbanks.

The above risk management options will be reported separately by others.

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11 Applicability Statement

This report has been prepared by Beca Limited (Beca) on the specific instructions of Otago Regional Council (Client). It is solely for our Client's use for the purpose for which it is intended in accordance with the agreed scope of work. Any use or reliance by any person contrary to the above, to which Beca has not given its prior written consent, is at that person's own risk.

Should you be in any doubt as to the applicability of this report and/or its recommendations for the proposed development as described herein, and/or encounter materials on site that differ from those described herein, it is essential that you discuss these issues with the authors before proceeding with any work based on this document.

In preparing this report Beca has relied on key information as listed in the Reference list.

Unless specifically stated otherwise in this report, Beca has relied on the accuracy, completeness, currency and sufficiency of all information provided to it by, or on behalf of, the Client, including the information listed above, and has not sought independently to verify the information provided.

This report should be read in full, having regard to all stated assumptions, limitations and disclaimers. No part of this report shall be taken out of context, and, to the maximum extent permitted by law, no responsibility is accepted by Beca for the use of any part of this report in any context, or for any purpose, other than that stated herein.

A

Appendix A – Gap Analysis

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21 December 2023

Otago Regional Council
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Attention: Simon Robinson

Dear Simon,

Glenorchy and Kinloch Natural Hazards Risk Assessment - Gap Analysis

Beca Limited (Beca) has been engaged by Otago Regional Council (ORC) to conduct risk analysis of natural hazards in Glenorchy and Kinloch. As part of the study, Beca has undertaken a gap analysis in accordance with our proposal dated 3 February 2023. The gap analysis involved review of outcomes from existing studies to determine what additional information is expected to be required to undertake the full scope of this study, through both qualitative and quantitative analysis. The gap analysis summary table is attached to this letter, which has been updated from the version submitted on 15 December to address ORC comments.

The gap analysis has been conducted based on the following assumptions:

- We have not undertaken independent checking of the validity of data or existing studies provided, in accordance with the scope of this study.
- The qualitative and quantitative risk analysis will generally be conducted in accordance with Otago Regional Council (ORC) proposed regional policy statement (RPS) 2021 - hearing panel version (Appendix 6, https://www.orc.govt.nz/media/12206/00-proposed-amendments-porps.pdf).
- As instructed by ORC, the one departure from the proposed RPS is that the qualitative analysis should be undertaken considering two scenarios for each hazard (instead of the three defined in the proposed RPS) where insufficient data are available for a third scenario to be assessed.
- During the workshop ORC clarified their intent that no further studies will be commissioned to inform the qualitative assessments, and proposed that qualitative analyses be undertaken based on existing data, where possible. For some hazards we have identified that qualitative risk analysis could only proceed with some further judgement based assessment, to be undertaken by Beca. Where insufficient data exist for a qualitative analysis, high level risk commentary will be provided.

The gap analysis table should be referred to for details of the identified gaps, and commentary on the level of certainty and limitations in applying the existing studies to a risk analysis process. Based on our review of the information provided and the above assumptions, we expect that the following hazards can be assessed qualitatively, with some further work required (as detailed in the gap analysis summary table):

- Liquefaction & lateral spread – Glenorchy only
- River flooding - Rees and Dart
- Lake Wakatipu flooding
- Seismic shaking
- Buckler Burn flood hazards.

We believe that the following hazards have insufficient information to conduct a qualitative assessment, without further studies:

- Bible Stream flooding - Glenorchy
- Buckler Burn debris flow
- Liquefaction and lateral spread - Kinloch
- Kinloch alluvial fan hazards from Gorge Creek – debris flow and flooding
- Lake Wakatipu tsunami
- Cumulative hazards – joint probability of flooding from all sources.

Depending on the outcome of the qualitative risk analysis, further studies may be required to undertake the quantitative risk analysis, as identified in the table. We will review the need for any further studies as the project progress and discuss it with yourselves where further work is required.

As noted above, we have identified further work required to undertake qualitative analyses, outside the scope of the original commission. We will proceed with the qualitative analysis in accordance with the above criteria, upon receipt of confirmation from yourselves.

Yours sincerely

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Attachments
Gap analysis summary table

Project: **Glenorchy and Kinloch Natural Hazards Risk Assessment**
Title: **Gap Analysis Summary**
Date: **21/12/2023**
Job #: **3160904**
Version: **2**

Number	Hazard type	Location	Gap subject	Details	Required for Qualitative	Required for Quantitative	Proposed approach to fill gap	Comments
1	Liquefaction and Lateral Spread	Kinloch	All parameters	Further assessment	Yes	Yes	**Not able to proceed with risk analysis.** ORC have indicated no further studies will be conducted for qualitative assessment.	Kinloch – MBIE level C, Detailed Area-Wide Assessment (as defined in *Planning and Engineering Guidance for Potentially Liquefaction-Prone Land, 2017*) required to complete qualitative and quantitative assessments. For hazards where no or limited data are available as agreed with ORC it will be sufficient to add general comments in our reports but not conduct a qualitative assessment.
2	Liquefaction and Lateral Spread	Glenorchy	Uncertainty	Approach to consider uncertainty - upper & lower bounds provided in existing study. Median missing.	Yes	Yes	**Likely able to proceed with judgement based assessment.** ORC to review with T&T the basis behind providing bounds in the first place. Justification of approach and agreement with ORC.	As directed by ORC at the gap analysis workshop, Beca to progress study and reporting using the bounds provided. This will require additional assessments and may result in a wide range of assessed risk at different return period scenarios.
3	Flooding	Rees/Dart	Scenario	Further scenarios required	No	Potentially	**Likely able to proceed with judgement based assessment.** Quantitative - re-run Rees/Dart model with additional return periods (confirm following qualitative assessment)	As instructed by ORC, we will proceed with a qualitative assessment based on the two magnitude scenarios available - the 100year ARI and 10yr lake level with current climate as scenario 1; and 100year ARI with 100year lake levels as scenario 2 as these two show the biggest differences in flood levels and consequences. The flood levels in the scenario 2 are dominated by the lake, we cannot assess the consequence of rare/unlikely event as we do not have the flood levels for Rees/Dart nor the lake.
4	Flooding	Buckler Burn	Likelihood	Flows modelled require return periods	No	Potentially	**Likely able to proceed with judgement based assessment.** Review progress during risk assessment and notify ORC if further work needed. Could be assessed by creating a hydrological model of Buckler Burn	Two previous estimates of flows provided for Buckler Burn (URS.2007 and NIWA, 2018). Two proposed approaches could be considered - assess the hydrology or assume the worst case and take the highest estimate of the URS and NIWA hydrology estimates. The worst case assumption would result in the 100-year event being estimated at 200m^3/sec (*Likely, according to Table 6 of the APP6)* , the second event would be defined at 250m^3/s (*Possible*). We would use the results of the LandRiverSea model (LRS, 2023). The 1999 event showed that the QT-GY road can be destroyed by flooding in the Buckler Burn. For the assessment, we will assume that road access to Glenorchy (from Queenstown) has been cut off in the "Likely" event. Update Dec 2023 - ORC agreed to use the two highest flood estimates method.
5	Flooding	Lake Wakatipu	Scenario	10yr, 100yr and 200 yr flood levels supplied	No	Yes	**Likely able to proceed with judgement based assessment.** ORC has supplied 200yr lake level to plot over LiDAR	Water levels of Lake Wakatipu are only available in combination with river flood levels and can not be distinguished. It should be relatively simple to extrapolate using the known lake levels (excerpt shown in URS report, table 3-5). However, the extrapolation of water levels at higher annualities should be within the bounds of what is possible with the length of the time series.
6	Flooding	All	Likelihood	Joint probability of flood from all sources	Yes	Yes	**Not able to proceed with risk analysis.** More work is required on joint probability	The probability of one river flooding at the same time as an adjacent river is similar to the individual probability (catchments are close to each other and will react based on their geology and shape). Therefore, we could assume that the joint probability of multiple river floods happening at the same time remains the same as the individual probability (a very conservative estimate). The flood level in Glenorchy is dominated by the lake and most residential areas are not affected at the simulated river flood events (at the 100yr events). At higher ARIs it is possible that a joint flood could lead to much higher consequences (i.e. more buildings being flooded and therefore reaching the catastrophic threshold). These higher ARI events are not yet simulated for any given river. Further work is required to estimate the joint probability of a lake flood event happening at the same time as a river flood event.

Project: Glenorchy and Kinloch Natural Hazards Risk Assessment
Title: Gap Analysis Summary
Date: 21/12/2023
Job #: 3160904
Version: 2

Number	Hazard type	Location	Gap subject	Details	Required for Qualitative	Required for Quantitative	Proposed approach to fill gap	Comments
7	Flooding	Bible Stream	Model results	Model results from the modelling of the stream	Yes	Yes	**Not able to proceed with risk analysis.**	With the given data (flood extent polygon only) we can not proceed to do a qualitative nor a quantitative analysis as we only have received the extent of the flood, not flood depth nor velocities are yet available. To be able to conduct qualitative and quantitative assessments both are needed. The flood extents of two events in the Bible Stream are both 100-year events but one has a simulated breaching of the Bible dam. The extent of both scenarios cover parts of Glenorchy's residential zone. Update Dec 2023: ORC supplied the 100yr flood extent
8	Flooding	Rees/Dart/Buckler Burn	Hazard	Modelled Hazard (AR&R) alignment with APP6	Yes	Yes	**Likely able to proceed with judgement based assessment.** Further justification (in line with work conducted previously in Queenstown)	We can align known hazards (H1-H6, as reported in the Rees/Dart and in the Buckler Burn report) with APP6 outlined quantitative assessment.
9	Flooding	Kinloch	Flood Model	No information on flooding from Gorge Creek in Kinloch	Yes	Yes	**Not able to proceed with risk analysis.** No risk analysis to be completed. Comments will be provided reflecting known risks based on available information (high-level assessment)	As agreed with ORC, for Kinloch hazards where no data is available (Gorge Creek flooding and debris flow), it will be sufficient to add general comments in our reports but not conduct a qualitative assessment as insufficient data exist. E.g. acknowledge the potential for the hazard based on the geomorphic setting however insufficient data to conduct a risk assessment – also considering the absence of events in recent history.
10	Seismic Shaking	All		Fragility equations / reported consequences	Yes	Yes	**Likely able to proceed with judgement based assessment.** Develop fragility equations, undertake assessments and assess expected consequences - Beca	Assessment of seismic shaking consequences is not available. Propose to use T&T estimated shaking levels for Glenorchy, but a reasonable level of further assessment is required. Shaking levels for Kinloch will need to be assessed. Fragility equations required to link shaking levels to damage category (i.e. "functionality comprised" for Buildings & Lifelines).
11	Debris Flow	Buckler Burn	RAMMS models	Further modelling (RAMMS)	Yes	Yes	**Not able to proceed with risk analysis without further studies.** Suggest that risk commentary be provided, based on all available studies.	GeoSolve have attempted to link modelled flow extents to 100 year ARI. This required generation of extremely large debris volumes modelled, and would also require a significant instability event prior to the 100 year ARI rainfall event. In reality this means the conditional probability would be significantly greater than 100 year ARI. Further work would be required to assess how credible the ARI relationship is and whether a second magnitude scenario can be justified from the larger modelled events, in order to complete a qualitative assessment (based on two magnitude scenarios as requested by ORC). Any qualitative assessments based on these models will likely have ranges of likelihood and consequence due to the uncertainty. Furthermore, the RAMMS models provided do not appear credible to inform risk analysis. Some assumptions (simulation resolution, release volume) would likely result in overestimating the spatial extents of an event and underestimating the depth. In order to undertake a defensible risk analysis, further desktop study, possible mapping to identify potential sources of landslides (block failure) or dam (hydrograph) failure scenarios assessment, along with refined RAMMS modelling would be required . A third magnitude scenario would also be required if proceeding to quantitative analysis. Other studies have been provided that would allow for a risk commentary to be made based on historic and geomorphic evidence.
12	Debris Flow	Kinloch	All information	No information available on debris flow risk at Gorge Creek in Kinloch	Yes	Yes	**Not able to proceed with risk analysis without further studies.** No risk analysis to be completed. Comments will be provided on known risks based on available information (high-level assessment)	For Kinloch hazards where no data is available (Gorge Creek flooding and debris flow) as agreed with ORC it will be sufficient to add general comments in our reports but not conduct a qualitative assessment as insufficient data exists. E.g. acknowledge the potential for the hazard based on the geomorphic setting however insufficient data to conduct a risk assessment – also considering the absence of events in recent history.
13	Lake Tsunami	All	All information	Insufficient hazard information to undertake assessments	Yes	Yes	**Not able to proceed with risk analysis.**	Rare event (8,000-11,000 return period) - no information specific to Glenorchy or Kinloch. As agreed with ORC we will include general comments on risk in our reports but not conduct risk analysis. Reference to be made to current PhD research project (linktr.ee/stephcoursey).

Project: Glenorchy and Kinloch Natural Hazards Risk Assessment
Title: Gap Analysis Summary
Date: 21/12/2023
Job #: 3160904
Version: 2

Number	Hazard type	Location	Gap subject	Details	Required for Qualitative	Required for Quantitative	Proposed approach to fill gap	Comments
14	Other	All	Cascading hazards	Ground surface following liquefaction/lateral spreading to assess flood risk	Yes	Yes	**Not able to proceed with cascading hazard risk analysis.** Ground profile post-liquefaction and lateral spread required to assess flood risk and elevated groundwater table. Further study required (T&T)	Little guidance within current studies of how the hazards will affect each other when considering cascading hazards
15	All	All	Consequence	Assessments of damage category required	Yes	Yes	**Likely able to proceed with judgement based assessment.** Prepare justification and agree process with ORC, in particular for liquefaction	Assumptions to be made to link outputs of assessments to damage category (i.e. “functionality comprised” for Buildings & Lifelines)
16	All	All	Temporal probability	Temporal probability scenario to be developed	No	Yes	**Likely able to proceed with judgement based assessment.** Agree credible scenario with ORC	Temporal probability scenario (amount of time person most at risk less ability to evade hazard) to be developed for all hazards.
17	All	All	Vulnerability	Damage ratio - proportion of property value lost as a result of the hazard	No	Yes	**Likely able to proceed with judgement based assessment.** Propose and agree damage ratio metrics with ORC	In accordance with our proposal, we intend to develop damage ratio metrics based on fundamental principles of the type of properties and their relative vulnerability to damage from different hazard types and magnitude.
18	All	All	Building information	Register of current building state/typology & infrastructure/ assumptions to be made	No	Yes	**Required to proceed for quantitative analysis** Undertake survey	Beca to conduct work prior to quantitative analysis.

B

Appendix B – Otago Regional Policy Statement – Hearing Panel Version

APP6 – Methodology for *natural hazard risk* assessment

Undertake the following four step process to determine the *natural hazard risk*.

Step 1 – Determine the likelihood

(1) ~~Using Table 6, a~~Assess the likelihood of three *natural hazard* scenarios occurring, representing a high likelihood, median likelihood, and the maximum credible event, using the best available information~~:~~.

(2) Use Table 6 to assign a likelihood descriptor to the three natural hazard scenarios.

(3) The likelihood assessment shall include consideration of the effect of climate change and Representative Concentration Pathways (RCP) scenarios.[1503]

Table 6 – Likelihood scale

Likelihood	Indicative frequency
Almost certain	Up to once every 50 years (2% AEP)
Likely	Once every 51 – 100 years (2 – 1% AEP)
Possible	Once every 101 – 1,000 years (1 – 0.11% AEP)
Unlikely	Once every 1,001 – 2,500 years (0.1 – 0.04% AEP)
Rare	2,501 years plus (<0.04% AEP)

Step 2 – *Natural hazard* consequence

Note 1: Table 7 shall be utilised by territorial authorities determining the level of risk presented by a hazard(s) when undertaking plan change or plan review processes.

Note 2: The matters listed in (1) to (11) provide useful considerations for territorial authorities, and are the primary considerations for resource consent applications triggering a risk assessment requirement in accordance with HAZ-NH-M3(7)(a) or HAZ-NH-M4(7)(a). [1504]

Using Table 7 and the matters listed in (1) to (10) below, assess the consequence (catastrophic, major, moderate, minor, or insignificant) of the *natural hazard* scenarios identified in step 1 considering:

(1) the nature and scale[1505] of activities in the area,

(2) individual and community vulnerability and resilience,[1506]

(3) impacts on individual and community health and safety,

(4) impacts on social, cultural and economic well-being,

(5) impacts on *infrastructure* and property, including access and services,

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[1503] 00138.147 QLDC
[1504] 00301.055 Port Otago
[1505] 00411.091 Wayfare
[1506] 00411.091 Wayfare

(6) available and viable *risk* reduction and hazard mitigation measures,

(7) *lifeline utilities*, essential and emergency services, and their co-dependence,

(8) implications for civil defence agencies and emergency services,

(9) the changing *natural hazard* environment,

(10) cumulative *effects* including *multiple* and *cascading hazards,* where present, and

(11) factors that may exacerbate a *natural hazard* event including the *effects* of *climate change*.

Table 7 – Consequence table

Severity of Impact	**Built**				**Health & Safety**
	Social/Cultural	*Buildings*	Critical *Buildings*	Lifelines	
Catastrophic **(V)**	≥25% of *buildings* of social/cultural significance within hazard ~~zone~~ impact area[1507] have functionality compromised	≥50% of affected *buildings* within hazard ~~zone~~ impact area[1508] have functionality compromised	≥25% of critical facilities within hazard ~~zone~~ impact area[1509] have functionality compromised	Out of service for > 1 month (affecting ≥20% of the town/city population) OR suburbs out of service for > 6 months (affecting < 20% of the town/city population)	> 10~~1~~ dead and/or > 1001 injured[1510]
Major **(IV)**	11-24% of *buildings* of social/cultural significance within hazard ~~zone~~ impact area[1511] have functionality compromised	21-49% of *buildings* within hazard ~~zone~~ impact area[1512] have functionality compromised	11-24% of *buildings* within hazard ~~zone~~ impact area[1513] have functionality compromised	Out of service for 1 week – 1 month (affecting ≥20% of the town/city population) OR suburbs out of service for 6 weeks to 6 months (affecting < 20% of the town/city population)	1~~1~~ – 10~~0~~ dead and/or 101 – 1000 injured[1514]
Moderate **(III)**	6-10% of *buildings* of social/cultural significance within hazard ~~zone~~ impact area[1515] have functionality compromised	11-20% of *buildings* within hazard ~~zone~~ impact area[1516] have functionality compromised	6-10% of *buildings* within hazard ~~zone~~ impact area[1517] have functionality compromised	Out of service for 1 day to 1 week (affecting ≥20% of the town/city population) OR suburbs out of service for 1 week to 6 weeks (affecting < 20% of the town/city population)	~~2 – 20 dead and/or~~ 11 – 100 injured[1518]

[1507] 00138.147 QLDC
[1508] 00138.147 QLDC
[1509] 00138.147 QLDC
[1510] 00138.147 QLDC
[1511] 00138.147 QLDC
[1512] 00138.147 QLDC
[1513] 00138.147 QLDC
[1514] 00138.147 QLDC
[1515] 00138.147 QLDC
[1516] 00138.147 QLDC
[1517] 00138.147 QLDC
[1518] 00138.147 QLDC

Minor **(II)**	1-5% of *buildings* of social/cultural significance within hazard ~~zone~~ impact area[1519] have functionality compromised	2-10% of *buildings* within hazard ~~zone~~ impact area[1520] have functionality compromised	1-5% of *buildings* within hazard ~~zone~~ impact area[1521] have functionality compromised	Out of service for 2 hours to 1 day (affecting ≥20% of the town/city population) OR suburbs out of service for 1 day to 1 week (affecting < 20% of the town/city population	~~1 dead and/or 1 –~~ 10 injured
Insignificant **(I)**	No *buildings* of social/cultural significance within hazard ~~zone~~ impact area[1522] have functionality compromised	< 1% of affected *buildings* within hazard ~~zone~~ impact area[1523] have functionality compromised	No damage within hazard ~~zone~~ impact area[1524], fully functional	Out of service for up to 2 hours (affecting ≥20% of the town/city population) OR suburbs out of service for up to 1 day (affecting < 20% of the town/city population	No dead No injured
When assessing consequences within this matrix, the final level of impact is assessed on the 'first past the post' principle, in that the consequence with the highest severity of impact applies. For example, if a *natural hazard* event resulted in moderate severity of impact across all of the categories, with the exception of critical *buildings* which had a 'major' severity of impact, the major impact is what the proposal would be assessed on. If a *natural hazard* event resulted in all of the consequences being at the same level (for example, all of the consequences are rated moderate), then the level of consequence is considered to be moderate. ~~When this assessment is being undertaken in accordance with HAZ-NH-M3(7)(a) or HAZ-NH-M4(7)(a) the text within Step 2 shall guide the assessment of *natural hazard* consequence.~~ [1525]					

Step 3 – Assessing ~~activities for~~[1526] *natural hazard risk*

Using the information within steps 1 and 2 above, complete Table 8 for each of the hazard scenarios considered, and identify if the risk from each of the scenarios is ~~and Table 8, assess whether the *natural hazard* scenarios will have an~~[1527] acceptable, tolerable, or significant ~~*risk* to people, property and communities, by considering:~~

~~(1) the *natural hazard risk* identified, including *residual risk*,~~

~~(2) any measures to avoid, remedy or mitigate those *risks*, including relocation and recovery methods,~~

~~(3) the long-term viability and affordability of those measures,~~

~~(4) flow on *effects* of the *risk* to other activities, individuals and communities, and~~

~~(5) the availability of, and ability to provide, *lifeline utilities*, and essential and emergency services,~~

[1519] 00138.147 QLDC
[1520] 00138.147 QLDC
[1521] 00138.147 QLDC
[1522] 00138.147 QLDC
[1523] 00138.147 QLDC
[1524] 00138.147 QLDC
[1525] 00301.055 Port Otago
[1526] 00138.147 QLDC
[1527] 00138.147 QLDC

~~during and after a *natural hazard* event.~~[1528]

Table 8 – Risk table

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

Notes:

Table 8 above has been included as a region-wide baseline. As set out in HAZ-NH-M2(1) *local authorities* are required to undertake a consultation process with communities, stakeholders and partners regarding *risk* levels thresholds and develop a *risk* table at a district or community scale. This region-wide baseline is to be used in the absence of a district or community scale *risk* table being developed.

~~When this assessment is being undertaken in accordance with HAZ-NH-M3(7)(a) or HAZ-NH-M4(7)(a) the text within Step 3 shall guide the assessment of *natural hazard risk*.~~[1529]

Step 4 – Undertake a quantitative *risk* assessment

While Steps 1-3 will qualitatively categorise *natural hazard risk* based on a community's understanding and acceptance level of *risk*, it will not provide quantitative understanding of the *risk* a *natural hazard* presents to the built environment, or health and safety.

If the assessment undertaken in Steps 1-3 determines that one of the three *natural hazard* scenarios generate *risk* that is significant, undertake a quantitative *risk* assessment utilising the following methodology:[1530]

(1) Based on the likelihood of a *natural hazard* event within the hazard zone (see Step 1), and including the potential impacts of *climate change* and sea level rise, select a representative range of at least ~~five~~ three[1531] hazard scenarios with varying likelihoods to model,[1532] including the maximum credible event.

(2) Model the Annual Individual Fatality Risk (AIFR)[1533] and Annual Property Risk (APR)[1534] for the

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[1528] 00138.147 QLDC

[1529] 00138.147 QLDC

[1530] This methodology has been developed in general accordance with the Australian Geomechanics Society, 2007 methodology, which may usefully provide additional guidance. (New footnote attributed to 00138.147 QLDC)

[1531] 00138.147 QLDC

[1532] The model should include an analysis of uncertainty.

[1533] Annual probability that an individual most at risk is killed in any one year as a result of the hazards occurring.

[1534] Annual probability of total property loss (relating to permanent structures) as a result of the hazards occurring.

range of hazard scenarios across the hazard zone, and create loss exceedance distributions.

(3) Analyse loss exceedance distributions and determine losses.

(4) Assign the risk level ~~Implementing a first-past-the-post principle for the AIFR and APR~~:[1535]

  (a) for areas of new development where the ~~greatest~~[1536] AIFR or APR is:

    (i) less than 1 x 10^{-6} per year, the *risk* is re-categorised as acceptable,

    (ii) between 1 x 10^{-6} and 1 x 10^{-5} per year, the *risk* is re-categorised as tolerable, or

    (iii) greater than 1 x 10^{-5} per year, the *risk* is re-categorised as significant.

  (b) for areas with existing development, where the ~~greatest~~[1537] AIFR or APR is:

    (i) less than 1 x 10^{-5} per year, the *risk* is re-categorised as acceptable;

    (ii) between 1 x 10^{-5} and 1 x 10^{-4} per year, the *risk* is re-categorised as tolerable; or

    (iii) greater than 1 x 10^{-4} per year, the *risk* is re-categorised as significant.

~~(5) Following the quantitative *risk* assessment, a *risk* level is assigned to the hazard area.~~[1538]

AIFR and APR are the selected *risk* metrics as they represent the likely consequences of a wide range of *natural hazards*. For example, some *natural hazards*, generally, do not have the capacity to cause fatalities, but may result in widespread damage to property, while other *natural hazards* have a high capacity to cause fatalities. A first-past-the-post principle to the re-categorisation of *risk* is applied to ensure that decisions are based on the greatest *risk* present between the two metrics.

If the level of knowledge or uncertainty regarding the likelihood or consequences of a *natural hazard* event precludes the use of Step 4, then a precautionary approach to assessing and managing the *risk* should be applied, as set out in HAZ-NH-P5.

[1535] 00138.147 QLDC

[1536] 00138.147 QLDC

[1537] 00138.147 QLDC

[1538] 00138.147 QLDC

C

Appendix C – Flooding Risk Analysis Process

Flooding qualitative risk analysis process

Built Environment

Lifelines

The percentage of Glenorchy and Kinloch residential areas that is flooded (≥H2) or not accessible via road (out-of-service) was calculated with the following equation:

$$Area\ out\ of\ service = \frac{\sum_{H2}^{H6} Residential\ area\ out\ of\ service}{Entire\ residential\ area\ in\ Glenorchy\ and\ Kinloch} * 100 \qquad (3)$$

Buildings

To account for any inaccuracies in the LINZ dataset, satellite image, or model results, buildings were buffered by 2m to ensure that the individual risk to houses was not underestimated. The highest intersecting Flood Hazard Vulnerability Classification for each building was used to estimate whether the building's functionality is compromised (Equation 4).

The built environment was assessed per Flood Hazard Vulnerability Classification individually. Equation 4 describes the method applied to assess level of risk per built environment (critical buildings, amenities of cultural and social importance and all buildings) for each Flood Hazard Vulnerability Classification.

$$Built\ environment\ assessment\ = \frac{\sum[houses(+buffer\ ) \cap_{H1}^{H6} \max flood\ hazard]}{total\ number\ of\ houses\ in\ hazard\ impact\ area} * 100 \qquad (4)$$

The flood risk within the study area is either: Acceptable, Tolerable or Significant and is determined based on the simulated Flood Hazard Vulnerability Classification.

RPS (ORC,2022) determines the Consequence of the impact, ranging from Insignificant to Catastrophic, based on the percentage of buildings within each hazard zone that have their functionality compromised. The number of buildings in each hazard impact zone varies depending on the scenario being considered. According to the definition of the hazard impact area all buildings within the Tolerable and Significant risk area will have their *functionality compromised* as they are subject to a flood hazard. Buildings inside the Acceptable risk area are not affected by the flood at all. Since all buildings within the hazard impact area are affected by the flood, the Catastrophic consequence is always triggered.

Figure C-1 shows that Flood Hazard Vulnerability Classifications H1 – H4 can cause low hazard to structures. The green line in the graph is described as the "*minimum criteria for building stability in existing flood affected areas"* (Smith et al., 2014). H5 and H6 are categorized as causing moderate/high and extreme hazard to structures, respectively. In this study flood hazard H4 is also considered to pose a Significant flood risk due to the accompanying flood depth of up to 2m.

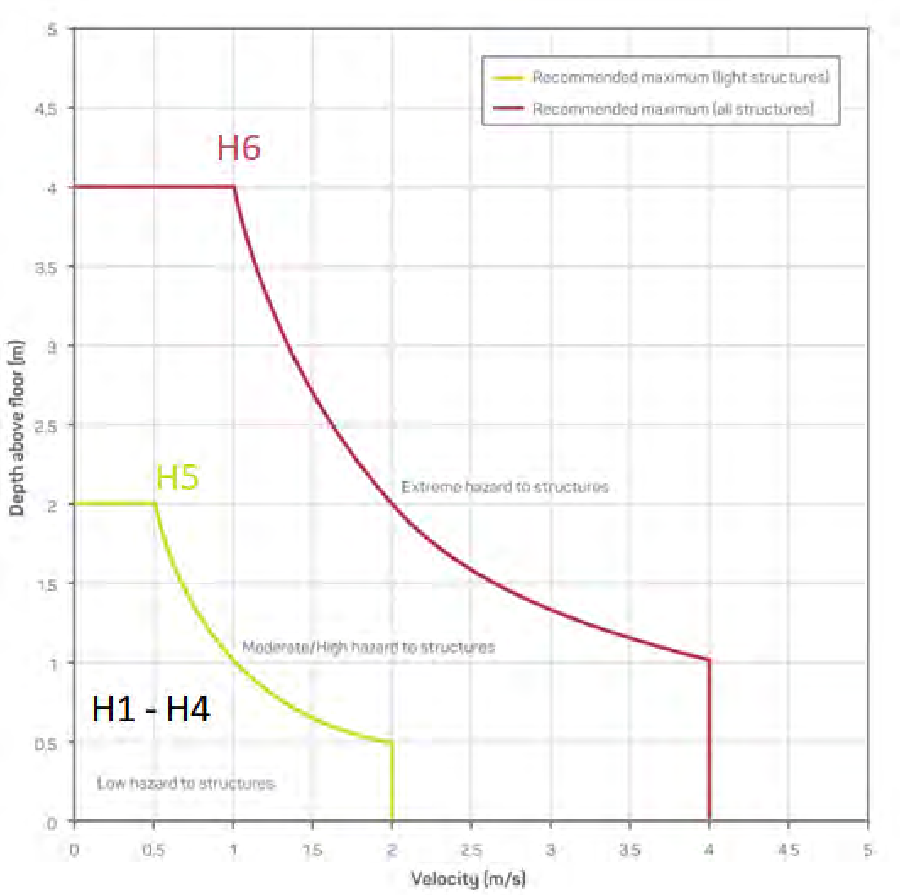

Figure C-1: Linking the stability of buildings to flood hazard (altered from Smith et al. 2014, from the AIDR Guideline 2017)

Public Health and Safety

The APP6 (ORC, 2022) guidance uses the criteria of number of deaths and/or injured to assess the Public Health and Safety Risk posed by a flood. Cox et al. (2010) analyzed the stability (resilience) of people in floods and linked this to the Flood Hazard Vulnerability Classifications (H1 – H6). The hazard classification is split into hazard thresholds for children and adults (Figure C-2). The thresholds for deaths and injuries based on the Flood Hazard Vulnerability Classifications used in this study are outlined in Table C-1.

Table C-1: Adapted link between Flood Hazard Vulnerability Classification to injuries and deaths. Based on Cox et al. (2010).

Population	H1	H2	H3	H4	H5	H6
Adults	no risk	injured	injured	injured	death	death
Children	injured	death	death	death	death	death

To calculate the number of deaths and injuries in Glenorchy, due to flooding, the population density was estimated and compared to the Flood Hazard Vulnerability Classification extents. The population density is calculated for children and adults separately and is based on the demographics and the residential area outlined in Figure C-4.

Using the extent of the individual Flood Hazard Vulnerability Classifications, and the population density of children and adults (Figure C-3) the following equation (5) was used to estimate the Public Health and Safety consequences.

$$Health\ and\ Safety = \sum_{H1}^{H6} death_{children} + death_{adults} + injured_{children} + injured_{adults} \quad (5)$$

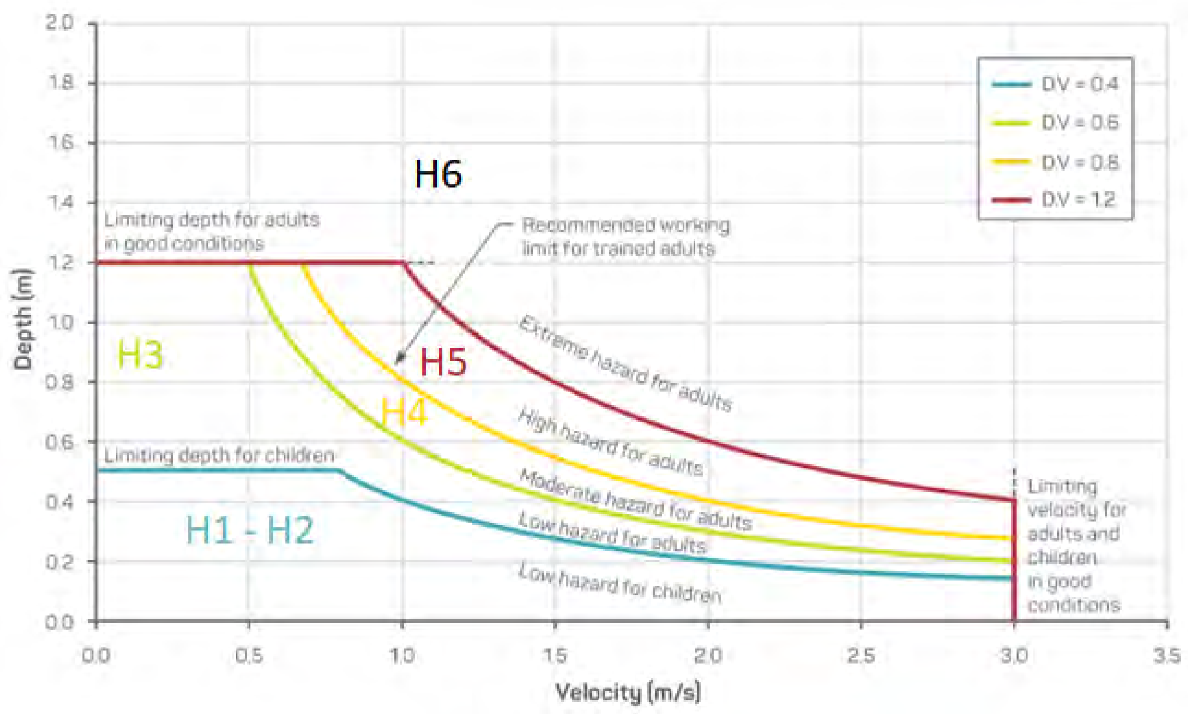

Figure C-2: Linking people stability to flood hazard (altered after Cox et al. 2010, from the AIDR Guideline 2017)

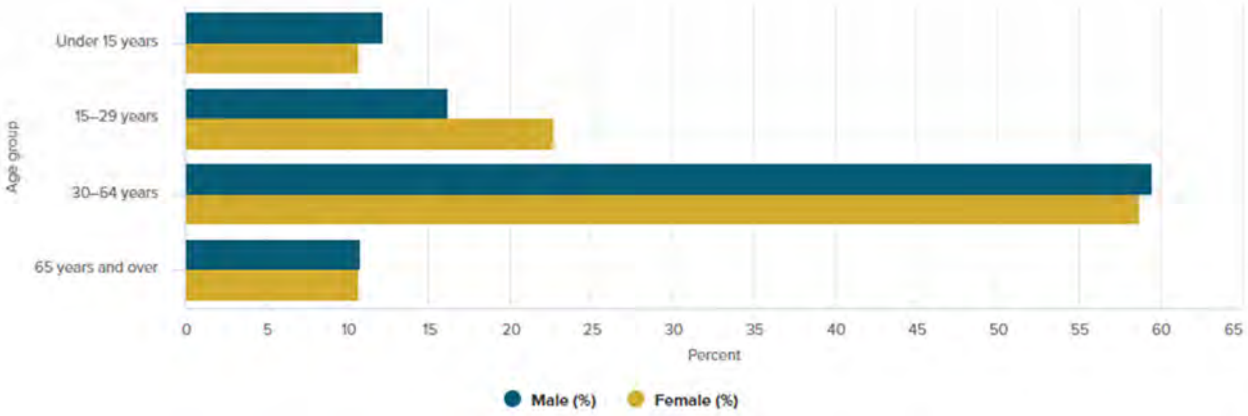

Figure C-3: Population demographics for Glenorchy based on census 2018 (source Stats NZ)

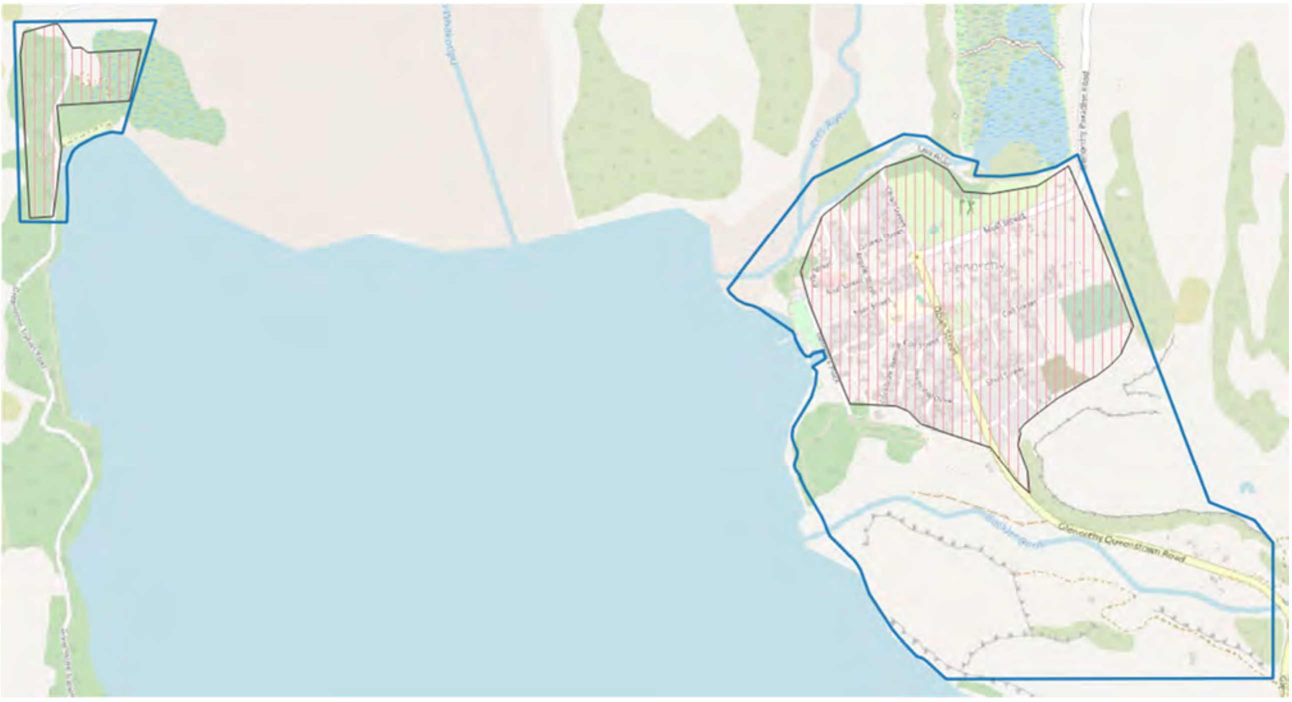

Figure C-4: Showing the study area (blue) and the township zone (provided by QLDC). The AIFR and APR metrics shown in Figure 4-6 and Figure 5-4 were estimated using the township zone.

River Flooding Qualitative Risk Analysis Results

Rees/Dart

Table C-2: Lifeline results for Rees/Dart flooding

Scenario	Area *out of service*[3] [ha]	Area *out of service* [%]	Assumed duration of road closure (due to flooding and repairs)	Consequences
Likely	11.2 + 1.4	16	1 – 6 weeks	Moderate
Possible	17 + 1.4	23	1 week – 1 month	Major

Table C-3: Count of buildings per scenario and hazard class defined along the flood impact areas of the Rees/Dart scenarios.

Scenario	Hazard Impact area	Count of cultural/social amenities	Buildings flooded	Count of critical buildings
Likely	Acceptable	3	321	6
Likely	Tolerable	0	23	1
Likely	Significant	4	3	0
Possible	Acceptable	1	281	4
Possible	Tolerable	2	62	3

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[3] Shown as area in Glenorchy + Kinloch

Scenario	Hazard Impact area	Count of cultural/social amenities	Buildings flooded	Count of critical buildings
Possible	Significant	4	4	0

Table C-4: Built environment qualitative assessment results of the Rees/Dart flood scenarios. N/A referring to not applicable as there are no respective buildings in this flood impact area.

Scenario	Hazard impact area	Cultural/Social amenities	All Buildings	Critical Buildings	Consequence
Likely	Acceptable	*Insignificant*	*Insignificant*	*Insignificant*	*Insignificant*
Likely	Tolerable	*N/A*	*Catastrophic*	*Catastrophic*	*Catastrophic*
Likely	Significant	*Catastrophic*	*Catastrophic*	*N/A*	*Catastrophic*
Possible	Acceptable	*Insignificant*	*Insignificant*	*Insignificant*	*Insignificant*
Possible	Tolerable	*Catastrophic*	*Catastrophic*	*Catastrophic*	*Catastrophic*
Possible	Significant	*Catastrophic*	*Catastrophic*	*N/A*	*Catastrophic*

Table C-5: Public Health and Safety results and their consequences for Rees/Dart flooding. Values are rounded to nearest integer value.

Scenario	Deaths	Injuries	Consequence
Likely	7	54	*Major*
Possible	12	82	*Catastrophic*

Buckler Burn

Table C-6: Lifeline results for Buckler Burn flooding

Scenario	Area *out of service* [ha]	Area *out of service* [%]	Assumed duration of road closure (due to flooding and repairs)	Consequences
Likely	80	100	1 day – 1 week	*Moderate*
Possible	80	100	1 day – 1 week	*Moderate*

Table C-7: Built environment qualitative assessment results of the Buckler Burn flood scenarios. N/A referring to not applicable as there are no respective buildings in this flood impact area.

Scenario	Hazard impact area	Cultural/Social amenities	All Buildings	Critical Buildings	Consequence
Likely	Acceptable	*N/A*	*Insignificant*	*N/A*	*N/A*
Likely	Tolerable	*N/A*	*Catastrophic*	*N/A*	*Catastrophic*
Likely	Significant	*N/A*	*Insignificant*	*N/A*	*Insignificant*
Possible	Acceptable	*N/A*	*Insignificant*	*N/A*	*N/A*
Possible	Tolerable	*N/A*	*Catastrophic*	*N/A*	*Catastrophic*
Possible	Significant	*N/A*	*Insignificant*	*N/A*	*Insignificant*

Table C-8: Public Health and Safety results and their consequences for rounded to nearest integer value.

Scenario	Deaths	Injuries	Consequence
Likely	2	10	Major
Possible	2	12	Major

Lake Flooding Qualitative Risk Analysis Results

Table C-9: Lifeline results for Lake Wakatipu flooding

Scenario	Area *out of service*[4] [ha]	Area *out of service* [%]	Assumed duration of road closure (due to flooding and repairs)	Consequences
Likely	22 + 1.4	30	1 day – 1 week	Moderate
Possible	30 + 1.4	40	1 day – 1 week	Moderate

Table C-10: Count of buildings per scenario and hazard class defined along the flood impact areas of Lake Wakatipu flood scenarios.

Scenario	Hazard Impact area	Count of cultural/social amenities	Count of buildings	Count of critical buildings
Likely	Acceptable	1	270	4
Likely	Tolerable	1	61	2
Likely	Significant	3	16	1
Possible	Acceptable	1	270	4
Possible	Tolerable	1	62	0
Possible	Significant	3	38	3

Table C-11: Built environment qualitative assessment results of the Lake Wakatipu flood scenarios. N/A referring to not applicable as there are no respective buildings in this flood impact area.

Scenario	Hazard impact area	Cultural/Social amenities	All Buildings	Critical Buildings	Consequence
Likely	Acceptable	*Insignificant*	*Insignificant*	*Insignificant*	*Insignificant*
Likely	Tolerable	*Catastrophic*	*Catastrophic*	*Catastrophic*	*Catastrophic*
Likely	Significant	*Catastrophic*	*Catastrophic*	*Catastrophic*	*Catastrophic*
Possible	Acceptable	*Insignificant*	*Insignificant*	*Insignificant*	*Insignificant*
Possible	Tolerable	*Catastrophic*	*Catastrophic*	*N/A*	*Catastrophic*
Possible	Significant	*Catastrophic*	*Catastrophic*	*Catastrophic*	*Catastrophic*

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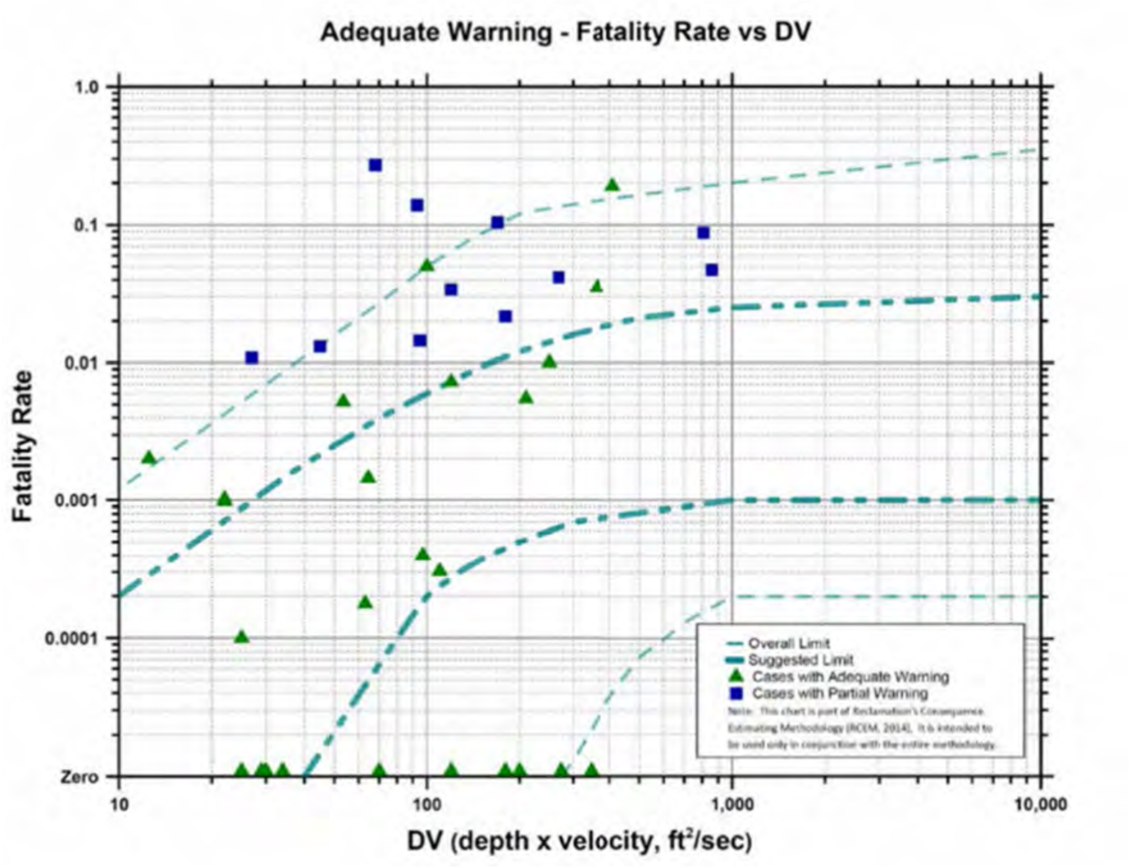
[4] Devided into the area in Glenorchy and Kinloch

Flooding quantitative risk analysis process



Note: This chart is part of Reclamation's Consequence Estimating Methodology (RCEM, 2014). It is intended to be used only in conjunction with the entire methodology.

Figure C-5: Fatality rates of flood and dam failure events. DV describes the severity of a flood. The flood results in Glenorchy are <70ft^2/s. From: Feinberg et al. (2016).

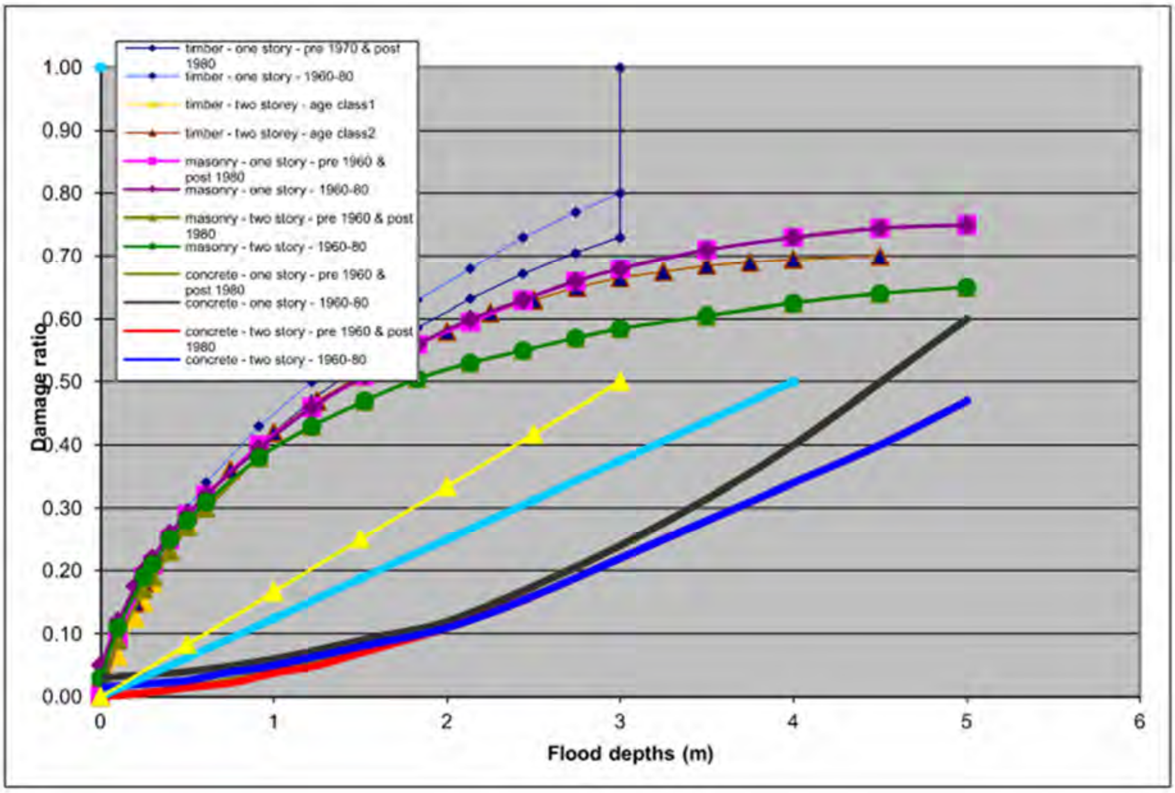


Figure C-6: Flood fragility curve. In this study the fragility curve: *timber – one story – pre 1970 & post 1980* was used. Source: NIWA, 2010.

D

Appendix D – Seismic Shaking Risk Analysis Process

Seismic shaking risk analysis process

Qualitative Risk Analysis

Seismic shaking has been linked to estimated building damage to support qualitative assessment of risk by the following basis:

- A range of spectral accelerations have been calculated for a lightweight single storey timber framed building for the three earthquake hazard scenarios presented in Section 6.3. Lightweight single storey timber buildings are predominantly designed using New Zealand Standard 3604, which assumes a fundamental period (T) of 0.4 second for seismic bracing (Ma et al, 2022). This period is adopted to derive the spectral accelerations in accordance with the New Zealand Seismic standards (NZS1170.5). Uma et al (2008) undertook a study to determine the vulnerability of New Zealand structures to damage for different levels of shaking (refer Figure D-1). The fragility equations derived show what proportion of structures will reach a define Damage State (DS) for increasing level of seismic demand. For lightweight timber framed structures, four fragility equations were derived: one for each of the Damage States as defined by the guidance in Hazus (FEMA, 2022).
- The spectral acceleration (SA) has been converted to a spectral displacement (SD) for comparison with the fragility equation (Uma et al, 2008) using the simple equation below (Lumantarna et al, 2010). The calculated spectral displacement ranged from 2mm (25 year return period earthquake) to 8mm (1500 return period earthquake).

$$SD = SA\left(\frac{T}{2\pi}\right)^2$$

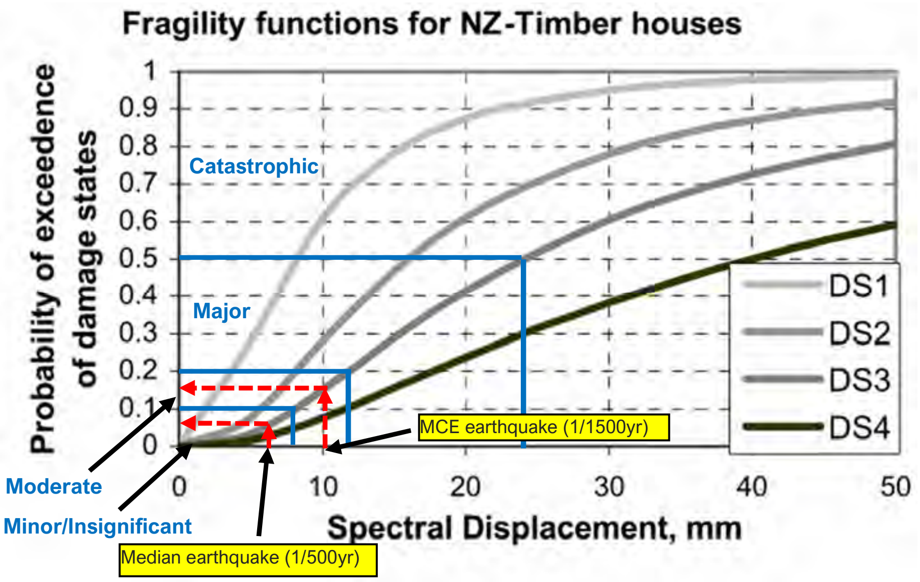


Figure D-1: Fragility Equation for timber houses in New Zealand (Ulma et al, 2008). The calculated Spectral Displacements for the MCE and Median earthquake events are overlaid for buildings (yellow and red) along with the severity of impact categories (Table 7, APP6 ORC (2022)).

- Hazus Extensive Structural Damage (historically DS3) has been conservatively assessed as “functionality compromised” the effects on the building are described was “permanent lateral movement of floors and roof and slippage of structure over foundations” (FEMA, 2022). The more severe Complete Structural Damage (historically DS4) is described as “large permanent lateral displacement or may be in imminent danger of collapse”. Practically the threshold for functionally compromised is at a point between

Complete and Extensive Structural Damage (historically DS4 and DS3). The MBIE Field Guide: Rapid Post Disaster Building Usability Assessment - Earthquakes (2014) provides guidance on observable structural factors that compromise occupancy (i.e. functionality). These include building or story significantly leaning, partial of total collapse of walls of roof, severe damage to structural columns or beams, spalling or bucking of walls, significant damage to foundation.

Sensitivity: General

E

Appendix E – Liquefaction and Lateral Spread Risk Analysis Process

Liquefaction and lateral spread analysis process

Qualitative Risk Analysis

The consequences of liquefaction and lateral spreading on buildings and infrastructure has been assessed using the available existing studies (T+T, 2022) and we have adopted the following approach to complete the assessment.

Liquefaction Damage

The MBIE/MfE Guidance (2017) noted that the Liquefaction Severity Number (LSN) values could be used to estimate the likelihood of various degrees of land damage during seismic events. T+T (2022) produced figures of (LSN) over Glenorchy for different return period earthquakes as part of their 2022 “Level C” liquefaction and lateral spreading assessment. LSN is a liquefaction and lateral spreading damage index, which was developed by T+T following observations and analysis from the 2010 to 2011 Canterbury Earthquake Sequence. A higher LSN number is indicative of shallower and/or thicker deposits of liquefaction and a greater likelihood of land damage. Correspondingly, a lower LSN corresponds to a lower likelihood of liquefaction induced land damage. T+T’s LSN figures were assessed over a grid of 100m by 100m and they considered lower and upper bound scenarios for range of different return period earthquakes. The index accounts for the effects of both liquefaction and lateral spreading.

T+T (2022) grouped the LSN into five categories ranging from 0 to 8 (None to Minor) to 25+ (High to Severe). The T+T LSN categories have been linked to three categories of liquefaction induced land damage presented in the MBIE/MfE Guidance (2017) (Table E-1). The MBIE/MfE damage categories provide descriptions of the effects of liquefaction dominated damage on the built environment. The “Moderate to Severe” category (LSN >20) is described as land damage causing “substantial damage and disruption to buildings and infrastructure and repair may be difficult or uneconomic” and in accordance with ORC (2022) has been assessed as buildings that are “functionality compromised”. Buildings in the “Minor to Moderate” category (LSN of 8 to 20) will still have damage, but this is reported to be “repairable” and the building functionality is not assessed to be compromised.

Table E-1: Assessed LSN (T+T,2022) to MBIE/MfE degree of liquefaction induced ground damage

Assessed LSN[A]			**Degree of liquefaction - induced ground damage** [B]
Minimum	Maximum	Category	
0	8	None to Minor	None to Minor
8	16	Minor	Minor to Moderate
16	20	Minor to Moderate	
20	25	Moderate to High	Moderate to Severe
25		High to Severe	

[A] T+T Glenorchy Liquefaction Vulnerability Assessment (May 2022)

[B] MBIE/MfE, Planning and engineering guidance for potentially liquefaction-prone land (September 2017)

DEGREE OF LIQUEFACTION-INDUCED GROUND DAMAGE (example photographs)	TYPICAL CONSEQUENCES AT THE GROUND SURFACE These are examples of the type of damage that would be expected, they are not intended to be criteria for calculation
None to Minor	– ***None to Minor*** no signs of ejected liquefied material at the ground surface[1]. – No more than minor differential settlement of the ground surface (eg undulations less than 25 mm in height). – No apparent lateral spreading ground movement (eg only hairline ground cracks). – Liquefaction causes no or only cosmetic damage to buildings and infrastructure (but damage may still occur due to other earthquake effects).
Minor to Moderate	– ***Minor to Moderate*** quantities of ejected liquefied material at the ground surface (eg less than 25 percent of a typical residential site covered[2]); and/or – Moderate differential settlement of the ground surface (eg undulations 25–100 mm in height). – No significant lateral spreading ground movement (eg ground cracks less than 50 mm wide may be present, but pattern of cracking suggests the cause is primarily ground oscillation or settlement rather than lateral spreading). – Liquefaction causes moderate but typically repairable damage to buildings and infrastructure. Damage may be substantially less where liquefaction was addressed during design (eg enhanced foundations).
Moderate to Severe	– Large quantities of ejected liquefied material at the ground surface (eg more than 25 percent of a typical residential site covered[2]); and/or – ***Moderate to Severe*** differential settlement of the ground surface (eg undulations more than 100 mm in height); and/or – Significant lateral spreading ground movement (eg ground cracks greater than 50 mm wide, with pattern of cracking suggesting direction of movement downslope or towards a free-face). – Liquefaction causes substantial damage and disruption to buildings and infrastructure, and repair may be difficult or uneconomic in some cases. Damage may be substantially less, and more likely to be repairable, where liquefaction was addressed during design (eg enhanced foundations and robust infrastructure detailing).

Figure E-1: MBIE/MfE degree of liquefaction induced ground damage, source MBIE/MfE (2017)

Some variation in the observed liquefaction consequences is expected within the study area owing to variability in the ground conditions, and assessment methodology. A 2015 study by T+T (titled Canterbury Earthquake Sequence: Increased Liquefaction Vulnerability Assessment Methodology) compared the ground damage observations (MBIE/MfE, Table E-1) to the assessed LSN for properties in Christchurch following the 2010/2011 Canterbury Earthquake Sequence (refer to Table E-1). The study has been used to infer the proportion of properties with "Moderate to Severe" land damage and therefore the proportion of buildings with "functionality compromised" for a given earthquake hazard scenario. Based on observations from a site walkover in September 2023, the average building type in Glenorchy appears to be similar to the broad range of building types in Christchurch comprising single storey residential construction. While the study is based on Christchurch and is not specific to Glenorchy, its observations provide an indication of the distribution of expected land damage.

The dashed lines on Figure E-2 show the inferred link between the assessed LSN for a given area and the proportion of land with Moderate to Severe land damage. For example, where the LSN is greater than 20, we have assessed greater than 50% of the buildings will have “functionality compromised” and this is defined as a Catastrophic (V) severity of impact as summarised in Table E-2.

Table E-2 : Inferred relationship of soil LSN to Severity of Impact to Buildings (ORC, 2022)

Liquefaction Severity Number (LSN) ^{A}	**Degree of liquefaction – induced ground damage**	**Assessed Proportion of Buildings damaged by liquefaction such that they are “functionality compromised ^{A}**	**Severity of Impact (Table 7, ORC (2022)) - Buildings**
<8	None to Minor	<20%	Moderate (III), Minor (II) & Insignificant (I)
8 to 20	Minor to Moderate	21 to 49%	Major (IV)
>20	Moderate to Severe	>50%	Catastrophic (V)

^{A} Broad categories developed from Beca interpretation of T+T (2015) study assessing land damage and calculated LSN in Christchurch following the 2010/2011 Canterbury Earthquake Sequence.

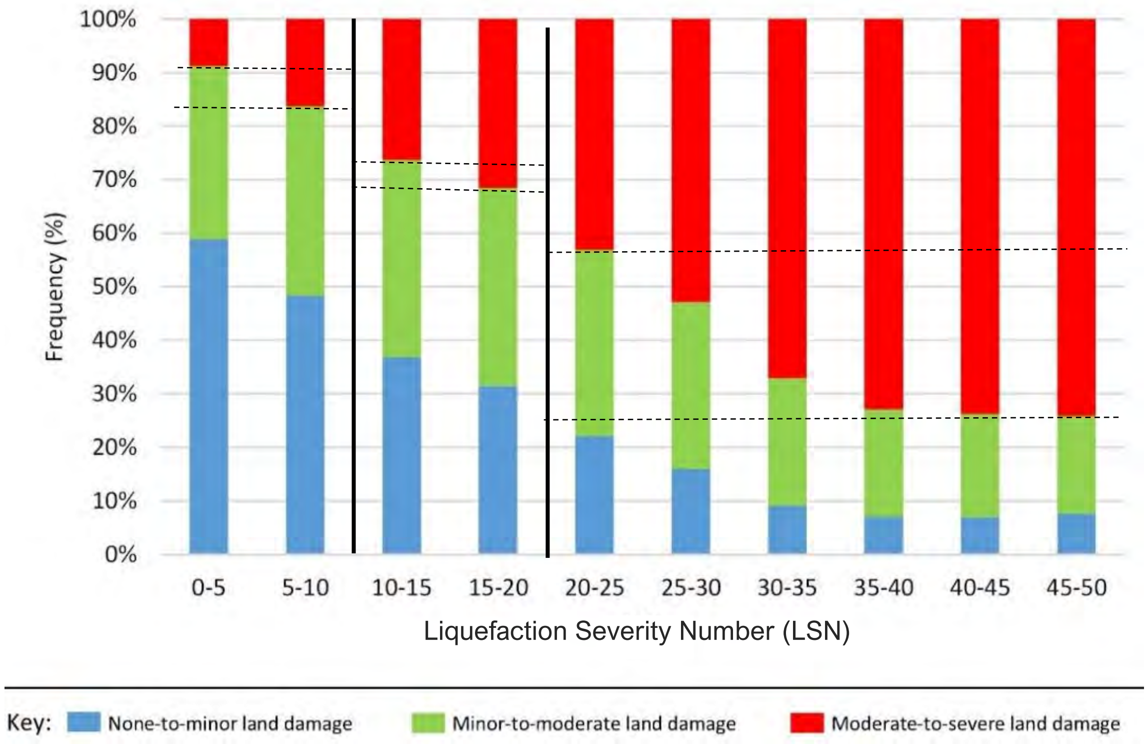


Figure E-2: Observed land damage & calculated LSN for properties in Christchurch following the 2010 to 2011 Canterbury Earthquake Sequence (Tonkin + Taylor, 2015). Modified for clarity of description.

Quantitative Assessment – Annual Property Risk

The quantitative estimation of Annual Property Risk as described in Section 3.5.2.

Land Damage

To assess property risks the T+T (2022) assessment of liquefaction and lateral spread in Glenorchy has been adopted for land damage vulnerability. With correlation between LSN and land damage as presented Table E-1 considered for zones where liquefaction damage dominates.

Building Damage

As described in Section 3.5.2, the approach to estimate the annual property risk (APR) requires estimating the building vulnerability to damage ($V_{(D:T)}$). An international literature review was undertaken to consider methods adopted in risk studies to estimate the vulnerability of damage to buildings. The Hazus multi-hazard loss estimation methodology (FEMA 2022) outlines the methodology to estimate the potential building damage due to ground failure. However, FEMA (2022) noted that there is no existing fragility relationship between the likelihood of damage of building and ground damage. Therefore, engineering judgement-based approach is considered for this quantitative assessment.

The 2010/2011 Canterbury earthquake sequence (CES) provides a real-world scenario to estimate building damage in response to land damage. Rogers et al., (2015) reported frequency of occurrence of building damage ratio for various levels of liquefaction land damage as presented in the histogram within Figure E-3. The BDR presented in the paper is equivalent to the $V_{(D:T)}$, represents the residential house damage repair costs normalised with respect to the financial value of each house. The BDR is found to be low in the areas where land damage was none to Minor. Conversely, Moderate to Severe land damage was observed in areas with high BDR (refer Figure E-3). Despite the case-study being based in Christchurch and not specific to Glenorchy, it provides insight into the distribution of expected land damage to building damage associated with liquefaction and Minor to Moderate lateral spread (<1m). This relationship is considered appropriate for the buildings within Glenorchy as the dominate building is lightweight timber frame buildings of 1-2 stories which is also the dominate building typology in Christchurch.

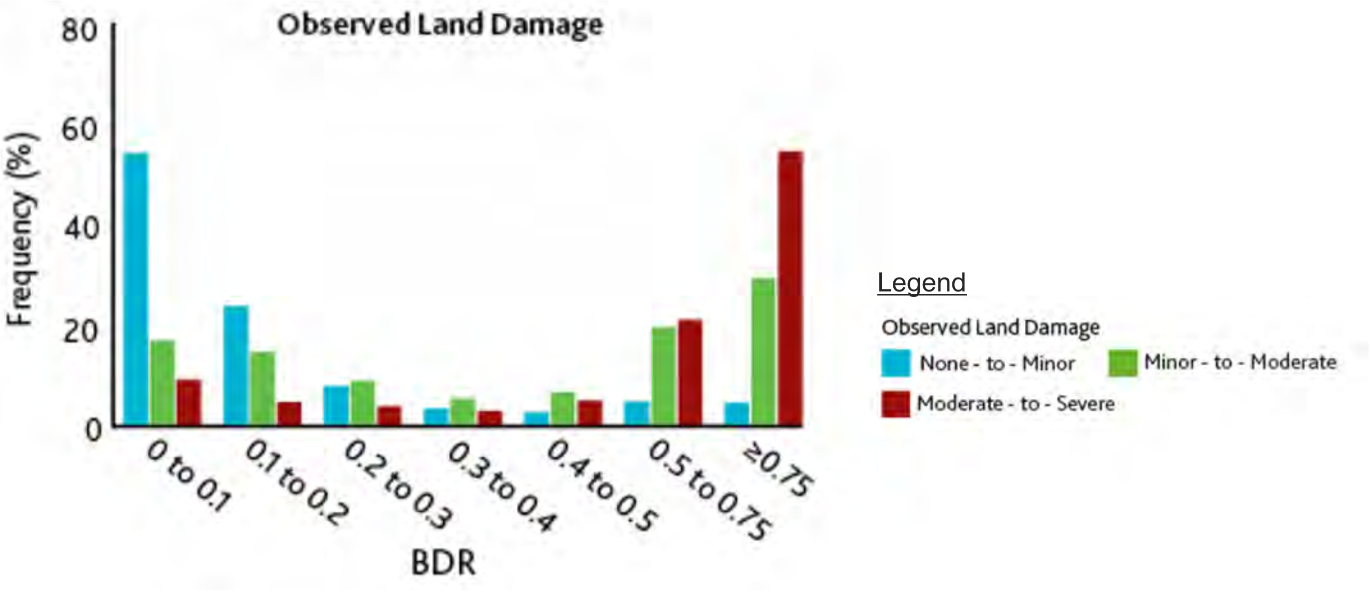


Figure E-3: Building Damage Ratio compared against the frequency recorded for the levels of liquefaction observed land damage in the 2010/2011 Canterbury earthquakes (from Rogers et al, 2015)

The frequency of occurrence of building damage ratio being within a set range for various levels of liquefaction land damage (refer Figure E-3 sourced from Roders et al, 2015) has been used to estimate a typical building damage ratio for the broad land liquefaction land damage categories adopted for the project, the adopted values presented in Table E-3 below.

Table E-3: Assessed building damage ratio based on land damage vulnerability

Assessed LSN[A]	Degree of liquefaction- induced ground damage [B]	Building Damage Ratio [C] (%)
0 – 8	None to Minor	15
8 - 16	Minor to Moderate	50
> 20	Moderate to Severe	70

[A] T+T Glenorchy Liquefaction Vulnerability Assessment (May 2022)

[B] MBIE/MfE, Planning and engineering guidance for potentially liquefaction-prone land (September 2017)

[C] Based on frequence of Observed building damage ratio during CES (Rogers et al., 2015)

F

Appendix F – Qualitative Risk Level Maps

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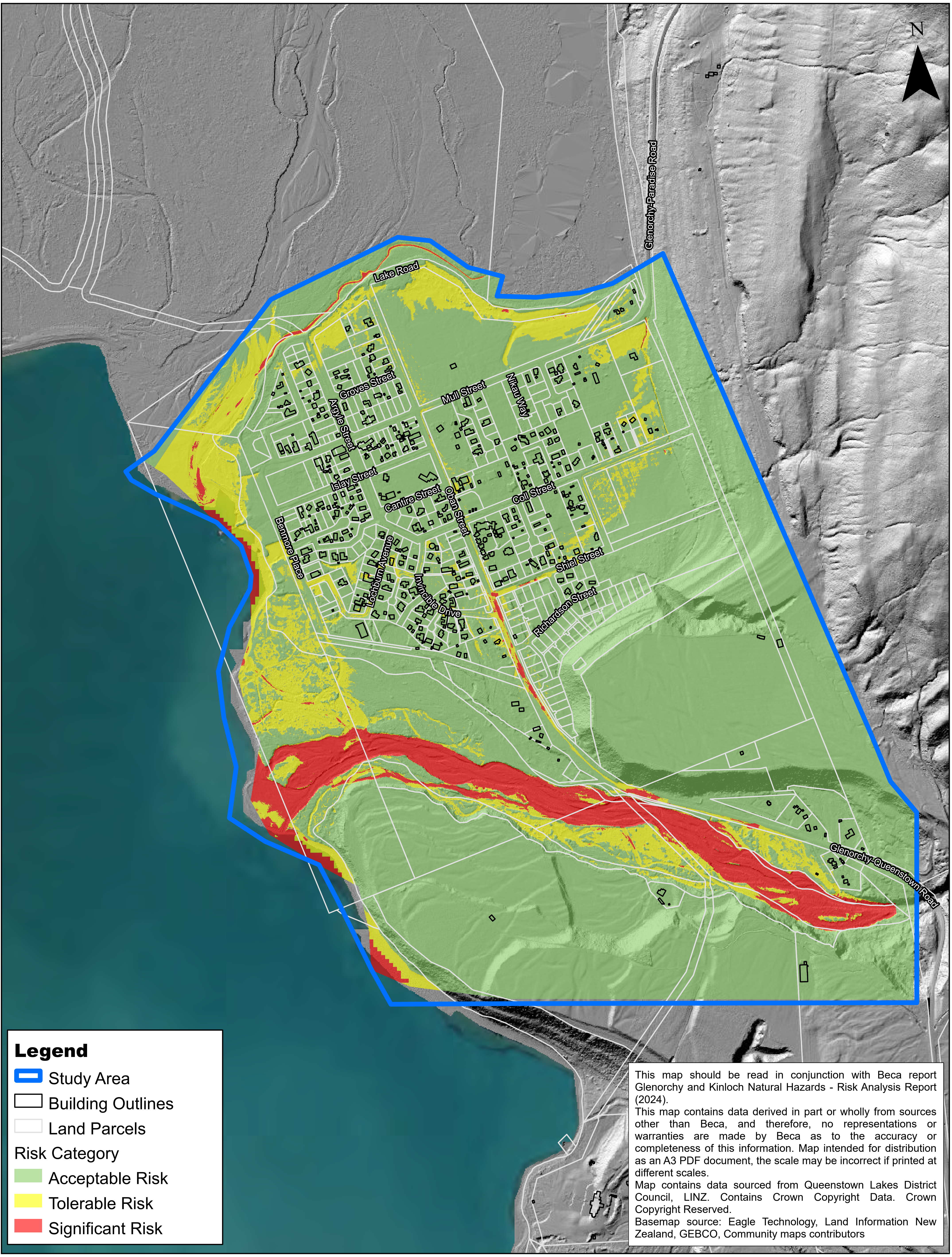

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0 200
Metres

Revision	0.1
Status	Final
Author	ZT825
Verifier	BDJ2
Date	26/08/2024

Buckler Burn Flooding
Qualitative Buildings Risk
200 m3/s River Flood &
10 Year ARI Lake Level
Glenorchy

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Project	Glenorchy Kinloch Natural Hazard RA
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Discipline	GIS
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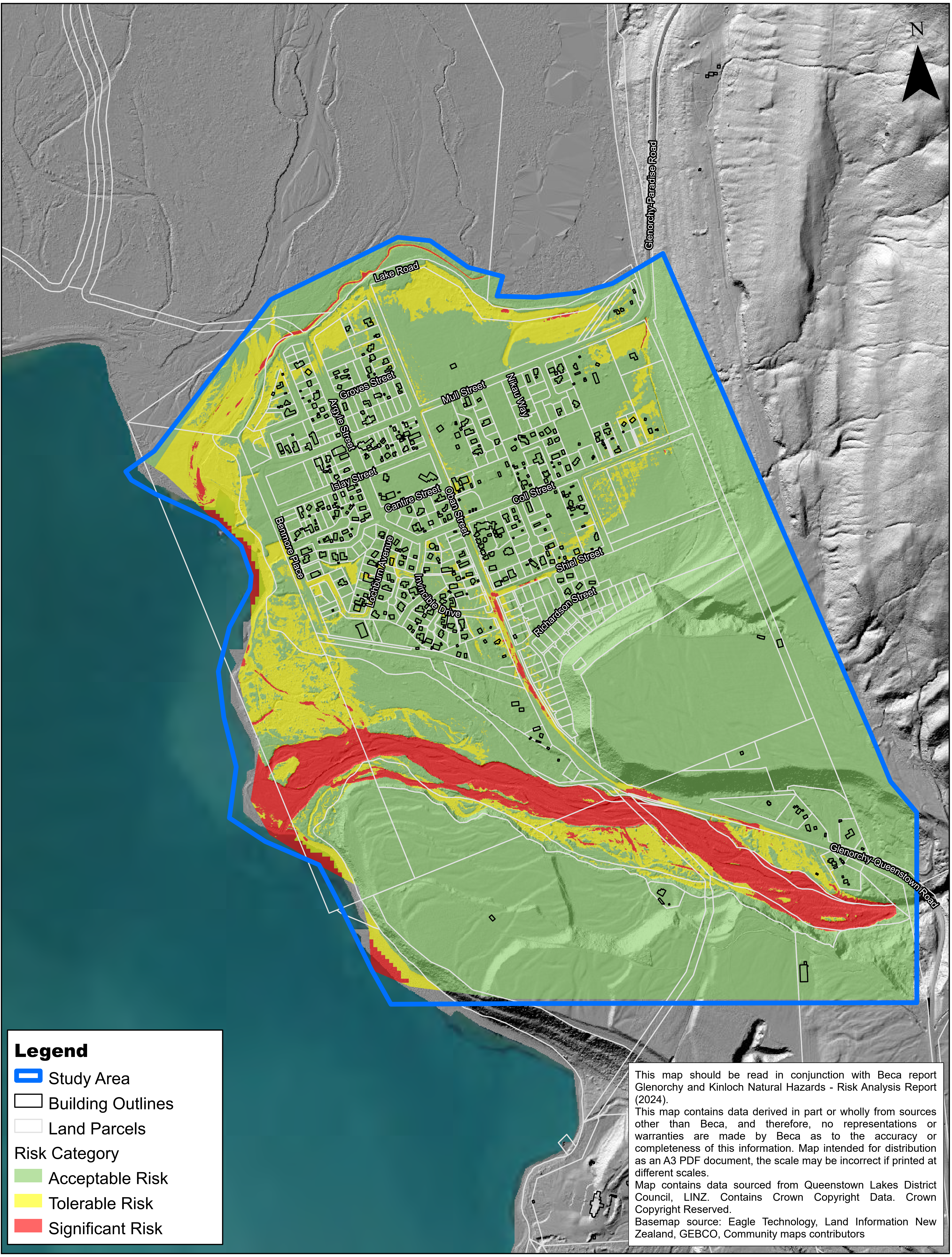

Legend

- 🟦 Study Area
- ☐ Building Outlines
- ☐ Land Parcels

Risk Category

- 🟩 Acceptable Risk
- 🟨 Tolerable Risk
- 🟥 Significant Risk

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Buckler Burn Flooding
Qualitative Buildings Risk
250 m3/s River Flood &
10 Year ARI Lake Level
Glenorchy

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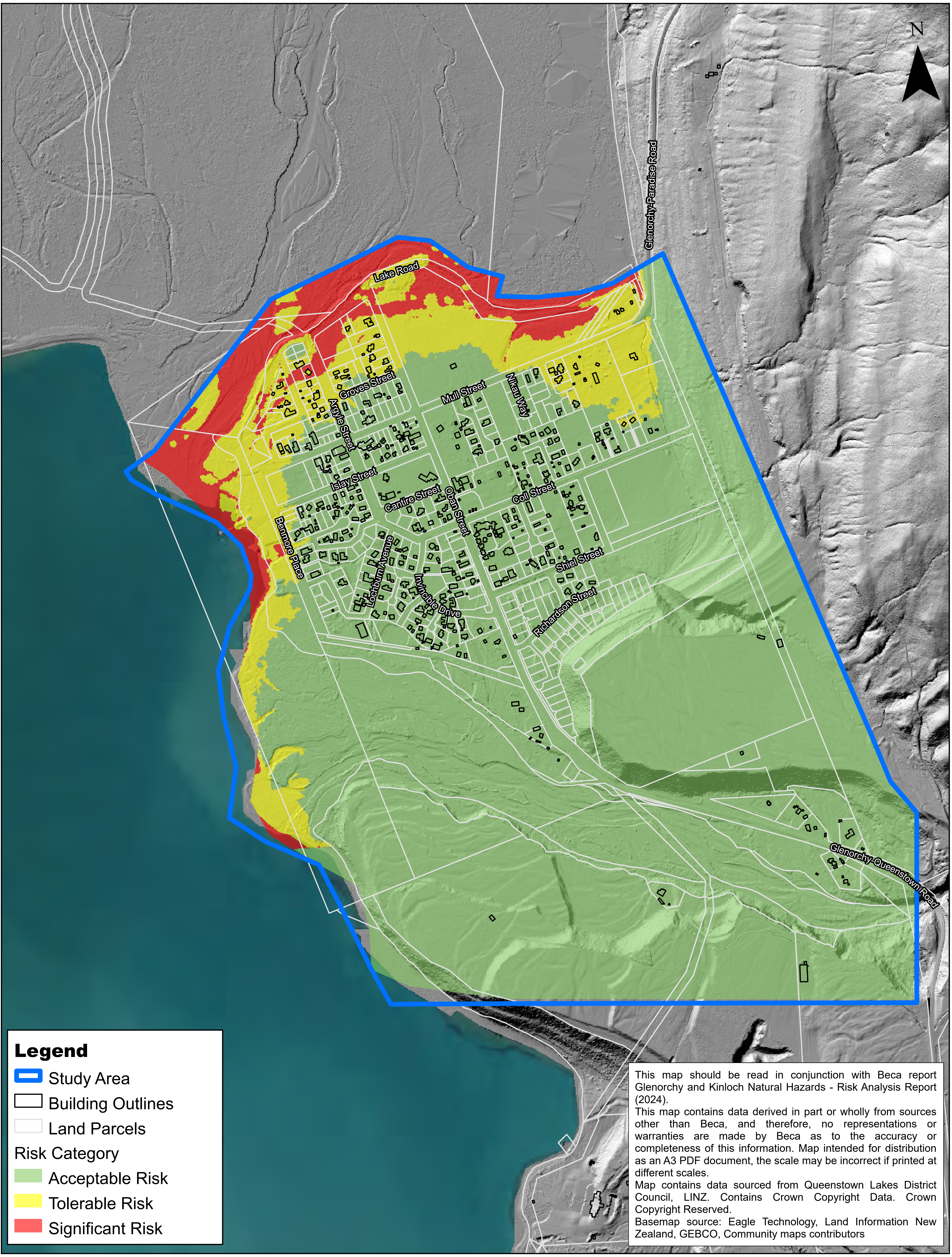

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Rees/Dart Flooding
Qualitative Buildings Risk
100 Year ARI River Flood &
10 Year ARI Lake Level
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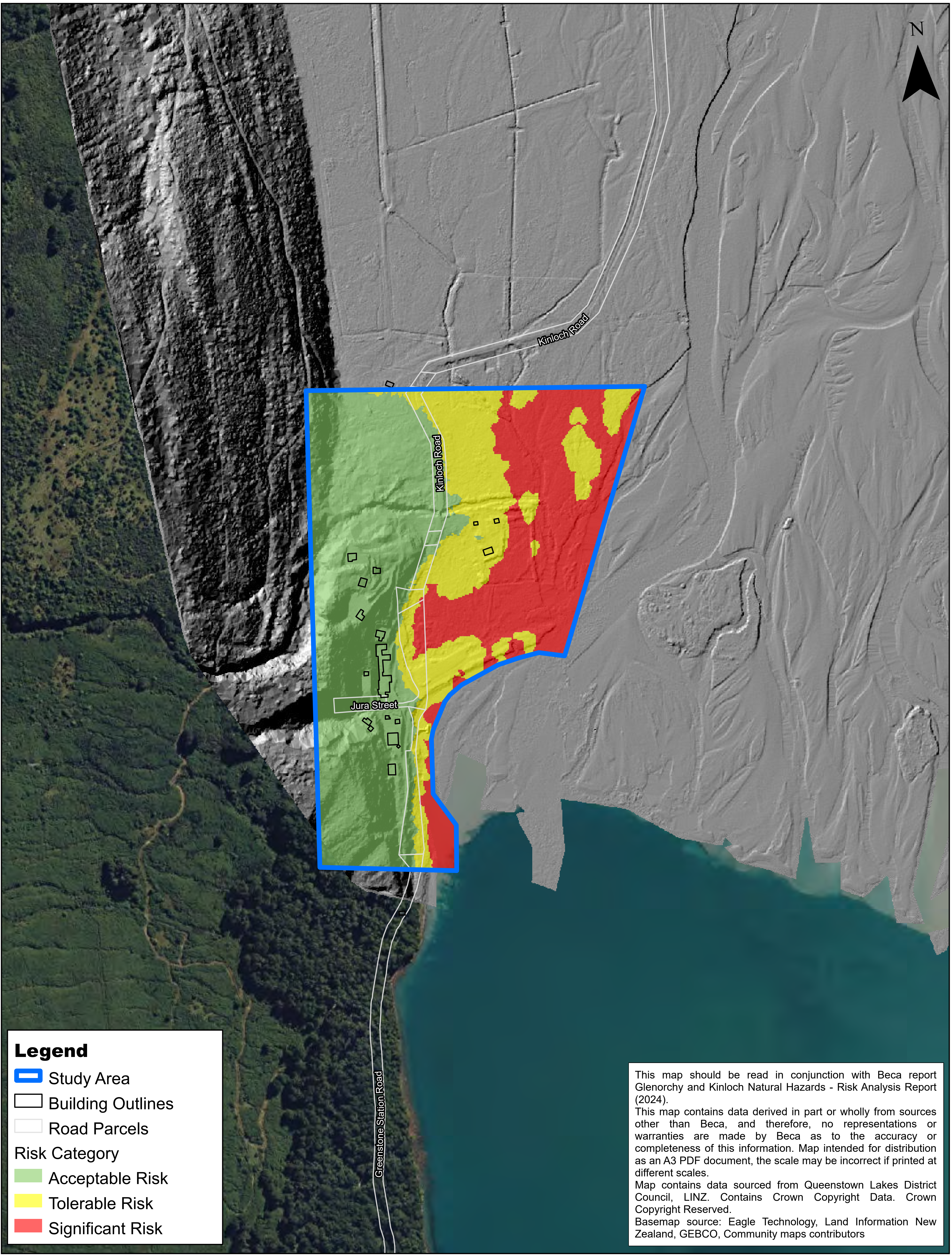

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Rees/Dart Flooding
Qualitative Buildings Risk
100 Year ARI River Flood &
10 Year ARI Lake Level
Kinloch

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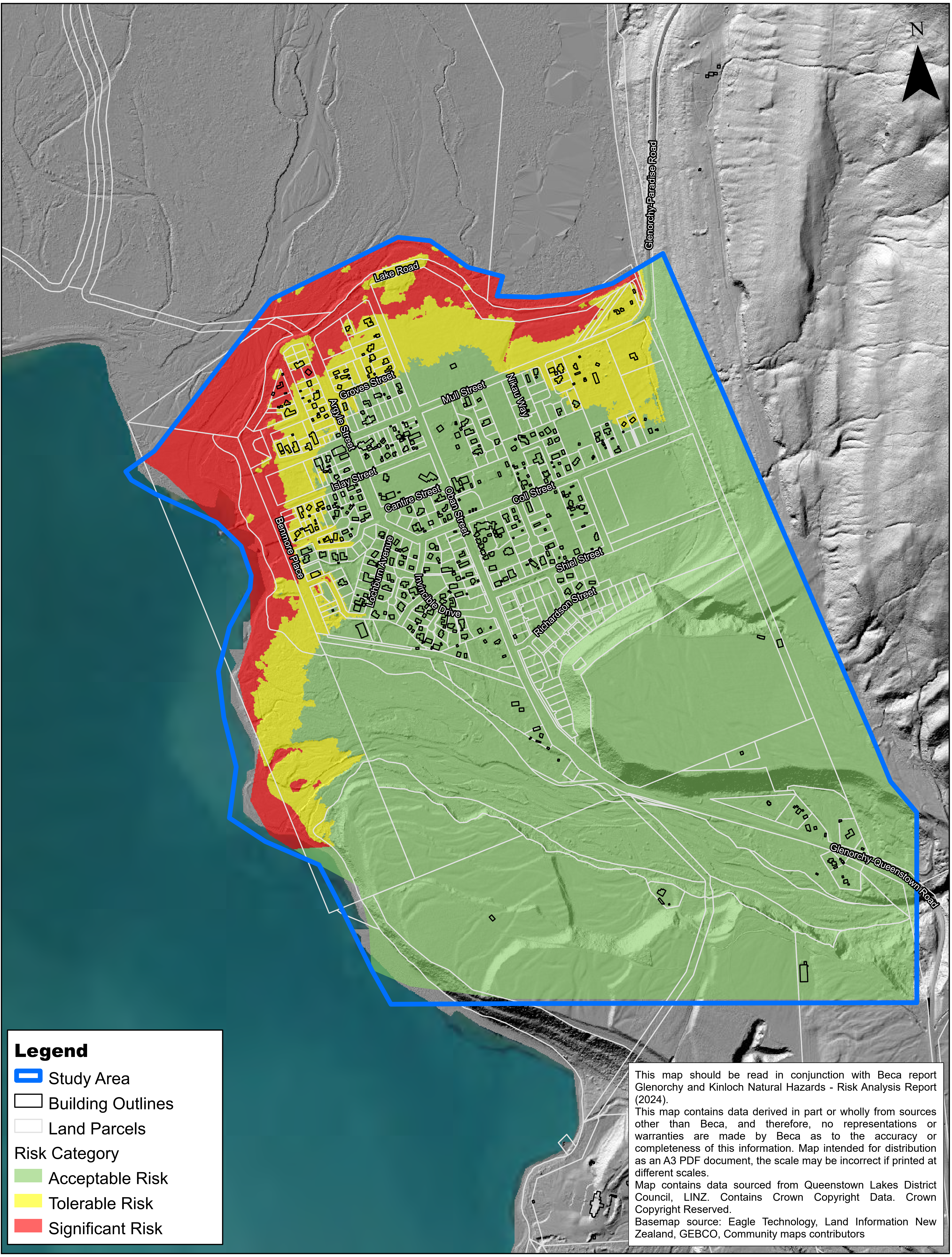

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Qualitative Buildings Risk
100 Year ARI River Flood &
100 Year ARI Lake Level
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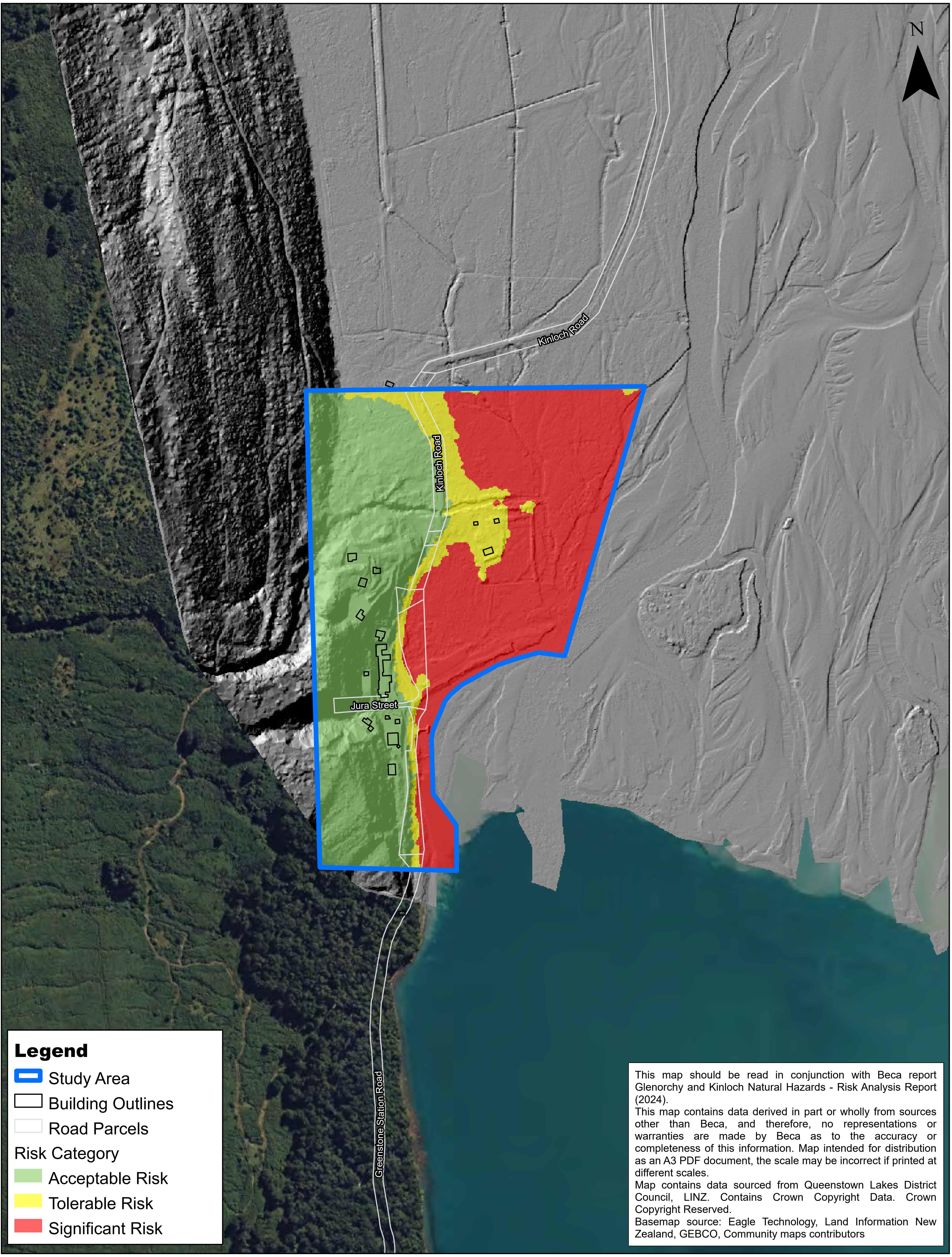

Legend

- 🟦 Study Area
- ☐ Building Outlines
- ☐ Road Parcels

Risk Category

- 🟩 Acceptable Risk
- 🟨 Tolerable Risk
- 🟥 Significant Risk

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Rees/Dart Flooding
Qualitative Buildings Risk
100 Year ARI River Flood &
100 Year ARI Lake Level
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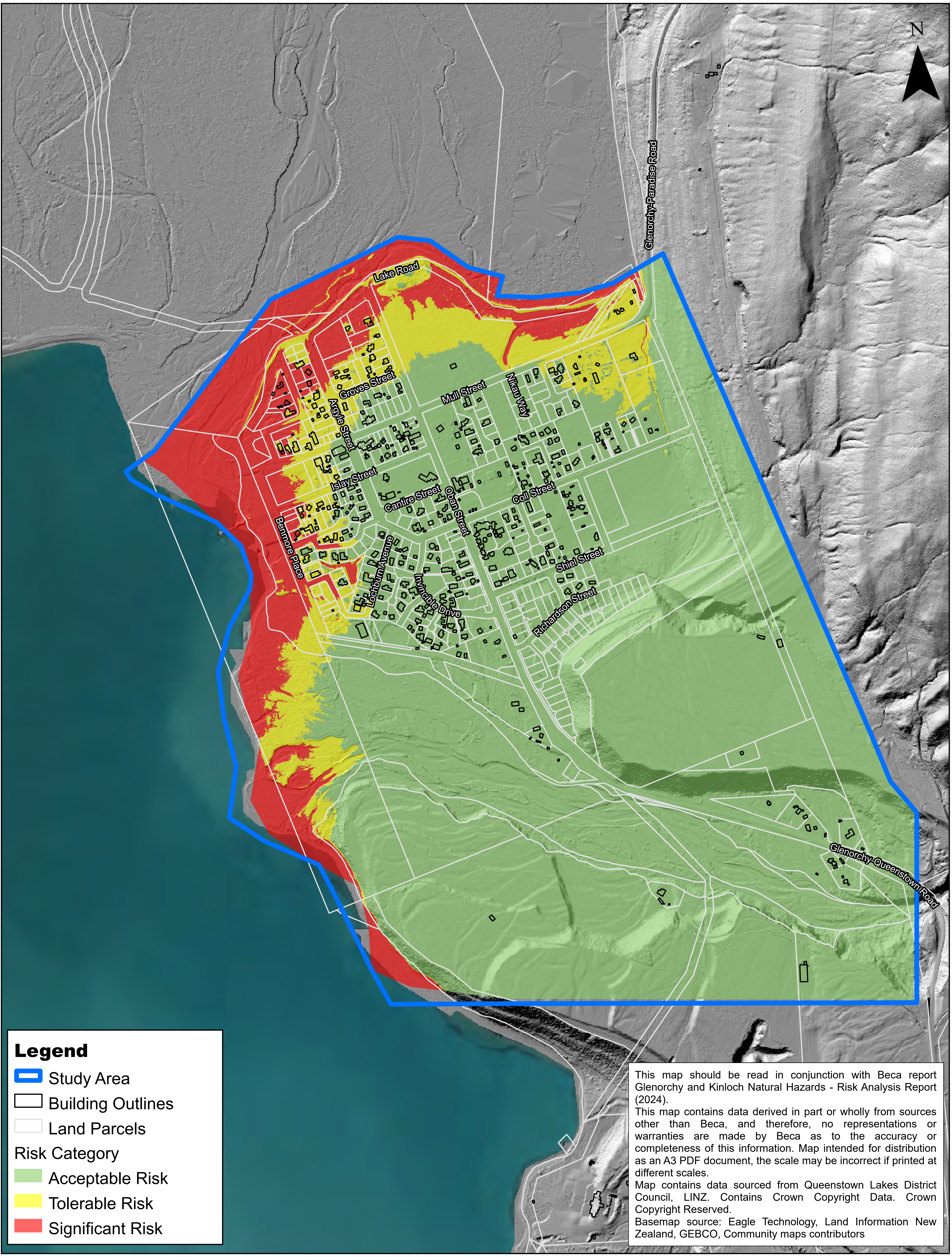

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Lake Flood
Qualitative Buildings Risk
100 Year Average Return Period
Glenorchy

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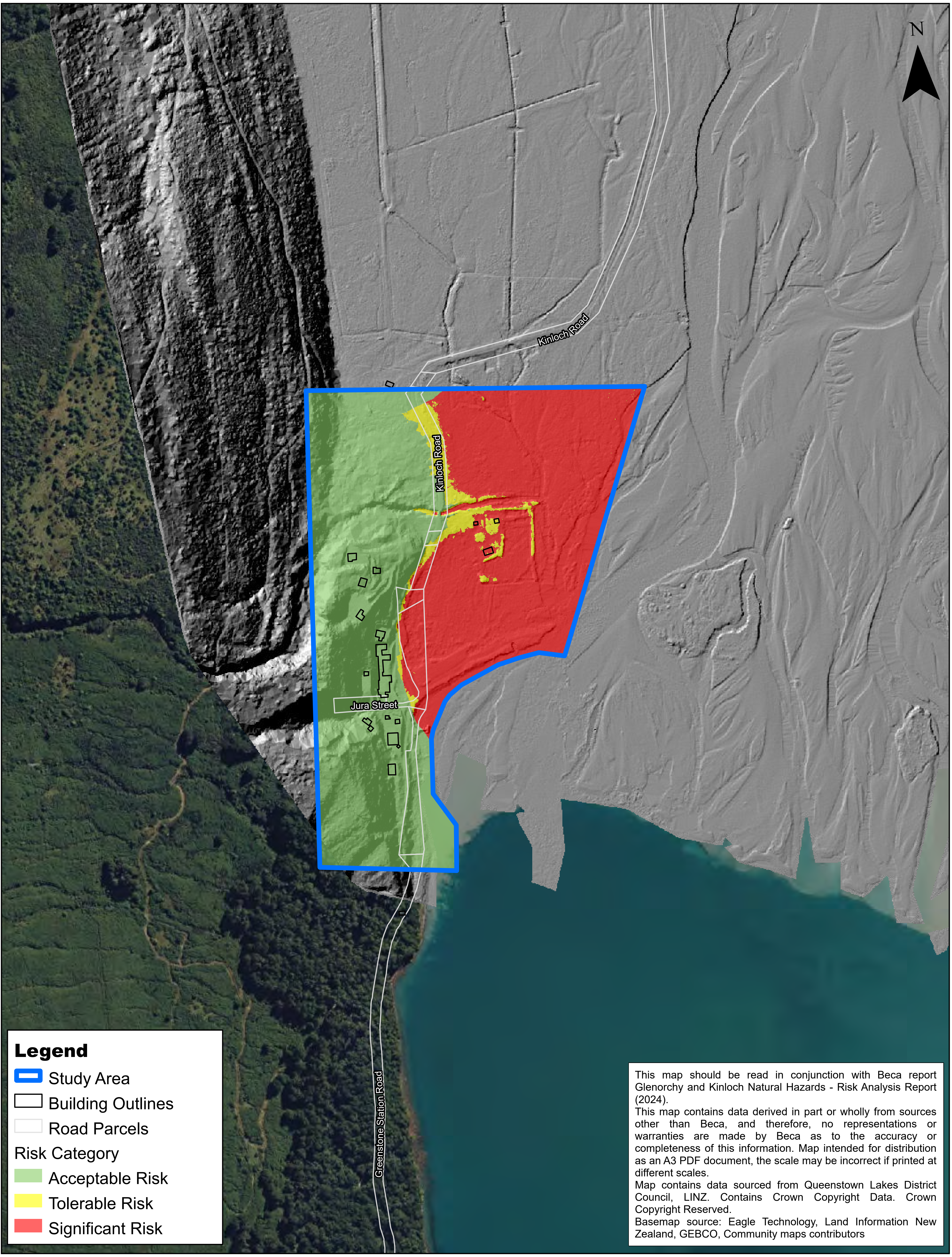

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Lake Flood
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100 Year Average Return Period
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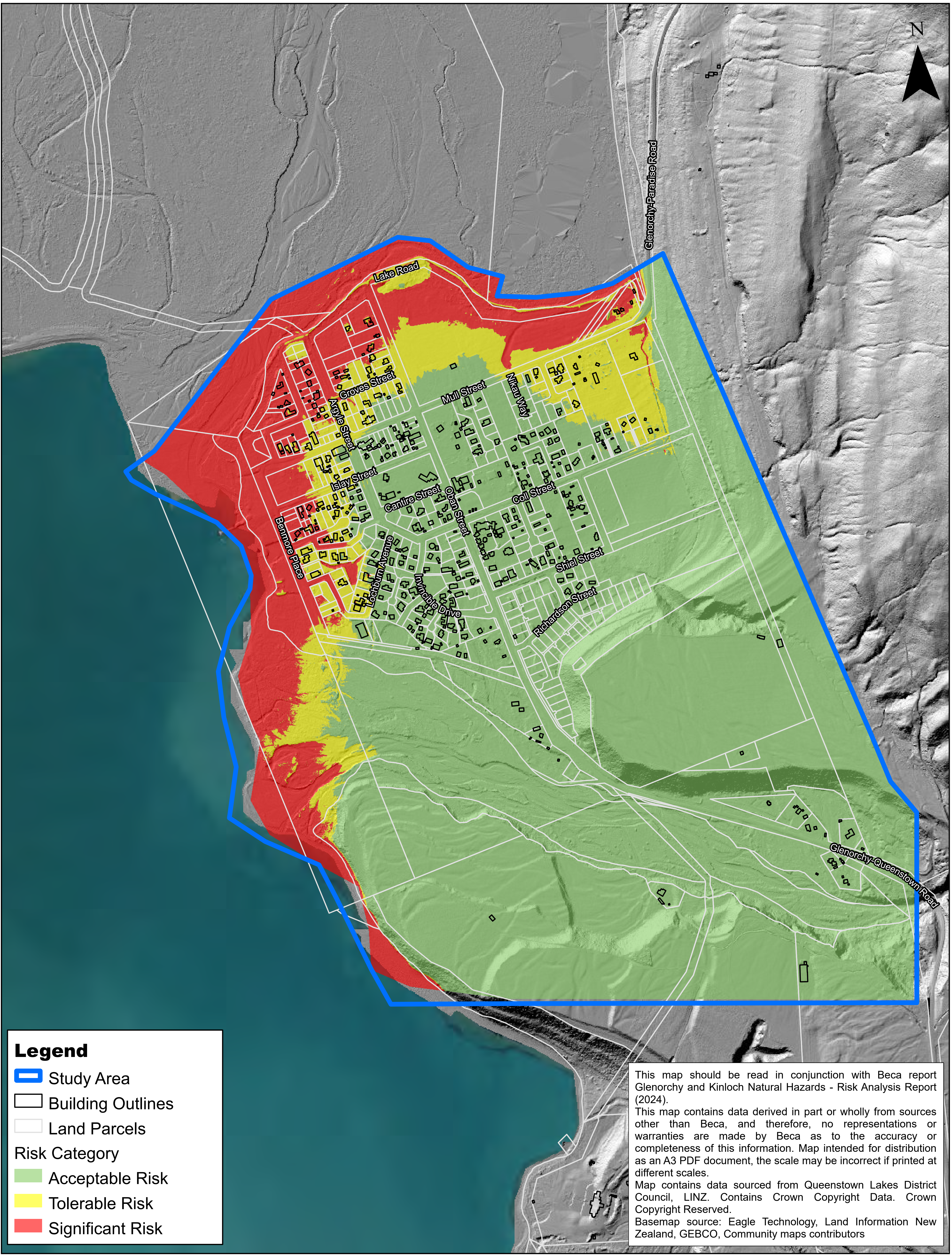

Legend

- Study Area
- Building Outlines
- Land Parcels

Risk Category

- 🟩 Acceptable Risk
- 🟨 Tolerable Risk
- 🟥 Significant Risk

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Lake Flood
Qualitative Buildings Risk
200 Year Average Return Period
Glenorchy

Beca

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Drawing Number	GIS-3160904-01-006-01

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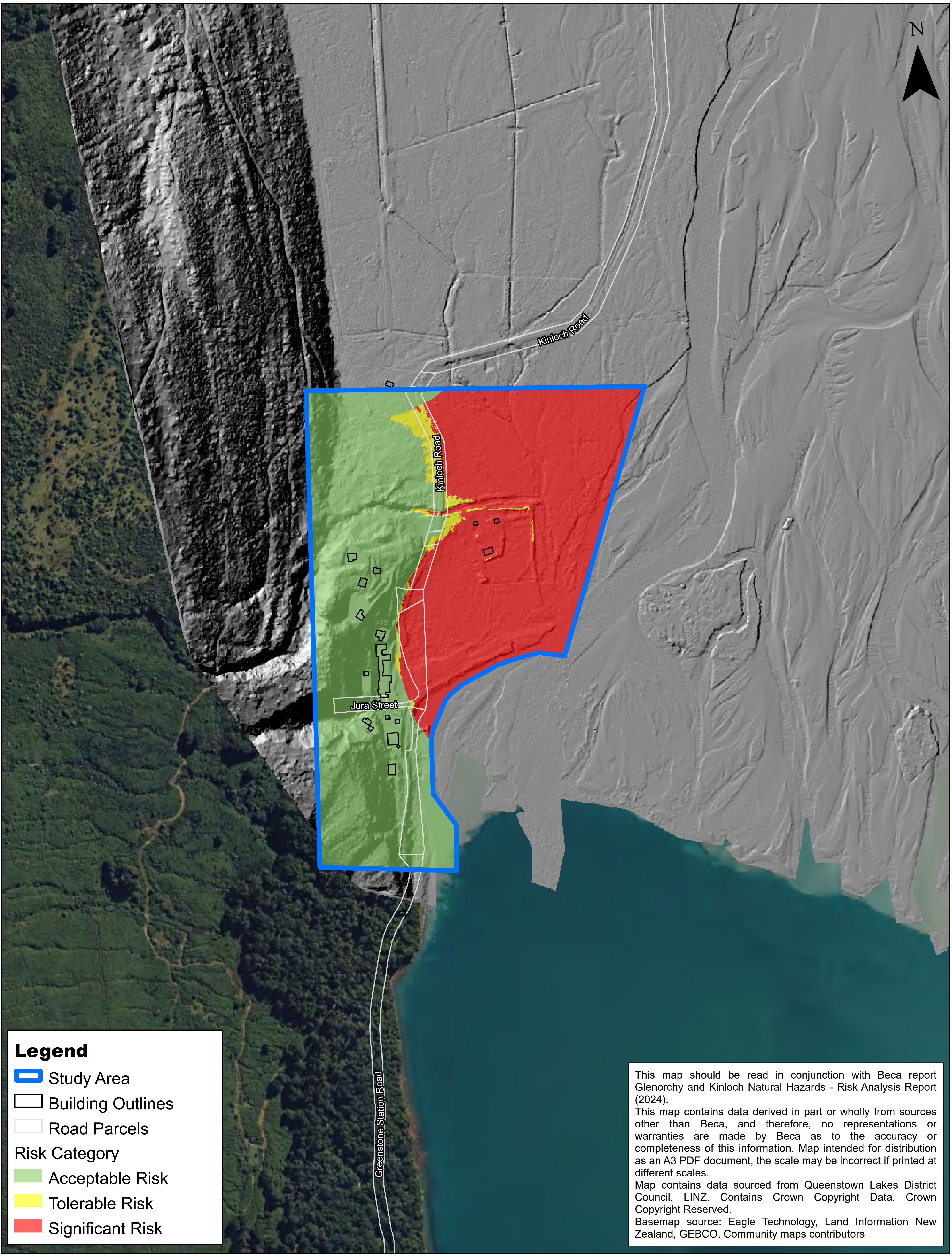

Legend

- 🟦 Study Area
- ☐ Building Outlines
- ☐ Road Parcels

Risk Category

- 🟩 Acceptable Risk
- 🟨 Tolerable Risk
- 🟥 Significant Risk

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Map Scale @ A3: 1:5,000

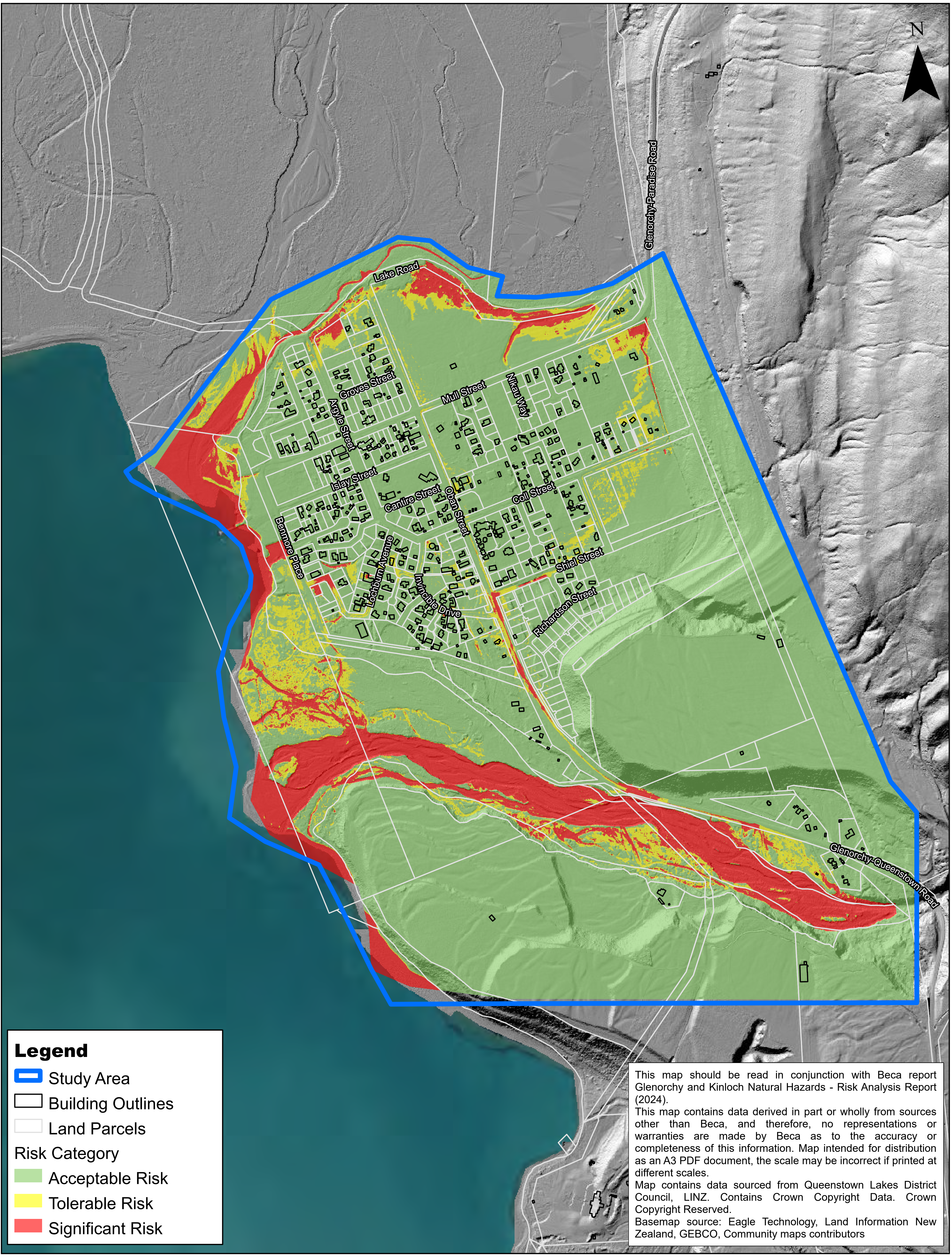
0 200
Metres

Revision	0.1
Status	Final
Author	ZT825
Verifier	BDJ2
Date	26/08/2024

Lake Flood
Qualitative Buildings Risk
200 Year Average Return Period
Kinloch

Beca

Project	Glenorchy Kinloch Natural Hazard RA
Client	Otago Regional Council
Discipline	GIS
Drawing Number	GIS-3160904-01-006-02



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Map Scale @ A3: 1:8,500

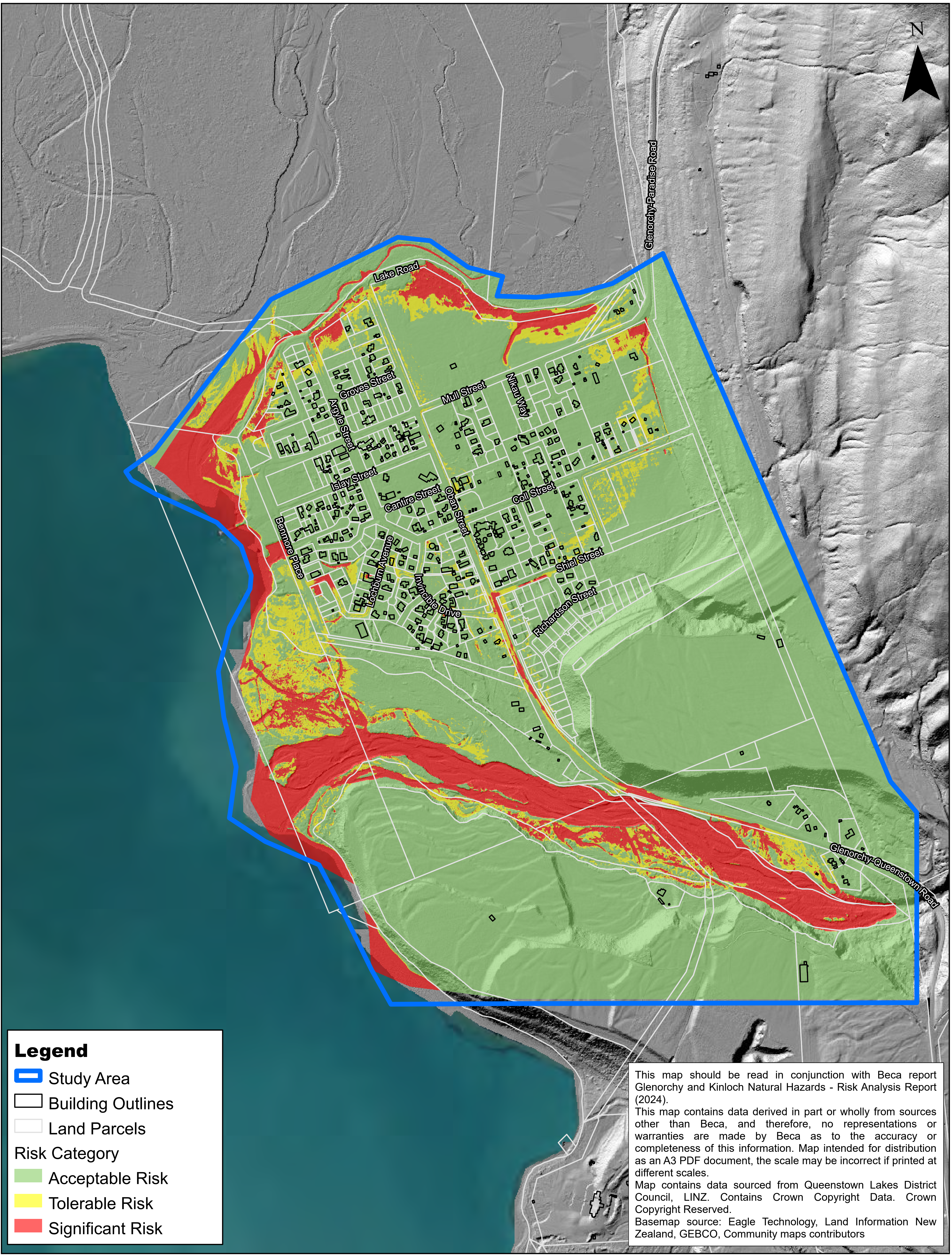
0 200
Metres

Revision	0.1
Status	Final
Author	ZT825
Verifier	BDJ2
Date	26/08/2024

Buckler Burn Flooding
Qualitative Lifelines Risk
200 m3/s River Flood &
10 Year ARI Lake Level
Glenorchy

Beca

Project	Glenorchy Kinloch Natural Hazard RA
Client	Otago Regional Council
Discipline	GIS
Drawing Number	GIS-3160904-01-007-01



Legend

- Study Area
- Building Outlines
- Land Parcels

Risk Category

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- 🟥 Significant Risk

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Map Scale @ A3: 1:8,500

0 200
Metres

Revision	0.1
Status	Final
Author	ZT825
Verifier	BDJ2
Date	26/08/2024

Buckler Burn Flooding
Qualitative Lifelines Risk
250 m3/s River Flood &
10 Year ARI Lake Level
Glenorchy

Beca

Project	Glenorchy Kinloch Natural Hazard RA
Client	Otago Regional Council
Discipline	GIS
Drawing Number	GIS-3160904-01-008-01

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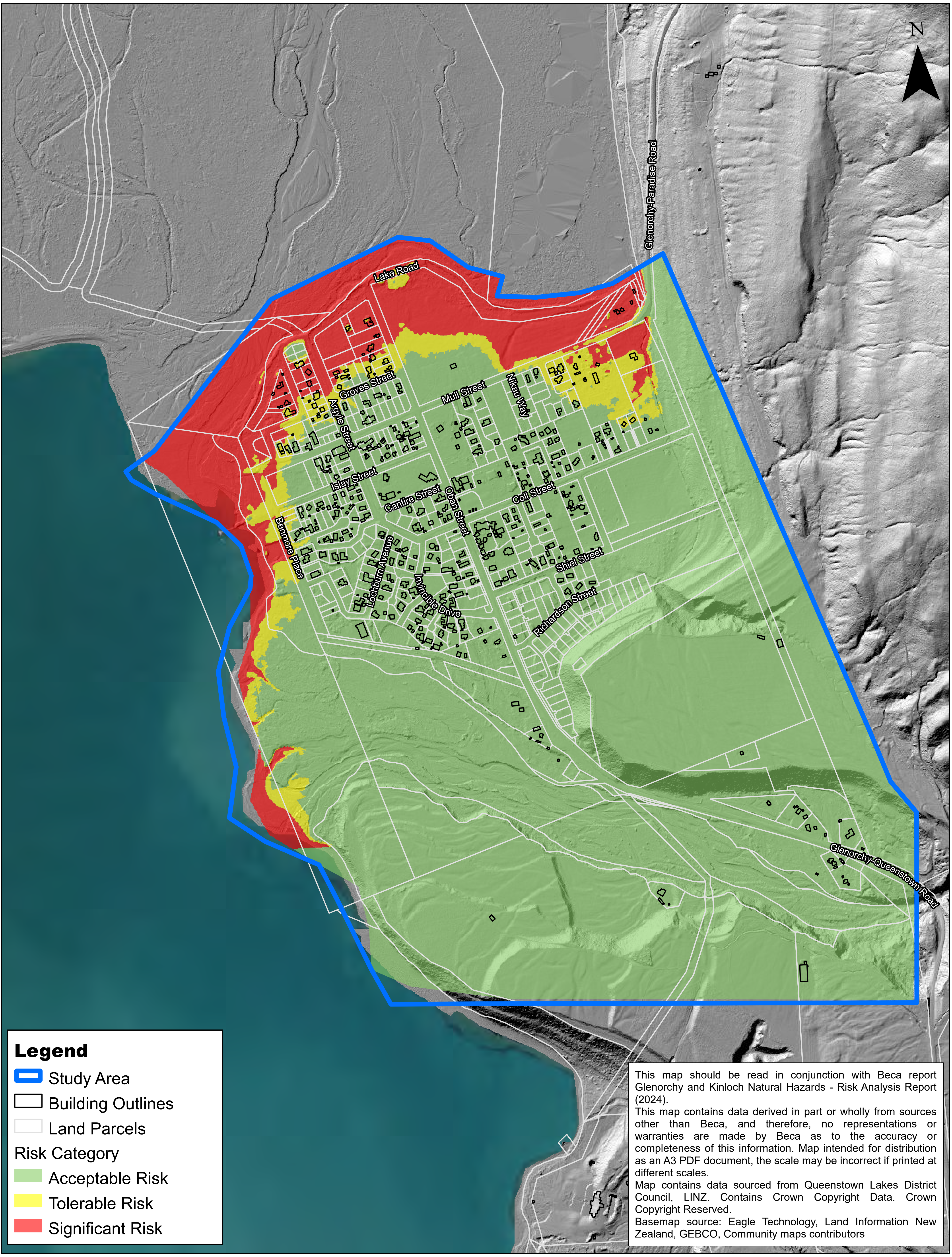
Path: P:\316\3160904\1-WIP\WG-GIS\01-Map\GlenorchyKinloch_ReportMaps\GlenorchyKinloch_ReportMaps.aprx Map Layout: 01 Qualitative - Flooding Date Printed: 26/08/2024



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Revision	0.1
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Author	ZT825
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Rees/Dart Flooding
Qualitative Lifelines Risk
100 Year ARI River Flood &
10 Year ARI Lake Level

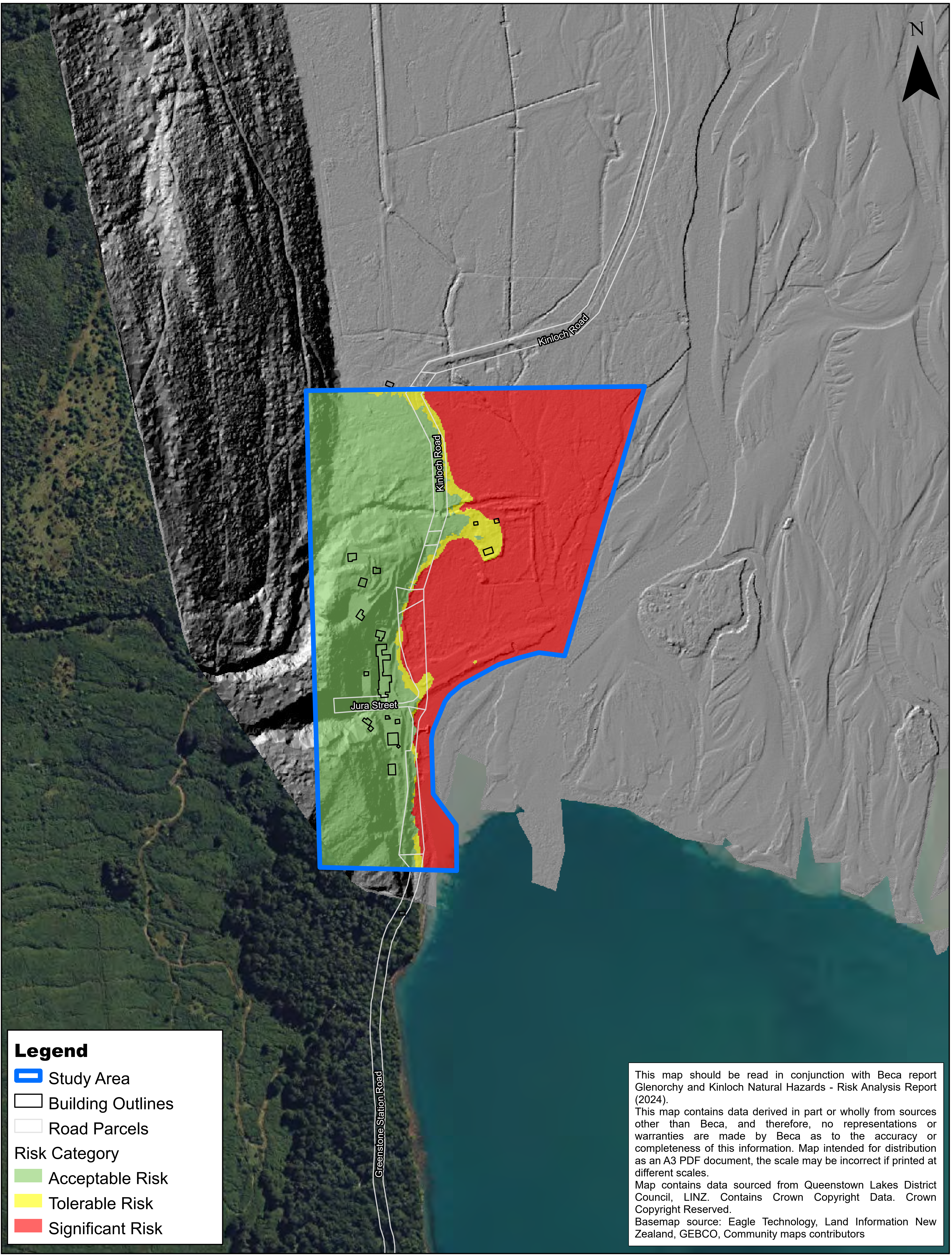
Glenorchy

Beca

Project	Glenorchy Kinloch Natural Hazard RA
Client	Otago Regional Council
Discipline	GIS
Drawing Number	GIS-3160904-01-009-01

GIS@beca.com

Path: P:\316\3160904\1-WIP\WG-GIS\01-Map\GlenorchyKinloch_ReportMaps\GlenorchyKinloch_ReportMaps.aprx Map Layout: 01 Qualitative - Flooding Date Printed: 26/08/2024



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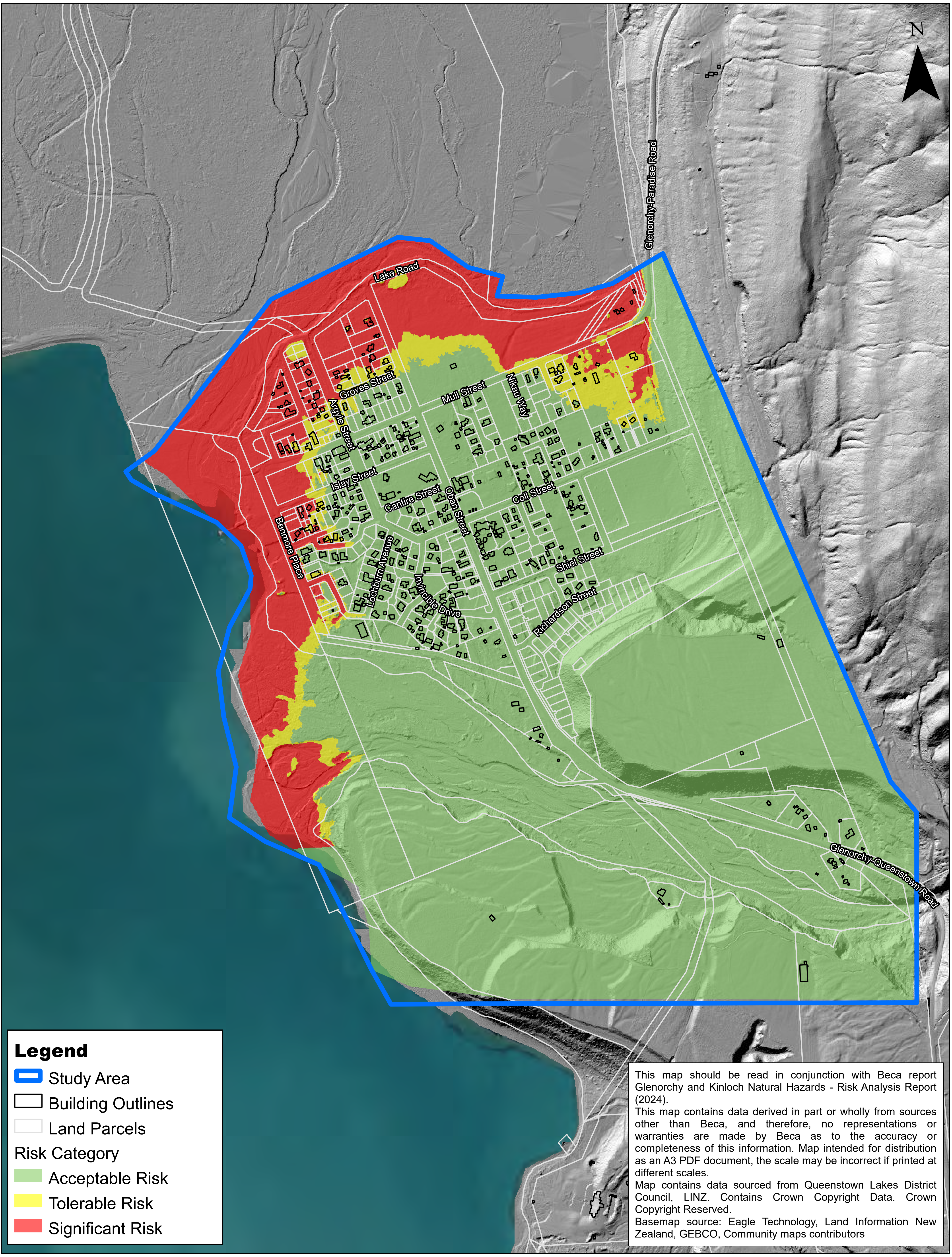
Rees/Dart Flooding
Qualitative Lifelines Risk
100 Year ARI River Flood &
10 Year ARI Lake Level
Kinloch

Beca

Project	Glenorchy Kinloch Natural Hazard RA
Client	Otago Regional Council
Discipline	GIS
Drawing Number	GIS-3160904-01-009-02



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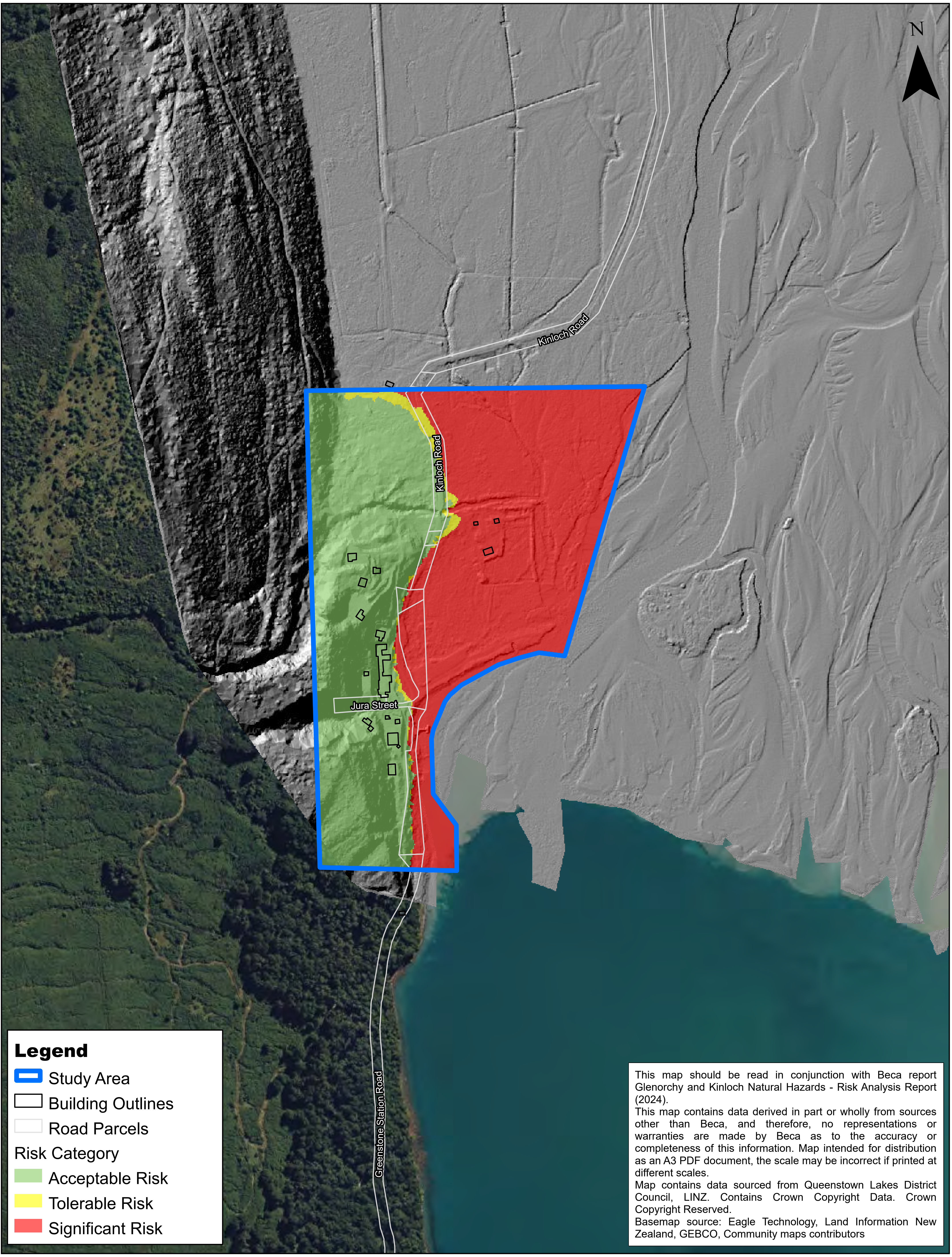
Rees/Dart Flooding
Qualitative Lifelines Risk
100 Year ARI River Flood &
100 Year ARI Lake Level
Glenorchy

Beca

Project	Glenorchy Kinloch Natural Hazard RA
Client	Otago Regional Council
Discipline	GIS
Drawing Number	GIS-3160904-01-010-01

GIS@beca.com

Path: P:\316\3160904\1-WIP\WG-GIS\01-Map\GlenorchyKinloch_ReportMaps\GlenorchyKinloch_ReportMaps.aprx Map Layout: 01 Qualitative - Flooding Date Printed: 26/08/2024



Legend

- ▭ Study Area
- ▭ Building Outlines
- ▭ Road Parcels

Risk Category

- 🟩 Acceptable Risk
- 🟨 Tolerable Risk
- 🟥 Significant Risk

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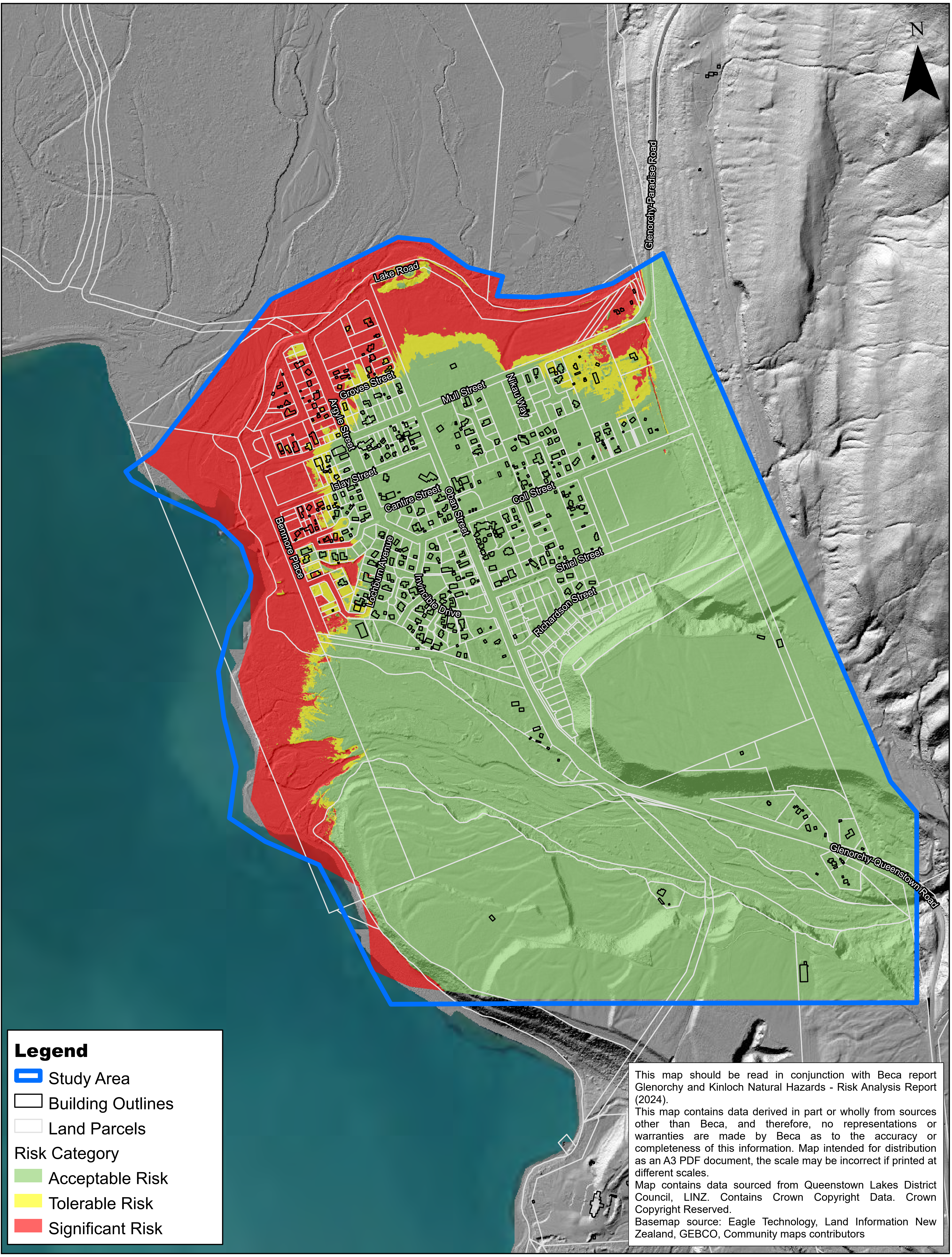
Rees/Dart Flooding
Qualitative Lifelines Risk
100 Year ARI River Flood &
100 Year ARI Lake Level
Kinloch

Beca

Project	Glenorchy Kinloch Natural Hazard RA
Client	Otago Regional Council
Discipline	GIS
Drawing Number	GIS-3160904-01-010-02

GIS@beca.com



Legend

🟦 Study Area

☐ Building Outlines

☐ Land Parcels

Risk Category

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🟥 Significant Risk

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Map Scale @ A3: 1:8,500

0 200

Metres

Revision 0.1
Status Final
Author ZT825
Verifier BDJ2
Date 26/08/2024

Lake Flood
Qualitative Lifelines Risk
100 Year Average Return Period

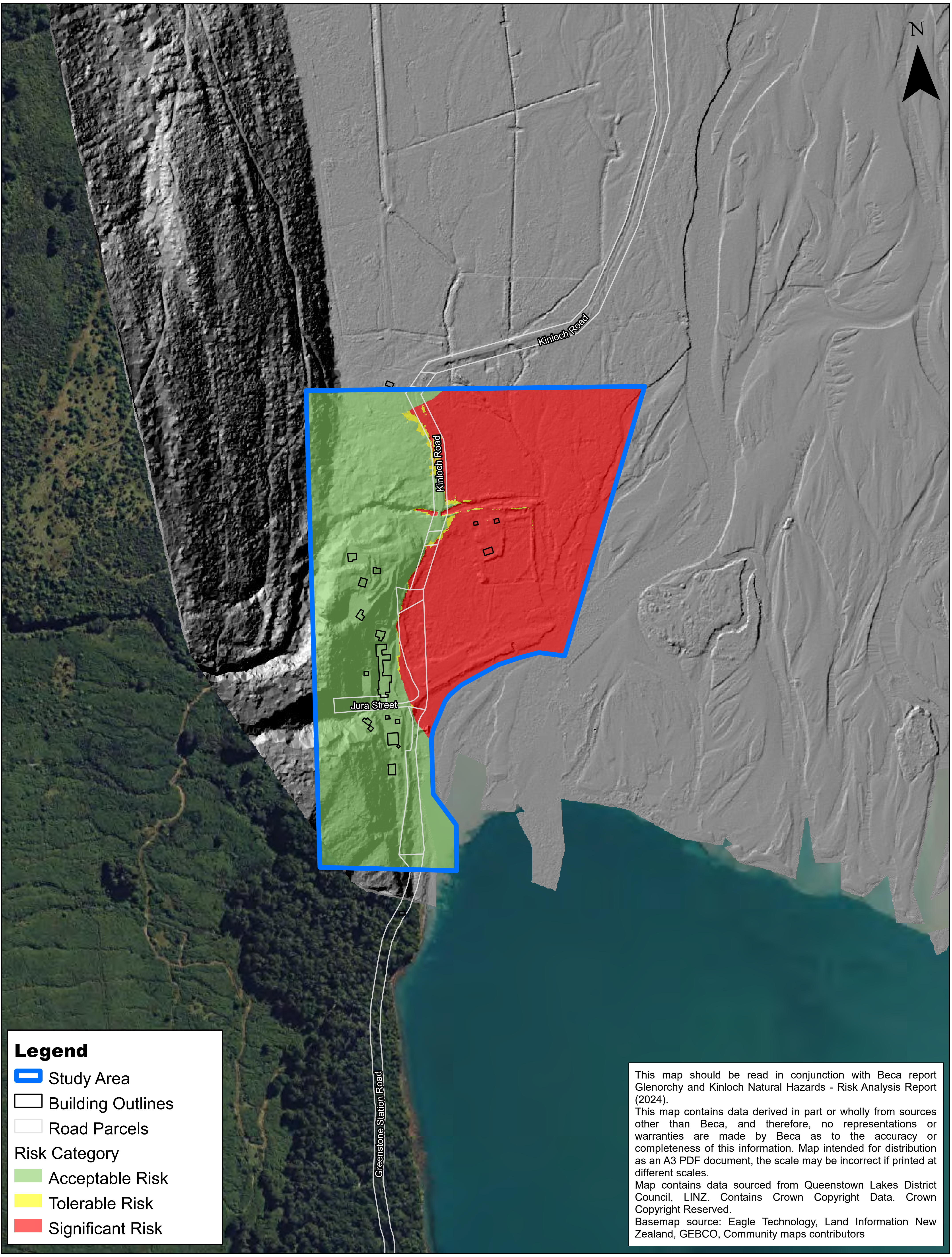
Glenorchy

Beca

Project Glenorchy Kinloch Natural Hazard RA
Client Otago Regional Council
Discipline GIS
Drawing Number GIS-3160904-01-011-01

GIS@beca.com

Path: P:\316\3160904\1-WIP\WG-GIS\01-Map\GlenorchyKinloch_ReportMaps\GlenorchyKinloch_ReportMaps.aprx Map Layout: 01 Qualitative - Flooding Date Printed: 26/08/2024



Legend

- 🟦 Study Area
- ☐ Building Outlines
- ☐ Road Parcels

Risk Category

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Revision	0.1
Status	Final
Author	ZT825
Verifier	BDJ2
Date	26/08/2024

Lake Flood
Qualitative Lifelines Risk
100 Year Average Return Period
Kinloch

Beca

Project	Glenorchy Kinloch Natural Hazard RA
Client	Otago Regional Council
Discipline	GIS
Drawing Number	GIS-3160904-01-011-02

GIS@beca.com

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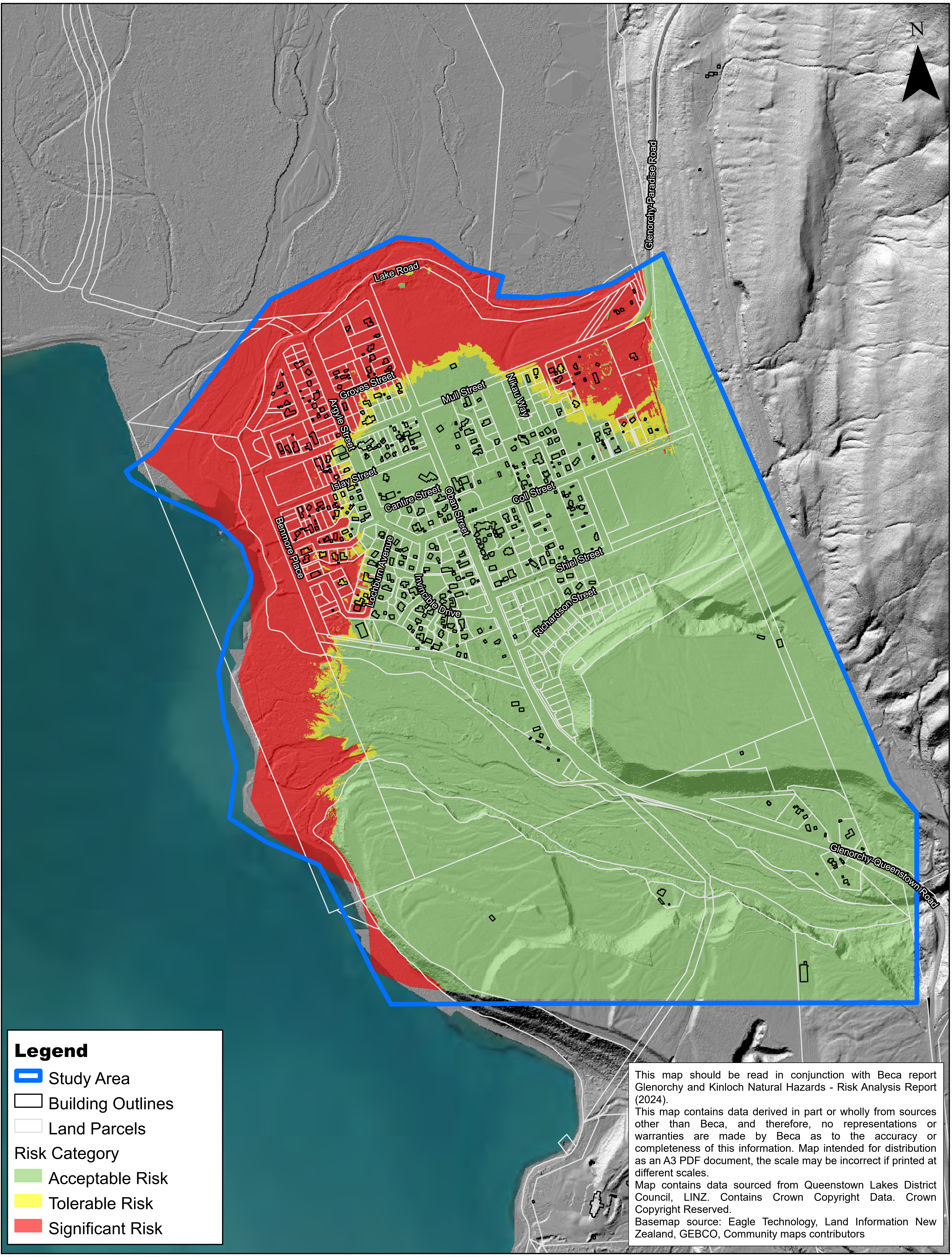

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0 200
Metres

Revision	0.1
Status	Final
Author	ZT825
Verifier	BDJ2
Date	26/08/2024

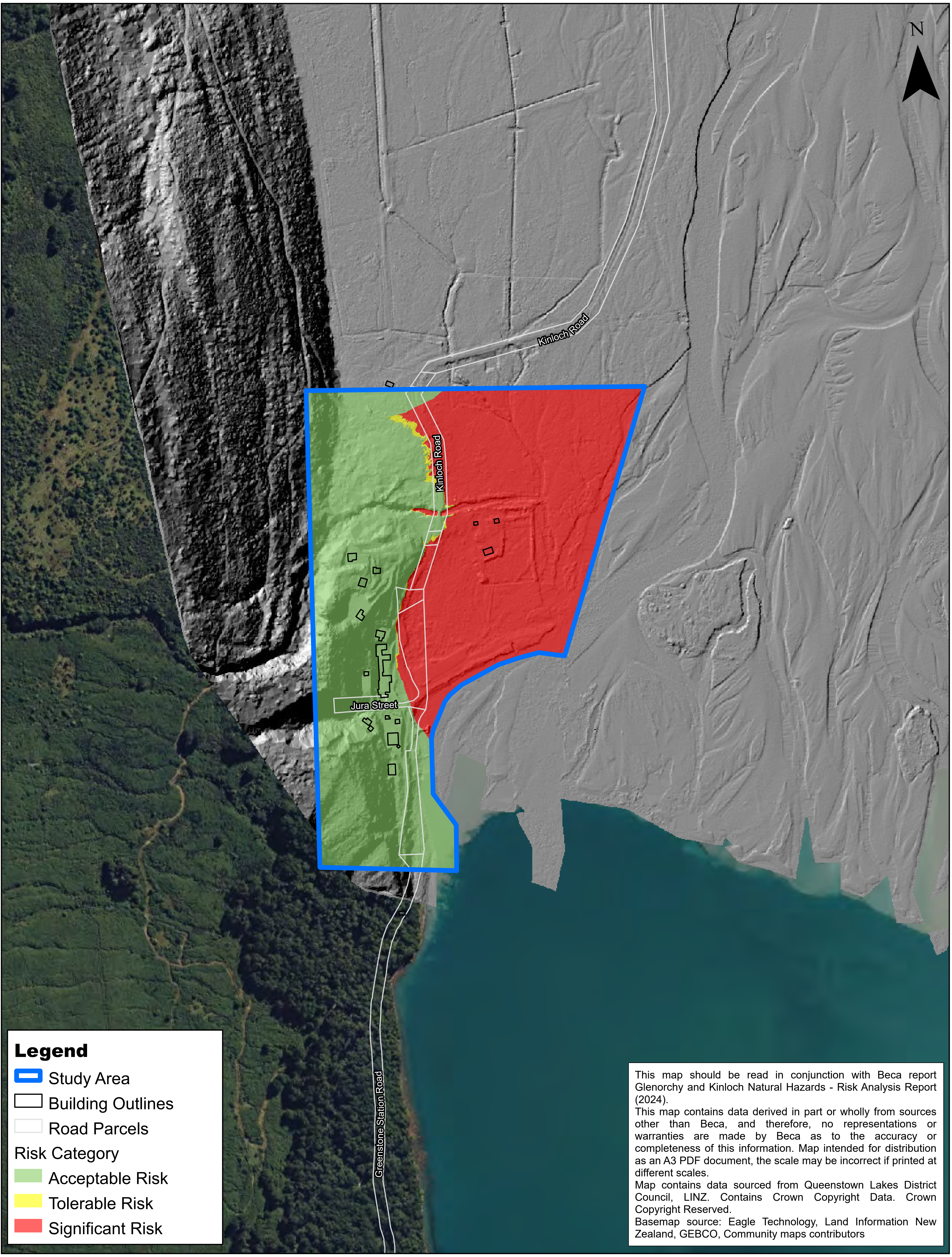
Lake Flood
Qualitative Lifelines Risk
200 Year Average Return Period
Glenorchy

Beca

Project	Glenorchy Kinloch Natural Hazard RA
Client	Otago Regional Council
Discipline	GIS
Drawing Number	GIS-3160904-01-012-01

GIS@beca.com

Path: P:\316\3160904\1-WIP\WG-GIS\01-Map\GlenorchyKinloch_ReportMaps\GlenorchyKinloch_ReportMaps.aprx Map Layout: 01 Qualitative - Flooding Date Printed: 26/08/2024



Legend

- ▭ Study Area
- ☐ Building Outlines
- ☐ Road Parcels

Risk Category

- 🟩 Acceptable Risk
- 🟨 Tolerable Risk
- 🟥 Significant Risk

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Lake Flood
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200 Year Average Return Period
Kinloch

Beca

Project	Glenorchy Kinloch Natural Hazard RA
Client	Otago Regional Council
Discipline	GIS
Drawing Number	GIS-3160904-01-012-02

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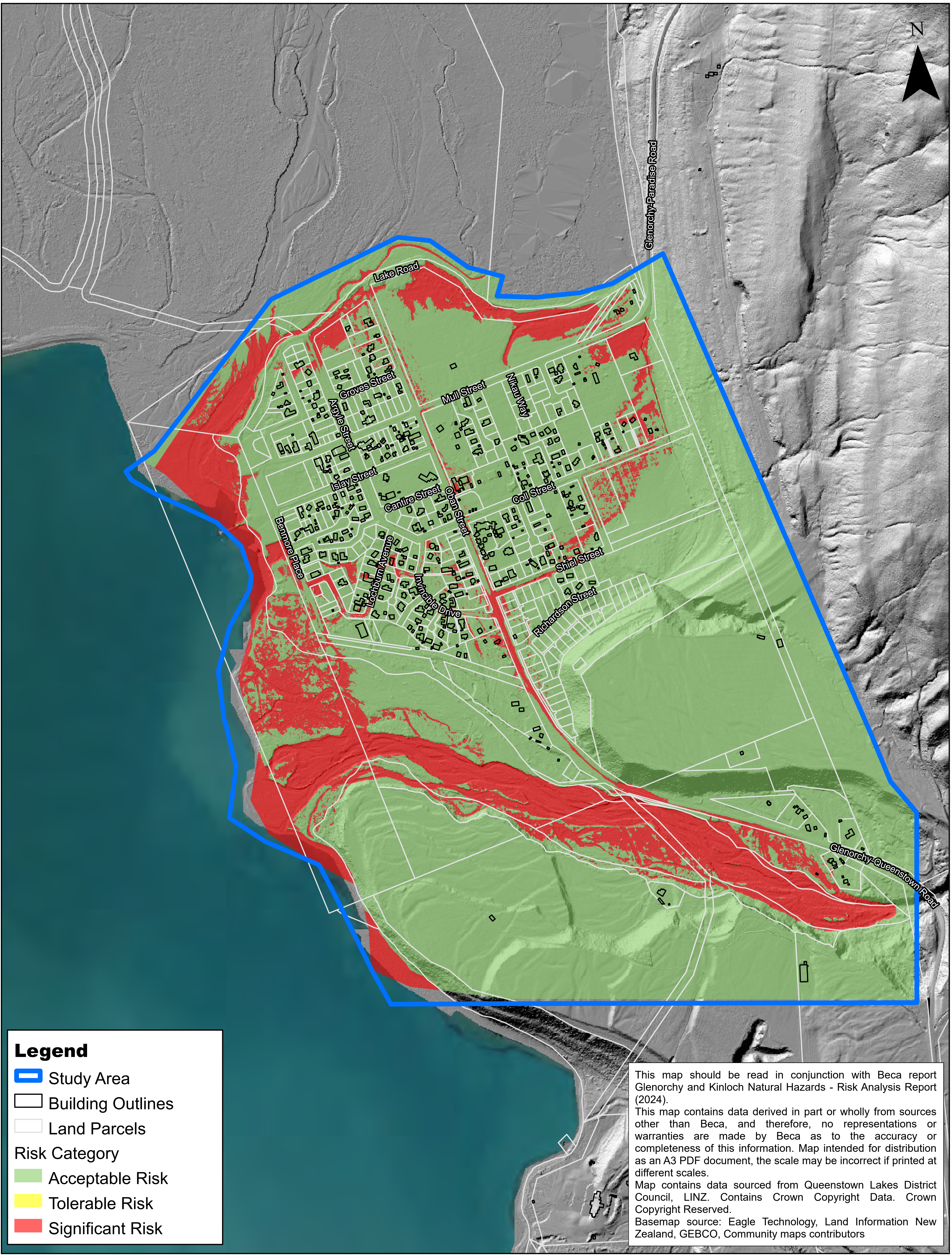

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Buckler Burn Flooding
Qualitative Health & Safety Risk
200 m3/s River Flood &
10 Year ARI Lake Level
Glenorchy

Beca

Project	Glenorchy Kinloch Natural Hazard RA
Client	Otago Regional Council
Discipline	GIS
Drawing Number	GIS-3160904-01-013-01

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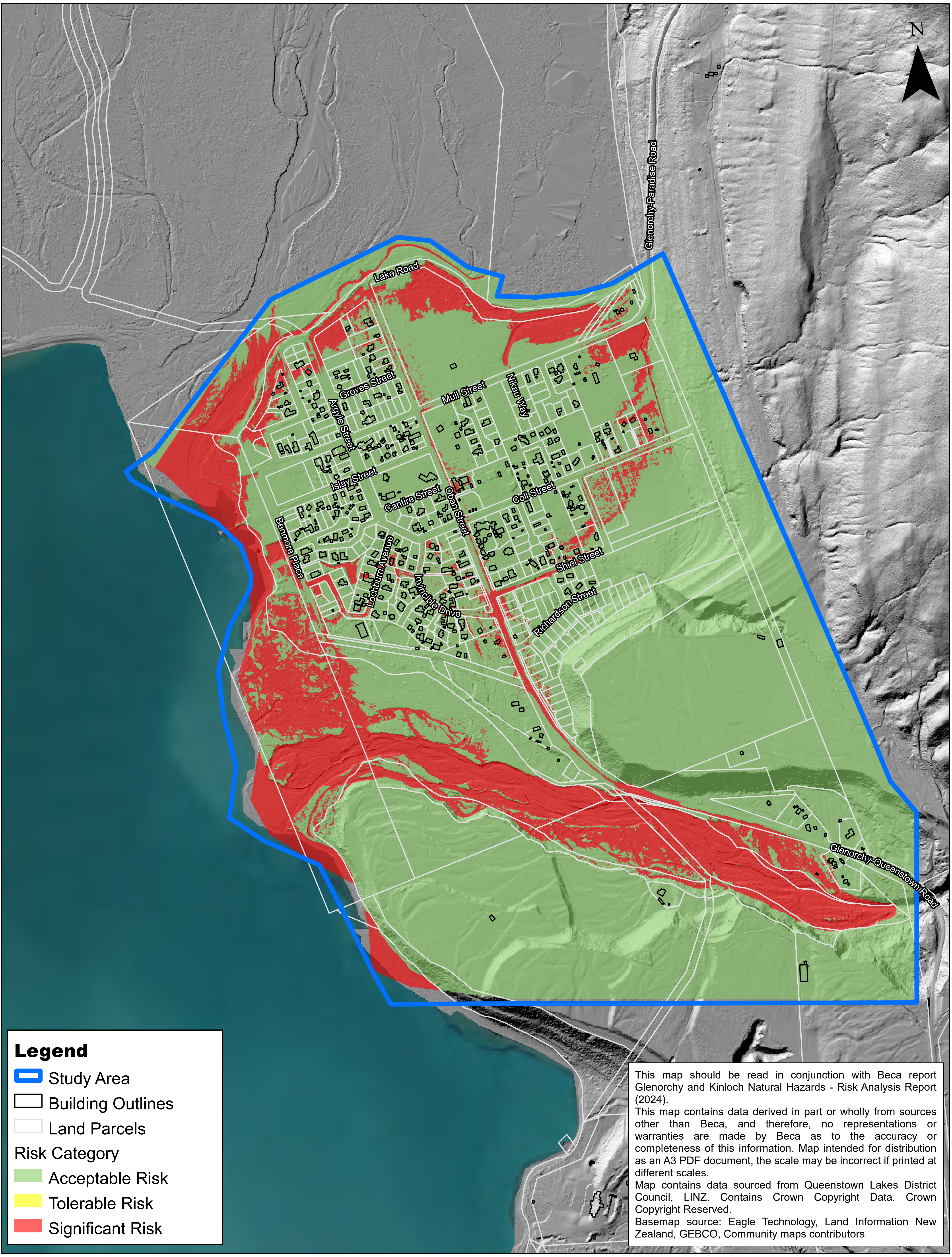
Path: P:\316\3160904\1-WIP\WG-GIS\01-Map\GlenorchyKinloch_ReportMaps\GlenorchyKinloch_ReportMaps.aprx Map Layout: 01 Qualitative - Flooding Date Printed: 26/08/2024



Legend

- Study Area
- Building Outlines
- Land Parcels

Risk Category

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- 🟨 Tolerable Risk
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Buckler Burn
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250 m3/s River Flood &
10 Year ARI Lake Level
Glenorchy

Beca

Project	Glenorchy Kinloch Natural Hazard RA
Client	Otago Regional Council
Discipline	GIS
Drawing Number	GIS-3160904-01-014-01

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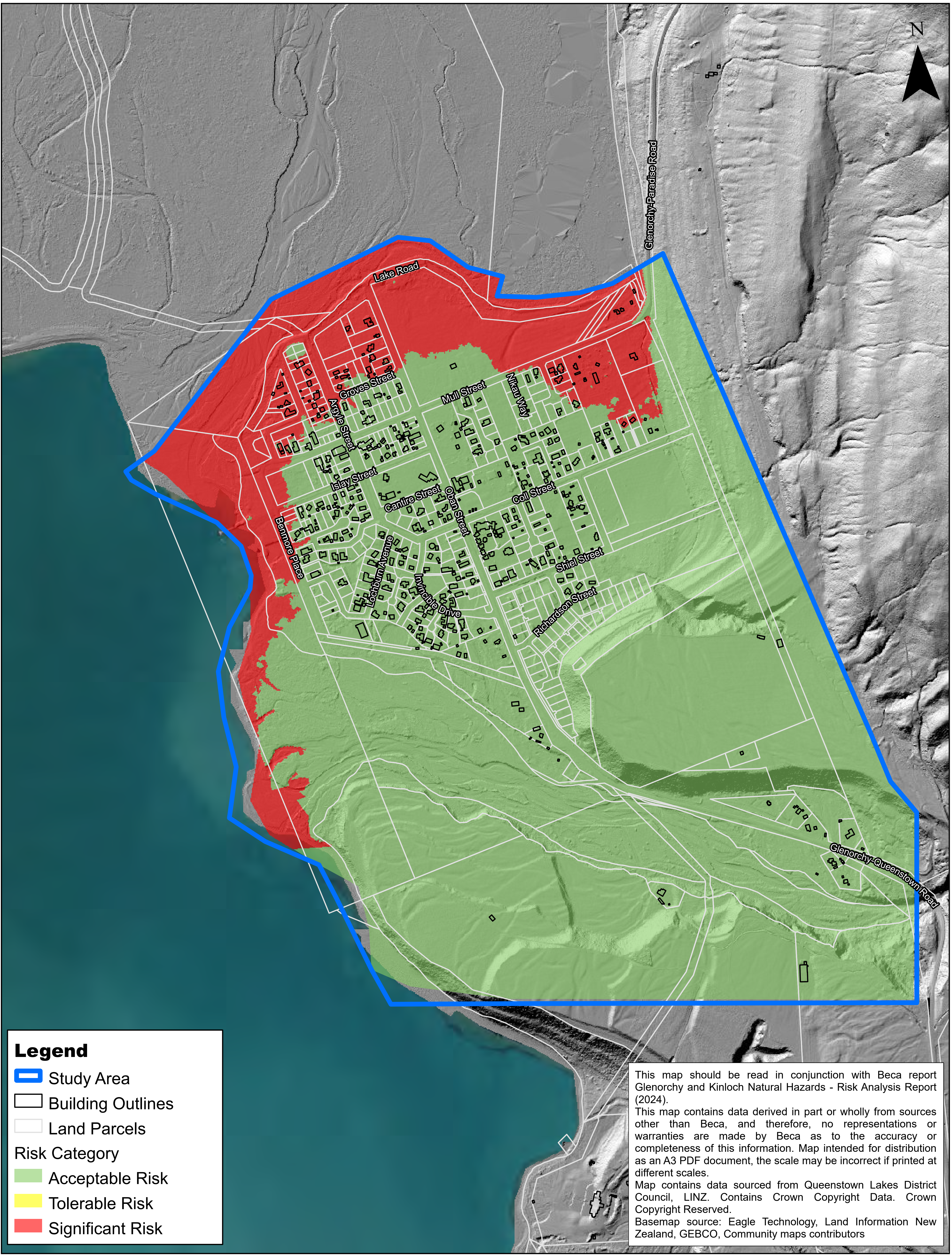

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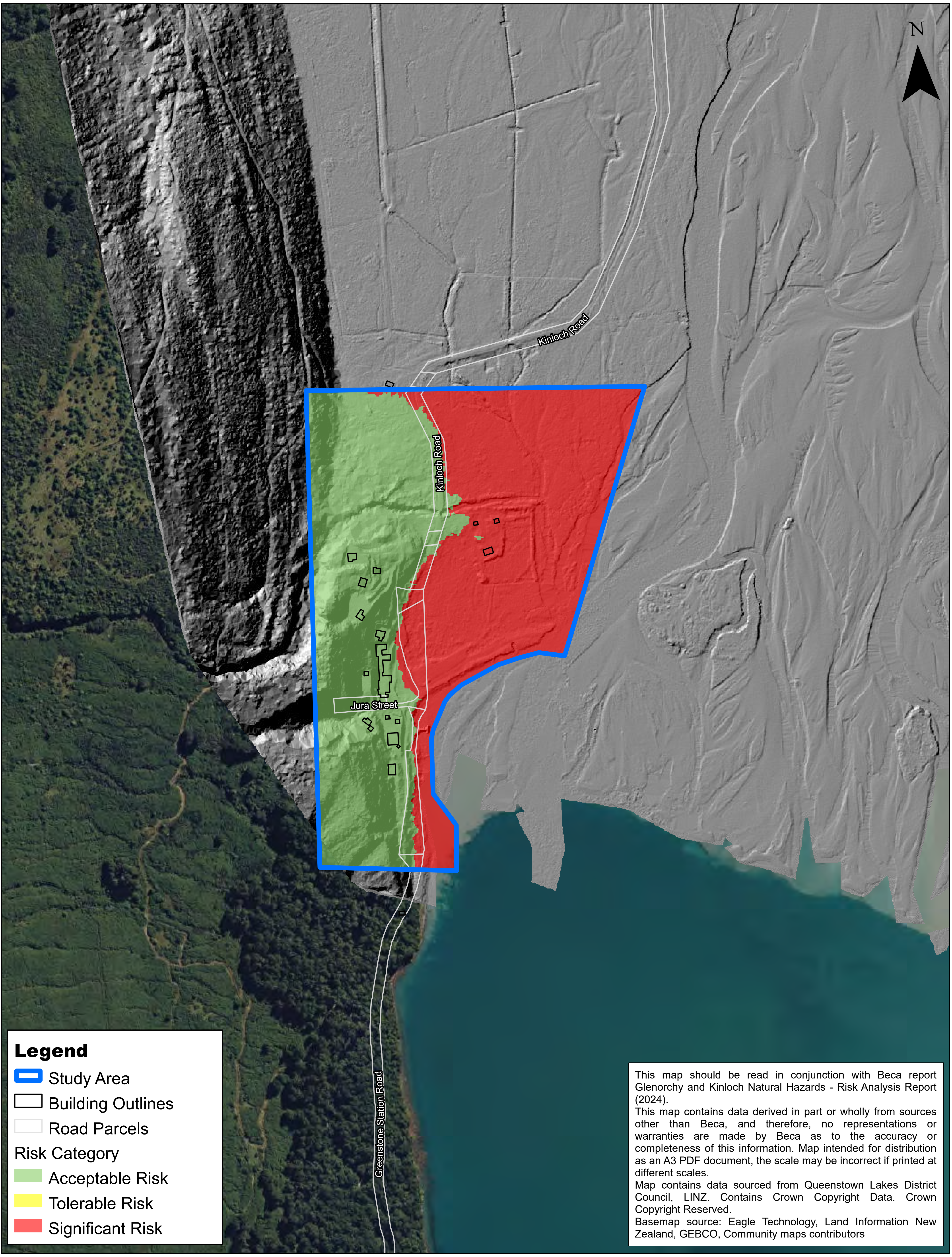

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Client	Otago Regional Council
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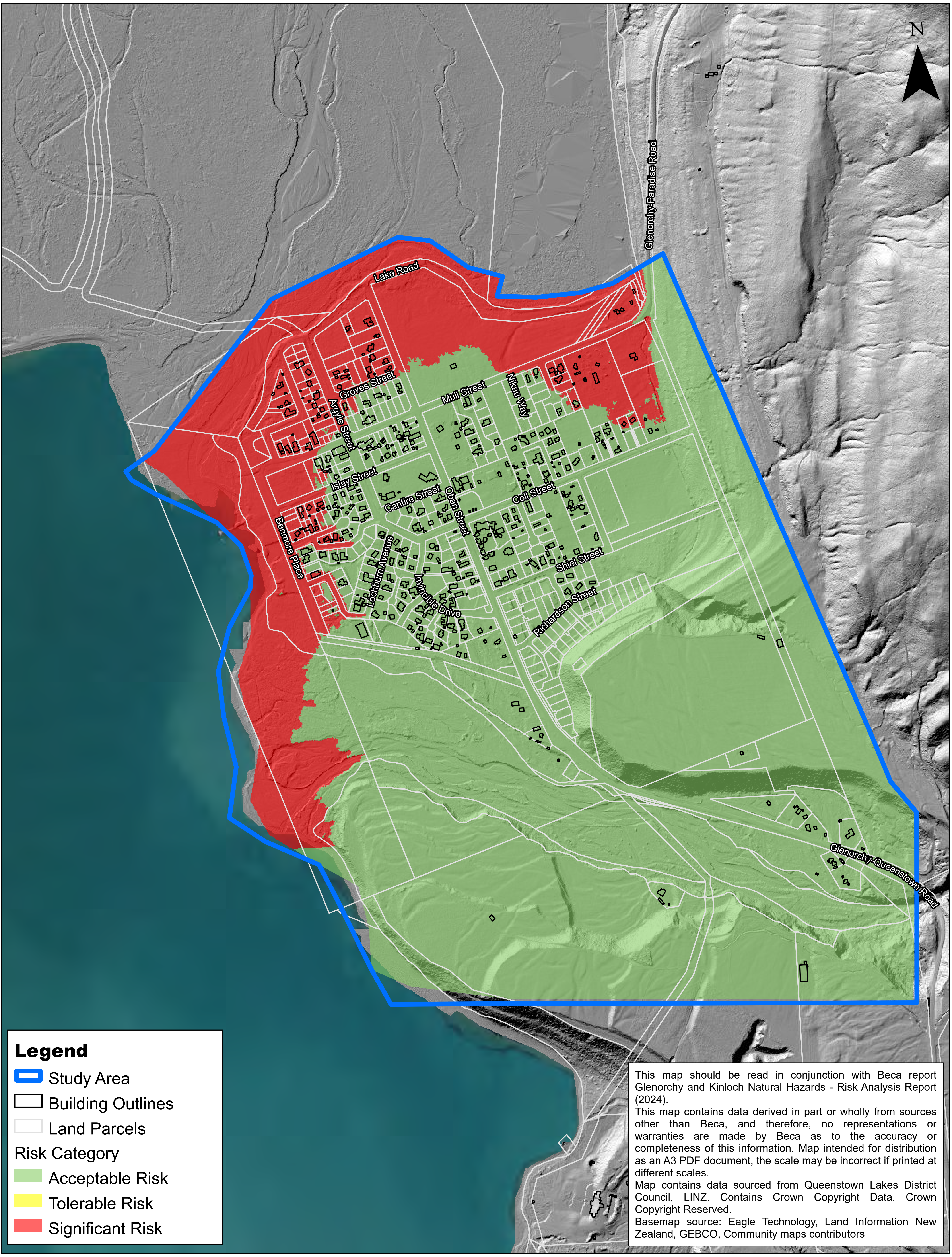

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Rees/Dart Flooding
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Glenorchy

Project	Glenorchy Kinloch Natural Hazard RA
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Discipline	GIS
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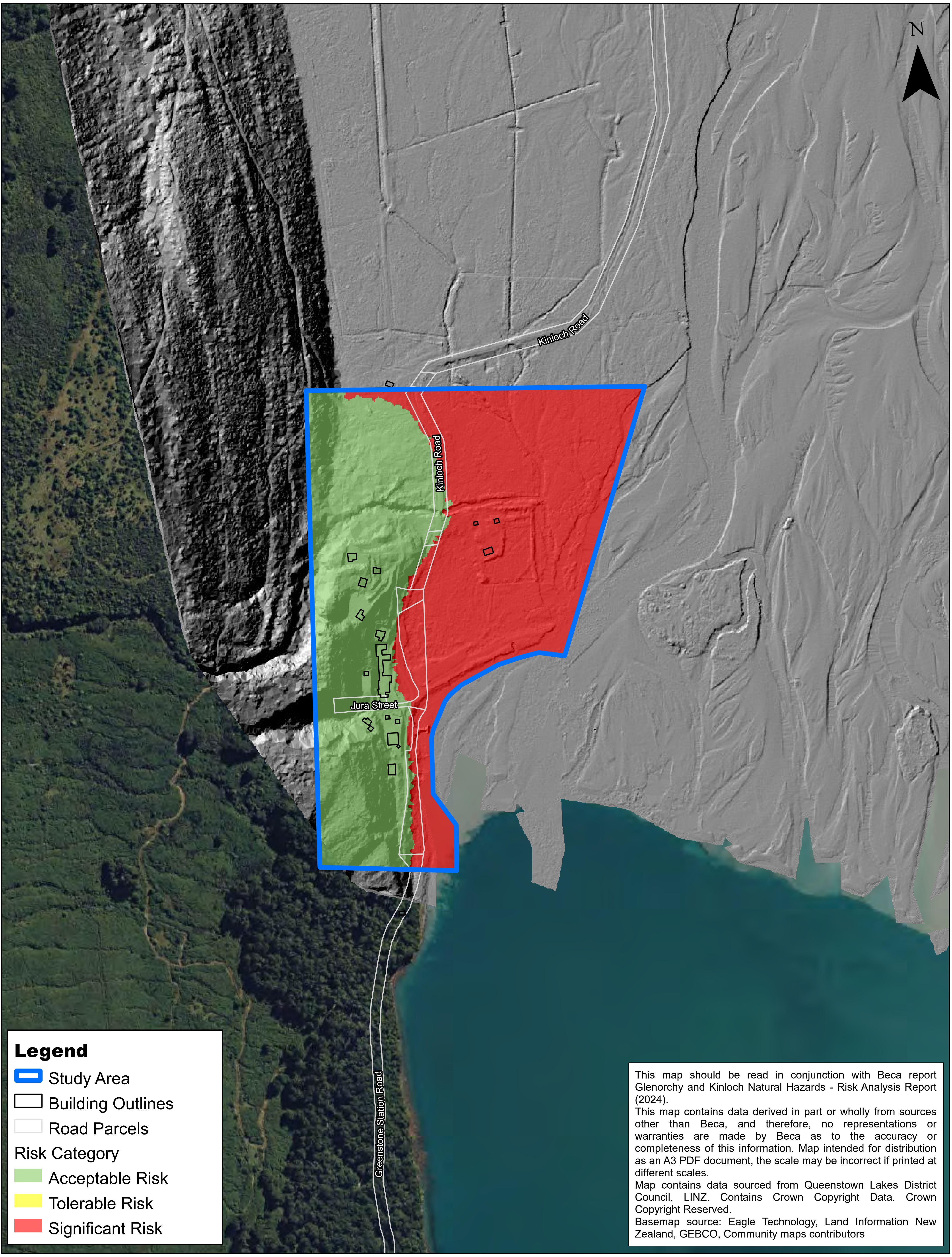

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GIS@beca.com

Path: P:\316\3160904\1-WIP\WG-GIS\01-Map\GlenorchyKinloch_ReportMaps\GlenorchyKinloch_ReportMaps.aprx Map Layout: 01 Qualitative - Flooding Date Printed: 26/08/2024

Map Scale @ A3: 1:5,000

0 200
Metres

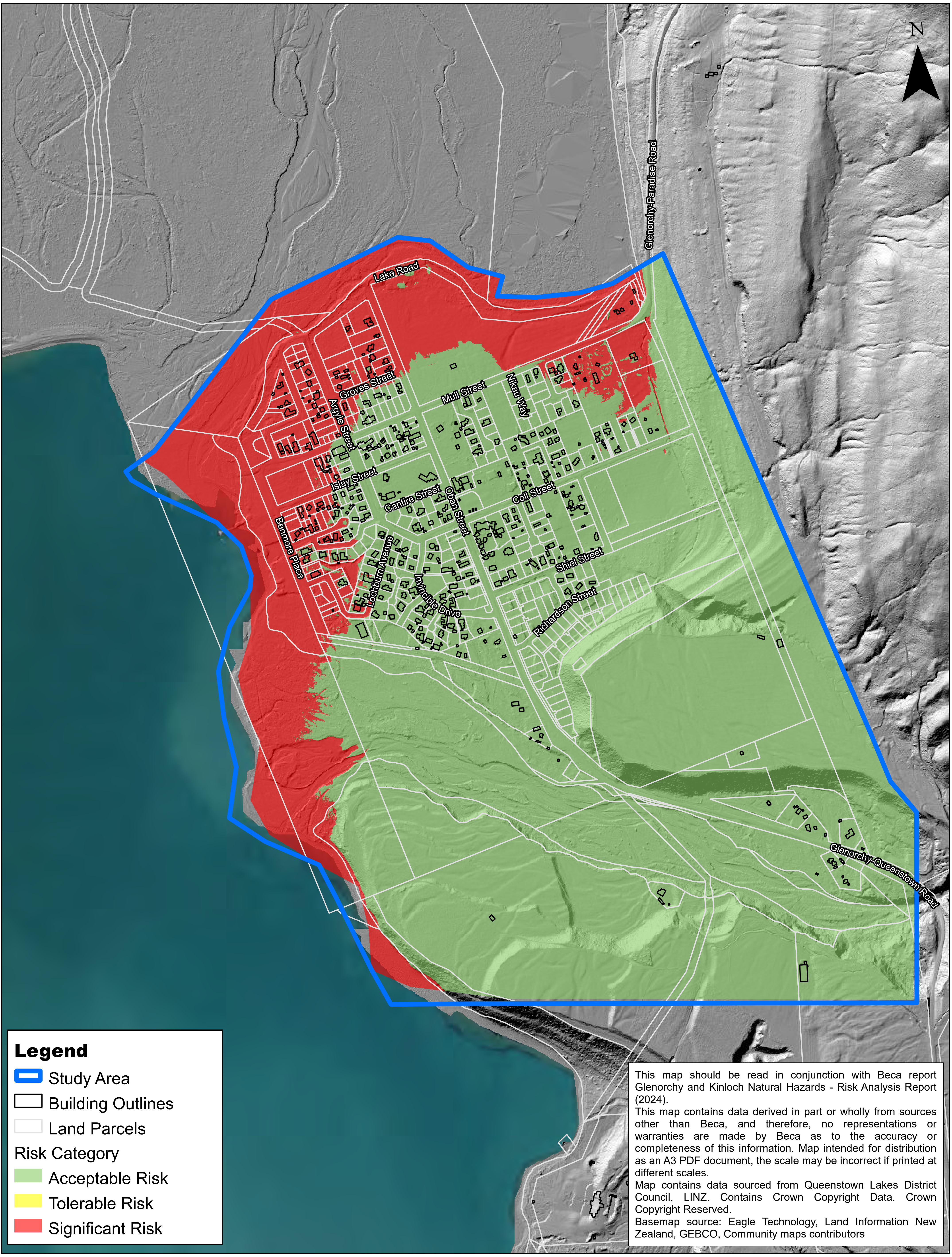
Revision	0.1
Status	Final
Author	ZT825
Verifier	BDJ2
Date	26/08/2024

Rees/Dart Flooding
Qualitative Health & Safety Risk
100 Year ARI River Flood and
100 Year ARI Lake Level
Kinloch

Beca

Project	Glenorchy Kinloch Natural Hazard RA
Client	Otago Regional Council
Discipline	GIS
Drawing Number	GIS-3160904-01-016-02

GIS@beca.com



Legend

- 🟦 Study Area
- ☐ Building Outlines
- ☐ Land Parcels

Risk Category

- 🟩 Acceptable Risk
- 🟨 Tolerable Risk
- 🟥 Significant Risk

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Map Scale @ A3: 1:8,500

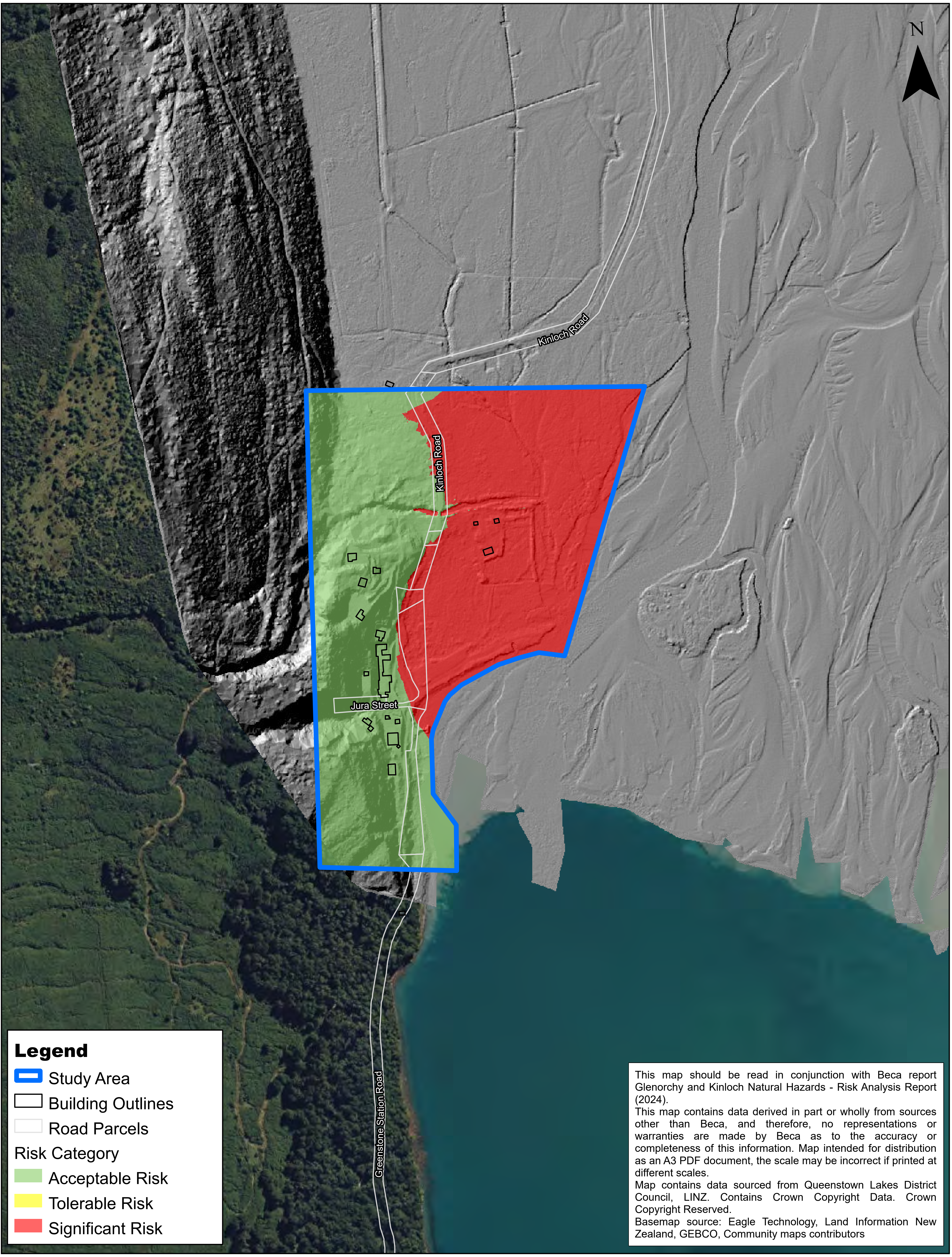
0 200
Metres

Revision 0.1
Status Final
Author ZT825
Verifier BDJ2
Date 26/08/2024

Lake Flood
Qualitative Health & Safety Risk
100 Year Average Return Period
Glenorchy

Beca

Project Glenorchy Kinloch Natural Hazard RA
Client Otago Regional Council
Discipline GIS
Drawing Number GIS-3160904-01-017-01



Legend

- 🟦 Study Area
- ☐ Building Outlines
- ☐ Road Parcels

Risk Category

- 🟩 Acceptable Risk
- 🟨 Tolerable Risk
- 🟥 Significant Risk

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0 200
Metres

Revision	0.1
Status	Final
Author	ZT825
Verifier	BDJ2
Date	26/08/2024

Lake Flood
Qualitative Health & Safety Risk
100 Year Average Return Period
Kinloch

Beca

Project	Glenorchy Kinloch Natural Hazard RA
Client	Otago Regional Council
Discipline	GIS
Drawing Number	GIS-3160904-01-017-02

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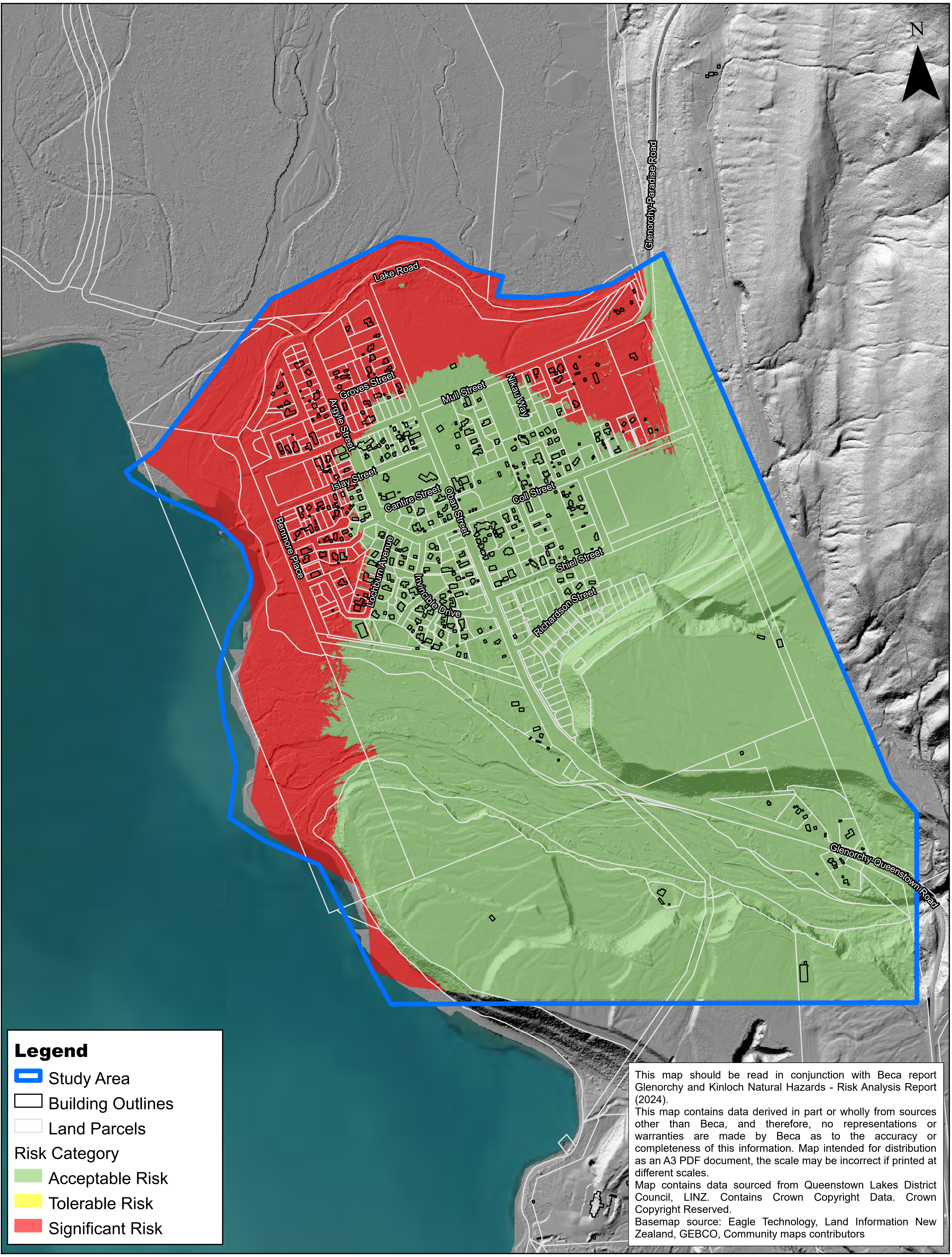

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Map Scale @ A3: 1:8,500

0 200
Metres

Revision	0.1
Status	Final
Author	ZT825
Verifier	BDJ2
Date	26/08/2024

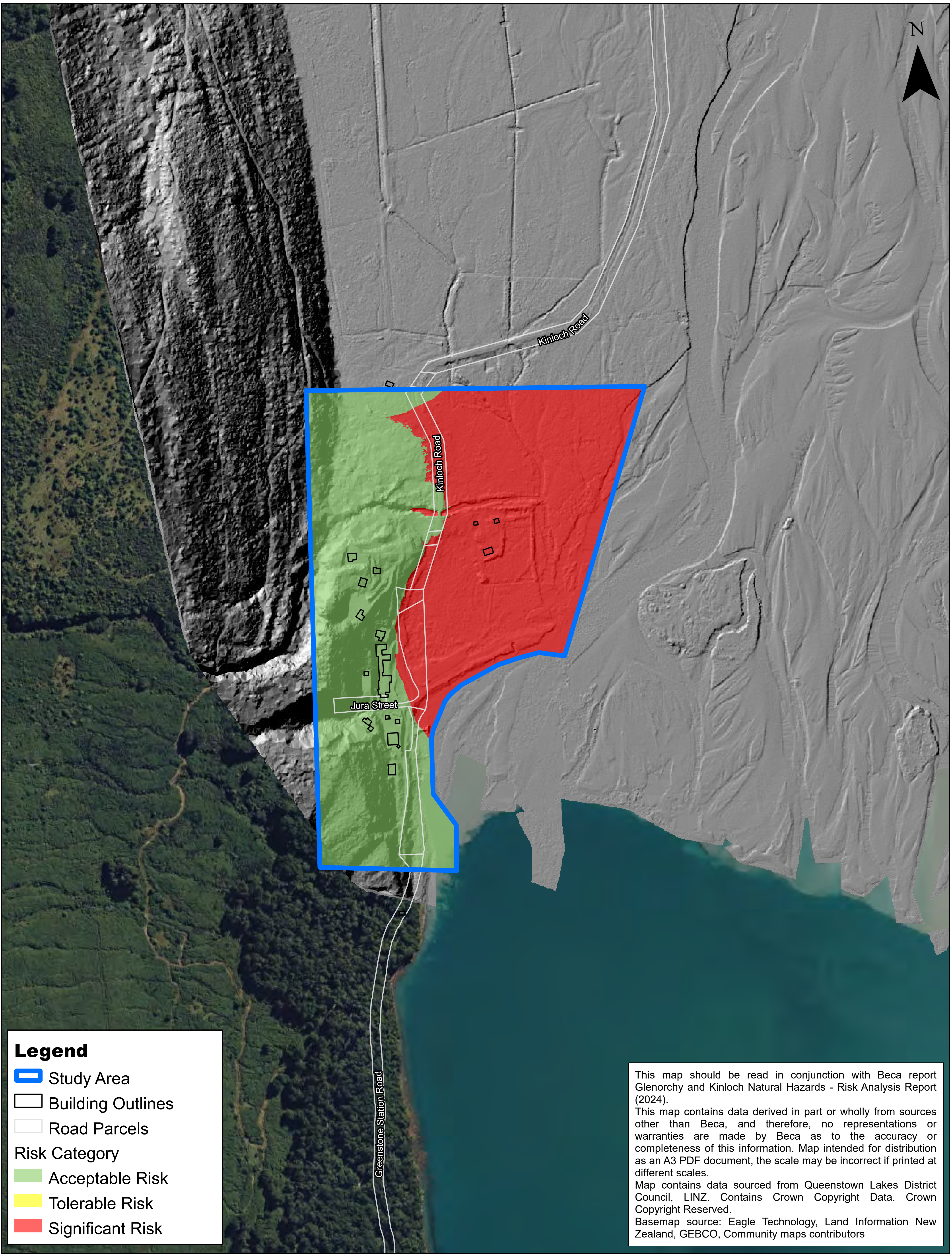
Lake Flood
Qualitative Health & Safety Risk
200 Year Average Return Period
Glenorchy

Beca

Project	Glenorchy Kinloch Natural Hazard RA
Client	Otago Regional Council
Discipline	GIS
Drawing Number	GIS-3160904-01-018-01

GIS@beca.com

Path: P:\316\3160904\1-WIP\WG-GIS\01-Map\GlenorchyKinloch_ReportMaps\GlenorchyKinloch_ReportMaps.aprx Map Layout: 01 Qualitative - Flooding Date Printed: 26/08/2024



Legend

- 🟦 Study Area
- ☐ Building Outlines
- ☐ Road Parcels

Risk Category

- 🟩 Acceptable Risk
- 🟨 Tolerable Risk
- 🟥 Significant Risk

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Map Scale @ A3: 1:5,000

0 200
Metres

Revision	0.1
Status	Final
Author	ZT825
Verifier	BDJ2
Date	26/08/2024

Lake Flood
Qualitative Health & Safety Risk
200 Year Average Return Period
Kinloch

Beca

Project	Glenorchy Kinloch Natural Hazard RA
Client	Otago Regional Council
Discipline	GIS
Drawing Number	GIS-3160904-01-018-02

GIS@beca.com

Path: P:\3160904\1-WIP\WG-GIS\01-Map\GlenorchyKinloch_ReportMaps\GlenorchyKinloch_ReportMaps.aprx Map Layout: 02 Qualitative - Seismic Shaking Date Printed: 26/08/2024

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Map Scale @ A3: 1:8,500

0 200
Metres

Revision	0.1
Status	Final
Author	ZT825
Verifier	BDJ2
Date	26/08/2024

Seismic Shaking
Qualitative Buildings/Health & Safety Risk
25 Year Average Return Period

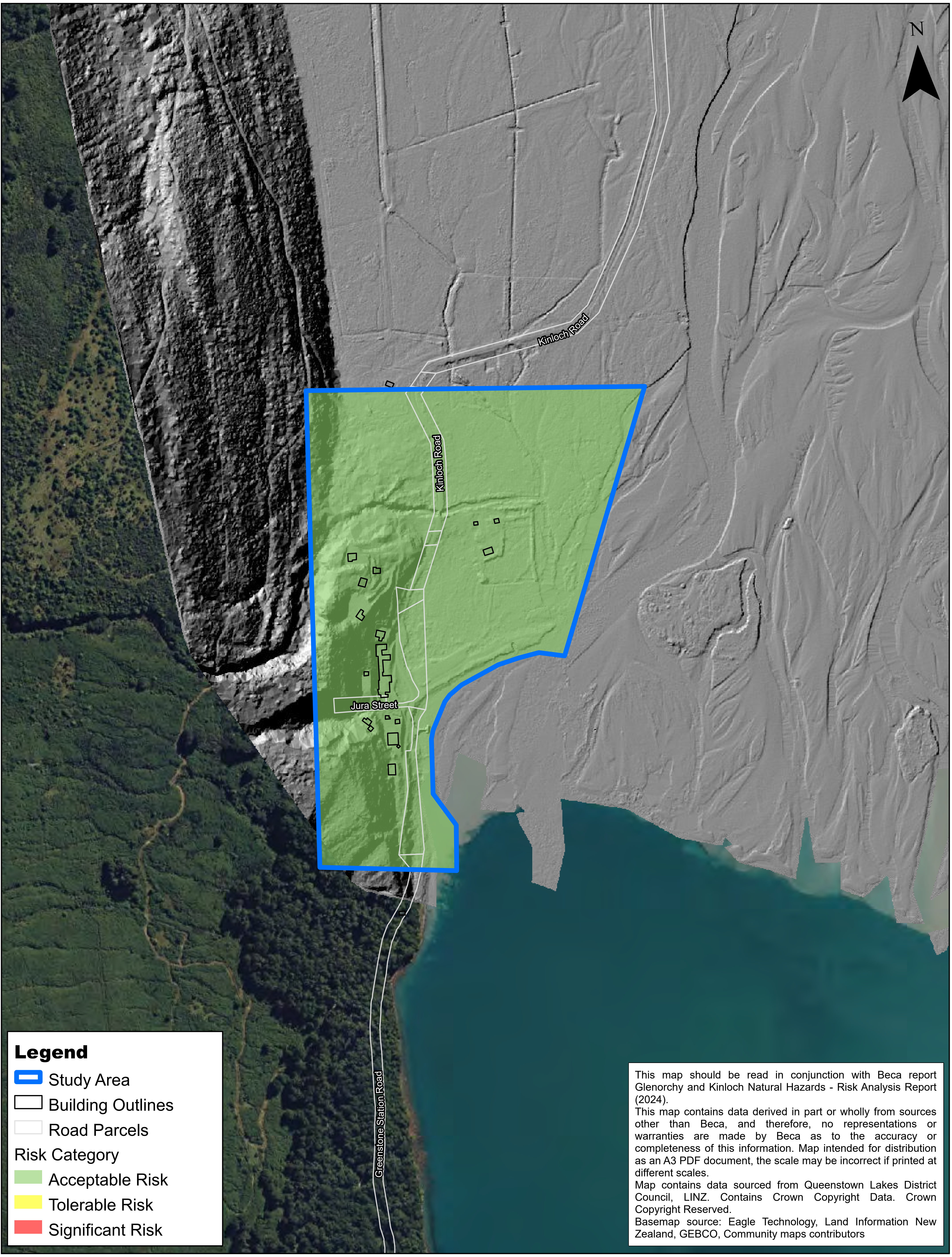
Glenorchy

Beca

Project	Glenorchy Kinloch Natural Hazard RA
Client	Otago Regional Council
Discipline	GIS
Drawing Number	GIS-3160904-02-001-01

GIS@beca.com

Path: P:\316\3160904\1-WIP\WG-GIS\01-Map\GlenorchyKinloch_ReportMaps\GlenorchyKinloch_ReportMaps.aprx Map Layout: 02 Qualitative - Seismic Shaking Date Printed: 26/08/2024



Legend

- 🟦 Study Area
- ☐ Building Outlines
- ☐ Road Parcels

Risk Category

- 🟩 Acceptable Risk
- 🟨 Tolerable Risk
- 🟥 Significant Risk

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Map Scale @ A3: 1:5,000

0 200
Metres

Revision	0.1
Status	Final
Author	ZT825
Verifier	BDJ2
Date	26/08/2024

Seismic Shaking
Qualitative Buildings/Health & Safety Risk
25 Year Average Return Period

Kinloch

Beca

Project	Glenorchy Kinloch Natural Hazard RA
Client	Otago Regional Council
Discipline	GIS
Drawing Number	GIS-3160904-02-001-02

GIS@beca.com

Path: P:\3160\3160904\1-WIP\WG-GIS\01-Map\GlenorchyKinloch_ReportMaps\GlenorchyKinloch_ReportMaps.aprx Map Layout: 02 Qualitative - Seismic Shaking Date Printed: 26/08/2024

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Map Scale @ A3: 1:8,500

0 200
Metres

Revision	0.1
Status	Final
Author	ZT825
Verifier	BDJ2
Date	26/08/2024

Seismic Shaking
Qualitative Buildings/Health & Safety Risk
500 Year Average Return Period

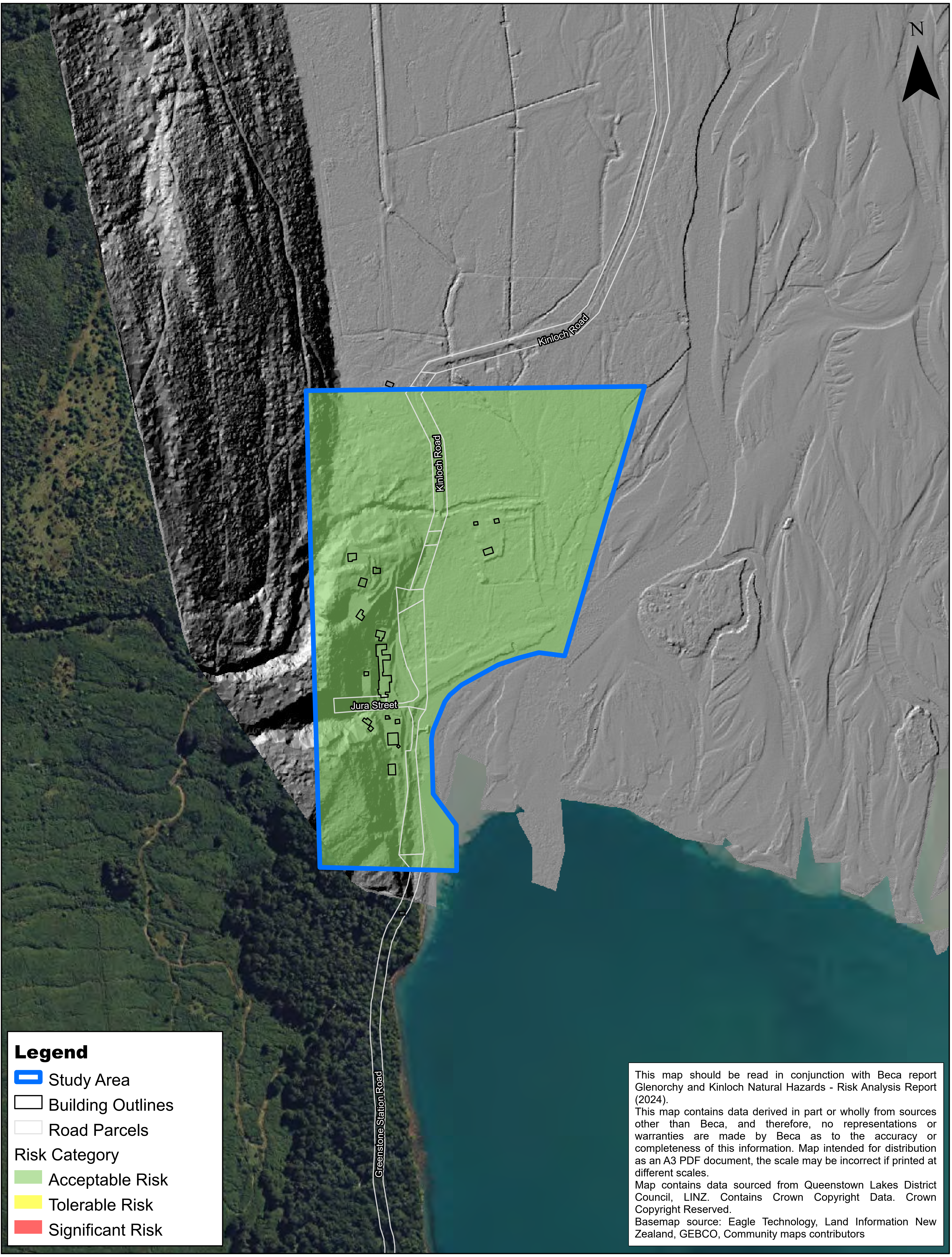
Glenorchy

Beca

Project	Glenorchy Kinloch Natural Hazard RA
Client	Otago Regional Council
Discipline	GIS
Drawing Number	GIS-3160904-02-002-01

GIS@beca.com

Path: P:\316\3160904\1-WIP\WG-GIS\01-Map\GlenorchyKinloch_ReportMaps\GlenorchyKinloch_ReportMaps.aprx Map Layout: 02 Qualitative - Seismic Shaking Date Printed: 26/08/2024



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Map Scale @ A3: 1:5,000

0 200
Metres

Revision	0.1
Status	Final
Author	ZT825
Verifier	BDJ2
Date	26/08/2024

Seismic Shaking
Qualitative Buildings/Health & Safety Risk
500 Year Average Return Period

Kinloch

Beca

Project	Glenorchy Kinloch Natural Hazard RA
Client	Otago Regional Council
Discipline	GIS
Drawing Number	GIS-3160904-02-002-02

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Legend

- 🟦 Study Area
- ☐ Building Outlines
- ☐ Land Parcels

Risk Category

- 🟩 Acceptable Risk
- 🟨 Tolerable Risk
- 🟥 Significant Risk

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Map Scale @ A3: 1:8,500

0 200
Metres

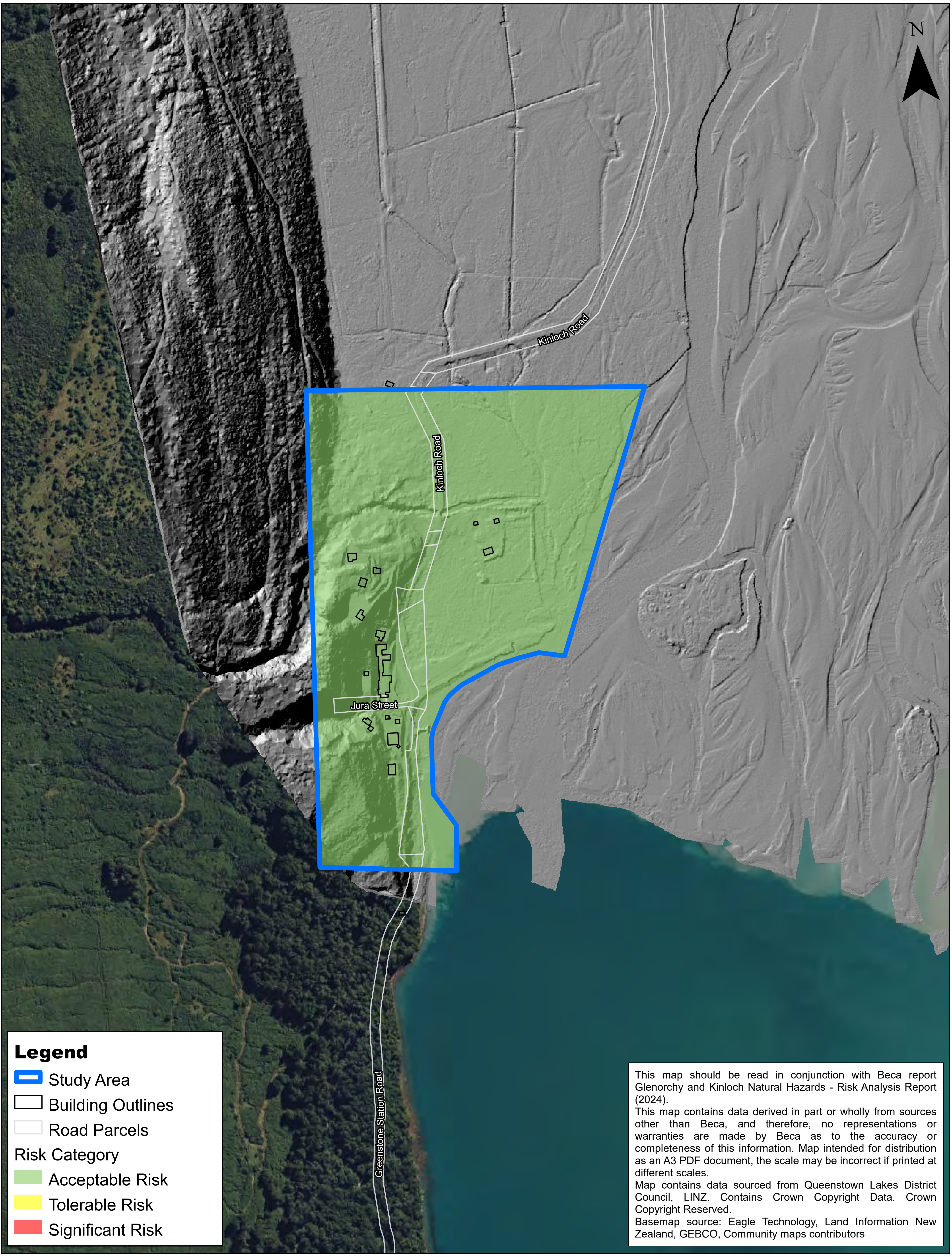
Revision	0.1
Status	Final
Author	ZT825
Verifier	BDJ2
Date	26/08/2024

Seismic Shaking
Qualitative Buildings/Health & Safety Risk
1500 Year Average Return Period

Glenorchy

Beca

Project	Glenorchy Kinloch Natural Hazard RA
Client	Otago Regional Council
Discipline	GIS
Drawing Number	GIS-3160904-02-003-01



Legend

- Study Area
- Building Outlines
- Road Parcels

Risk Category

- 🟩 Acceptable Risk
- 🟨 Tolerable Risk
- 🟥 Significant Risk

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Map Scale @ A3: 1:5,000

0 200
Metres

Revision 0.1
Status Final
Author ZT825
Verifier BDJ2
Date 26/08/2024

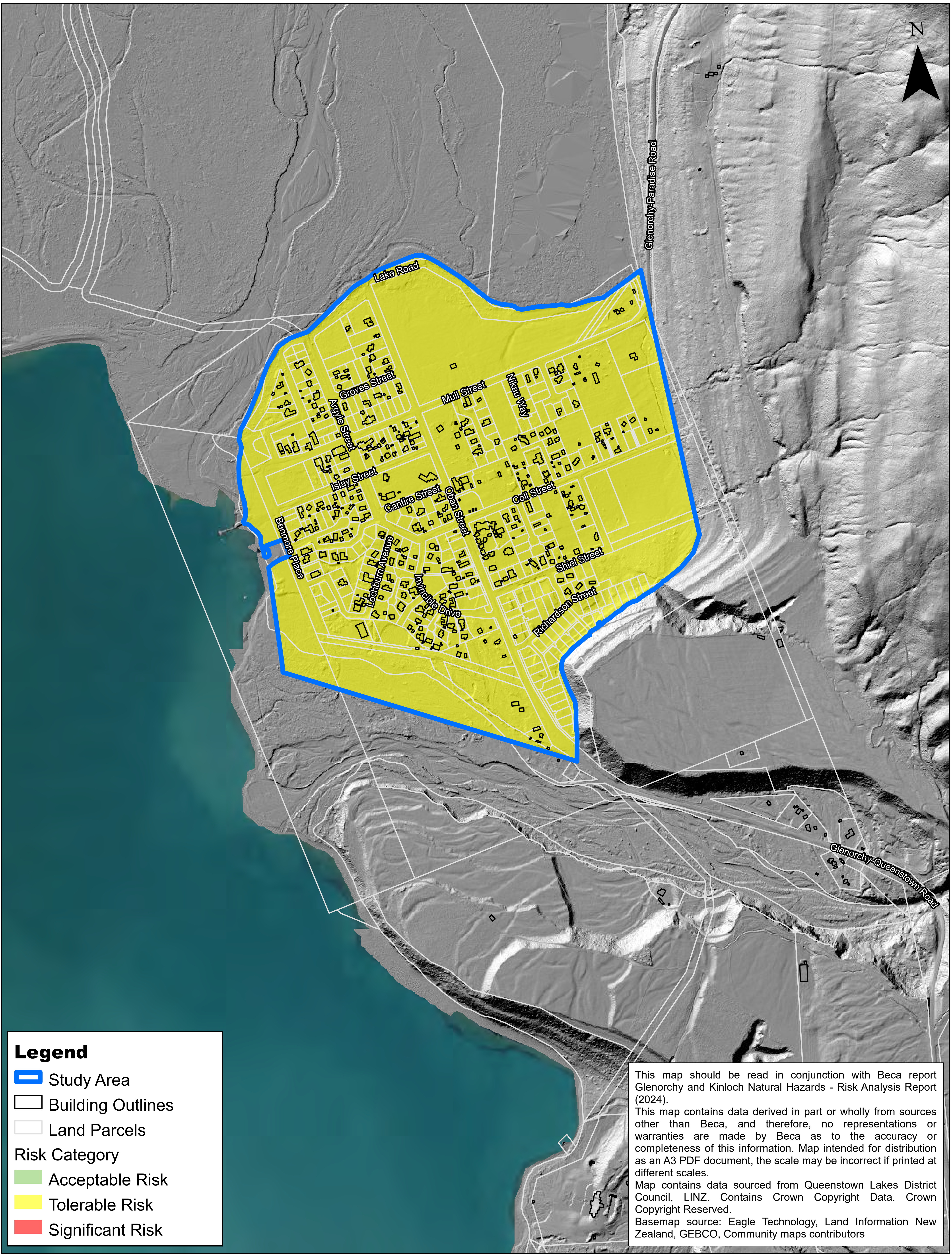
Seismic Shaking
Qualitative Buildings/Health & Safety Risk
1500 Year Average Return Period

Kinloch

Beca

Project	Glenorchy Kinloch Natural Hazard RA
Client	Otago Regional Council
Discipline	GIS
Drawing Number	GIS-3160904-02-003-02

GIS@beca.com



Legend

- Study Area
- Building Outlines
- Land Parcels

Risk Category

- 🟩 Acceptable Risk
- 🟨 Tolerable Risk
- 🟥 Significant Risk

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0 200
Metres

Revision	0.1
Status	Final
Author	ZT825
Verifier	BDJ2
Date	26/08/2024

Seismic Shaking
Qualitative Lifelines Risk
25 Year Average Return Period

Glenorchy

Beca

Project	Glenorchy Kinloch Natural Hazard RA
Client	Otago Regional Council
Discipline	GIS
Drawing Number	GIS-3160904-02-004-01

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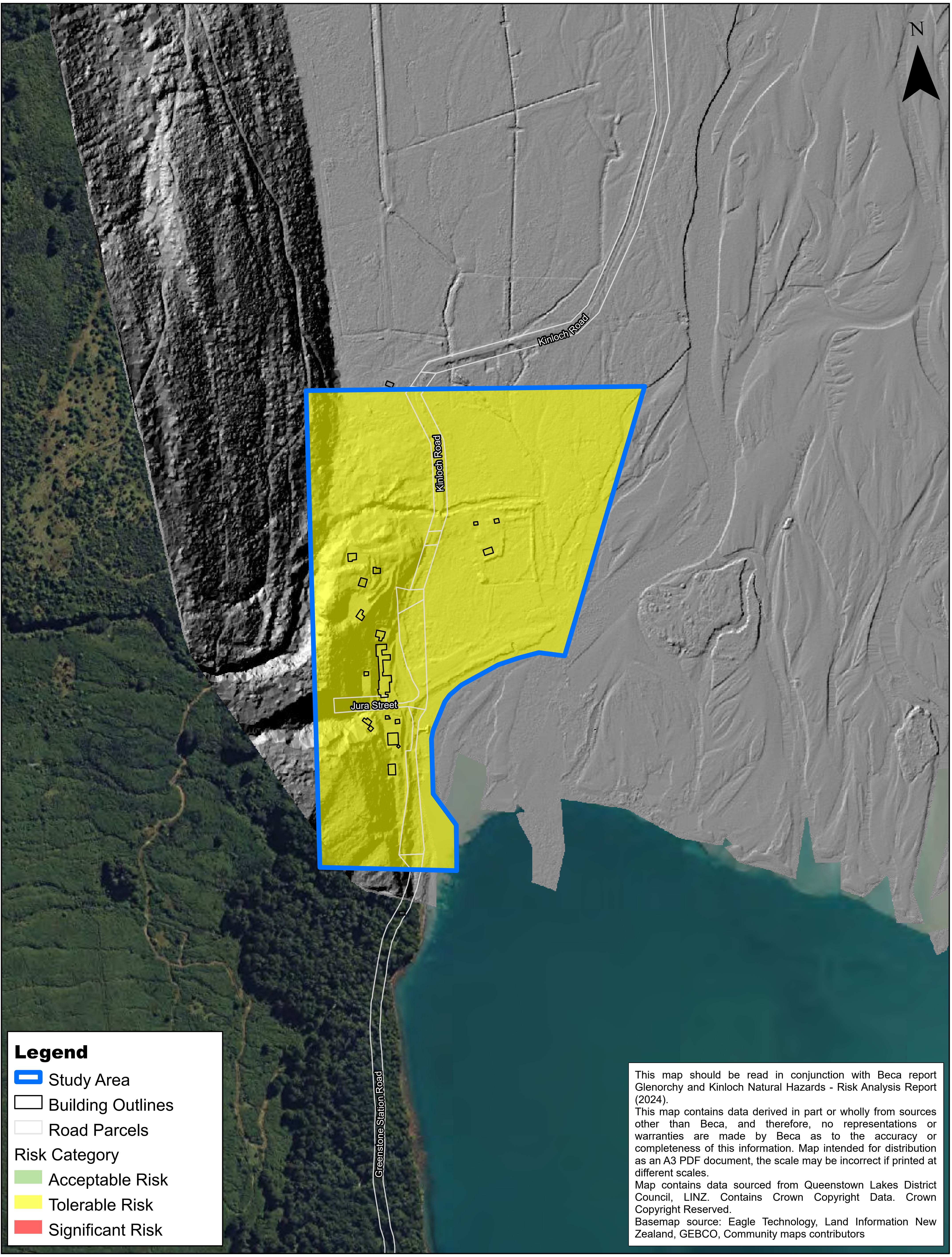

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Map Scale @ A3: 1:5,000

0 200
Metres

Revision 0.1
Status Final
Author ZT825
Verifier BDJ2
Date 26/08/2024

Seismic Shaking
Qualitative Lifelines Risk
25 Year Average Return Period

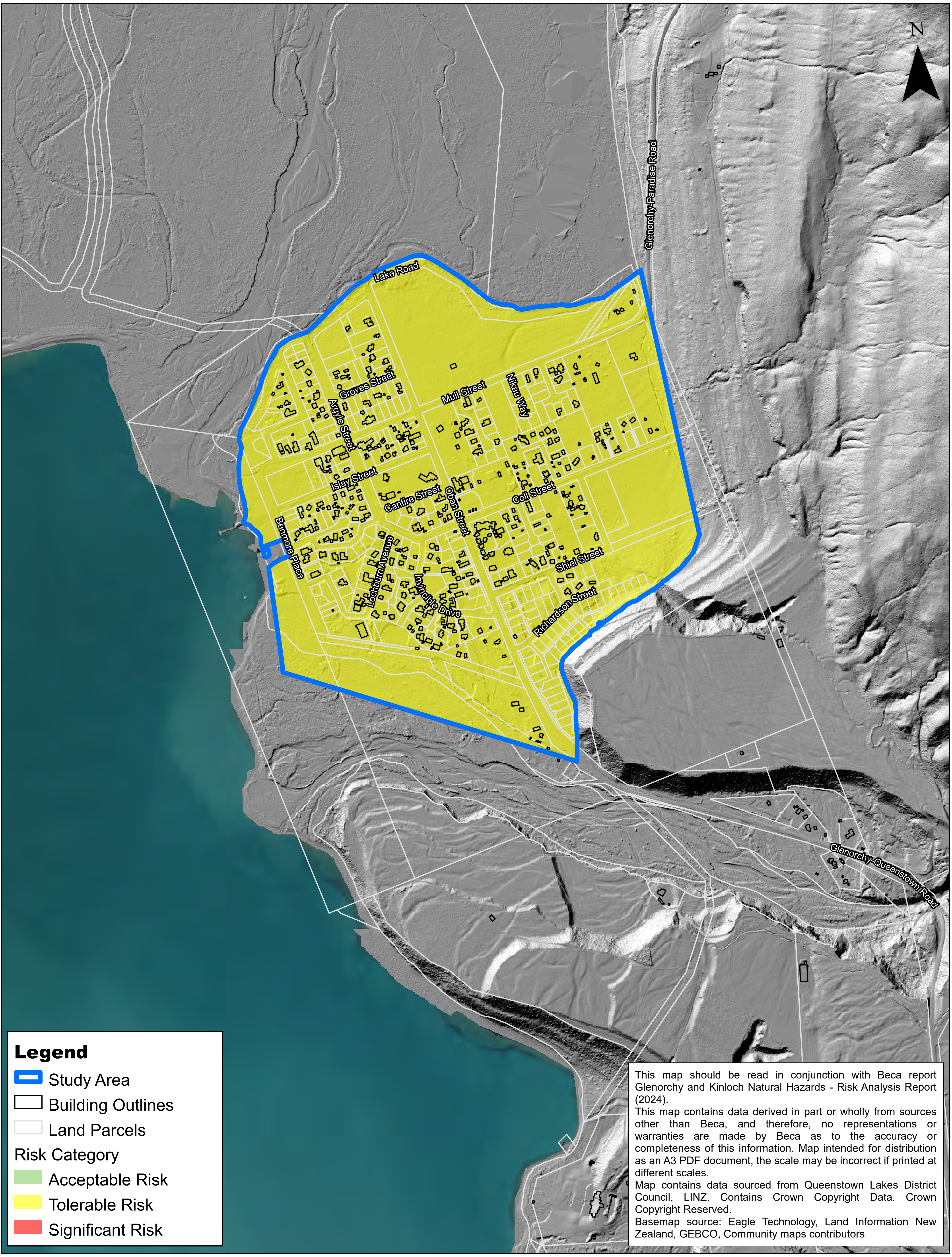
Kinloch

Beca

Project Glenorchy Kinloch Natural Hazard RA
Client Otago Regional Council
Discipline GIS
Drawing Number GIS-3160904-02-004-02

GIS@beca.com

Path: P:\316\3160904\1-WIP\WG-GIS\01-Map\GlenorchyKinloch_ReportMaps\GlenorchyKinloch_ReportMaps.aprx Map Layout: 02 Qualitative - Seismic Shaking Date Printed: 26/08/2024



Legend

- Study Area
- Building Outlines
- Land Parcels

Risk Category

- 🟩 Acceptable Risk
- 🟨 Tolerable Risk
- 🟥 Significant Risk

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Map Scale @ A3: 1:8,500

0 200
Metres

Revision	0.1
Status	Final
Author	ZT825
Verifier	BDJ2
Date	26/08/2024

Seismic Shaking
Qualitative Lifelines Risk
500 Year Average Return Period

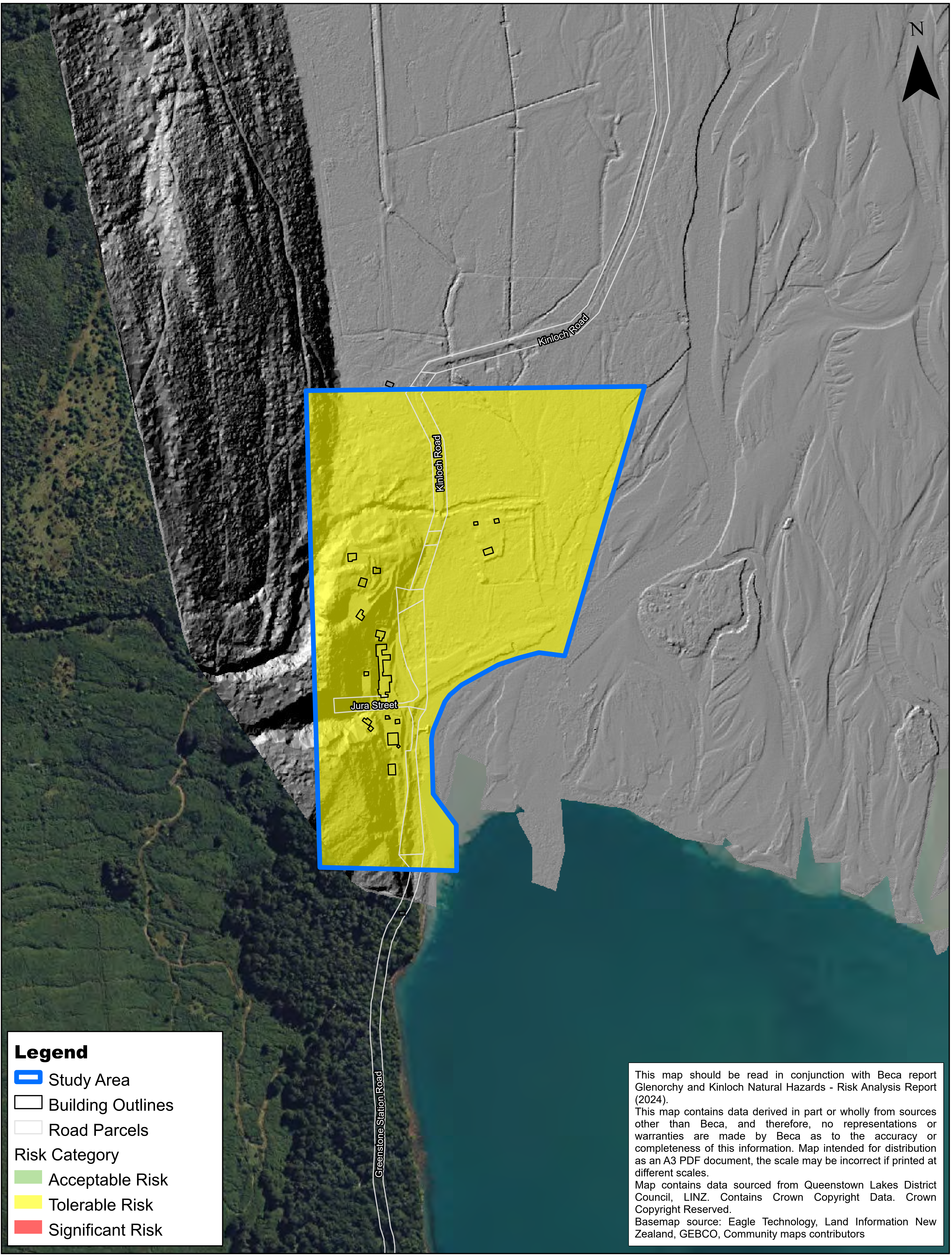
Glenorchy

Beca

Project	Glenorchy Kinloch Natural Hazard RA
Client	Otago Regional Council
Discipline	GIS
Drawing Number	GIS-3160904-02-005-01

GIS@beca.com

Path: P:\316\3160904\1-WIP\WG-GIS\01-Map\GlenorchyKinloch_ReportMaps\GlenorchyKinloch_ReportMaps.aprx Map Layout: 02 Qualitative - Seismic Shaking Date Printed: 26/08/2024



Legend

- 🟦 Study Area
- ☐ Building Outlines
- ☐ Road Parcels

Risk Category

- 🟩 Acceptable Risk
- 🟨 Tolerable Risk
- 🟥 Significant Risk

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Map Scale @ A3: 1:5,000

0 200
Metres

Revision 0.1
Status Final
Author ZT825
Verifier BDJ2
Date 26/08/2024

Seismic Shaking
Qualitative Lifelines Risk
500 Year Average Return Period

Kinloch

Beca

Project	Glenorchy Kinloch Natural Hazard RA
Client	Otago Regional Council
Discipline	GIS
Drawing Number	GIS-3160904-02-005-02

GIS@beca.com

Path: P:\316\3160904\1-WIP\WG-GIS\01-Map\GlenorchyKinloch_ReportMaps\GlenorchyKinloch_ReportMaps.aprx Map Layout: 02 Qualitative - Seismic Shaking Date Printed: 26/08/2024

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0 200
Metres

Revision 0.1
Status Final
Author ZT825
Verifier BDJ2
Date 26/08/2024

Seismic Shaking
Qualitative Lifelines Risk
1500 Year Average Return Period

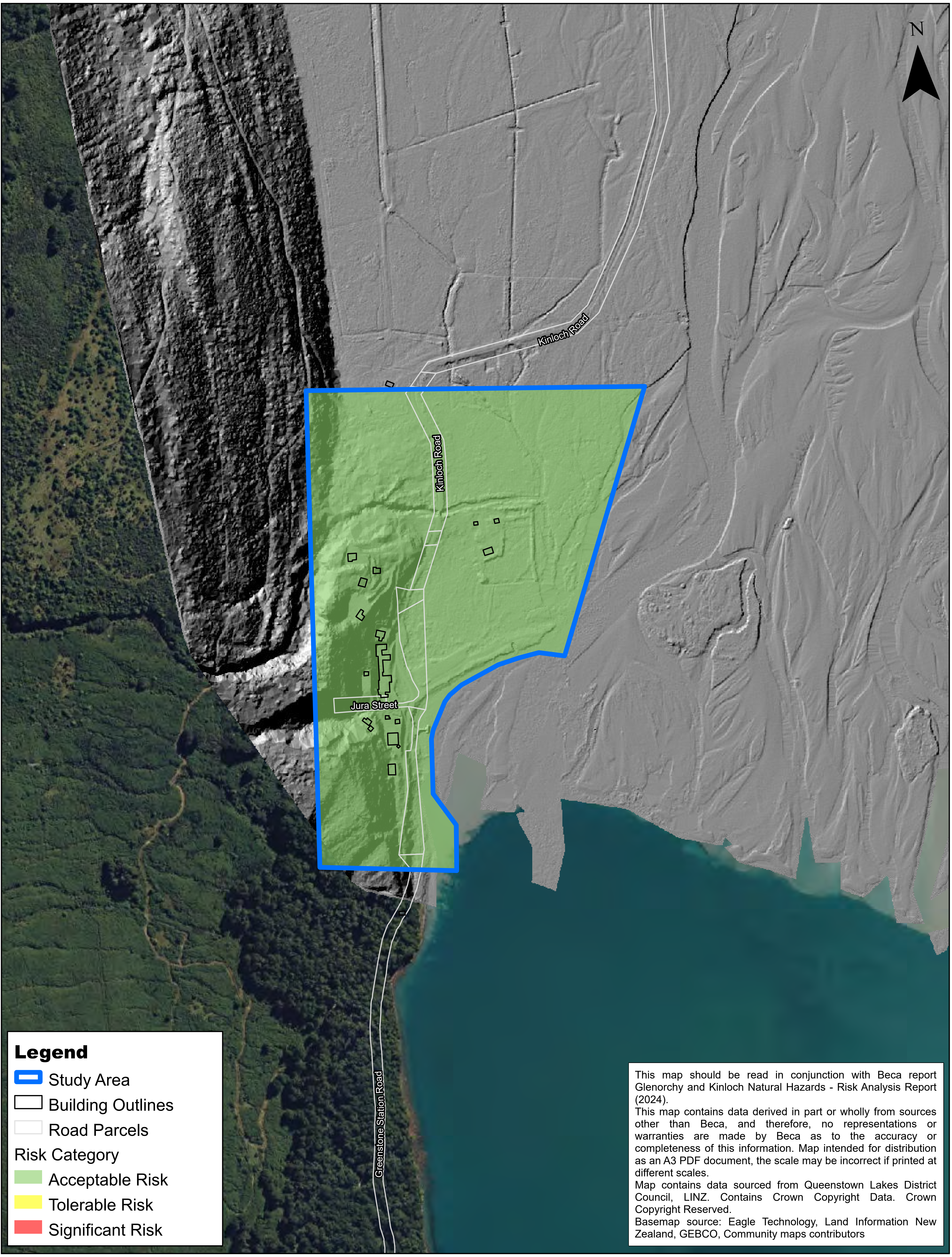
Glenorchy

Beca

Project Glenorchy Kinloch Natural Hazard RA
Client Otago Regional Council
Discipline GIS
Drawing Number GIS-3160904-02-006-01

GIS@beca.com

Path: P:\316\3160904\1-WIP\WG-GIS\01-Map\GlenorchyKinloch_ReportMaps\GlenorchyKinloch_ReportMaps.aprx Map Layout: 02 Qualitative - Seismic Shaking Date Printed: 26/08/2024



Legend

▭ Study Area
▭ Building Outlines
▭ Road Parcels

Risk Category

🟩 Acceptable Risk
🟨 Tolerable Risk
🟥 Significant Risk

This map should be read in conjunction with Beca report Glenorchy and Kinloch Natural Hazards - Risk Analysis Report (2024).
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Map Scale @ A3: 1:5,000

0 200
Metres

Revision 0.1
Status Final
Author ZT825
Verifier BDJ2
Date 26/08/2024

Seismic Shaking
Qualitative Lifelines Risk
1500 Year Average Return Period

Kinloch

Beca

Project	Glenorchy Kinloch Natural Hazard RA
Client	Otago Regional Council
Discipline	GIS
Drawing Number	GIS-3160904-02-006-02

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Path: P:\316\3160904\1-WIP\WG-GIS\01-Map\GlenorchyKinloch_ReportMaps\GlenorchyKinloch_ReportMaps.aprx Map Layout: 03 Qualitative - Liquefaction and Lateral Spread Date Printed: 26/08/2024

Map Scale @ A3: 1:8,500

0 200
Metres

Revision	0.1
Status	Final
Author	ZT825
Verifier	BDJ2
Date	26/08/2024

Liquefaction
Qualitative Buildings and Lifelines Risk
25 Year Average Return Period - Lower Bound
Glenorchy

Project	Glenorchy Kinloch Natural Hazard RA
Client	Otago Regional Council
Discipline	GIS
Drawing Number	GIS-3160904-03-001-01

GIS@beca.com

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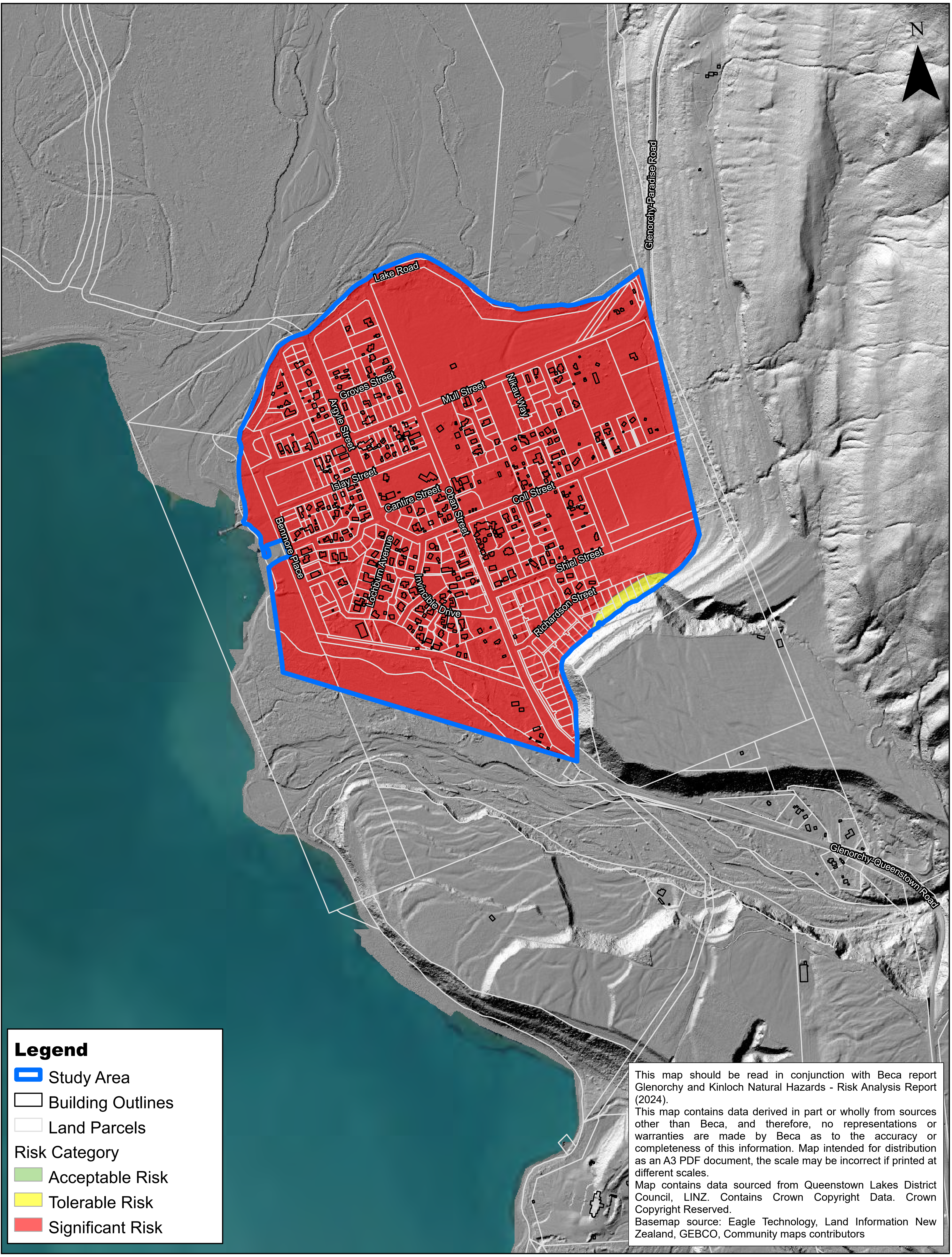

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Map Scale @ A3: 1:8,500

0 200
Metres

Revision 0.1
Status Final
Author ZT825
Verifier BDJ2
Date 26/08/2024

Liquefaction
Qualitative Buildings and Lifelines Risk
25 Year Average Return Period - Upper Bound
Glenorchy

Beca

Project Glenorchy Kinloch Natural Hazard RA
Client Otago Regional Council
Discipline GIS
Drawing Number GIS-3160904-03-002-01

GIS@beca.com

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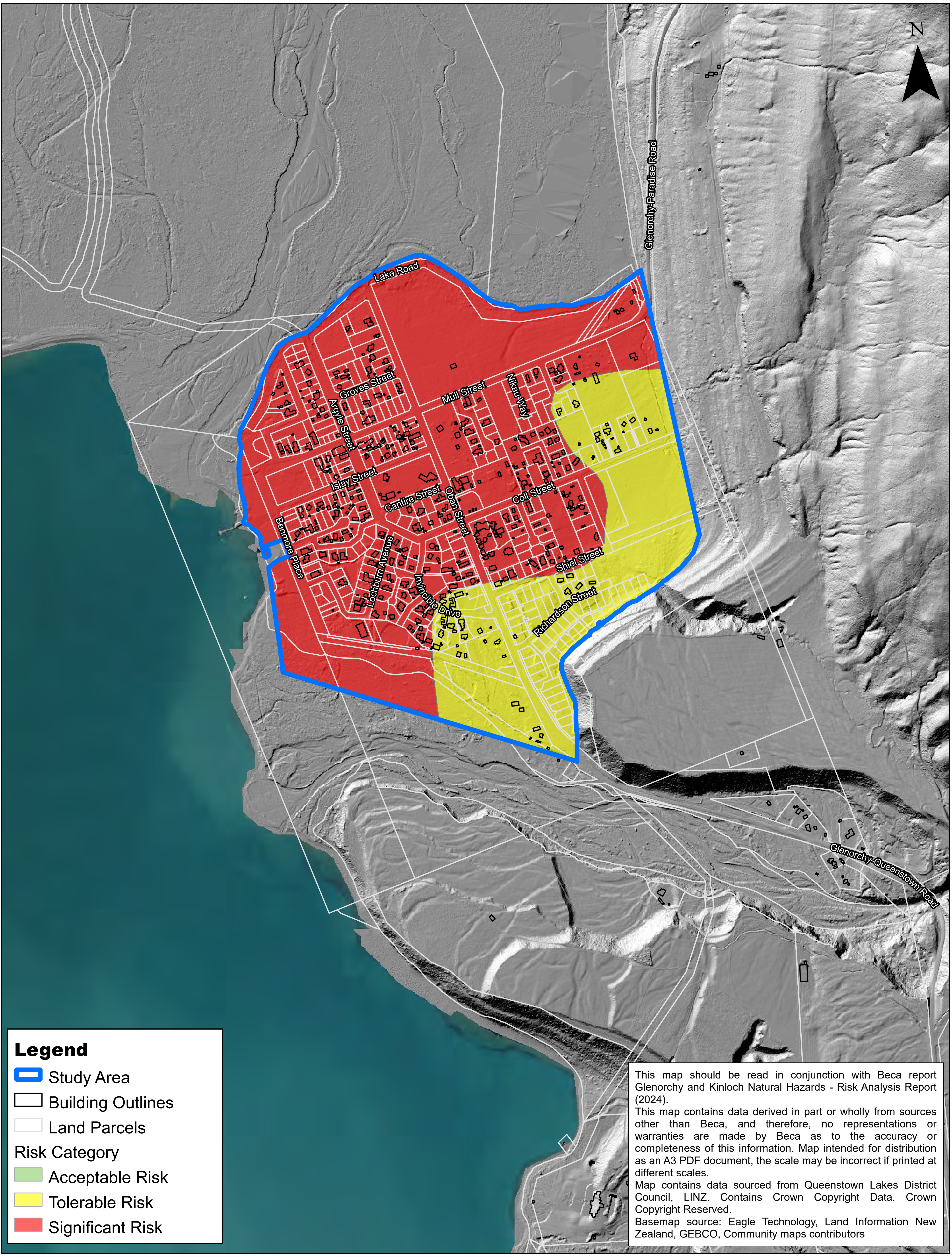

Legend

- ▭ Study Area
- ▭ Building Outlines
- ▭ Land Parcels

Risk Category

- 🟩 Acceptable Risk
- 🟨 Tolerable Risk
- 🟥 Significant Risk

This map should be read in conjunction with Beca report Glenorchy and Kinloch Natural Hazards - Risk Analysis Report (2024).

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Map Scale @ A3: 1:8,500

0 200
Metres

Revision	0.1
Status	Final
Author	ZT825
Verifier	BDJ2
Date	26/08/2024

Liquefaction
Qualitative Buildings and Lifelines Risk
Alpine Fault Rupture - Lower Bound
Glenorchy

Beca

Project	Glenorchy Kinloch Natural Hazard RA
Client	Otago Regional Council
Discipline	GIS
Drawing Number	GIS-3160904-03-003-01

GIS@beca.com

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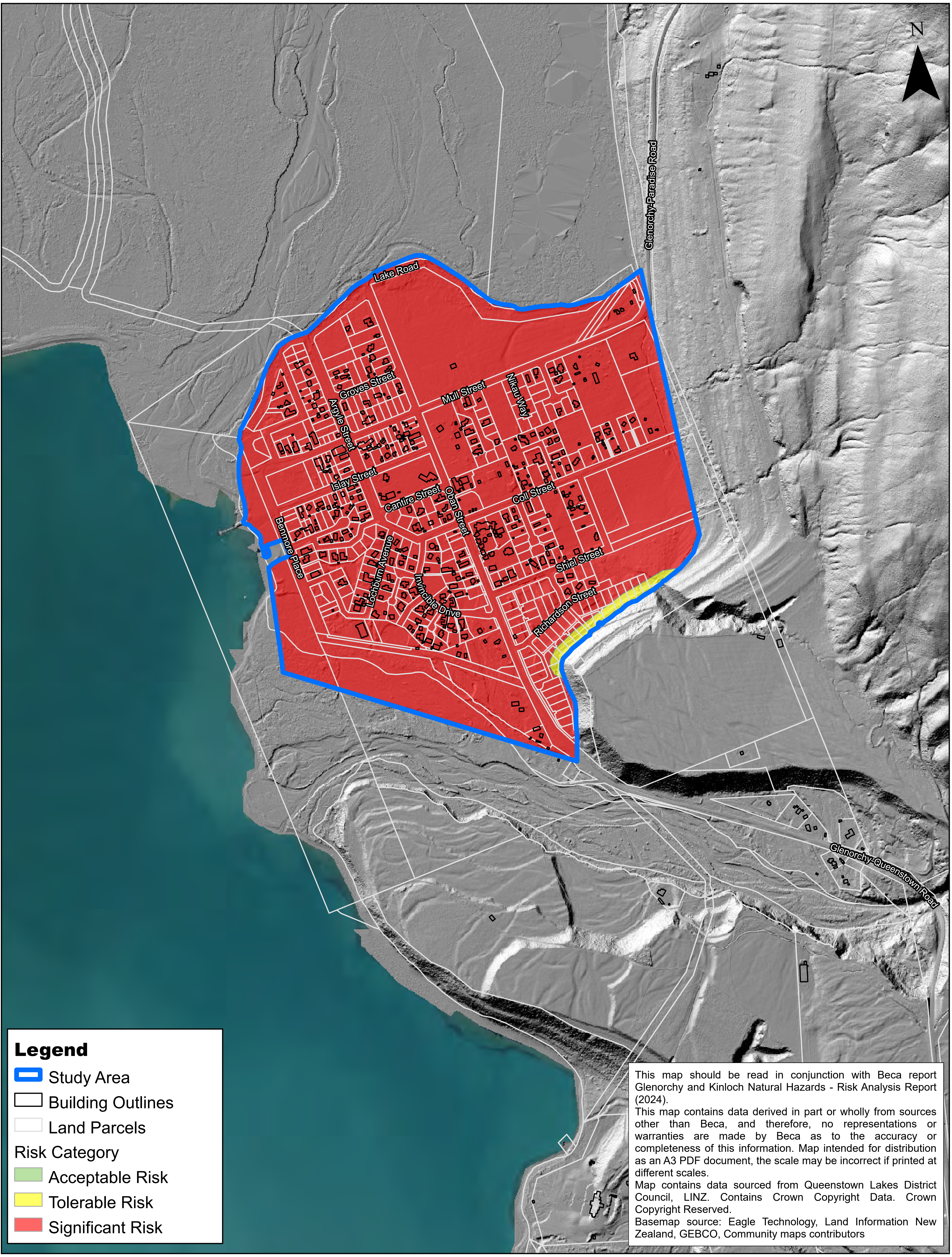

Legend

- 🟦 Study Area
- ☐ Building Outlines
- ☐ Land Parcels

Risk Category

- 🟩 Acceptable Risk
- 🟨 Tolerable Risk
- 🟥 Significant Risk

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Map Scale @ A3: 1:8,500

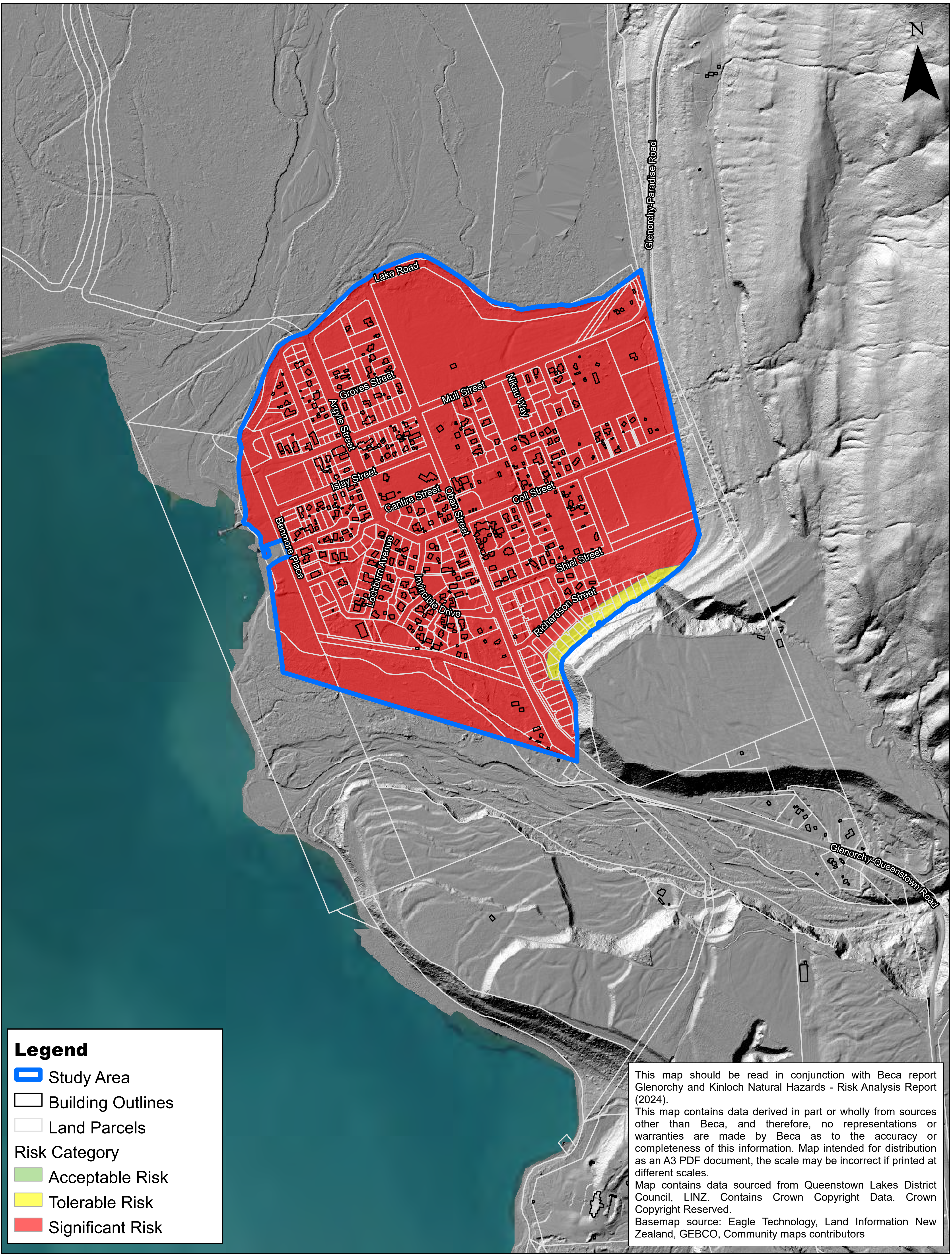
0 200
Metres

Revision	0.1
Status	Final
Author	ZT825
Verifier	BDJ2
Date	26/08/2024

Liquefaction
Qualitative Buildings and Lifelines Risk
Alpine Fault Rupture - Median
Glenorchy

Beca

Project	Glenorchy Kinloch Natural Hazard RA
Client	Otago Regional Council
Discipline	GIS
Drawing Number	GIS-3160904-03-004-01



Legend

- 🟦 Study Area
- ☐ Building Outlines
- ☐ Land Parcels

Risk Category

- 🟩 Acceptable Risk
- 🟨 Tolerable Risk
- 🟥 Significant Risk

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Map Scale @ A3: 1:8,500

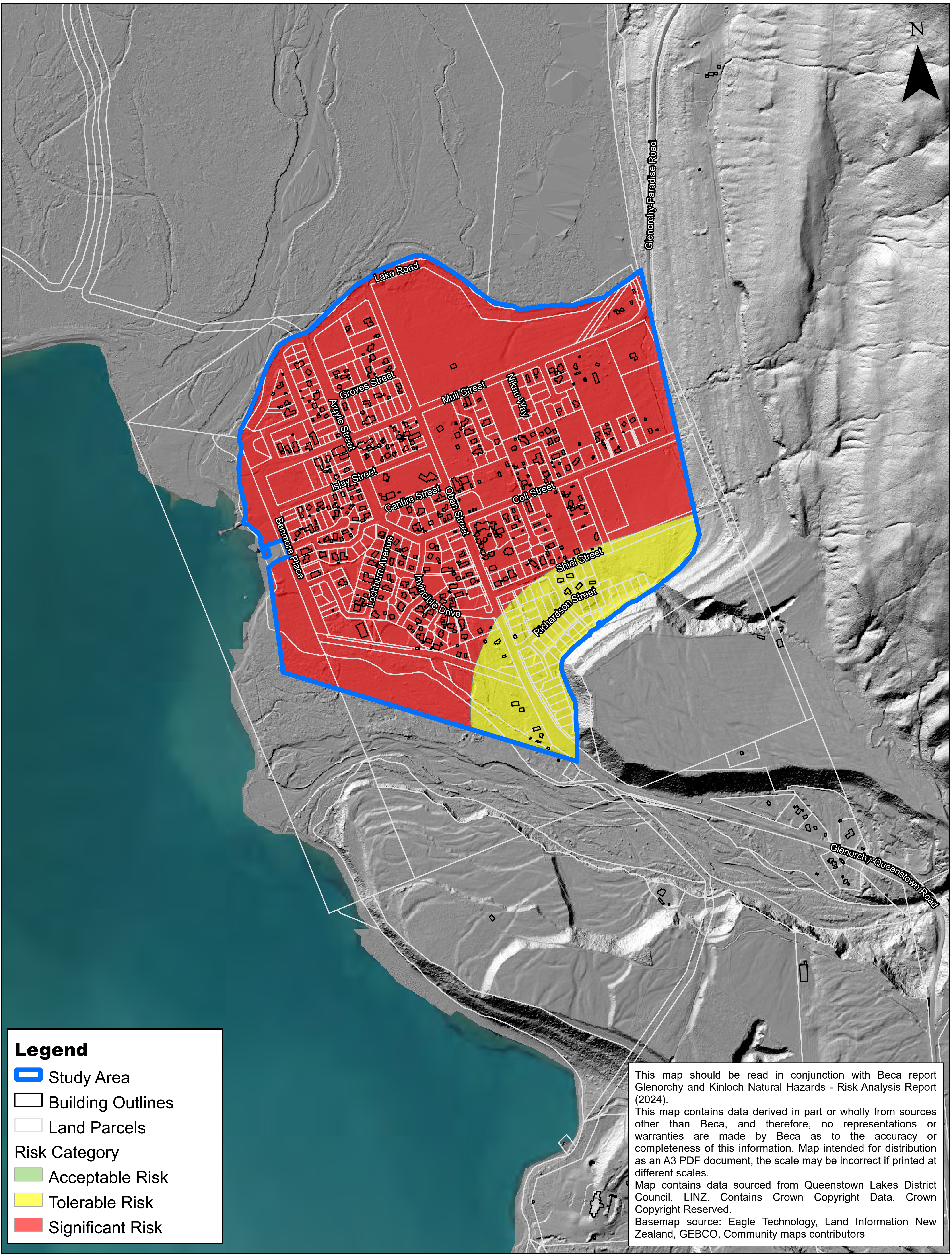
0 200
Metres

Revision 0.1
Status Final
Author ZT825
Verifier BDJ2
Date 26/08/2024

Liquefaction
Qualitative Buildings and Lifelines Risk
Alpine Fault Rupture - Upper Bound
Glenorchy

Beca

Project Glenorchy Kinloch Natural Hazard RA
Client Otago Regional Council
Discipline GIS
Drawing Number GIS-3160904-03-005-01



Legend
- Study Area
- Building Outlines
- Land Parcels

Risk Category
- 🟩 Acceptable Risk
- 🟨 Tolerable Risk
- 🟥 Significant Risk

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Path: P:\316\3160904\1-WIP\WG-GIS\01-Map\GlenorchyKinloch_ReportMaps\GlenorchyKinloch_ReportMaps.aprx Map Layout: 03 Qualitative - Liquefaction and Lateral Spread Date Printed: 26/08/2024

Map Scale @ A3: 1:8,500

0 200
Metres

Revision 0.1
Status Final
Author ZT825
Verifier BDJ2
Date 26/08/2024

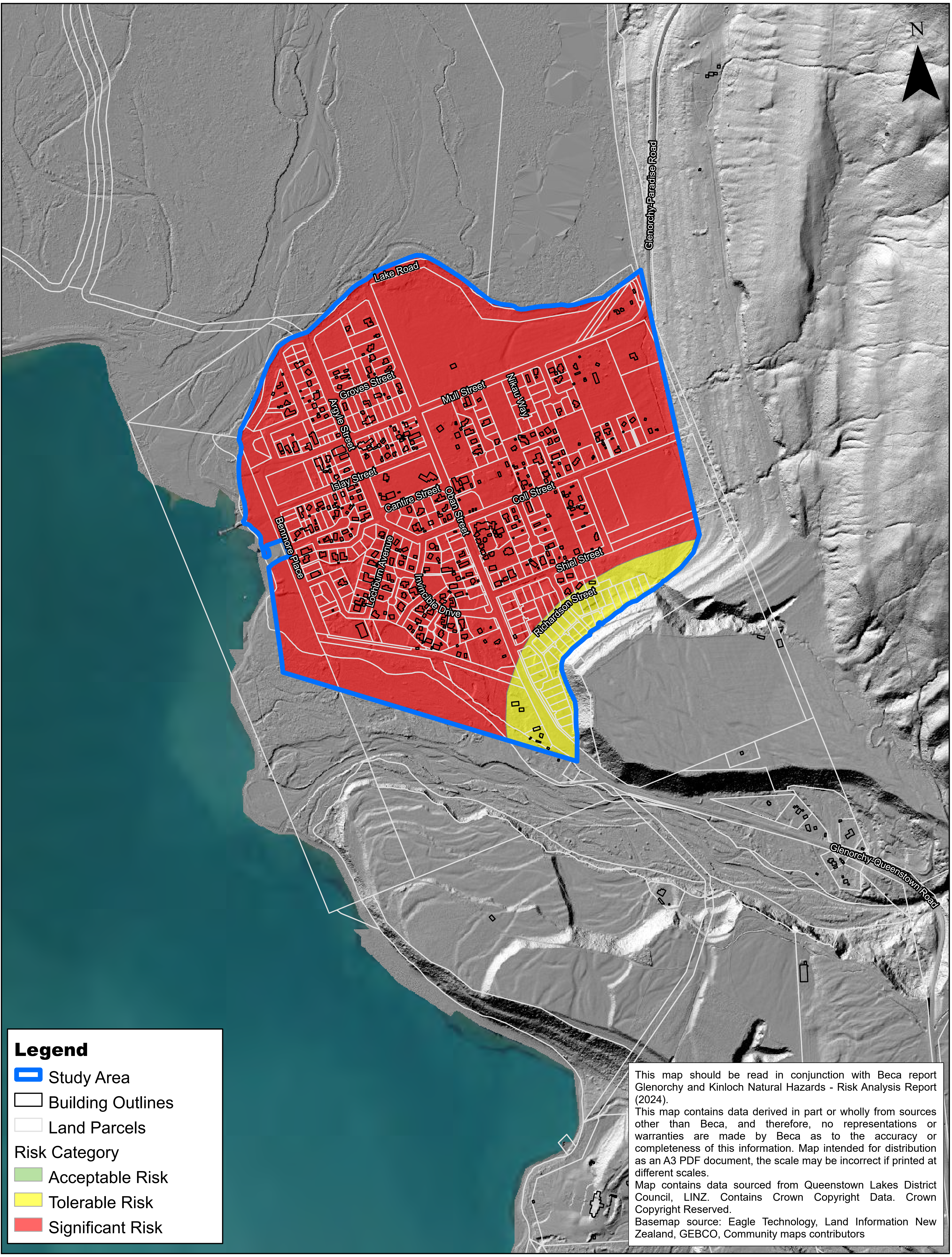
Liquefaction
Qualitative Buildings and Lifelines Risk
250 Year Average Return Period - Lower Bound
Glenorchy

Beca

Project Glenorchy Kinloch Natural Hazard RA
Client Otago Regional Council
Discipline GIS
Drawing Number GIS-3160904-03-006-01

GIS@beca.com

Path: P:\3160904\1-WIP\WG-GIS\01-Map\GlenorchyKinloch_ReportMaps\GlenorchyKinloch_ReportMaps.aprx Map Layout: 03 Qualitative - Liquefaction and Lateral Spread Date Printed: 26/08/2024



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Map Scale @ A3: 1:8,500

0 200
Metres

Revision	0.1
Status	Final
Author	ZT825
Verifier	BDJ2
Date	26/08/2024

Liquefaction
Qualitative Buildings and Lifelines Risk
250 Year Average Return Period - Upper Bound
Glenorchy

Beca

Project	Glenorchy Kinloch Natural Hazard RA
Client	Otago Regional Council
Discipline	GIS
Drawing Number	GIS-3160904-03-007-01

G

Appendix G – Quantitative Risk Maps

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Path: P:\316\3160904\1-WIP\WG-GIS\01-Map\GlenorchyKinloch_ReportMaps\GlenorchyKinloch_ReportMaps.aprx Map Layout: 04 Quantitative - Life Risk - Flooding Date Printed: 26/08/2024

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Map Scale @ A3: 1:8,500

0 200
Metres

Revision	0.1
Status	Final
Author	ZT825
Verifier	BDJ2
Date	26/08/2024

Buckler Burn Flooding
Annual Individual Fatality Risk
50 Year Average Return Period
Glenorchy

Beca

Project	Glenorchy Kinloch Natural Hazard RA
Client	Otago Regional Council
Discipline	GIS
Drawing Number	GIS-3160904-04-001-01

GIS@beca.com

Path: P:\316\3160904\1-WIP\WG-GIS\01-Map\GlenorchyKinloch_ReportMaps\GlenorchyKinloch_ReportMaps.aprx Map Layout: 04 Quantitative - Life Risk - Flooding Date Printed: 26/08/2024

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Map Scale @ A3: 1:8,500

0 200
Metres

Revision	0.1
Status	Final
Author	ZT825
Verifier	BDJ2
Date	26/08/2024

Buckler Burn Flooding
Annual Individual Fatality Risk
100 Year Average Return Period
Glenorchy

Beca

Project	Glenorchy Kinloch Natural Hazard RA
Client	Otago Regional Council
Discipline	GIS
Drawing Number	GIS-3160904-04-002-01

GIS@beca.com

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Map Scale @ A3: 1:8,500

0 200
Metres

Revision 0.1
Status Final
Author ZT825
Verifier BDJ2
Date 26/08/2024

Buckler Burn Flooding
Annual Individual Fatality Risk
500 Year Average Return Period
Glenorchy

Beca

Project Glenorchy Kinloch Natural Hazard RA
Client Otago Regional Council
Discipline GIS
Drawing Number GIS-3160904-04-003-01

GIS@beca.com

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Map Scale @ A3: 1:8,500

0 200
Metres

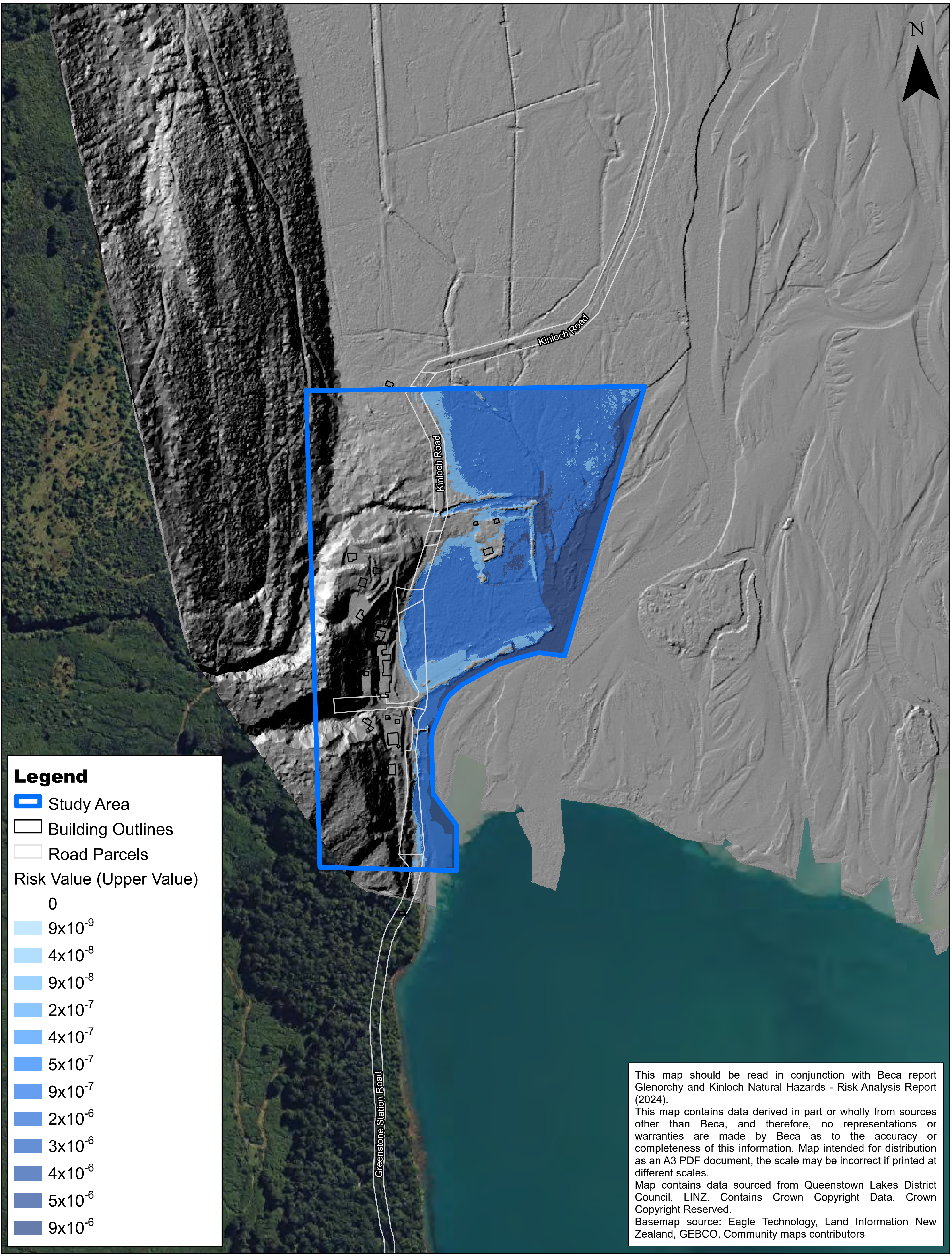
Revision	0.1
Status	Final
Author	ZT825
Verifier	BDJ2
Date	26/08/2024

Rees/Dart Flooding
Annual Individual Fatality Risk
50 Year Average Return Period
Glenorchy

Project	Glenorchy Kinloch Natural Hazard RA
Client	Otago Regional Council
Discipline	GIS
Drawing Number	GIS-3160904-04-004-01

GIS@beca.com

Path: P:\316\3160904\1-WIP\WG-GIS\01-Map\GlenorchyKinloch_ReportMaps\GlenorchyKinloch_ReportMaps.aprx Map Layout: 04 Quantitative - Life Risk - Flooding Date Printed: 26/08/2024



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Map Scale @ A3: 1:5,000

0 200
Metres

Revision	0.1
Status	Final
Author	ZT825
Verifier	BDJ2
Date	26/08/2024

Rees/Dart Flooding
Annual Individual Fatality Risk
50 Year Average Return Period
Kinloch

Beca

Project	Glenorchy Kinloch Natural Hazard RA
Client	Otago Regional Council
Discipline	GIS
Drawing Number	GIS-3160904-04-004-02

GIS@beca.com

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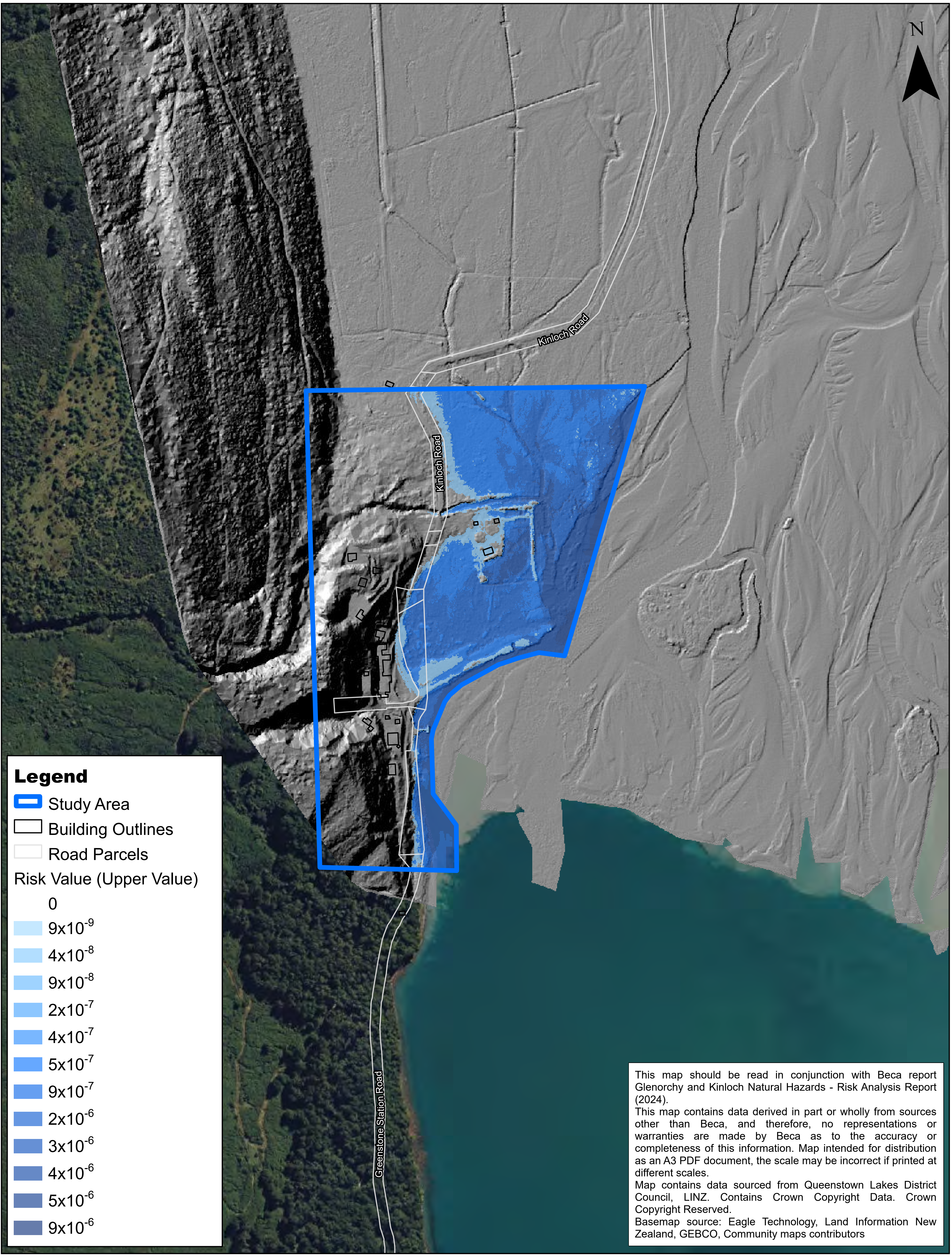
Rees/Dart Flooding
Annual Individual Fatality Risk
100 Year Average Return Period
Glenorchy

Beca

Project	Glenorchy Kinloch Natural Hazard RA
Client	Otago Regional Council
Discipline	GIS
Drawing Number	GIS-3160904-04-005-01

GIS@beca.com



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Map Scale @ A3: 1:5,000

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Metres

Revision	0.1
Status	Final
Author	ZT825
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Rees/Dart Flooding
Annual Individual Fatality Risk
100 Year Average Return Period
Kinloch

Beca

Project	Glenorchy Kinloch Natural Hazard RA
Client	Otago Regional Council
Discipline	GIS
Drawing Number	GIS-3160904-04-005-02

GIS@beca.com

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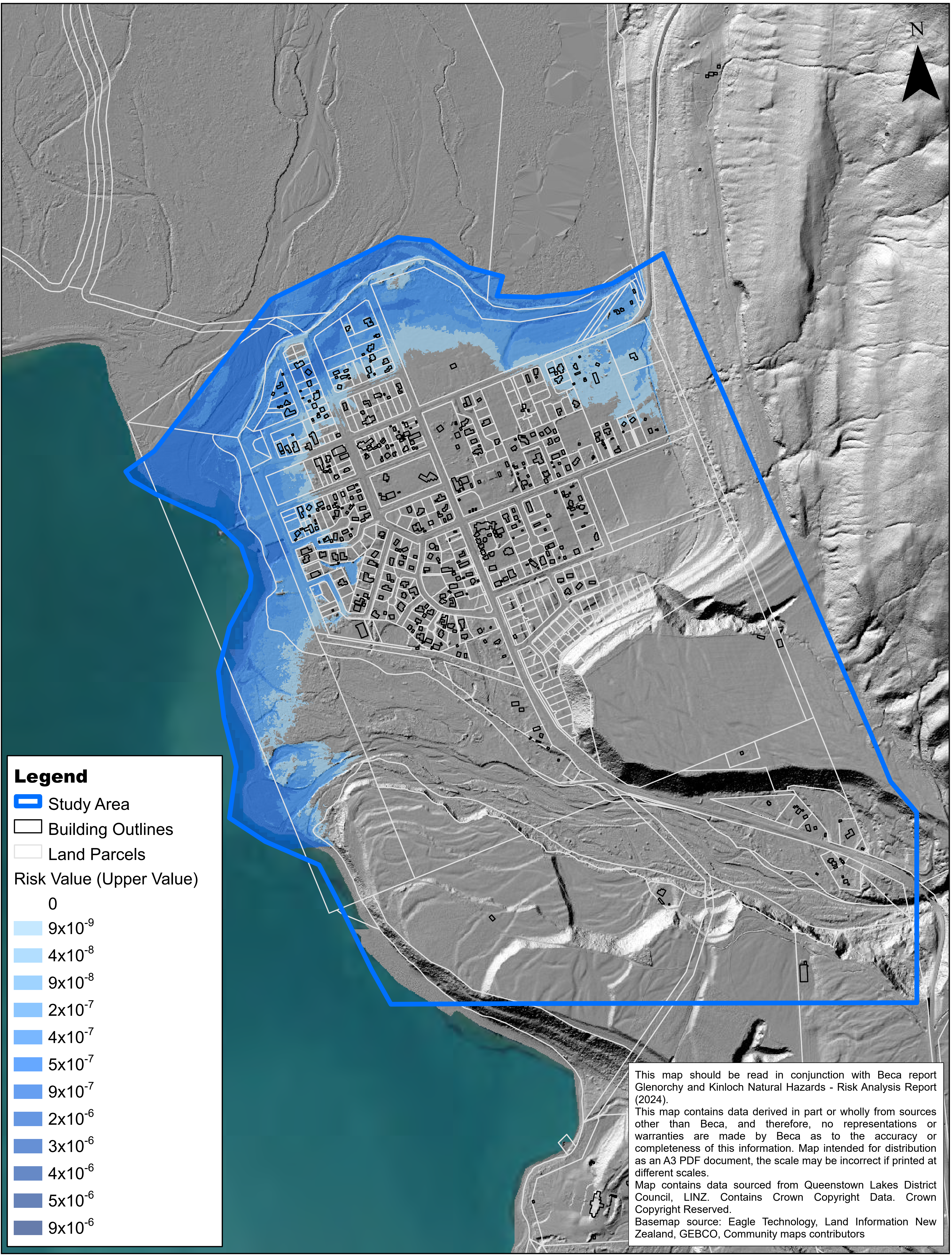

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0 200
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Revision	0.1
Status	Final
Author	ZT825
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Date	26/08/2024

Rees/Dart Flooding
Annual Individual Fatality Risk
500 Year Average Return Period
Glenorchy

Beca

Project	Glenorchy Kinloch Natural Hazard RA
Client	Otago Regional Council
Discipline	GIS
Drawing Number	GIS-3160904-04-006-01

GIS@beca.com

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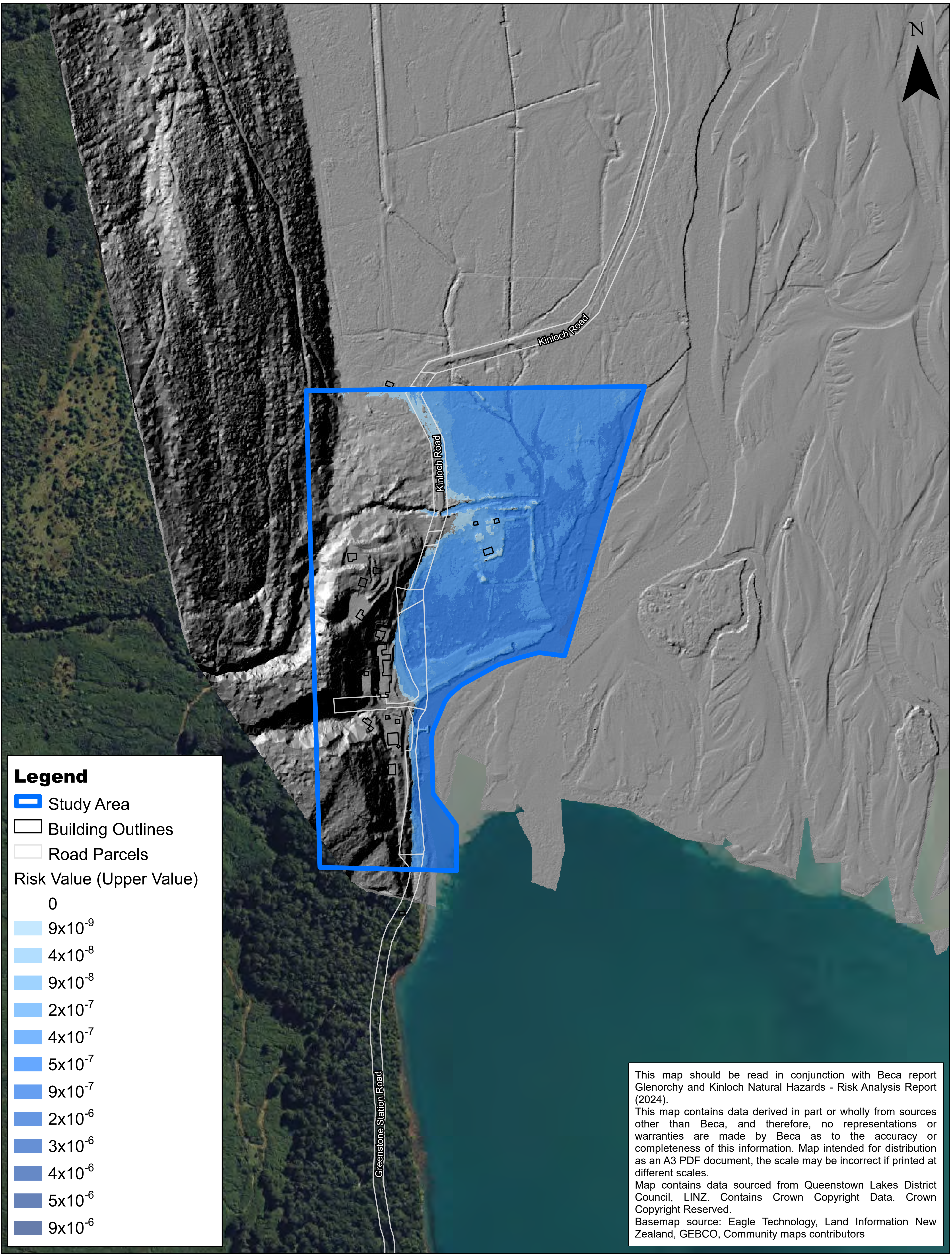

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Revision	0.1
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Verifier	BDJ2
Date	26/08/2024

Rees/Dart Flooding
Annual Individual Fatality Risk
500 Year Average Return Period
Kinloch

Beca

Project	Glenorchy Kinloch Natural Hazard RA
Client	Otago Regional Council
Discipline	GIS
Drawing Number	GIS-3160904-04-006-02

GIS@beca.com

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Map Scale @ A3: 1:8,500

0 200
Metres

Revision 0.1
Status Final
Author ZT825
Verifier BDJ2
Date 26/08/2024

Joint Scenario
Annual Individual Fatality Risk
50 Year Average Return Period
Glenorchy

Beca

Project Glenorchy Kinloch Natural Hazard RA
Client Otago Regional Council
Discipline GIS
Drawing Number GIS-3160904-04-007-01

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Revision	0.1
Status	Final
Author	ZT825
Verifier	BDJ2
Date	26/08/2024

Joint Scenario
Annual Individual Fatality Risk
100 Year Average Return Period
Glenorchy

Project	Glenorchy Kinloch Natural Hazard RA
Client	Otago Regional Council
Discipline	GIS
Drawing Number	GIS-3160904-04-008-01

GIS@beca.com

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Revision	0.1
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Author	ZT825
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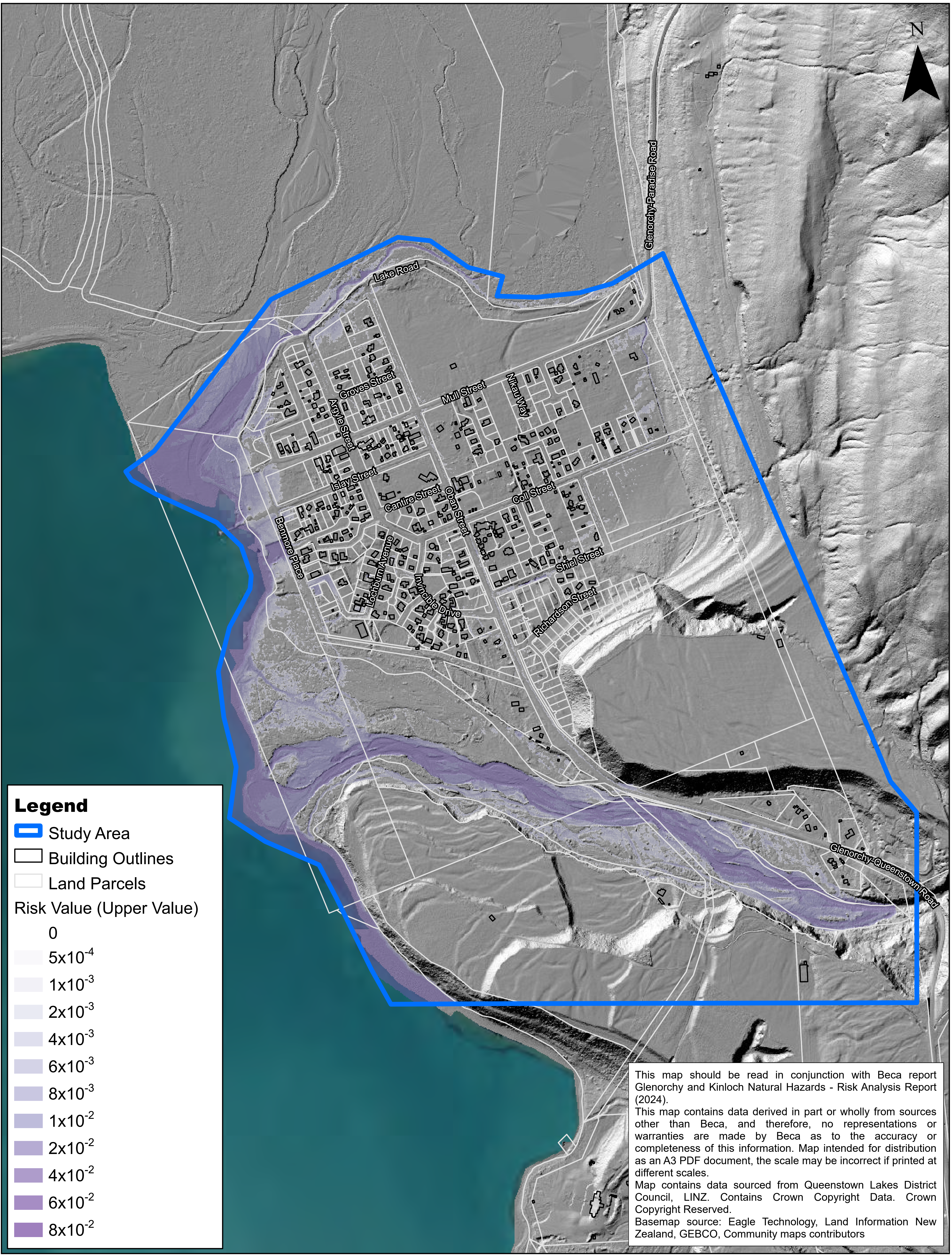
Joint Scenario
Annual Individual Fatality Risk
500 Year Average Return Period
Glenorchy

Beca

Project	Glenorchy Kinloch Natural Hazard RA
Client	Otago Regional Council
Discipline	GIS
Drawing Number	GIS-3160904-04-009-01

GIS@beca.com

Path: P:\316\3160904\1-WIP\WG-GIS\01-Map\GlenorchyKinloch_ReportMaps\GlenorchyKinloch_ReportMaps.aprx Map Layout: 05 Quantitative - Property Risk - Flooding Date Printed: 26/08/2024



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0 200
Metres

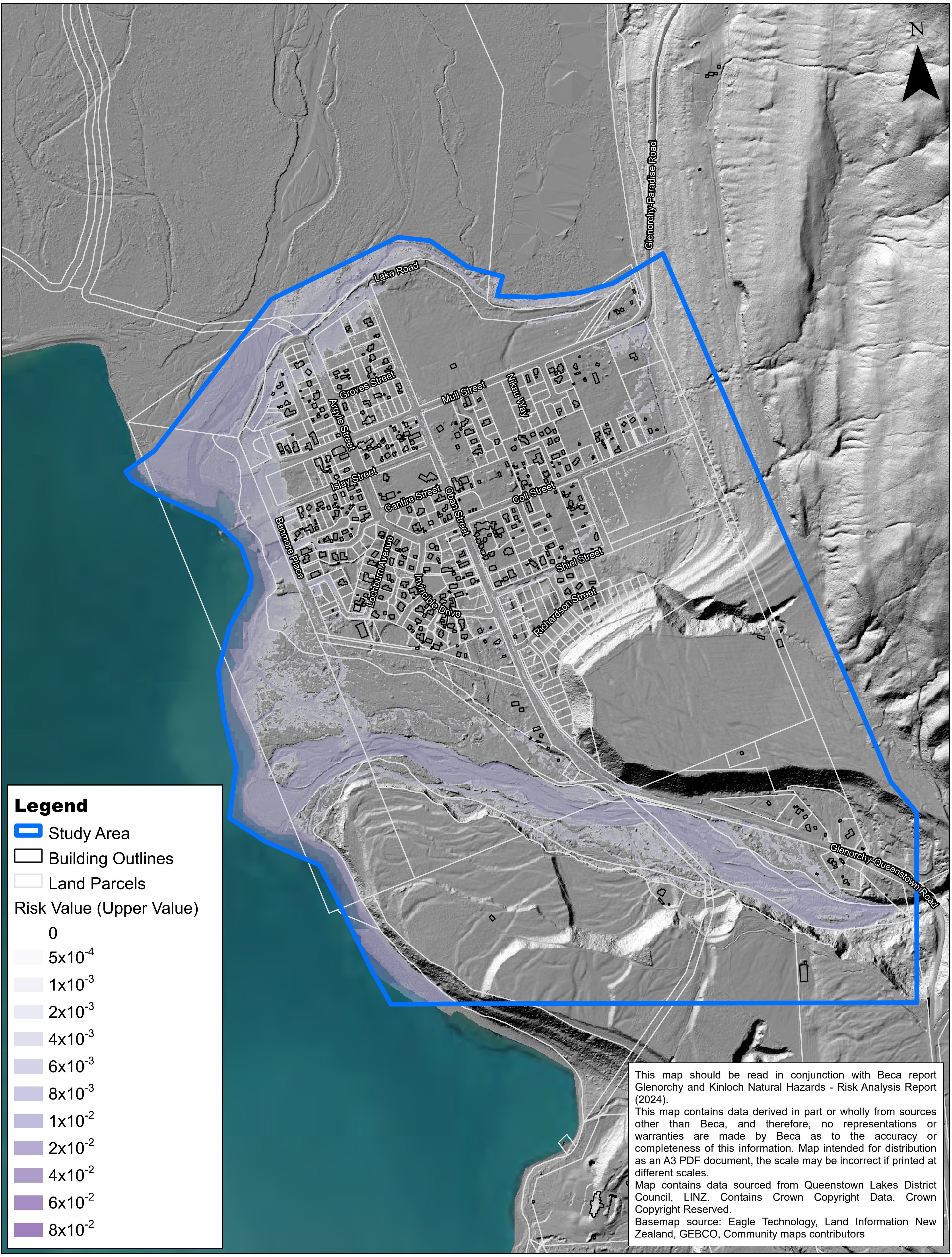
Revision 0.1
Status Final
Author ZT825
Verifier BDJ2
Date 26/08/2024

Buckler Burn Flooding
Annual Property Risk
50 Year Average Return Period
Glenorchy

Beca

Project Glenorchy Kinloch Natural Hazard RA
Client Otago Regional Council
Discipline GIS
Drawing Number GIS-3160904-05-001-01

GIS@beca.com



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Path: P:\316\3160904\1-WIP\WG-GIS\01-Map\GlenorchyKinloch_ReportMaps\GlenorchyKinloch_ReportMaps.aprx Map Layout: 05 Quantitative - Property Risk - Flooding Date Printed: 26/08/2024

Map Scale @ A3: 1:8,500

0 200
Metres

Revision	0.1
Status	Final
Author	ZT825
Verifier	BDJ2
Date	26/08/2024

Buckler Burn Flooding
Annual Property Risk
100 Year Average Return Period

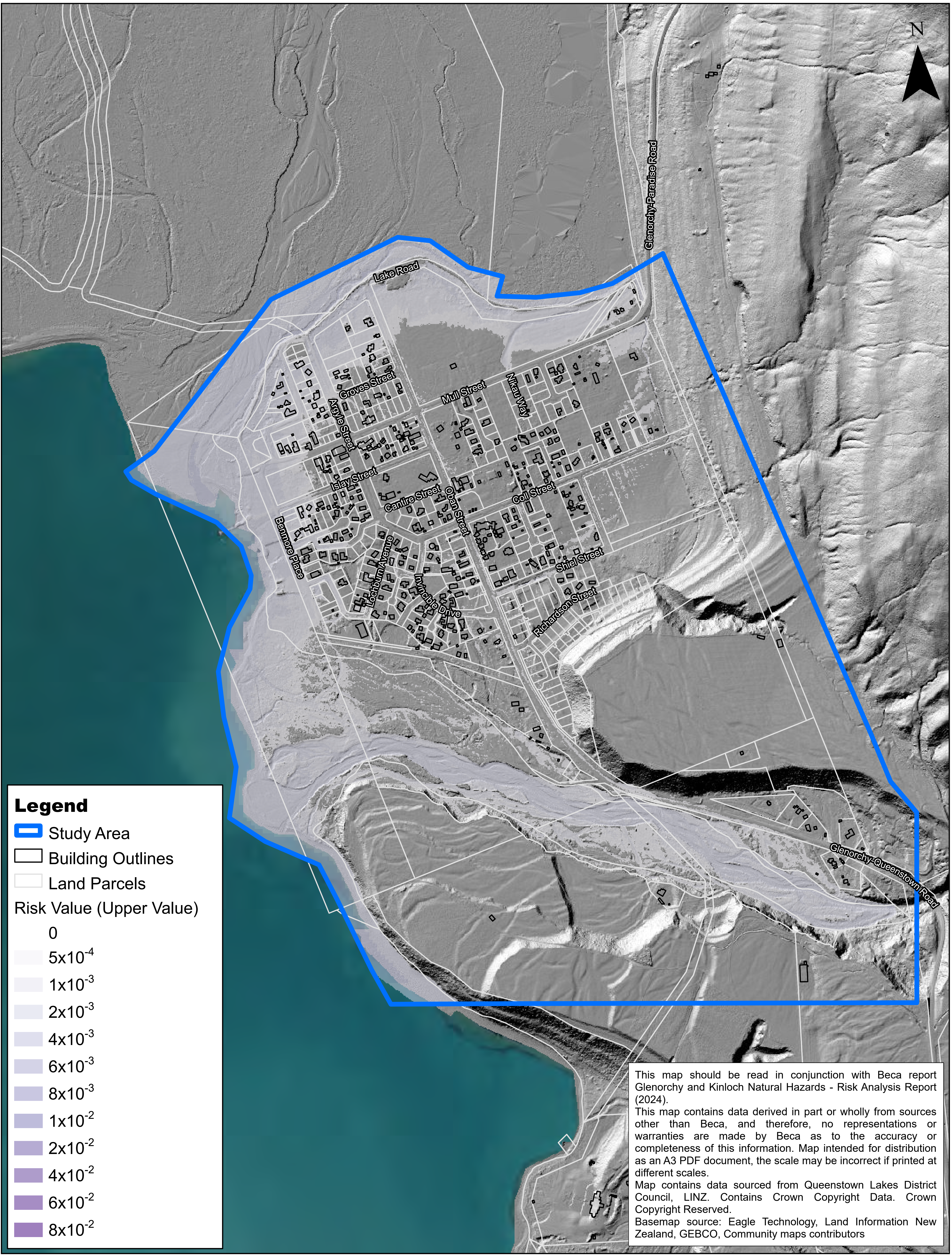
Glenorchy

Beca

Project	Glenorchy Kinloch Natural Hazard RA
Client	Otago Regional Council
Discipline	GIS
Drawing Number	GIS-3160904-05-002-01

GIS@beca.com

Path: P:\316\3160904\1-WIP\WG-GIS\01-Map\GlenorchyKinloch_ReportMaps\GlenorchyKinloch_ReportMaps.aprx Map Layout: 05 Quantitative - Property Risk - Flooding Date Printed: 26/08/2024



Legend

▭ Study Area

▭ Building Outlines

▭ Land Parcels

Risk Value (Upper Value)

- 0
- $5x10^{-4}$
- $1x10^{-3}$
- $2x10^{-3}$
- $4x10^{-3}$
- $6x10^{-3}$
- $8x10^{-3}$
- $1x10^{-2}$
- $2x10^{-2}$
- $4x10^{-2}$
- $6x10^{-2}$
- $8x10^{-2}$

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Map Scale @ A3: 1:8,500

0 200
Metres

Revision 0.1
Status Final
Author ZT825
Verifier BDJ2
Date 26/08/2024

Buckler Burn Flooding Annual Property Risk 500 Year Average Return Period

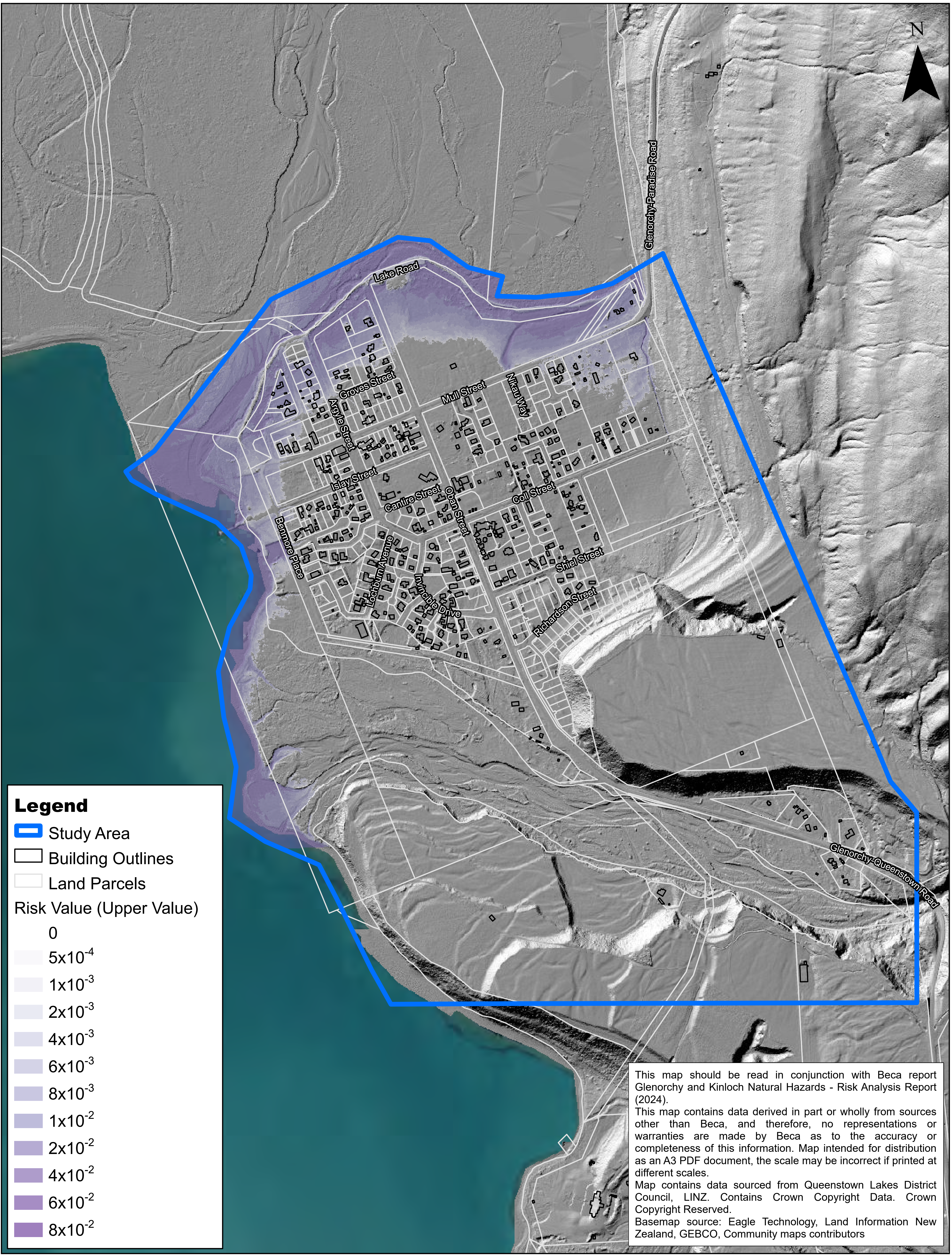
Glenorchy

Beca

Project Glenorchy Kinloch Natural Hazard RA
Client Otago Regional Council
Discipline GIS
Drawing Number GIS-3160904-05-003-01

GIS@beca.com

Path: P:\316\3160904\1-WIP\WG-GIS\01-Map\GlenorchyKinloch_ReportMaps\GlenorchyKinloch_ReportMaps.aprx Map Layout: 05 Quantitative - Property Risk - Flooding Date Printed: 26/08/2024



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Map Scale @ A3: 1:8,500

0 200
Metres

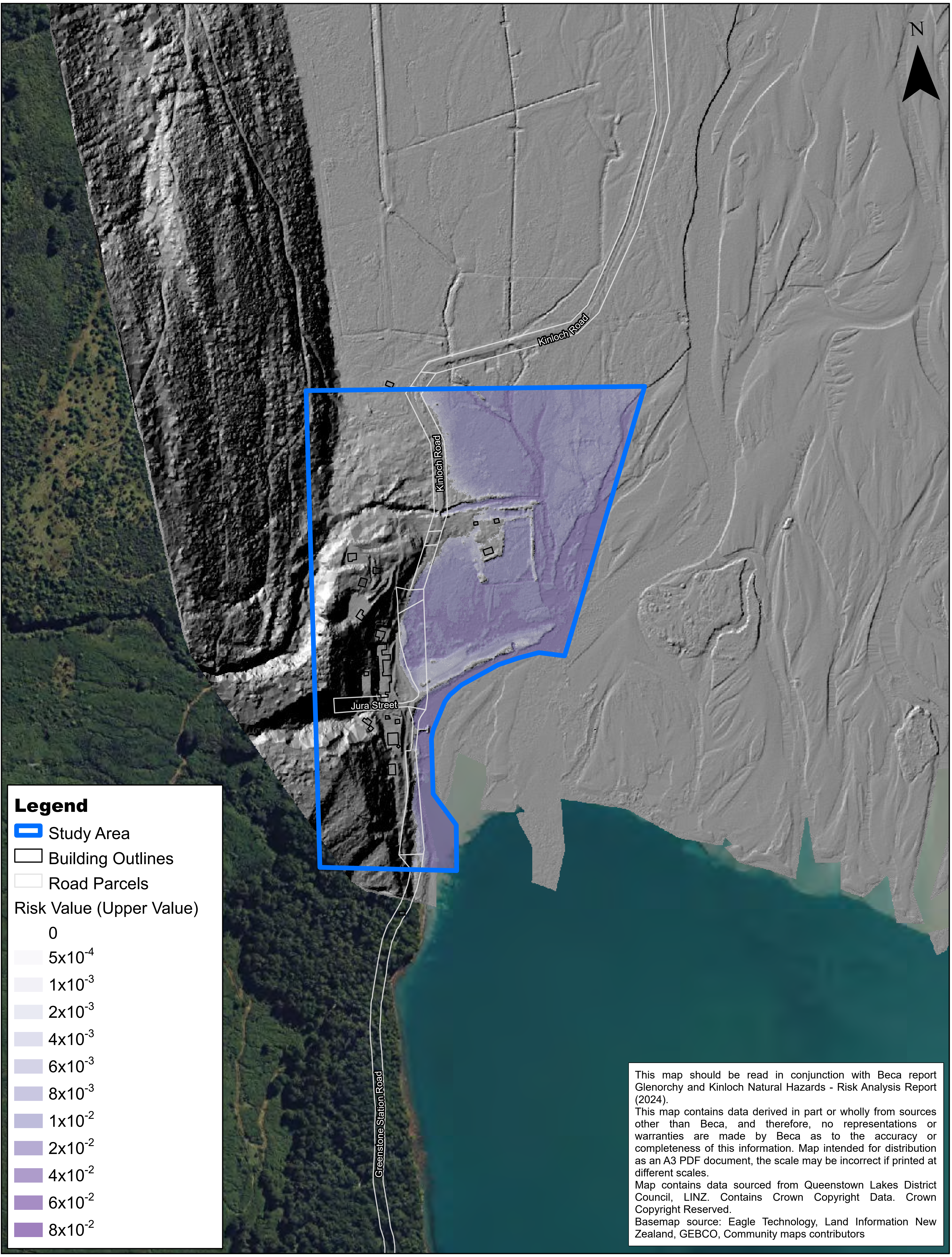
Revision	0.1
Status	Final
Author	ZT825
Verifier	BDJ2
Date	26/08/2024

Rees/Dart Flooding
Annual Property Risk
50 Year Average Return Period
Glenorchy

Project	Glenorchy Kinloch Natural Hazard RA
Client	Otago Regional Council
Discipline	GIS
Drawing Number	GIS-3160904-05-004-01

GIS@beca.com

Path: P:\316\3160904\1-WIP\WG-GIS\01-Map\GlenorchyKinloch_ReportMaps\GlenorchyKinloch_ReportMaps.aprx Map Layout: 05 Quantitative - Property Risk - Flooding Date Printed: 26/08/2024



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Map Scale @ A3: 1:5,000

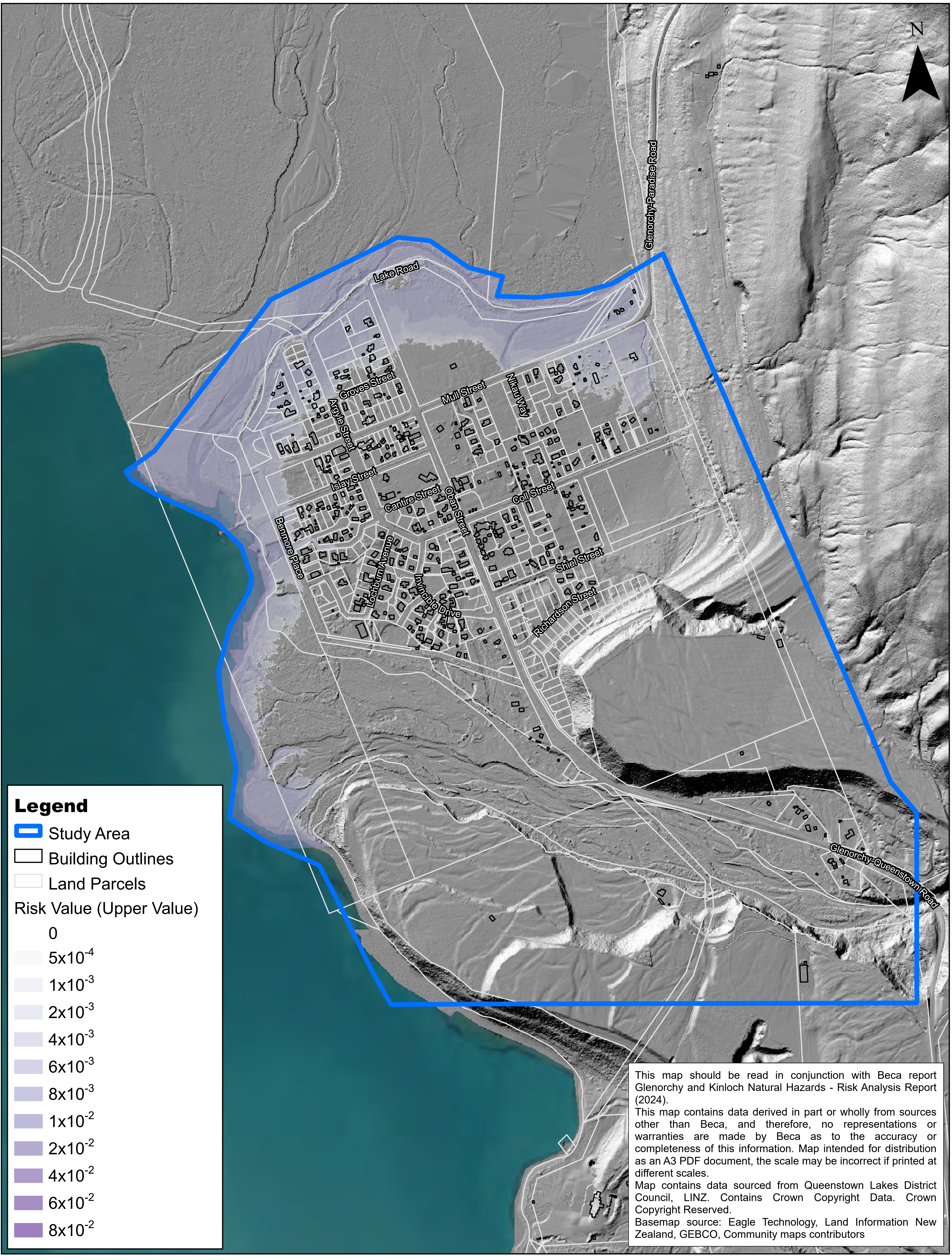
0 200
Metres

Revision	0.1
Status	Final
Author	ZT825
Verifier	BDJ2
Date	26/08/2024

Rees/Dart Flooding
Annual Property Risk
50 Year Average Return Period
Kinloch

Beca

Project	Glenorchy Kinloch Natural Hazard RA
Client	Otago Regional Council
Discipline	GIS
Drawing Number	GIS-3160904-05-004-02



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Map Scale @ A3: 1:8,500

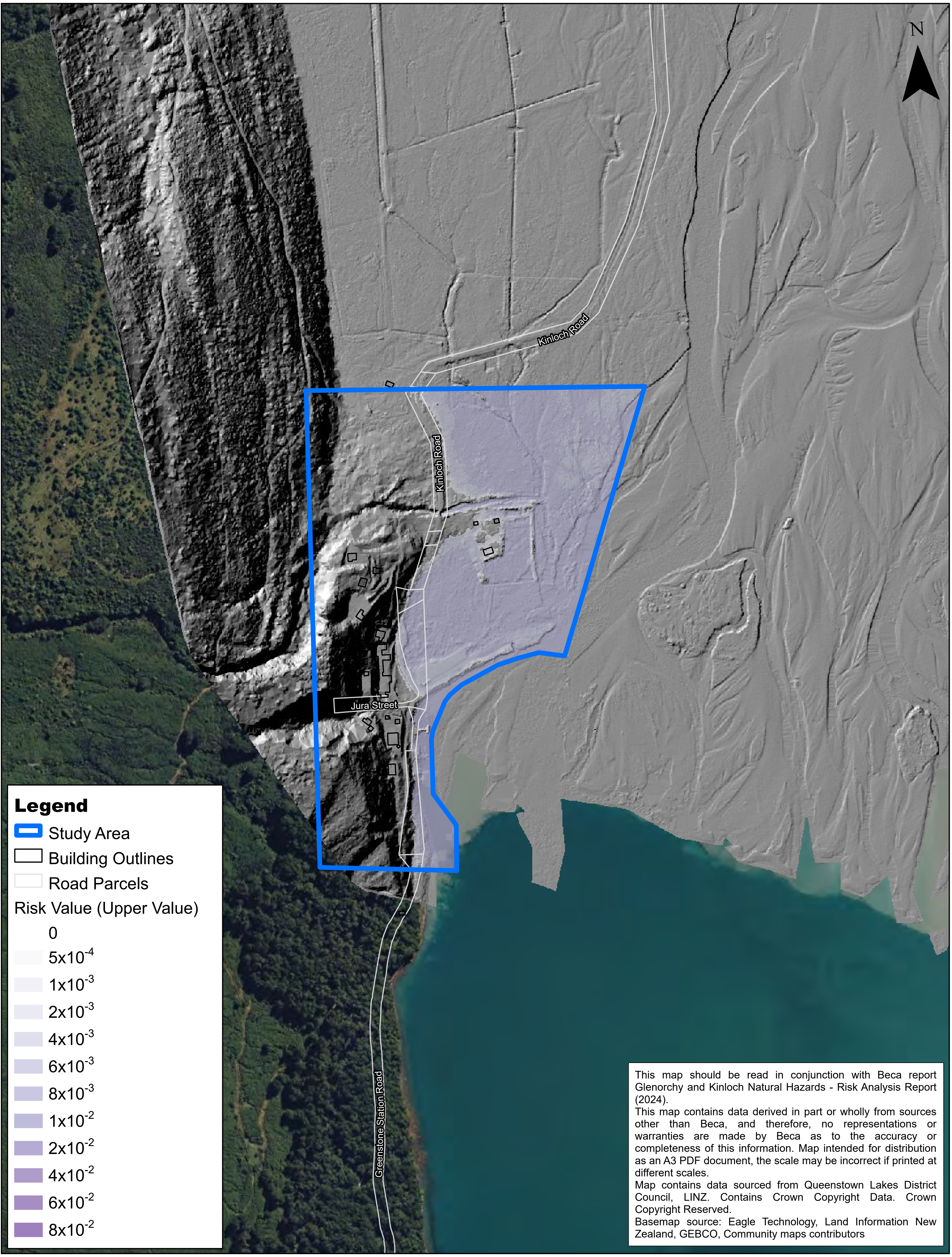
0 200
Metres

Revision	0.1
Status	Final
Author	ZT825
Verifier	BDJ2
Date	26/08/2024

Rees/Dart Flooding
Annual Property Risk
100 Year Average Return Period
Glenorchy

Beca

Project	Glenorchy Kinloch Natural Hazard RA
Client	Otago Regional Council
Discipline	GIS
Drawing Number	GIS-3160904-05-005-01



Legend

- ▭ Study Area
- ▭ Building Outlines
- ▭ Road Parcels

Risk Value (Upper Value)

- 0
- ▨ 5x10^{-4}
- ▨ 1x10^{-3}
- ▨ 2x10^{-3}
- ▨ 4x10^{-3}
- ▨ 6x10^{-3}
- ▨ 8x10^{-3}
- ▨ 1x10^{-2}
- ▨ 2x10^{-2}
- ▨ 4x10^{-2}
- ▨ 6x10^{-2}
- ▨ 8x10^{-2}

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Map Scale @ A3: 1:5,000

0 200
Metres

Revision 0.1
Status Final
Author ZT825
Verifier BDJ2
Date 26/08/2024

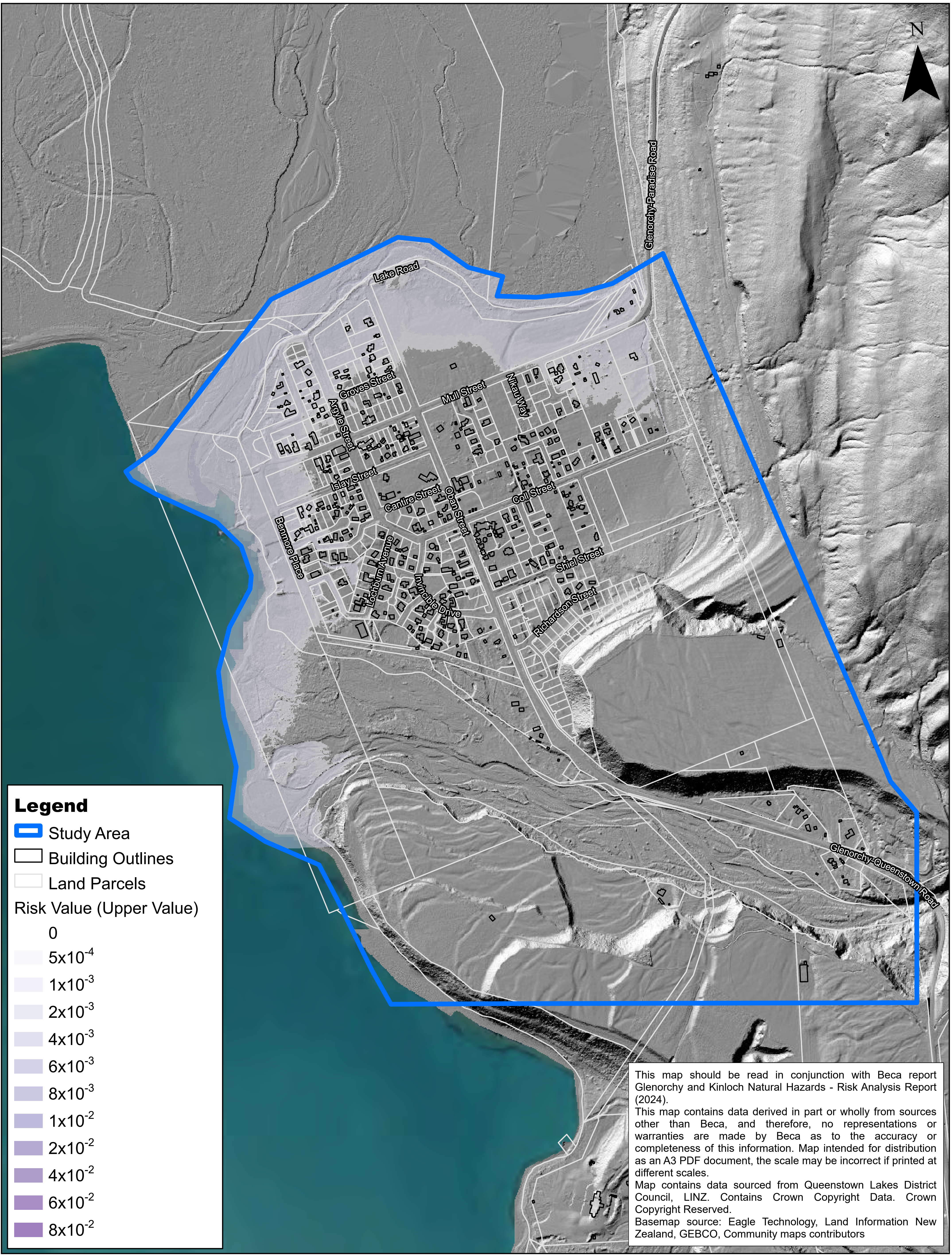
Rees/Dart Flooding
Annual Property Risk
100 Year Average Return Period
Kinloch

Beca

Project	Glenorchy Kinloch Natural Hazard RA
Client	Otago Regional Council
Discipline	GIS
Drawing Number	GIS-3160904-05-005-02

Path: P:\316\3160904\1-WIP\WG-GIS\01-Map\GlenorchyKinloch_ReportMaps\GlenorchyKinloch_ReportMaps.aprx Map Layout: 05 Quantitative - Property Risk - Flooding Date Printed: 26/08/2024

GIS@beca.com



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Map Scale @ A3: 1:8,500

0 200
Metres

Revision	0.1
Status	Final
Author	ZT825
Verifier	BDJ2
Date	26/08/2024

Rees/Dart Flooding
Annual Property Risk
500 Year Average Return Period

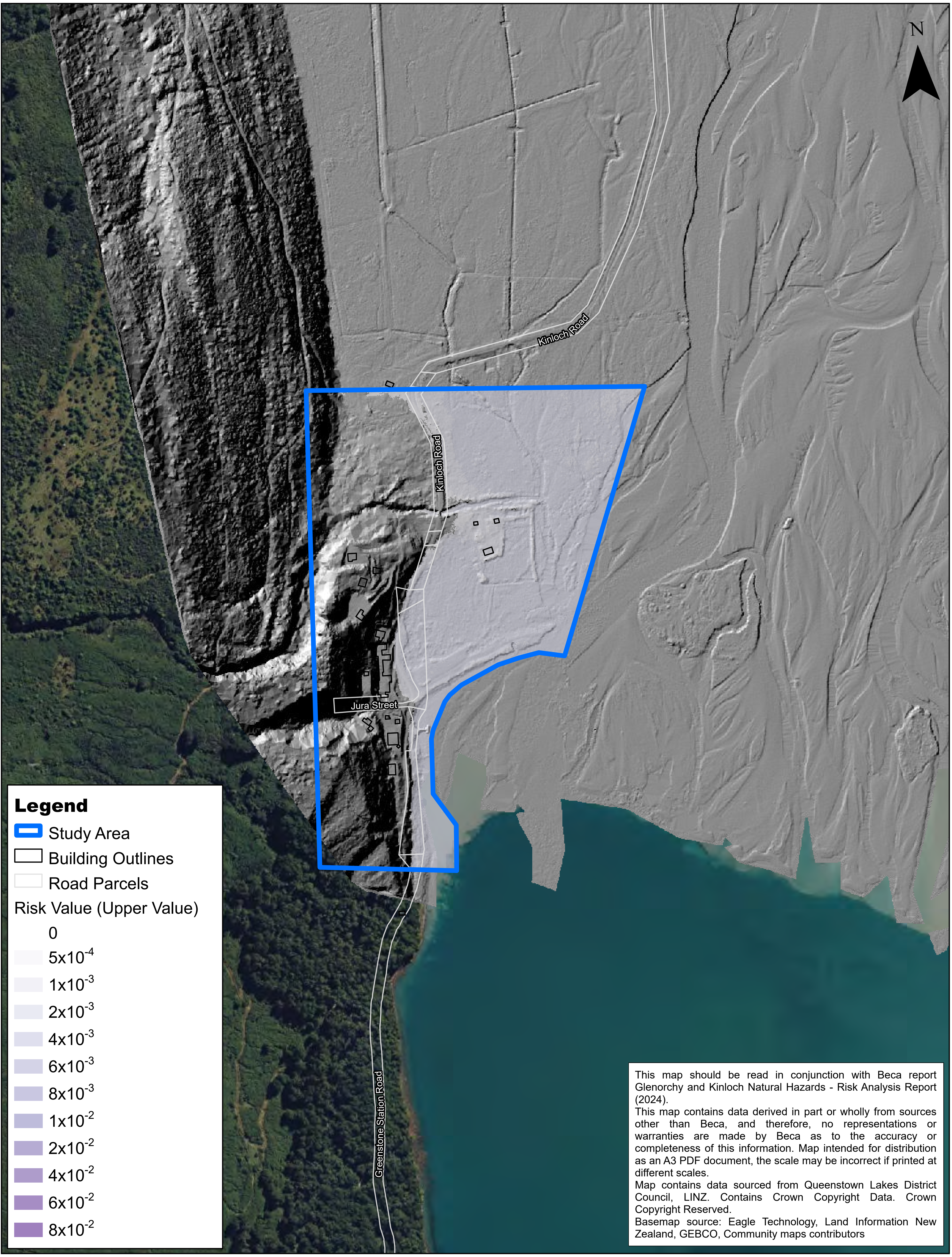
Glenorchy

Beca

Project	Glenorchy Kinloch Natural Hazard RA
Client	Otago Regional Council
Discipline	GIS
Drawing Number	GIS-3160904-05-006-01

GIS@beca.com

Path: P:\316\3160904\1-WIP\WG-GIS\01-Map\GlenorchyKinloch_ReportMaps\GlenorchyKinloch_ReportMaps.aprx Map Layout: 05 Quantitative - Property Risk - Flooding Date Printed: 26/08/2024



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Map Scale @ A3: 1:5,000

0 200
Metres

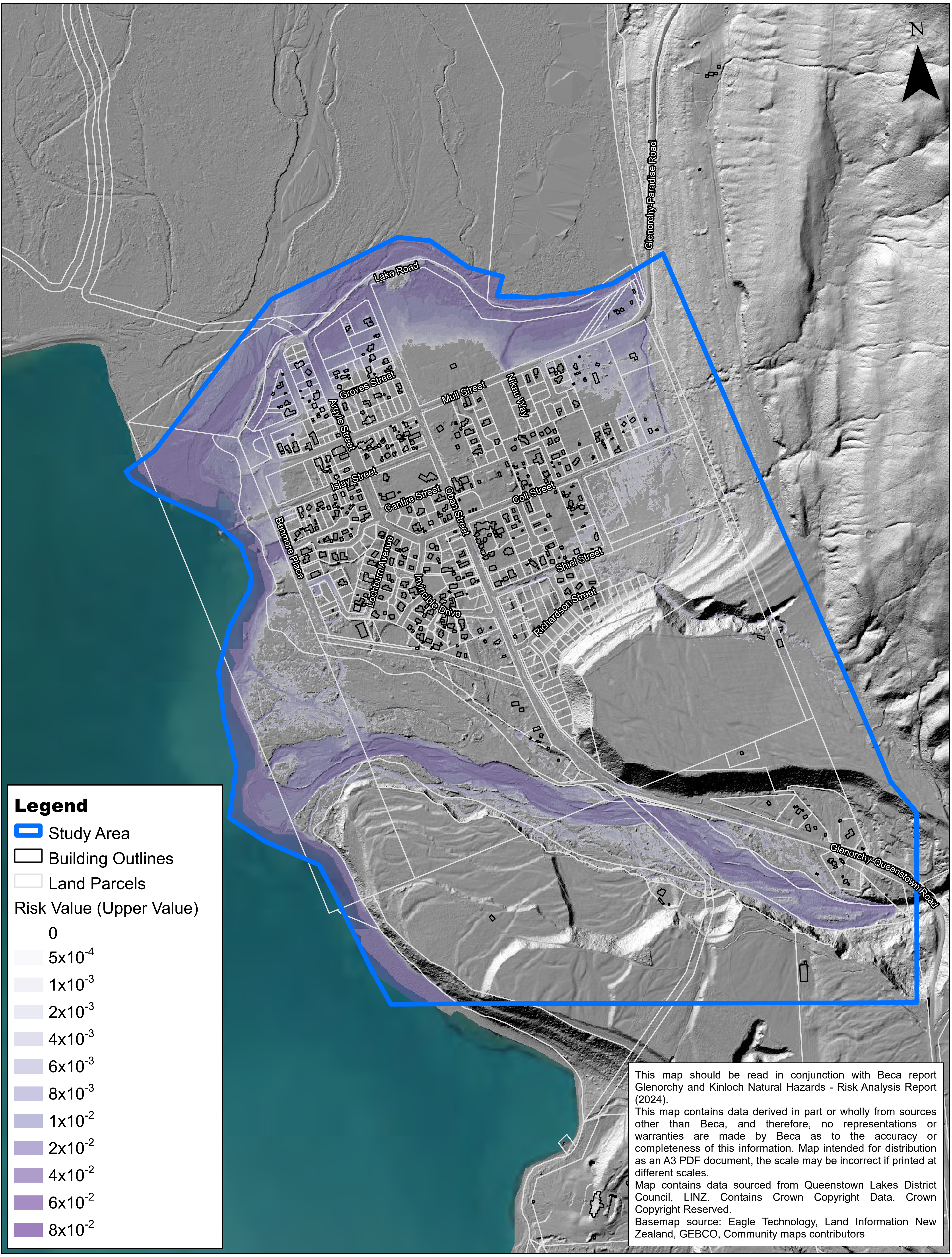
Revision	0.1
Status	Final
Author	ZT825
Verifier	BDJ2
Date	26/08/2024

Rees/Dart Flooding
Annual Property Risk
500 Year Average Return Period
Kinloch

Beca

Project	Glenorchy Kinloch Natural Hazard RA
Client	Otago Regional Council
Discipline	GIS
Drawing Number	GIS-3160904-05-006-02

GIS@beca.com



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Map Scale @ A3: 1:8,500

0 200
Metres

Revision	0.1
Status	Final
Author	ZT825
Verifier	BDJ2
Date	26/08/2024

Joint Scenario Flooding
Annual Property Risk
50 Year Average Return Period

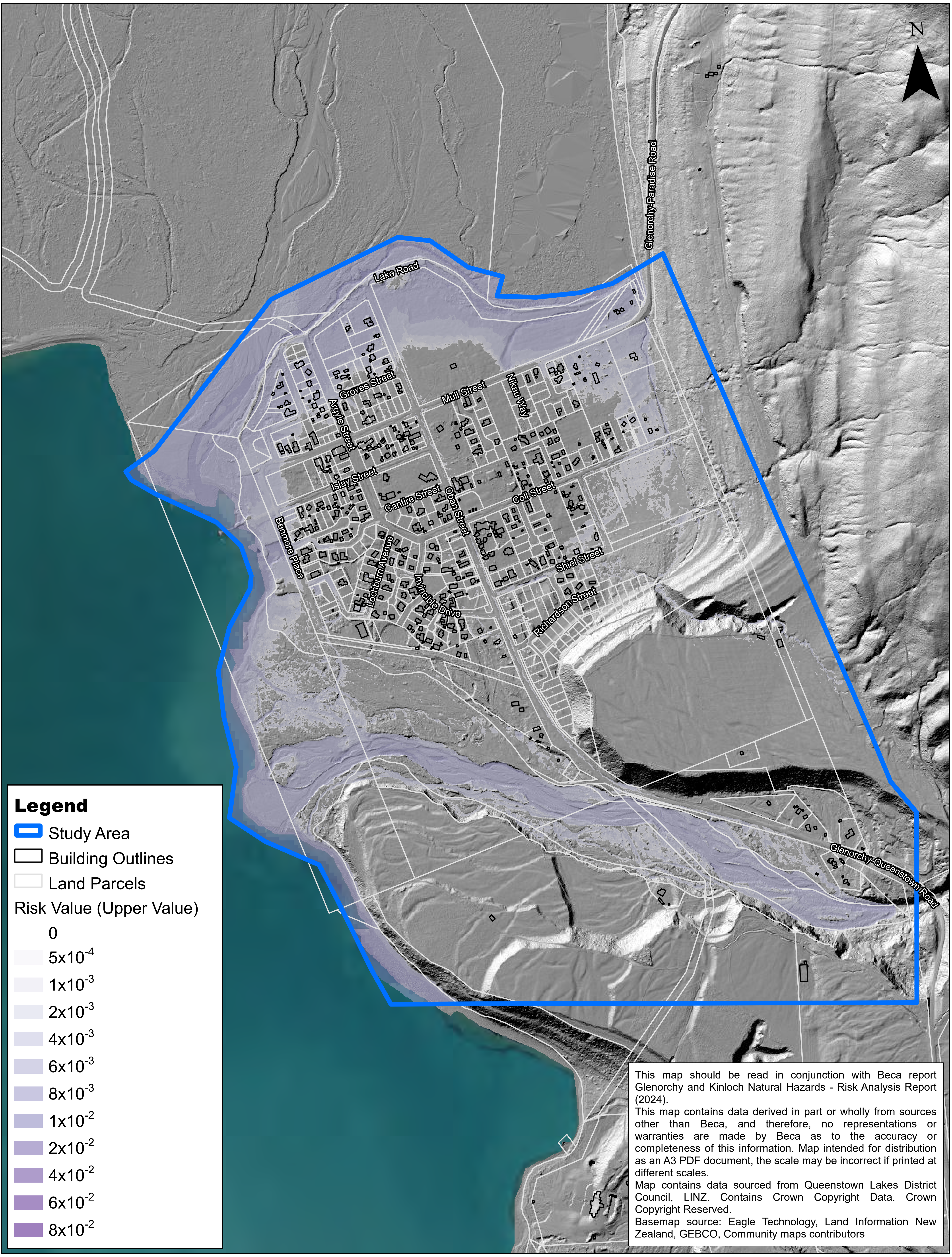
Glenorchy

Beca

Project	Glenorchy Kinloch Natural Hazard RA
Client	Otago Regional Council
Discipline	GIS
Drawing Number	GIS-3160904-05-007-01

GIS@beca.com

Path: P:\316\3160904\1-WIP\WG-GIS\01-Map\GlenorchyKinloch_ReportMaps\GlenorchyKinloch_ReportMaps.aprx Map Layout: 05 Quantitative - Property Risk - Flooding Date Printed: 26/08/2024



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Map Scale @ A3: 1:8,500

0 200
Metres

Revision 0.1
Status Final
Author ZT825
Verifier BDJ2
Date 26/08/2024

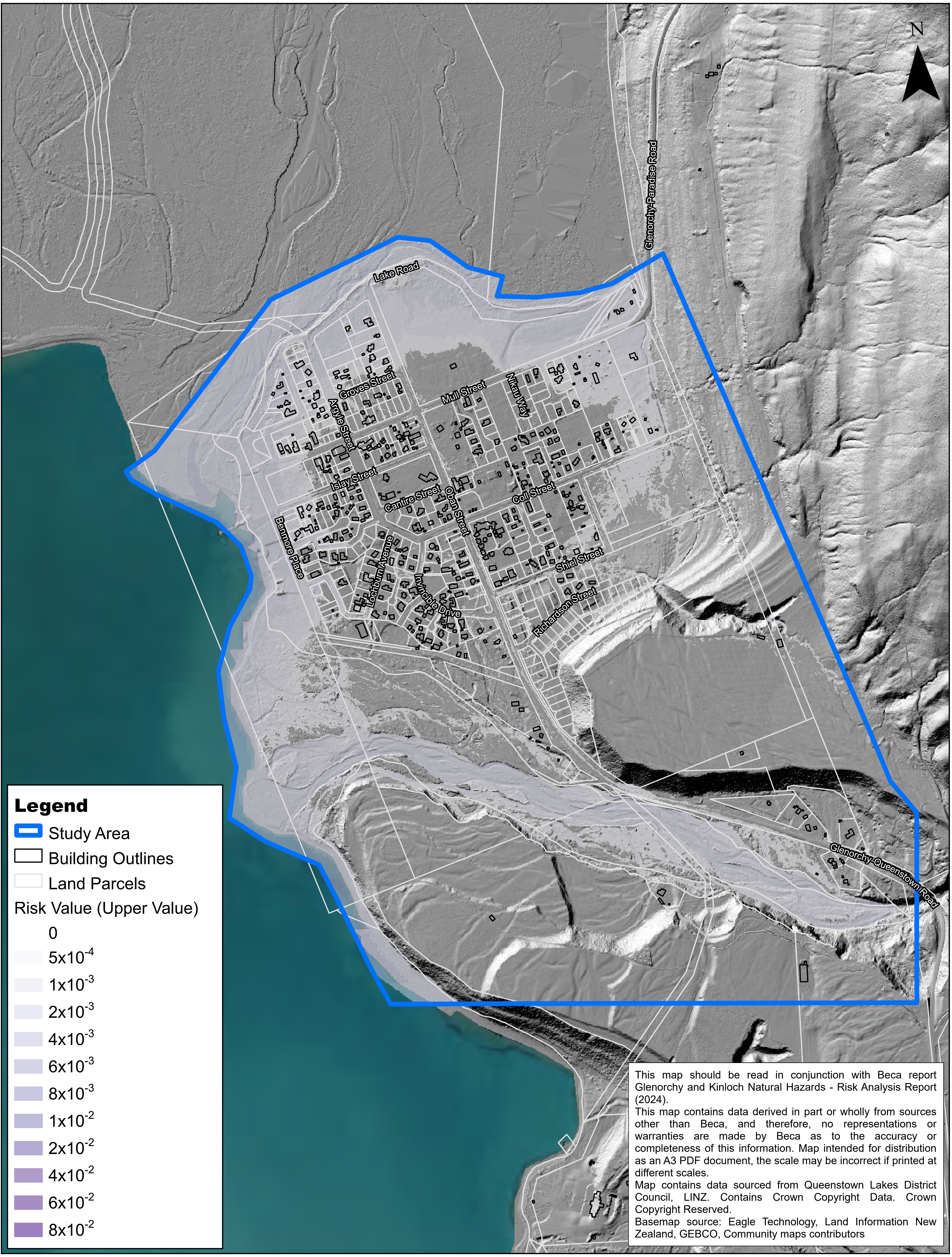
Joint Scenario Flooding
Annual Property Risk
100 Year Average Return Period

Glenorchy

Beca

Project Glenorchy Kinloch Natural Hazard RA
Client Otago Regional Council
Discipline GIS
Drawing Number GIS-3160904-05-008-01

GIS@beca.com



Legend

▭ Study Area
□ Building Outlines
□ Land Parcels

Risk Value (Upper Value)

- 0
- ▨ $5x10^{-4}$
- ▨ $1x10^{-3}$
- ▨ $2x10^{-3}$
- ▨ $4x10^{-3}$
- ▨ $6x10^{-3}$
- ▨ $8x10^{-3}$
- ▨ $1x10^{-2}$
- ▨ $2x10^{-2}$
- ▨ $4x10^{-2}$
- ▨ $6x10^{-2}$
- ▨ $8x10^{-2}$

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Map Scale @ A3: 1:8,500

0 200
Metres

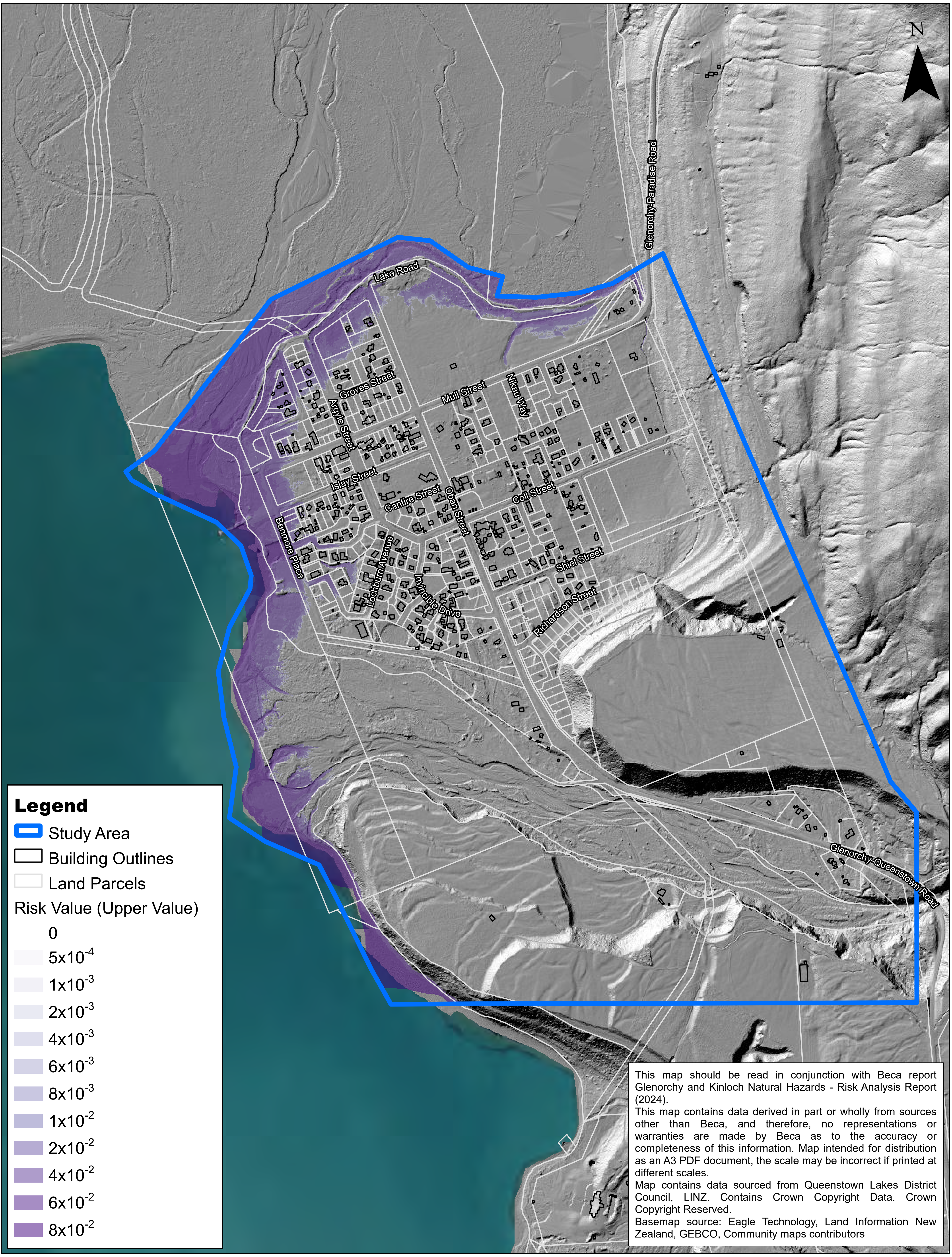
Revision	0.1
Status	Final
Author	ZT825
Verifier	BDJ2
Date	26/08/2024

Joint Scenario Flooding
Annual Property Risk
500 Year Average Return Period

Glenorchy

Beca

Project	Glenorchy Kinloch Natural Hazard RA
Client	Otago Regional Council
Discipline	GIS
Drawing Number	GIS-3160904-05-009-01



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Path: P:\3160904\1-WIP\WG-GIS\01-Map\GlenorchyKinloch_ReportMaps\GlenorchyKinloch_ReportMaps.aprx Map Layout: 05 Quantitative - Property Risk - Flooding Date Printed: 26/08/2024

Map Scale @ A3: 1:8,500

0 200
Metres

Revision 0.1
Status Final
Author ZT825
Verifier BDJ2
Date 26/08/2024

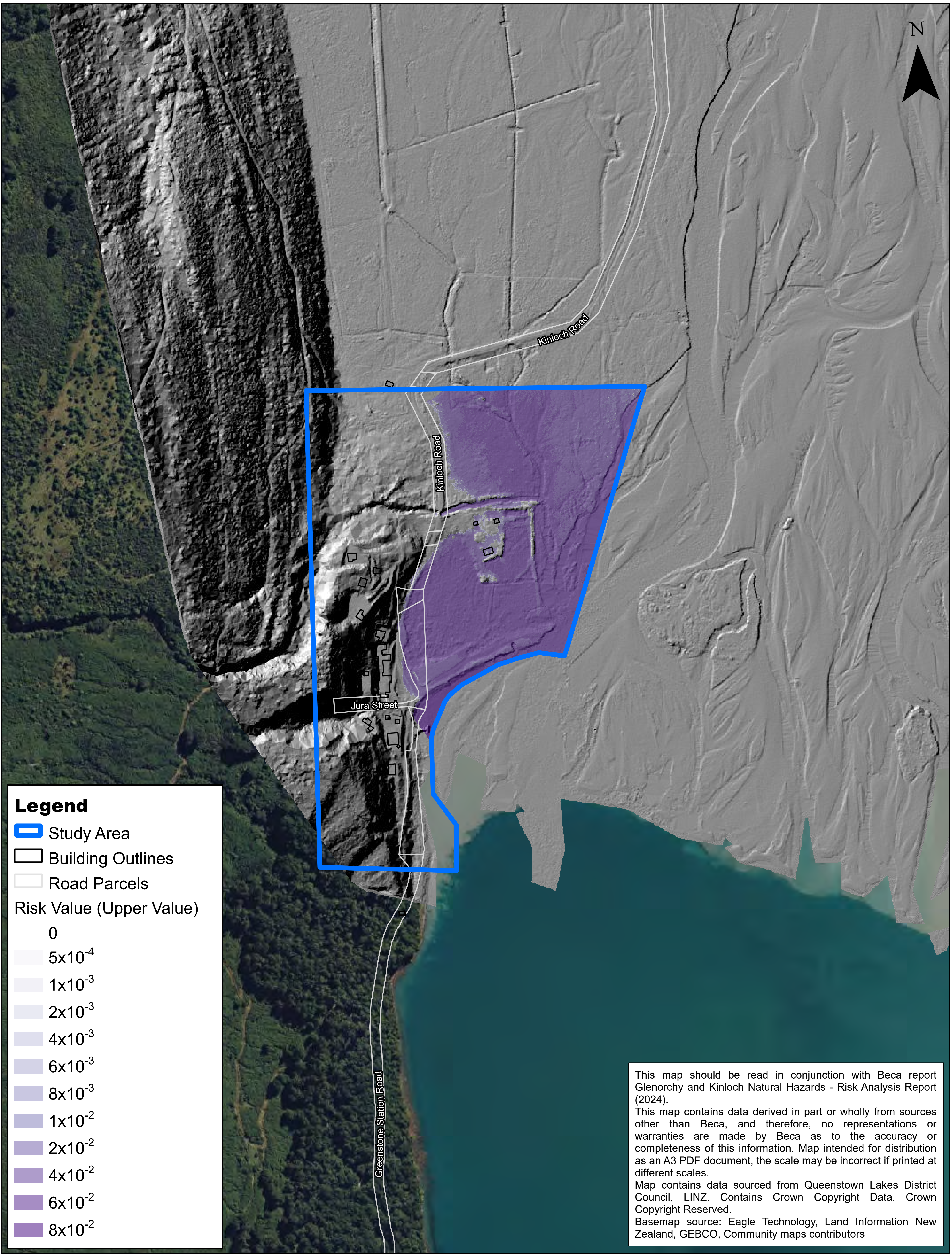
Lake Flood
Annual Property Risk
10 Year Average Return Period
Glenorchy

Beca

Project	Glenorchy Kinloch Natural Hazard RA
Client	Otago Regional Council
Discipline	GIS
Drawing Number	GIS-3160904-05-010-01

GIS@beca.com

Path: P:\316\3160904\1-WIP\WG-GIS\01-Map\GlenorchyKinloch_ReportMaps\GlenorchyKinloch_ReportMaps.aprx Map Layout: 05 Quantitative - Property Risk - Flooding Date Printed: 26/08/2024



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Map Scale @ A3: 1:5,000

0 200
Metres

Revision	0.1
Status	Final
Author	ZT825
Verifier	BDJ2
Date	26/08/2024

Lake Flood
Annual Property Risk
10 Year Average Return Period
Kinloch

Beca

Project	Glenorchy Kinloch Natural Hazard RA
Client	Otago Regional Council
Discipline	GIS
Drawing Number	GIS-3160904-05-010-02

GIS@beca.com

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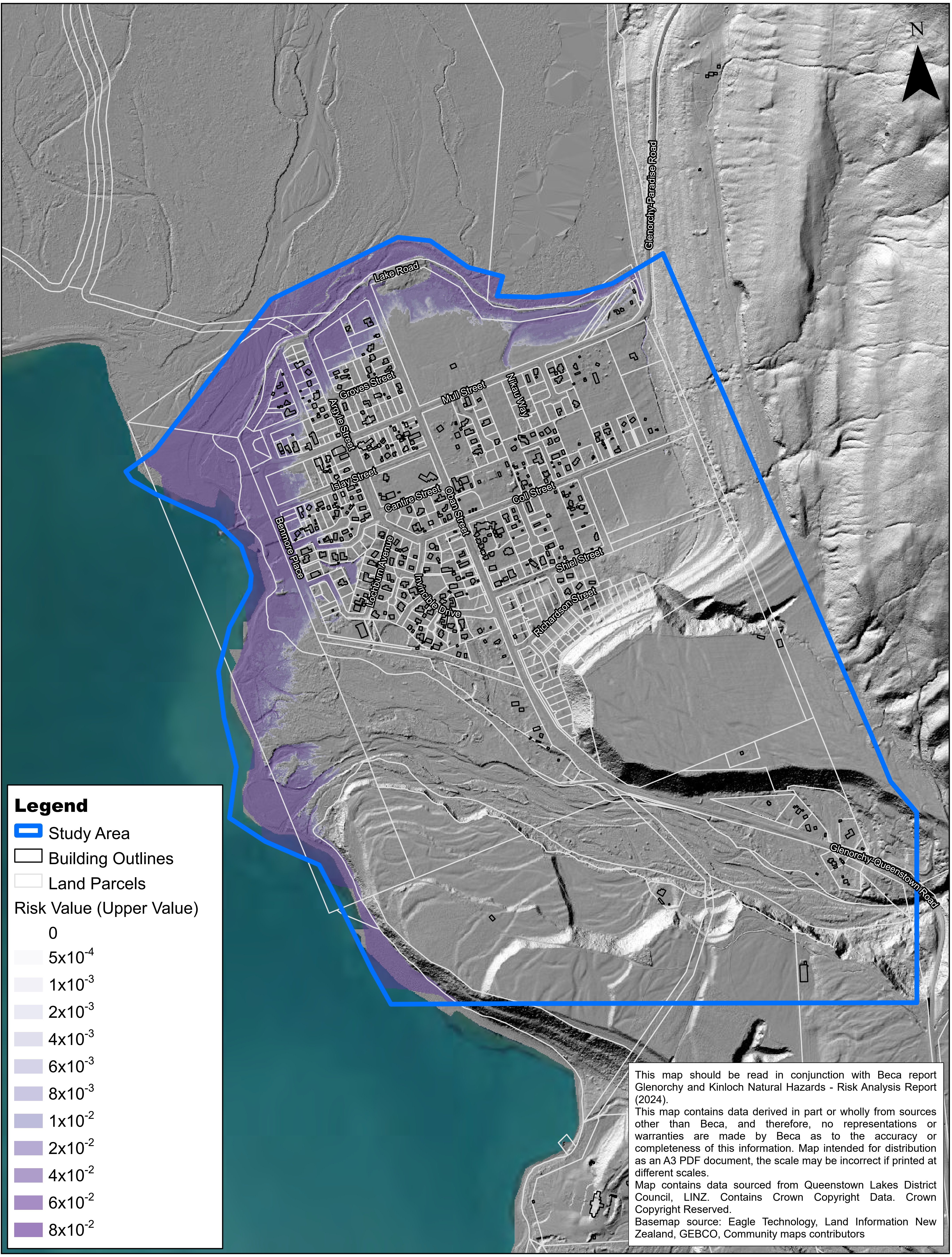

Legend

▭	Study Area
▭	Building Outlines
▭	Land Parcels

Risk Value (Upper Value)

	0
▨	$5x10^{-4}$
▨	$1x10^{-3}$
▨	$2x10^{-3}$
▨	$4x10^{-3}$
▨	$6x10^{-3}$
▨	$8x10^{-3}$
▨	$1x10^{-2}$
▨	$2x10^{-2}$
▨	$4x10^{-2}$
▨	$6x10^{-2}$
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Map Scale @ A3: 1:8,500

0 200
Metres

Revision	0.1
Status	Final
Author	ZT825
Verifier	BDJ2
Date	26/08/2024

Lake Flood
Annual Property Risk
20 Year Average Return Period

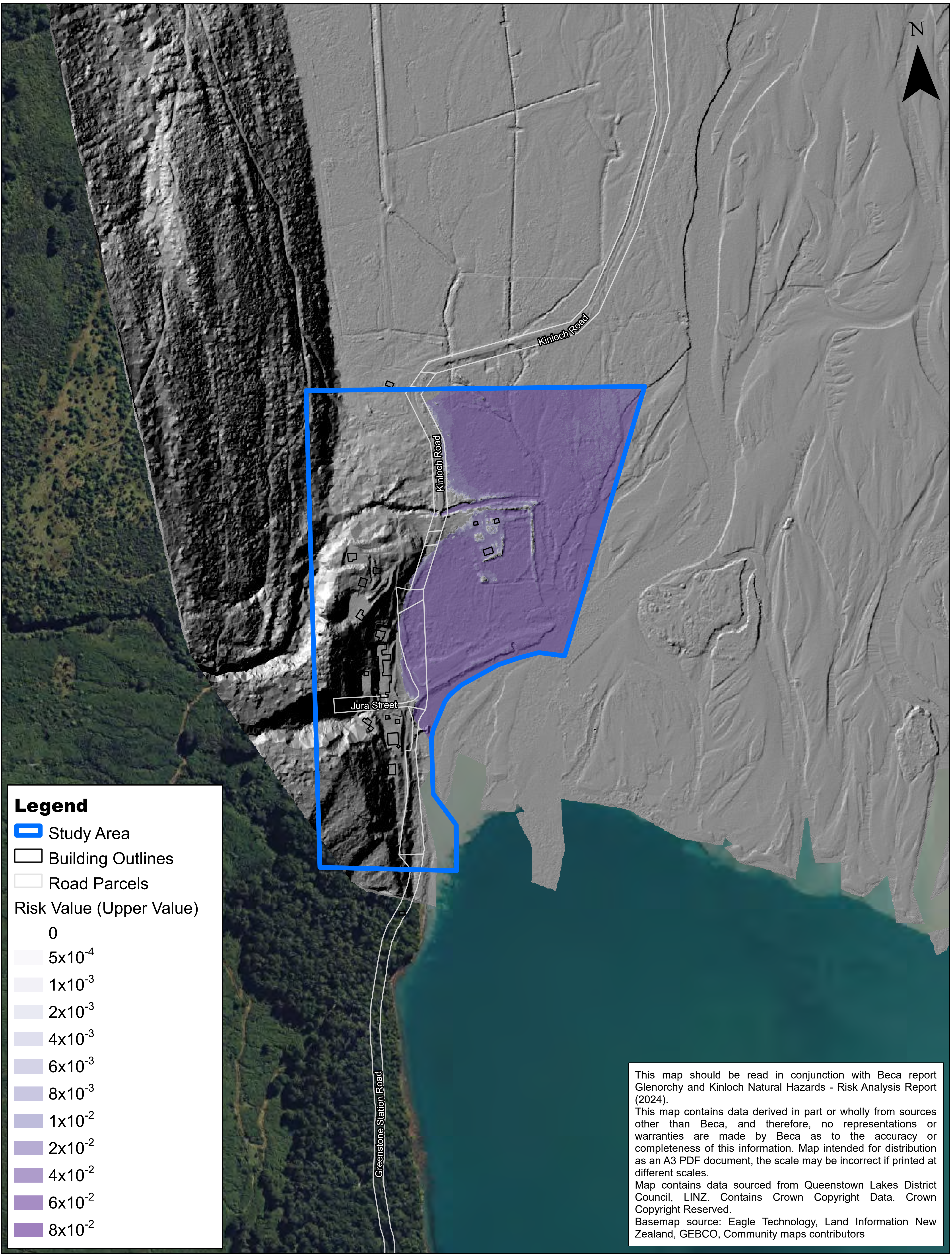
Glenorchy

Beca

Project	Glenorchy Kinloch Natural Hazard RA
Client	Otago Regional Council
Discipline	GIS
Drawing Number	GIS-3160904-05-011-01

GIS@beca.com

Path: P:\316\3160904\1-WIP\WG-GIS\01-Map\GlenorchyKinloch_ReportMaps\GlenorchyKinloch_ReportMaps.aprx Map Layout: 05 Quantitative - Property Risk - Flooding Date Printed: 26/08/2024



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Map Scale @ A3: 1:5,000

0 200
Metres

Revision	0.1
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Author	ZT825
Verifier	BDJ2
Date	26/08/2024

Lake Flood
Annual Property Risk
20 Year Average Return Period
Kinloch

Beca

Project	Glenorchy Kinloch Natural Hazard RA
Client	Otago Regional Council
Discipline	GIS
Drawing Number	GIS-3160904-05-011-02

GIS@beca.com

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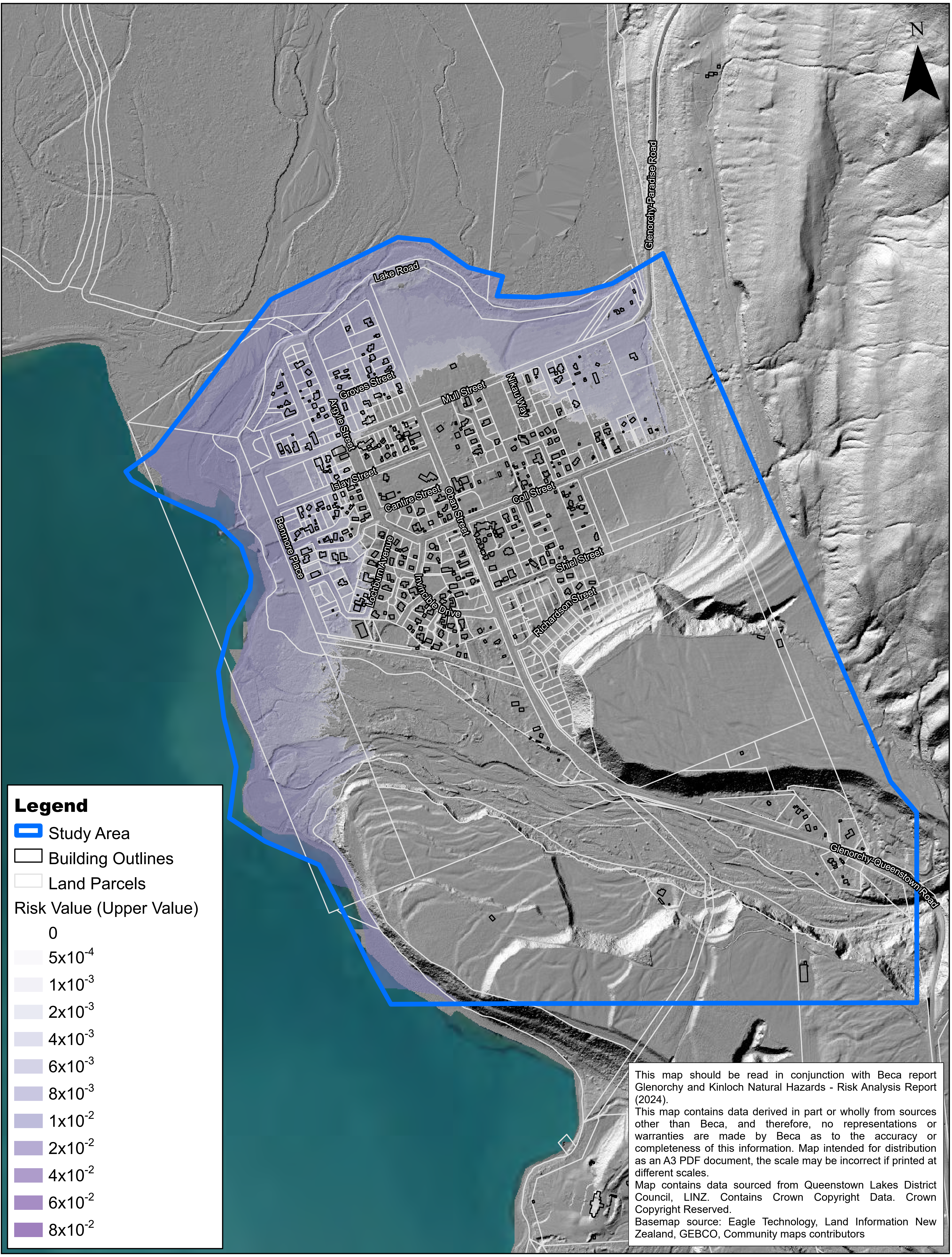

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0 200
Metres

Revision	0.1
Status	Final
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Date	26/08/2024

Lake Flood
Annual Property Risk
100 Year Average Return Period

Glenorchy

Beca

Project	Glenorchy Kinloch Natural Hazard RA
Client	Otago Regional Council
Discipline	GIS
Drawing Number	GIS-3160904-05-012-01

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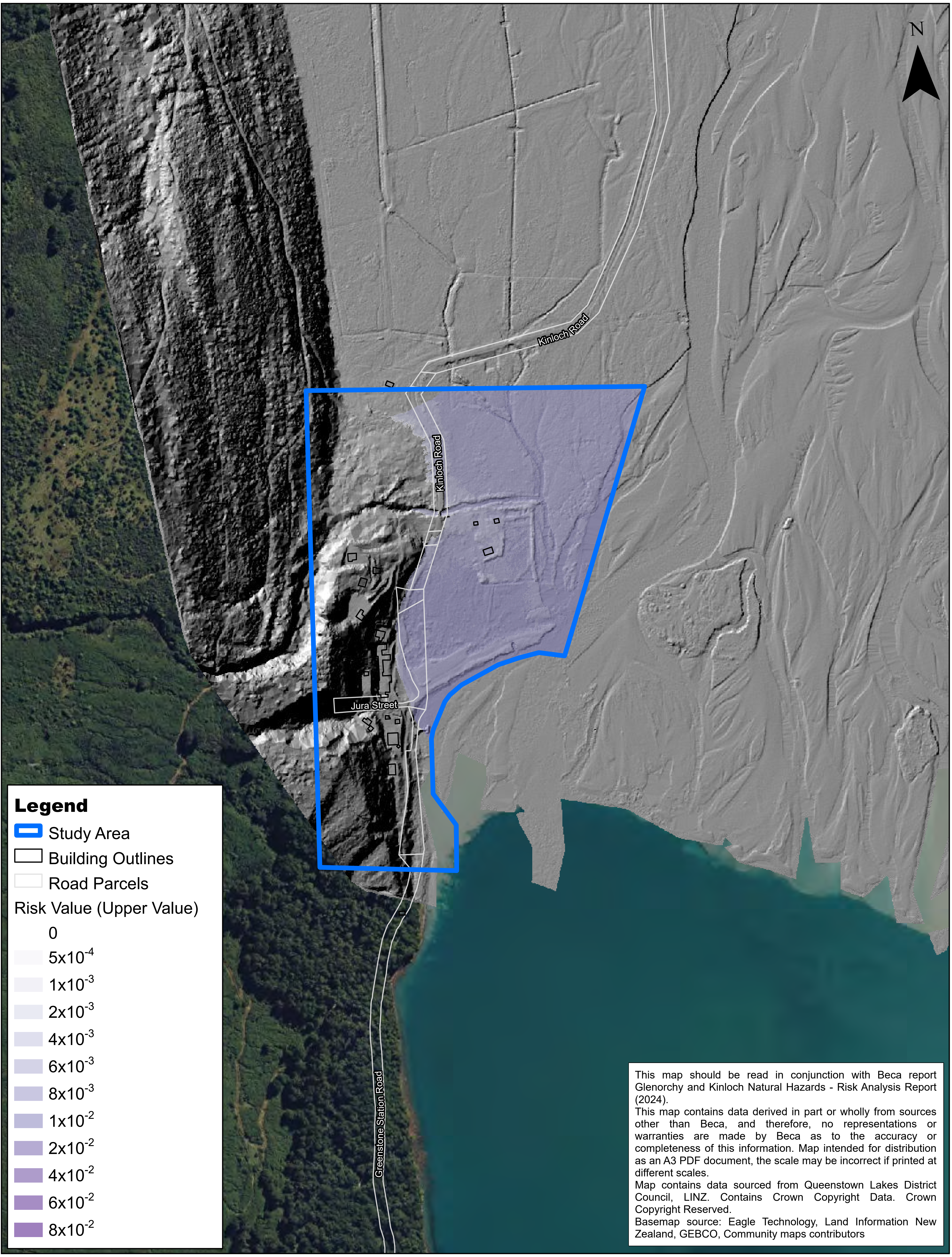
Path: P:\316\3160904\1-WIP\WG-GIS\01-Map\GlenorchyKinloch_ReportMaps\GlenorchyKinloch_ReportMaps.aprx Map Layout: 05 Quantitative - Property Risk - Flooding Date Printed: 26/08/2024



Legend

▭ Study Area
☐ Building Outlines
☐ Road Parcels

Risk Value (Upper Value)

0
▨ $5x10^{-4}$
▨ $1x10^{-3}$
▨ $2x10^{-3}$
▨ $4x10^{-3}$
▨ $6x10^{-3}$
▨ $8x10^{-3}$
▨ $1x10^{-2}$
▨ $2x10^{-2}$
▨ $4x10^{-2}$
▨ $6x10^{-2}$
▨ $8x10^{-2}$

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Map Scale @ A3: 1:5,000

0 200
Metres

Revision	0.1
Status	Final
Author	ZT825
Verifier	BDJ2
Date	26/08/2024

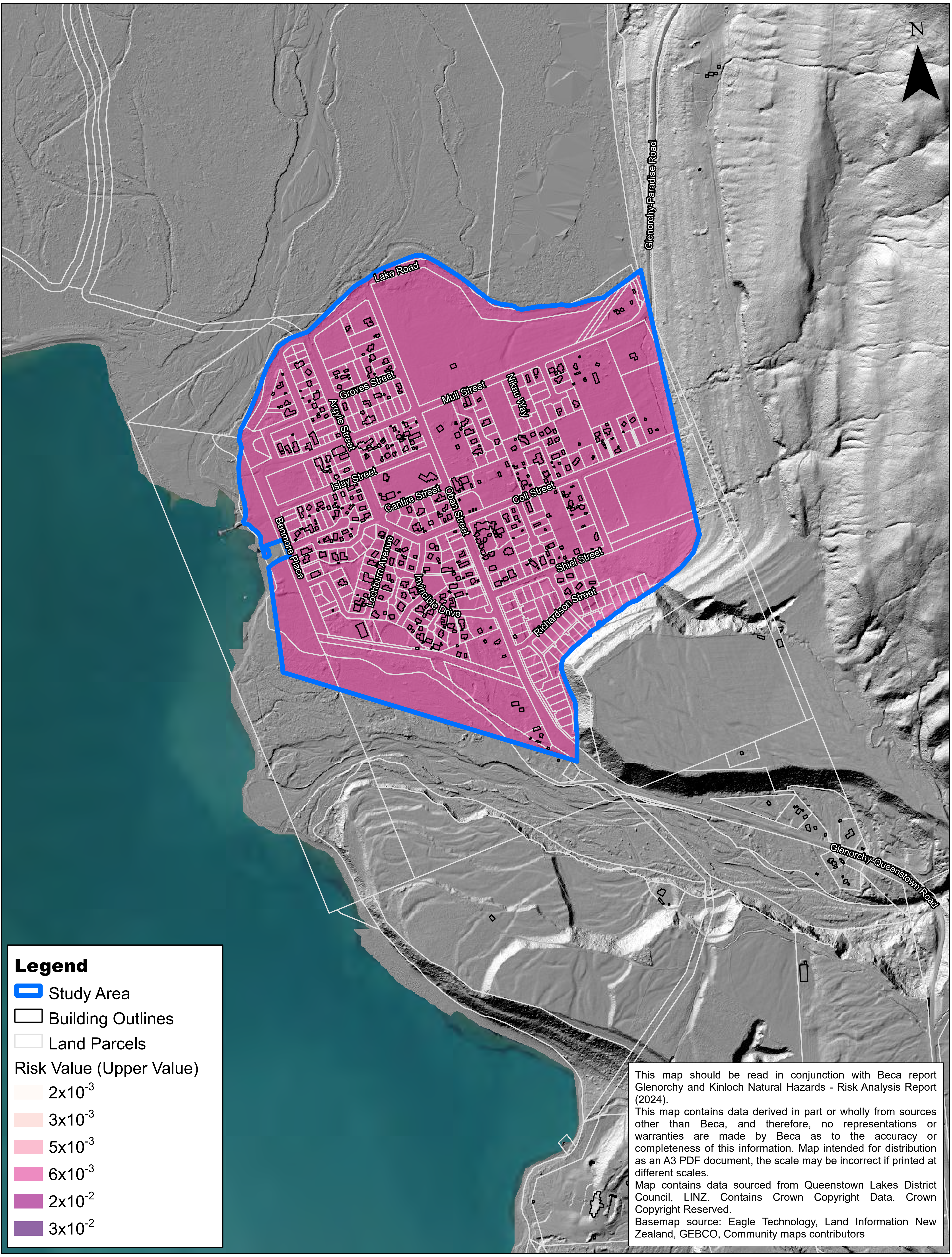
Lake Flood
Annual Property Risk
100 Year Average Return Period
Kinloch

Beca

Project	Glenorchy Kinloch Natural Hazard RA
Client	Otago Regional Council
Discipline	GIS
Drawing Number	GIS-3160904-05-012-02

GIS@beca.com

Path: P:\316\3160904\1-WIP\WG-GIS\01-Map\GlenorchyKinloch_ReportMaps\GlenorchyKinloch_ReportMaps.aprx Map Layout: 06 Quantitative - Property Risk - Liquefaction Date Printed: 26/08/2024



Legend

▭ Study Area

▭ Building Outlines

▭ Land Parcels

Risk Value (Upper Value)

▨ 2×10^{-3}

▨ 3×10^{-3}

▨ 5×10^{-3}

▨ 6×10^{-3}

▨ 2×10^{-2}

▨ 3×10^{-2}

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Map Scale @ A3: 1:8,500

0 200
Metres

Revision	0.1
Status	Final
Author	ZT825
Verifier	BDJ2
Date	26/08/2024

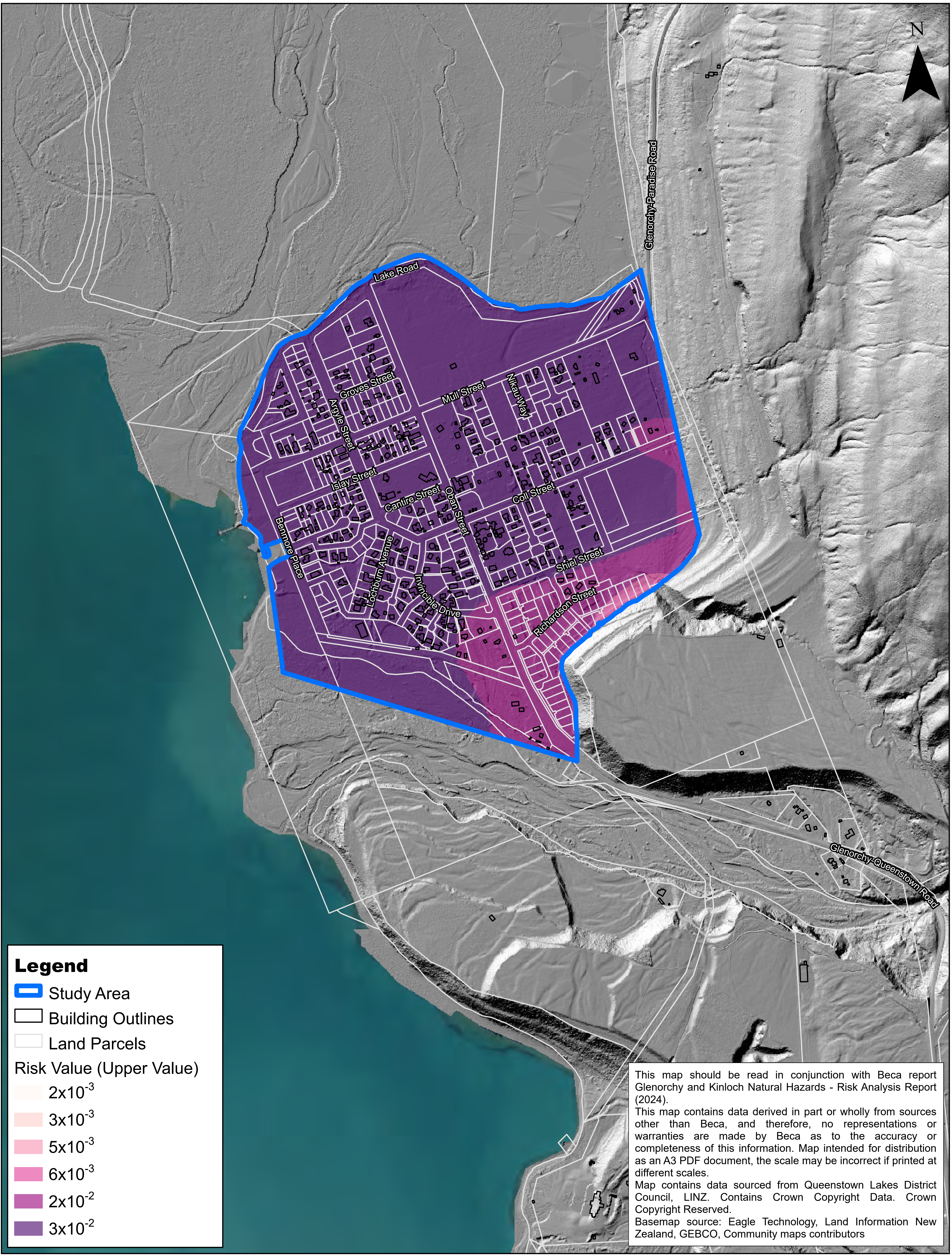
Liquefaction
Annual Property Risk
25 Year Average Return Period - Lower Bound

Glenorchy

Beca

Project	Glenorchy Kinloch Natural Hazard RA
Client	Otago Regional Council
Discipline	GIS
Drawing Number	GIS-3160904-06-001-01

GIS@beca.com



Legend

☐ Study Area

☐ Building Outlines

☐ Land Parcels

Risk Value (Upper Value)

■ $2x10^{-3}$

■ $3x10^{-3}$

■ $5x10^{-3}$

■ $6x10^{-3}$

■ $2x10^{-2}$

■ $3x10^{-2}$

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Map Scale @ A3: 1:8,500

0 200
Metres

Revision	0.1
Status	Final
Author	ZT825
Verifier	BDJ2
Date	26/08/2024

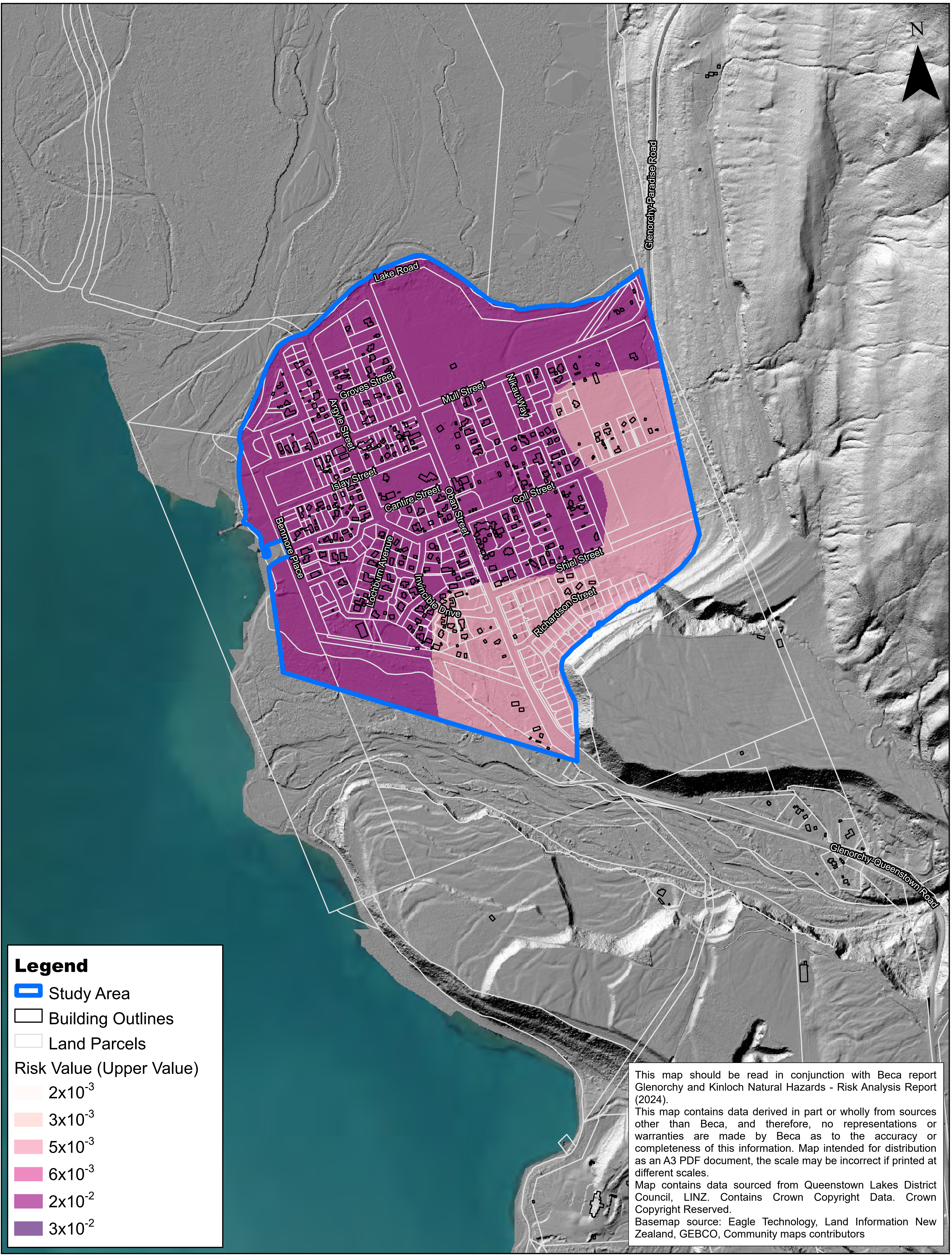
Liquefaction
Annual Property Risk
25 Year Average Return Period - Upper Bound

Glenorchy

Beca

Project	Glenorchy Kinloch Natural Hazard RA
Client	Otago Regional Council
Discipline	GIS
Drawing Number	GIS-3160904-06-002-01

GIS@beca.com



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Map Scale @ A3: 1:8,500

0 200
Metres

Revision 0.1
Status Final
Author ZT825
Verifier BDJ2
Date 26/08/2024

Liquefaction
Annual Property Risk
Alpine Fault Scenario - Lower Bound

Glenorchy

Beca

Project Glenorchy Kinloch Natural Hazard RA
Client Otago Regional Council
Discipline GIS
Drawing Number GIS-3160904-06-003-01

Path: P:\316\3160904\1-WIP\WG-GIS\01-Map\GlenorchyKinloch_ReportMaps\GlenorchyKinloch_ReportMaps.aprx Map Layout: 06 Quantitative - Property Risk - Liquefaction Date Printed: 26/08/2024

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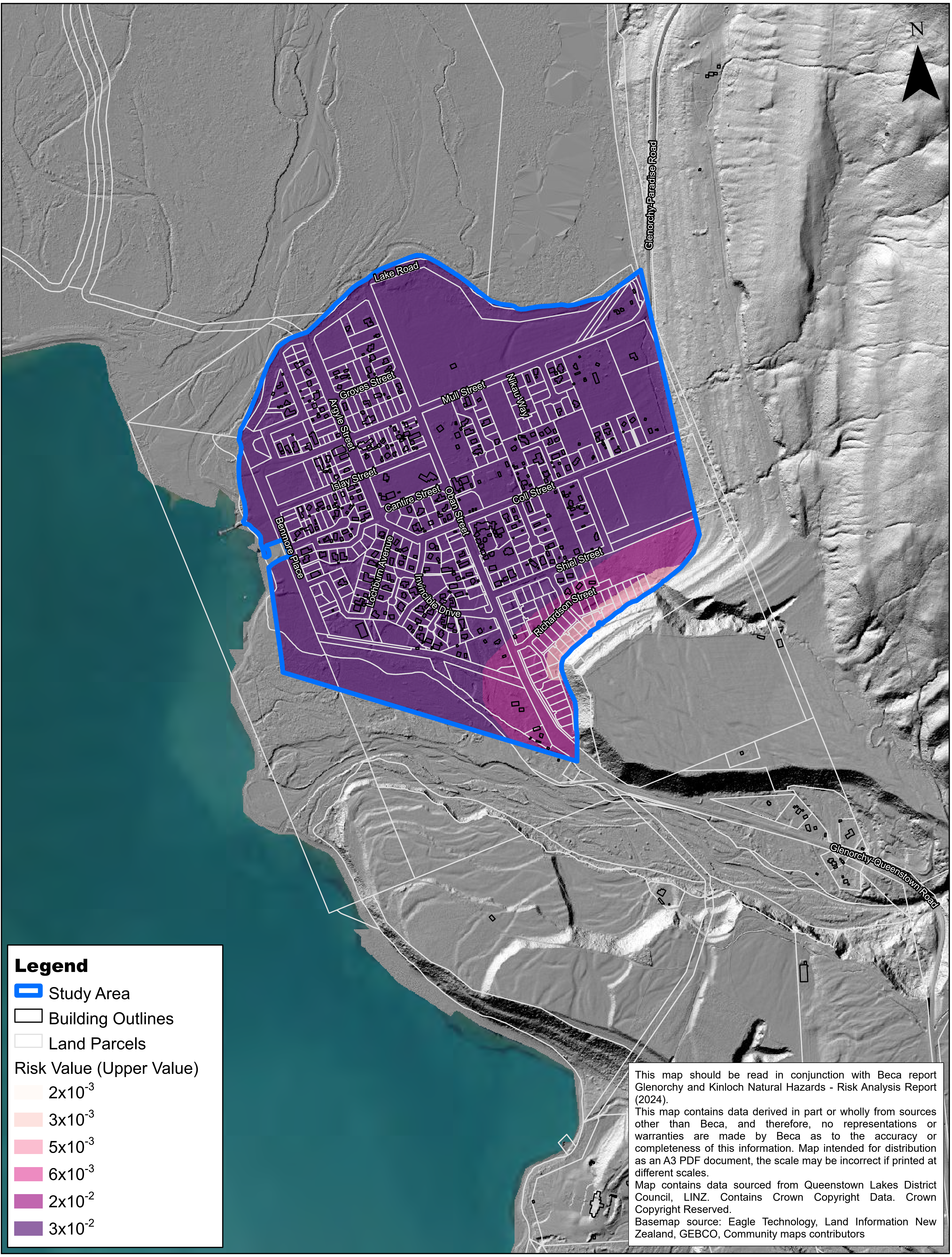

Legend

- Study Area
- Building Outlines
- Land Parcels

Risk Value (Upper Value)

- $2x10^{-3}$
- $3x10^{-3}$
- $5x10^{-3}$
- $6x10^{-3}$
- $2x10^{-2}$
- $3x10^{-2}$

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Map Scale @ A3: 1:8,500

0 200
Metres

Revision	0.1
Status	Final
Author	ZT825
Verifier	BDJ2
Date	26/08/2024

Liquefaction
Annual Property Risk
Alpine Fault Scenario - Median

Glenorchy

Beca

Project	Glenorchy Kinloch Natural Hazard RA
Client	Otago Regional Council
Discipline	GIS
Drawing Number	GIS-3160904-06-004-01

Path: P:\316\3160904\1-WIP\WG-GIS\01-Map\GlenorchyKinloch_ReportMaps\GlenorchyKinloch_ReportMaps.aprx Map Layout: 06 Quantitative - Property Risk - Liquefaction Date Printed: 26/08/2024

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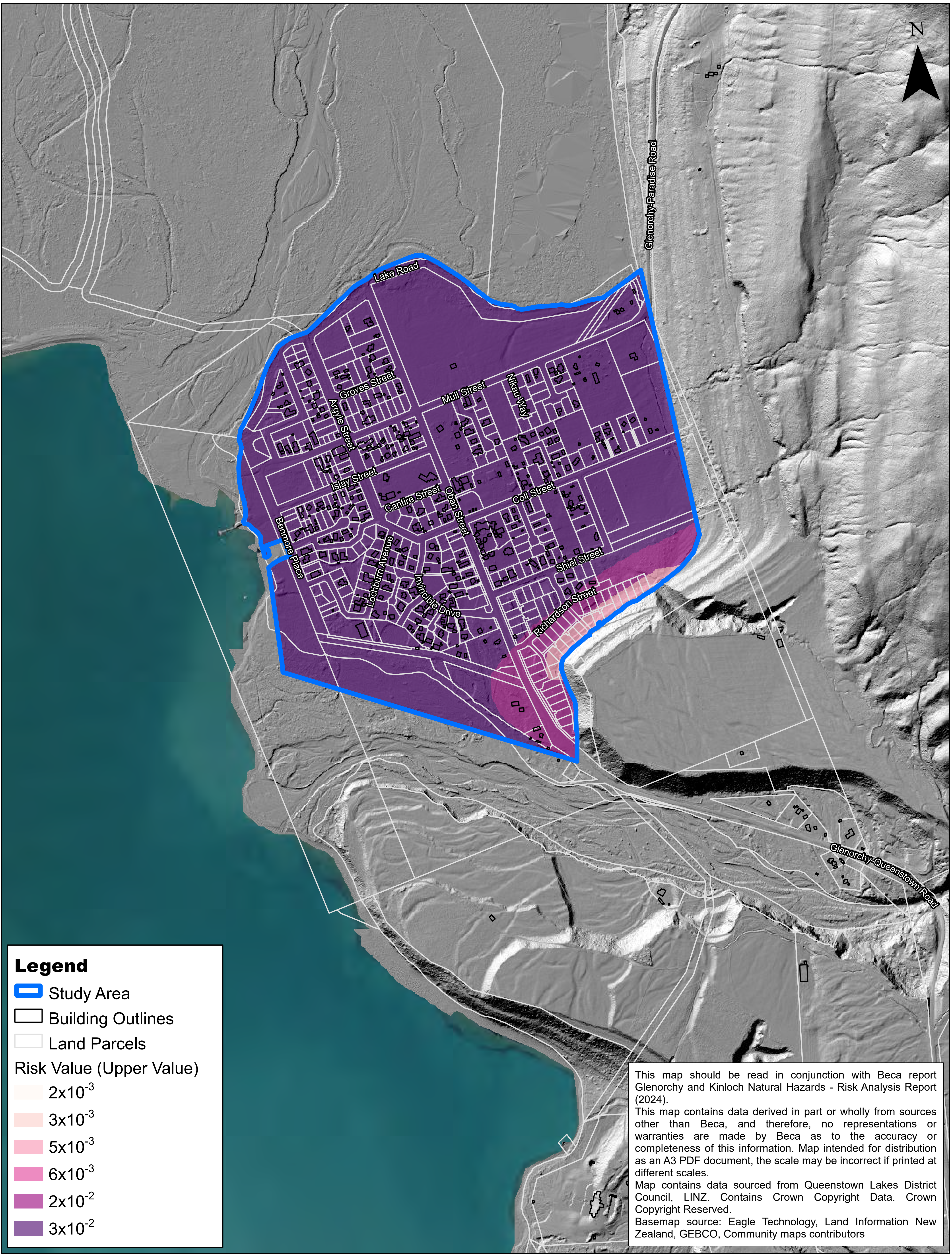
Path: P:\316\3160904\1-WIP\WG-GIS\01-Map\GlenorchyKinloch_ReportMaps\GlenorchyKinloch_ReportMaps.aprx Map Layout: 06 Quantitative - Property Risk - Liquefaction Date Printed: 26/08/2024



Legend

Study Area

Building Outlines

Land Parcels

Risk Value (Upper Value)

- $2x10^{-3}$
- $3x10^{-3}$
- $5x10^{-3}$
- $6x10^{-3}$
- $2x10^{-2}$
- $3x10^{-2}$

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Map Scale @ A3: 1:8,500

0 200
Metres

Revision	0.1
Status	Final
Author	ZT825
Verifier	BDJ2
Date	26/08/2024

Liquefaction
Annual Property Risk
Alpine Fault Scenario - Lower Bound

Glenorchy

Beca

Project	Glenorchy Kinloch Natural Hazard RA
Client	Otago Regional Council
Discipline	GIS
Drawing Number	GIS-3160904-06-005-01

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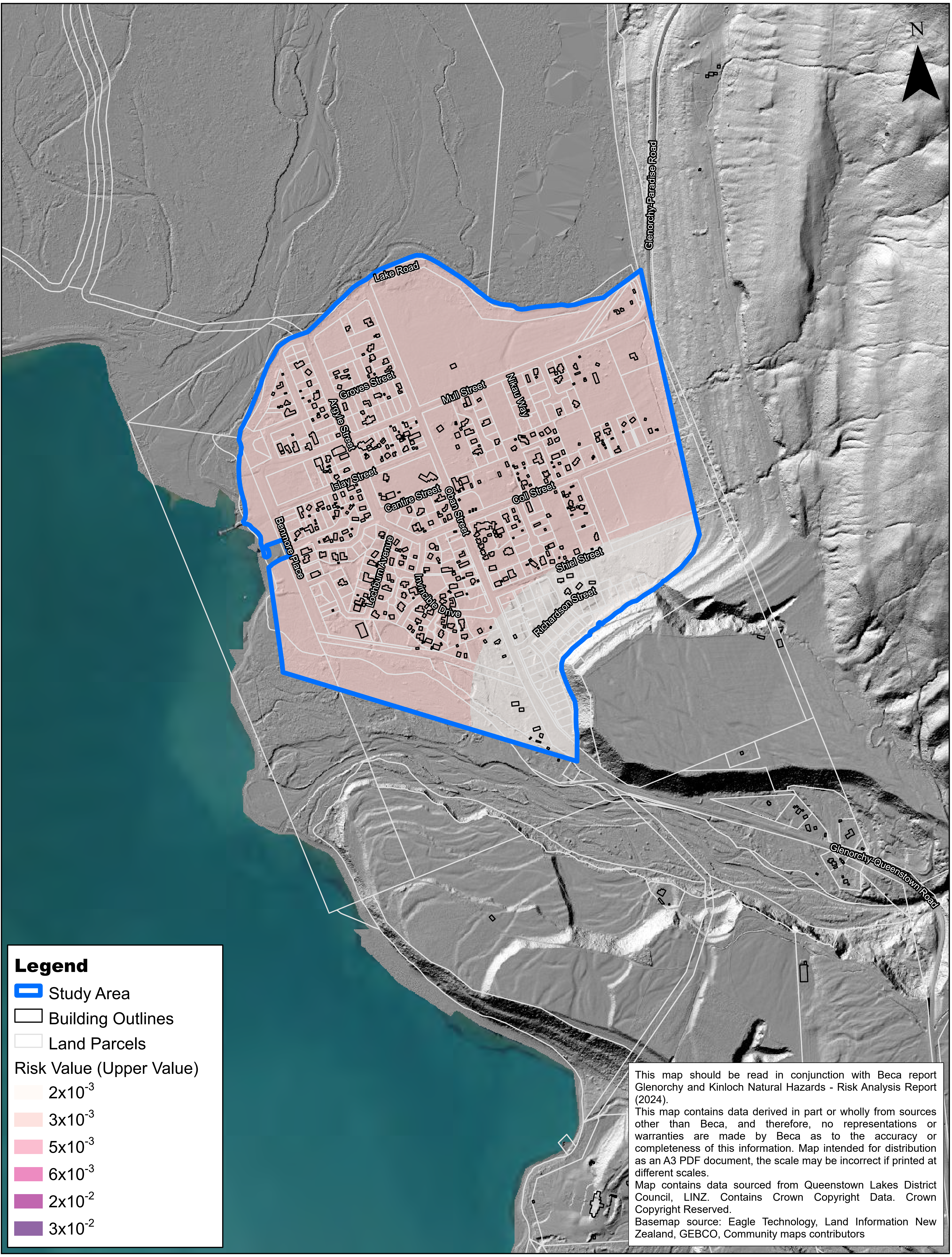
Path: P:\3160904\1-WIP\WG-GIS\01-Map\GlenorchyKinloch_ReportMaps\GlenorchyKinloch_ReportMaps.aprx Map Layout: 06 Quantitative - Property Risk - Liquefaction Date Printed: 26/08/2024



Legend

- 🟦 Study Area
- ☐ Building Outlines
- ☐ Land Parcels

Risk Value (Upper Value)

- $2x10^{-3}$
- $3x10^{-3}$
- $5x10^{-3}$
- $6x10^{-3}$
- $2x10^{-2}$
- $3x10^{-2}$

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Map Scale @ A3: 1:8,500

0 200
Metres

Revision	0.1
Status	Final
Author	ZT825
Verifier	BDJ2
Date	26/08/2024

Liquefaction
Annual Property Risk
250 Year Average Return Period - Lower Bound

Glenorchy

Beca

Project	Glenorchy Kinloch Natural Hazard RA
Client	Otago Regional Council
Discipline	GIS
Drawing Number	GIS-3160904-06-006-01

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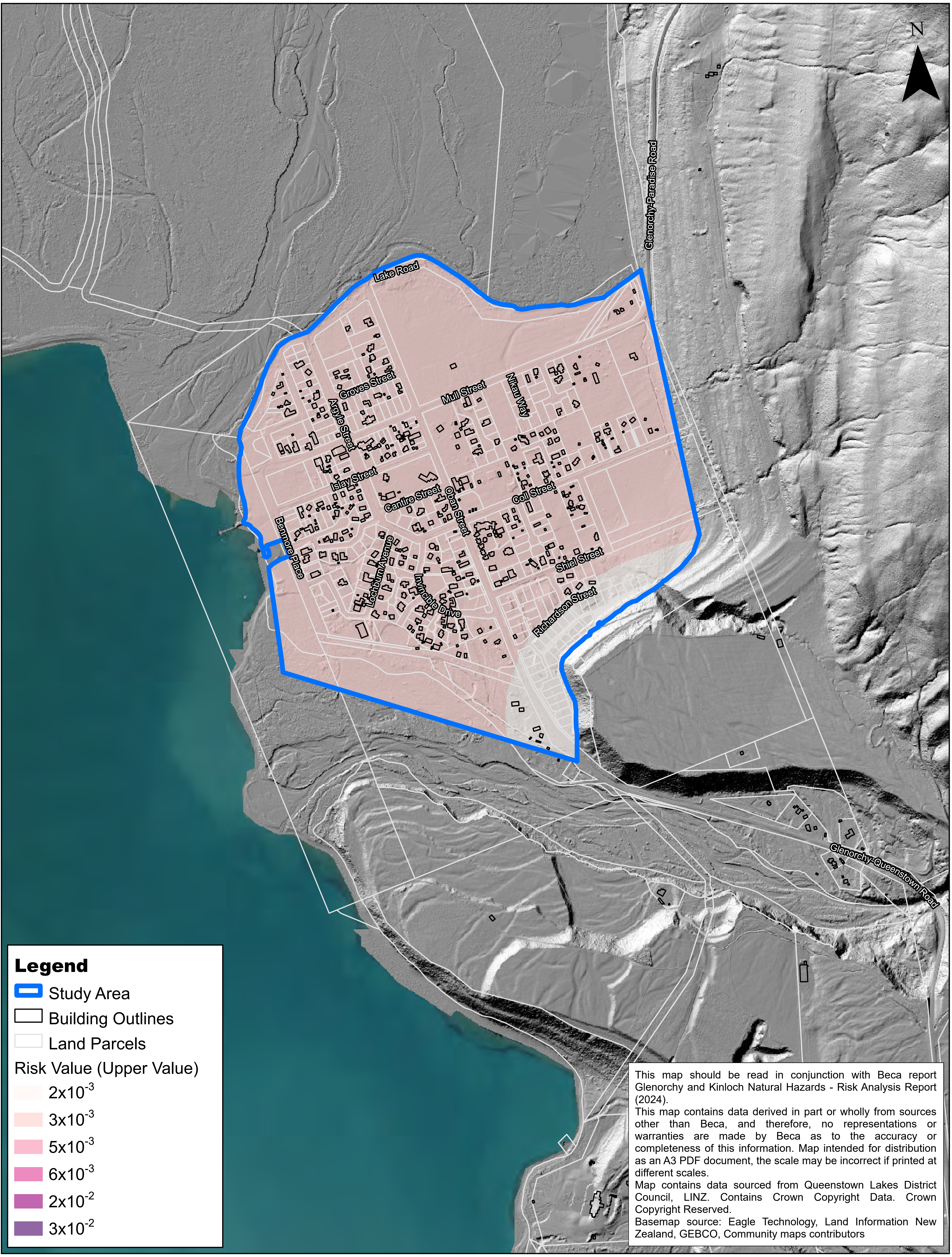
Path: P:\316\3160904\1-WIP\WG-GIS\01-Map\GlenorchyKinloch_ReportMaps\GlenorchyKinloch_ReportMaps.aprx Map Layout: 06 Quantitative - Property Risk - Liquefaction Date Printed: 26/08/2024



Legend

- ▭ Study Area
- ▭ Building Outlines
- ▭ Land Parcels

Risk Value (Upper Value)

- ▨ $2x10^{-3}$
- ▨ $3x10^{-3}$
- ▨ $5x10^{-3}$
- ▨ $6x10^{-3}$
- ▨ $2x10^{-2}$
- ▨ $3x10^{-2}$

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Map Scale @ A3: 1:8,500

0 200
Metres

Revision	0.1
Status	Final
Author	ZT825
Verifier	BDJ2
Date	26/08/2024

Liquefaction
Annual Property Risk
250 Year Average Return Period - Upper Bound

Glenorchy

Beca

Project	Glenorchy Kinloch Natural Hazard RA
Client	Otago Regional Council
Discipline	GIS
Drawing Number	GIS-3160904-06-007-01

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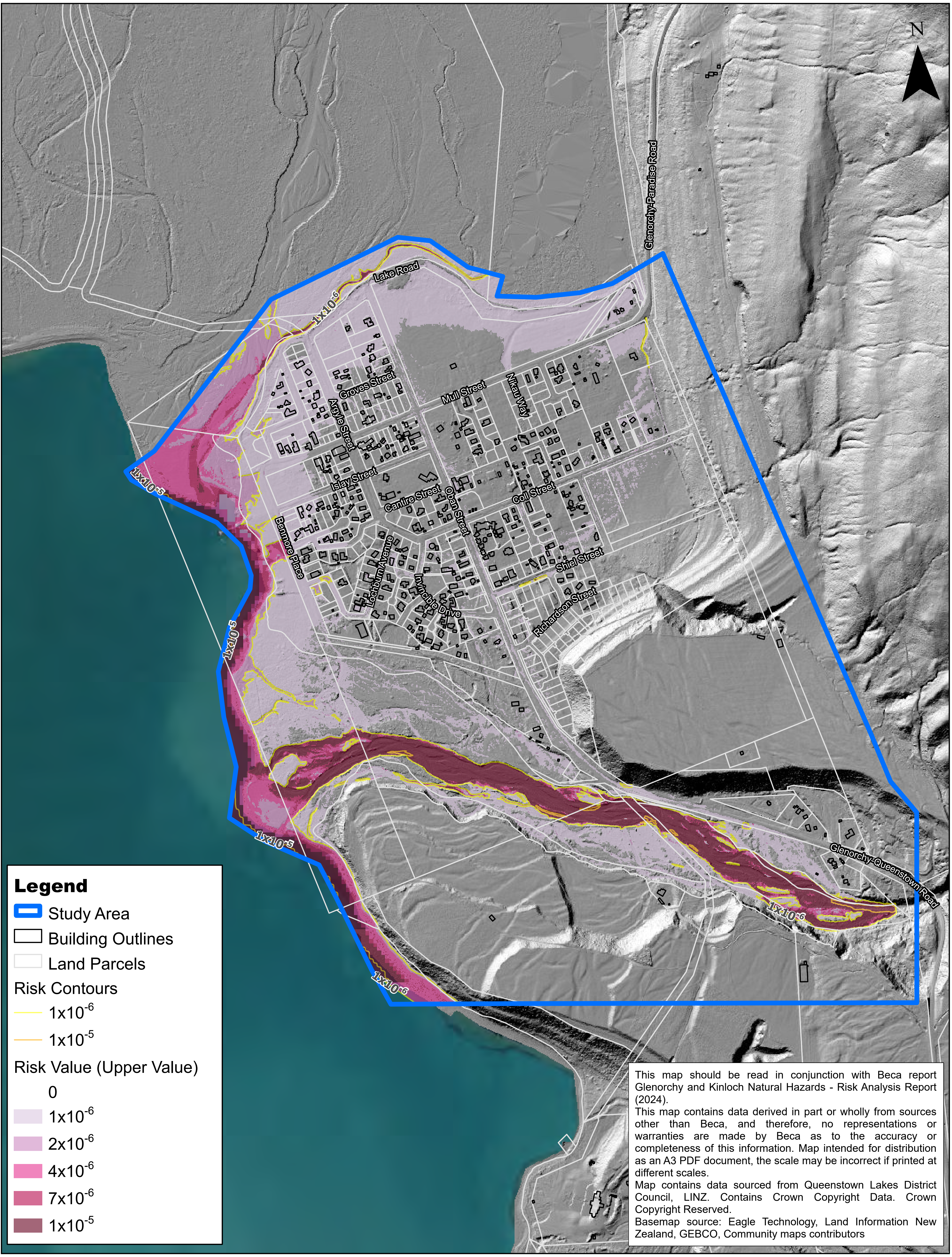
Path: P:\316\3160904\1-WIP\WG-GIS\01-Map\GlenorchyKinloch_ReportMaps\GlenorchyKinloch_ReportMaps.aprx Map Layout: 07 Quantitative - Combined Risk - AIFR Flooding Date Printed: 26/08/2024



Legend

- Study Area
- Building Outlines
- Land Parcels

Risk Contours

- $1x10^{-6}$
- $1x10^{-5}$

Risk Value (Upper Value)

- 0
- $1x10^{-6}$
- $2x10^{-6}$
- $4x10^{-6}$
- $7x10^{-6}$
- $1x10^{-5}$

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Map Scale @ A3: 1:8,500

0 200
Metres

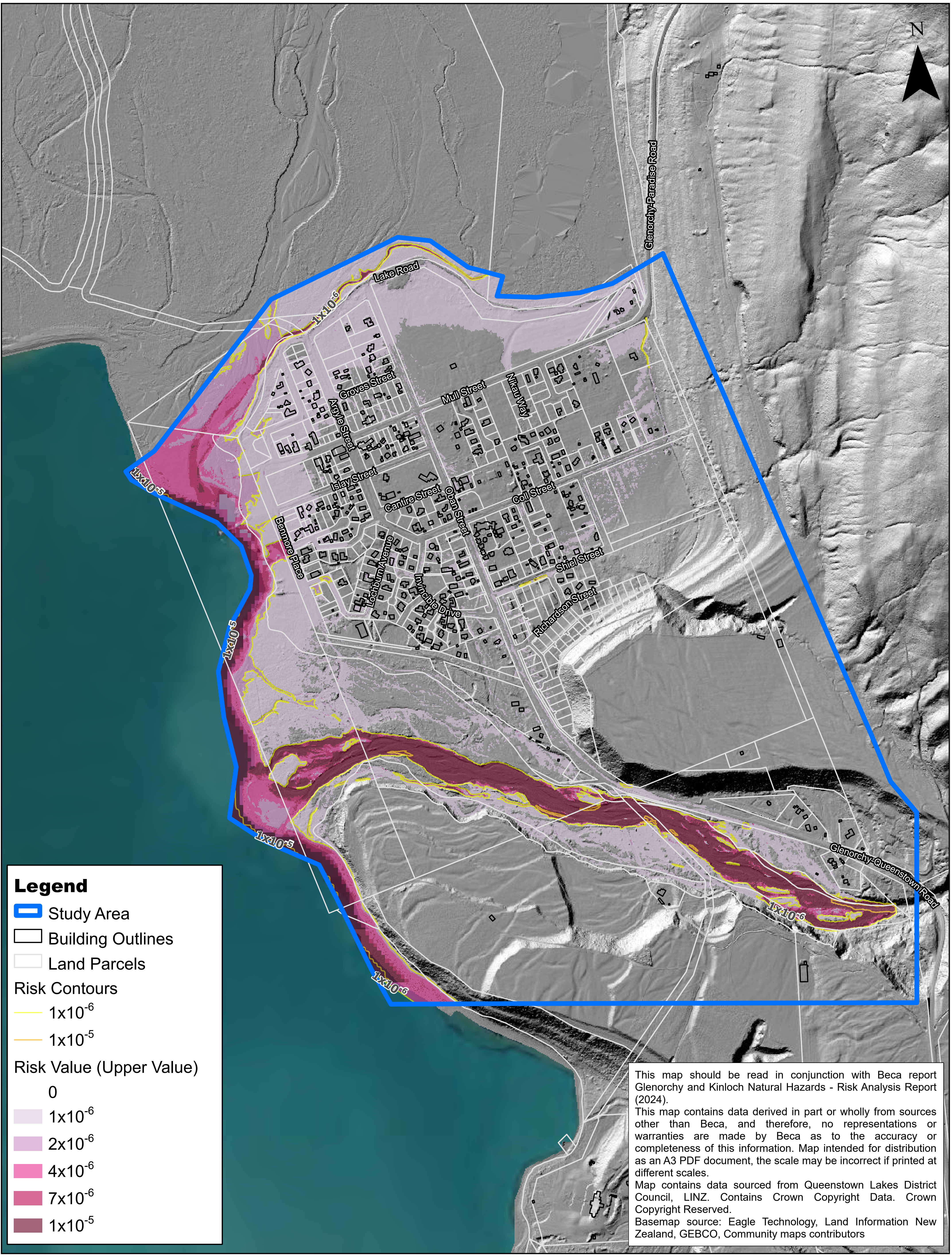
Revision	0.1
Status	Final
Author	ZT825
Verifier	BDJ2
Date	26/08/2024

Buckler Burn Flooding Annual Individual Fatality Risk Combined Scenarios

Glenorchy

Beca

Project	Glenorchy Kinloch Natural Hazard RA
Client	Otago Regional Council
Discipline	GIS
Drawing Number	GIS-3160904-07-001-01



Legend

- ▭ Study Area
- ▭ Building Outlines
- ▭ Land Parcels

Risk Contours

- $1x10^{-6}$
- $1x10^{-5}$

Risk Value (Upper Value)

- 0
- $1x10^{-6}$
- $2x10^{-6}$
- $4x10^{-6}$
- $7x10^{-6}$
- $1x10^{-5}$

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Path: P:\316\3160904\1-WIP\WG-GIS\01-Map\GlenorchyKinloch_ReportMaps\GlenorchyKinloch_ReportMaps.aprx Map Layout: 07 Quantitative - Combined Risk - AIFR Flooding Date Printed: 26/08/2024

Map Scale @ A3: 1:8,500

0 200
Metres

Revision	0.1
Status	Final
Author	ZT825
Verifier	BDJ2
Date	26/08/2024

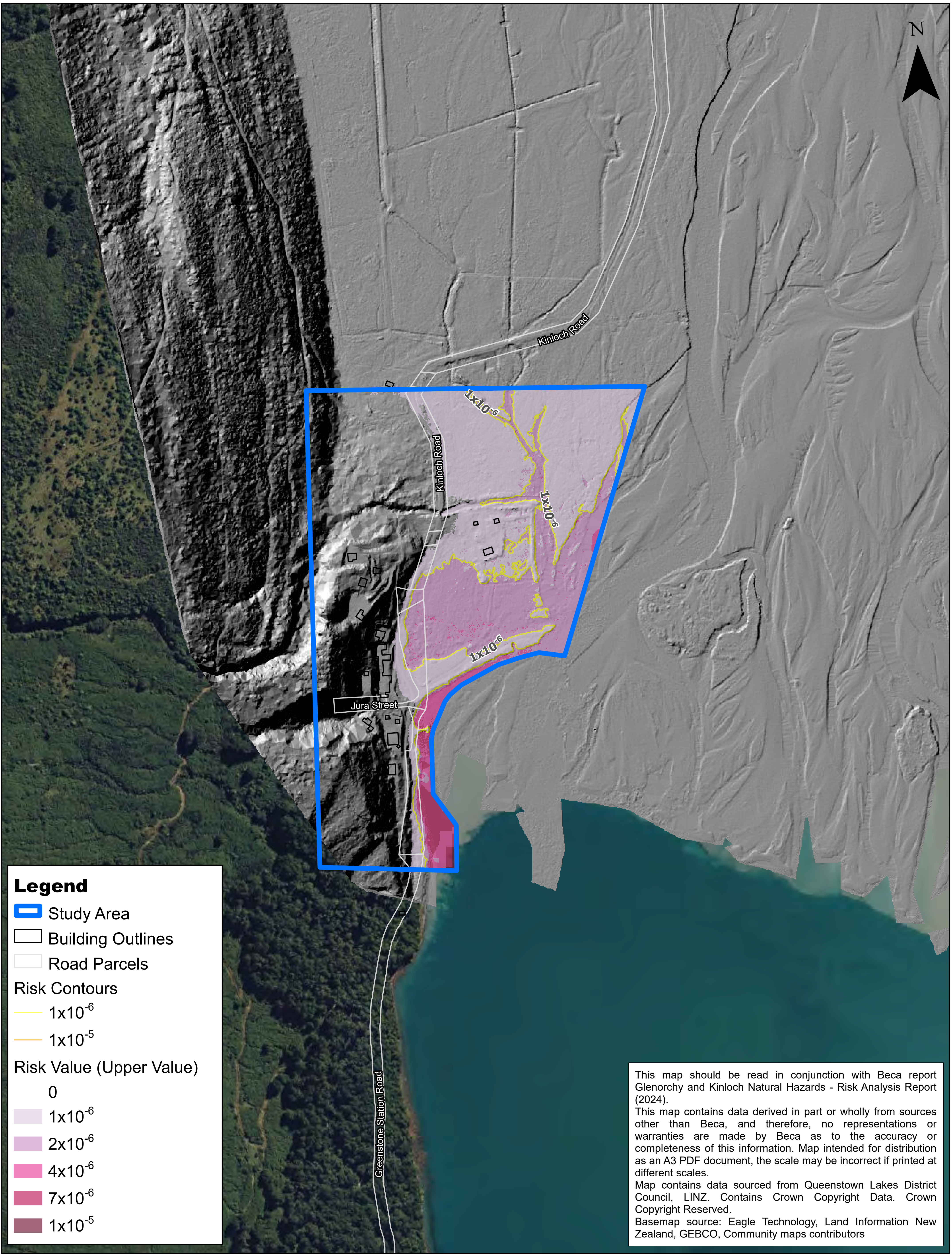
Rees/Dart Flooding
Annual Individual Fatality Risk
Combined Scenarios
Glenorchy

Beca

Project	Glenorchy Kinloch Natural Hazard RA
Client	Otago Regional Council
Discipline	GIS
Drawing Number	GIS-3160904-07-002-01

GIS@beca.com

Path: P:\316\3160904\1-WIP\WG-GIS\01-Map\GlenorchyKinloch_ReportMaps\GlenorchyKinloch_ReportMaps.aprx Map Layout: 07 Quantitative - Combined Risk - AIFR Flooding Date Printed: 26/08/2024



Legend

- Study Area
- Building Outlines
- Road Parcels

Risk Contours

- 1x10^{-6}
- 1x10^{-5}

Risk Value (Upper Value)

- 0
- 1x10^{-6}
- 2x10^{-6}
- 4x10^{-6}
- 7x10^{-6}
- 1x10^{-5}

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Map Scale @ A3: 1:5,000

0 200
Metres

Revision	0.1
Status	Final
Author	ZT825
Verifier	BDJ2
Date	26/08/2024

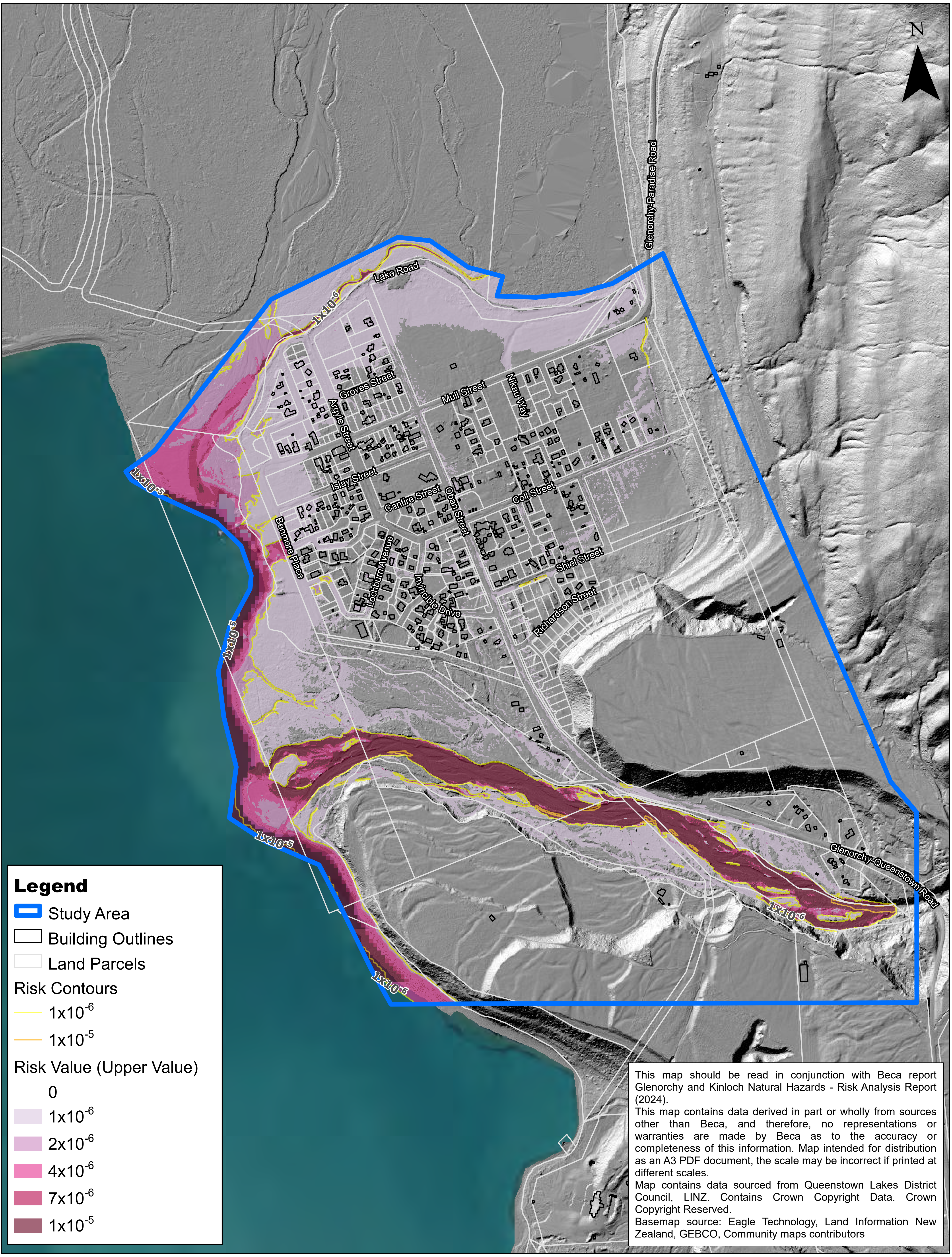
Rees/Dart Flooding
Annual Individual Fatality Risk
Combined Scenarios
Kinloch

Beca

Project	Glenorchy Kinloch Natural Hazard RA
Client	Otago Regional Council
Discipline	GIS
Drawing Number	GIS-3160904-07-002-02

GIS@beca.com

Path: P:\316\3160904\1-WIP\WG-GIS\01-Map\GlenorchyKinloch_ReportMaps\GlenorchyKinloch_ReportMaps.aprx Map Layout: 07 Quantitative - Combined Risk - AIFR Flooding Date Printed: 26/08/2024



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Map Scale @ A3: 1:8,500

0 200
Metres

Revision 0.1
Status Final
Author ZT825
Verifier BDJ2
Date 26/08/2024

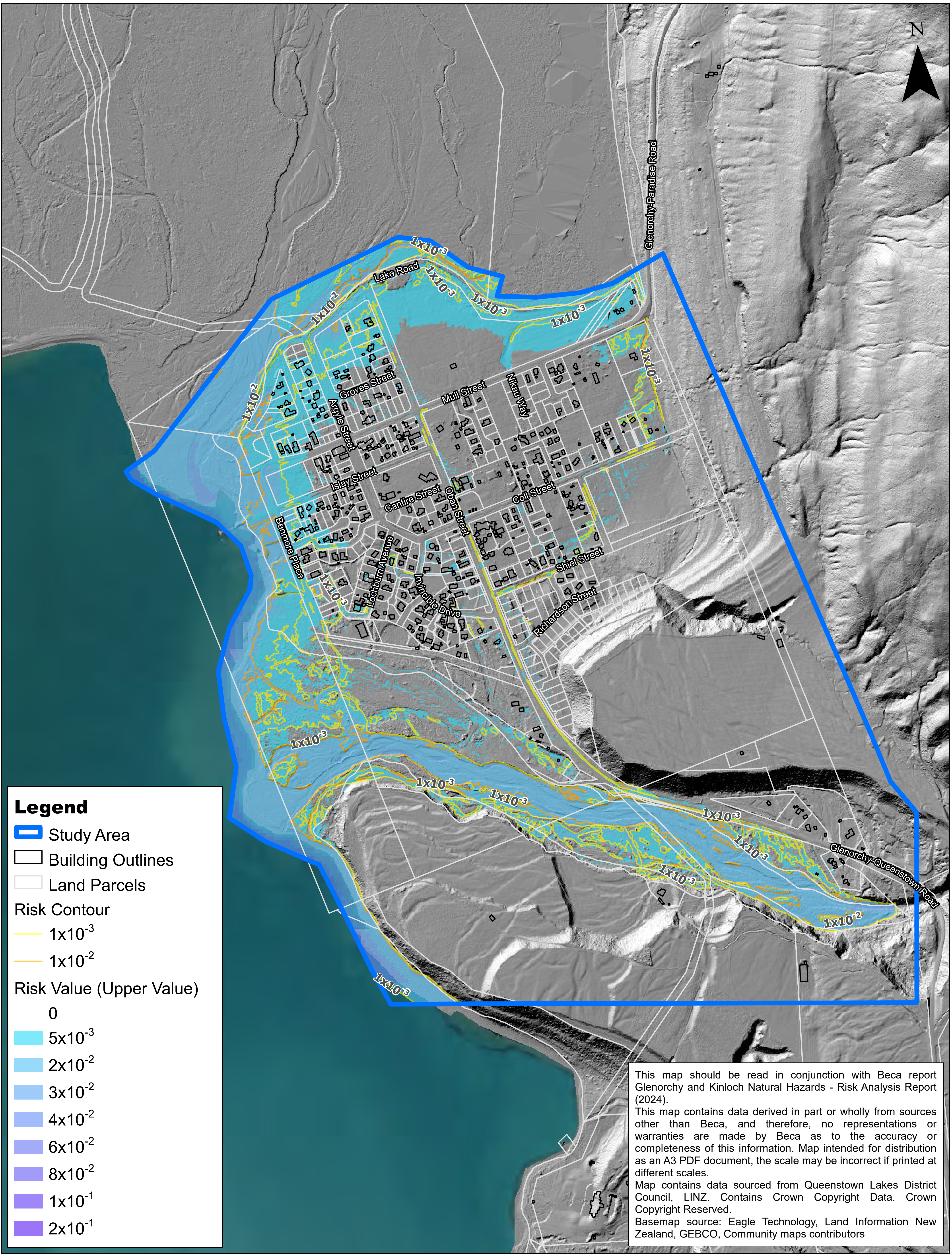
Joint Scenario
Annual Individual Fatality Risk
Combined Scenarios
Glenorchy

Beca

Project Glenorchy Kinloch Natural Hazard RA
Client Otago Regional Council
Discipline GIS
Drawing Number GIS-3160904-07-003-01

GIS@beca.com

Path: P:\316\3160904\1-WIP\WG-GIS\01-Map\GlenorchyKinloch_ReportMaps\GlenorchyKinloch_ReportMaps.aprx Map Layout: 08 Quantitative - Combined Risk - APR Flooding Date Printed: 26/08/2024



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Map Scale @ A3: 1:8,500

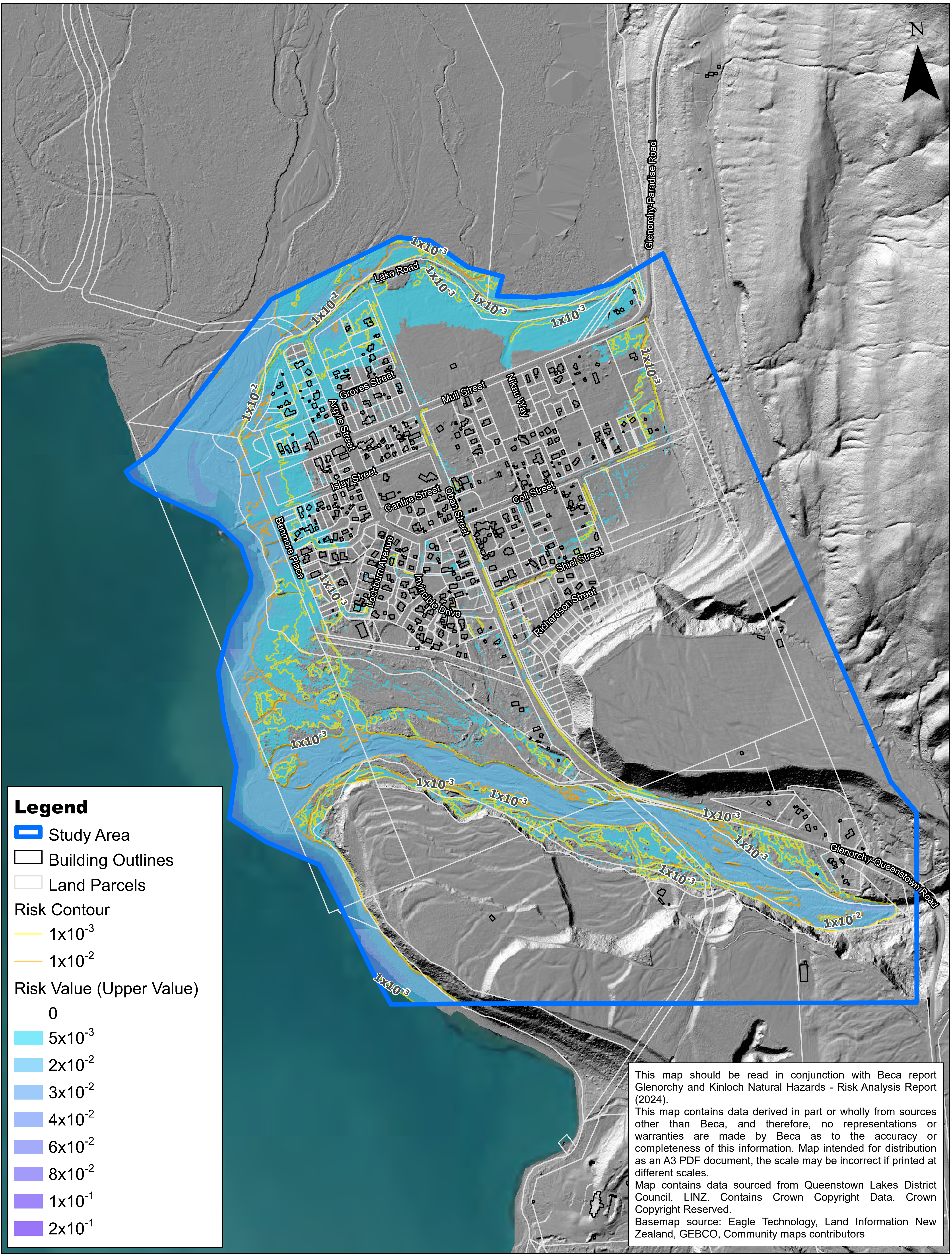
0 200
Metres

Revision	0.1
Status	Final
Author	ZT825
Verifier	BDJ2
Date	26/08/2024

Buckler Burn Flooding
Annual Property Risk
Combined Scenario
Glenorchy

Beca

Project	Glenorchy Kinloch Natural Hazard RA
Client	Otago Regional Council
Discipline	GIS
Drawing Number	GIS-3160904-08-001-01



Legend

Study Area

Building Outlines

Land Parcels

Risk Contour

$1x10^{-3}$

$1x10^{-2}$

Risk Value (Upper Value)

0

$5x10^{-3}$

$2x10^{-2}$

$3x10^{-2}$

$4x10^{-2}$

$6x10^{-2}$

$8x10^{-2}$

$1x10^{-1}$

$2x10^{-1}$

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Path: P:\316\3160904\1-WIP\WG-GIS\01-Map\GlenorchyKinloch_ReportMaps\GlenorchyKinloch_ReportMaps.aprx Map Layout: 08 Quantitative - Combined Risk - APR Flooding Date Printed: 26/08/2024

Map Scale @ A3: 1:8,500

0 200
Metres

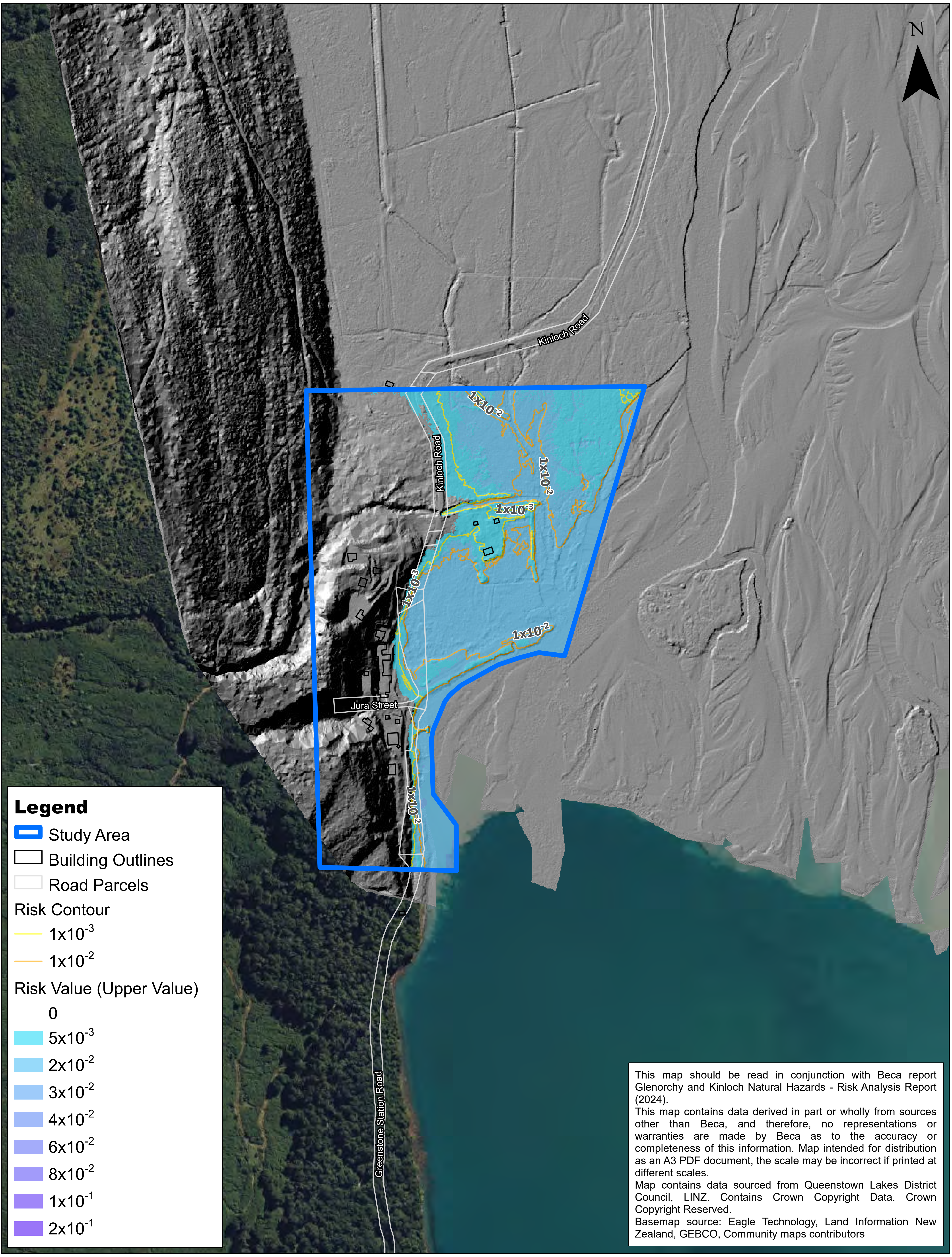
Revision	0.1
Status	Final
Author	ZT825
Verifier	BDJ2
Date	26/08/2024

Rees/Dart Flooding
Annual Property Risk
Combined Scenario
Glenorchy

Project	Glenorchy Kinloch Natural Hazard RA
Client	Otago Regional Council
Discipline	GIS
Drawing Number	GIS-3160904-08-002-01

GIS@beca.com

Path: P:\316\3160904\1-WIP\WG-GIS\01-Map\GlenorchyKinloch_ReportMaps\GlenorchyKinloch_ReportMaps.aprx Map Layout: 08 Quantitative - Combined Risk - APR Flooding Date Printed: 26/08/2024



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Map Scale @ A3: 1:5,000

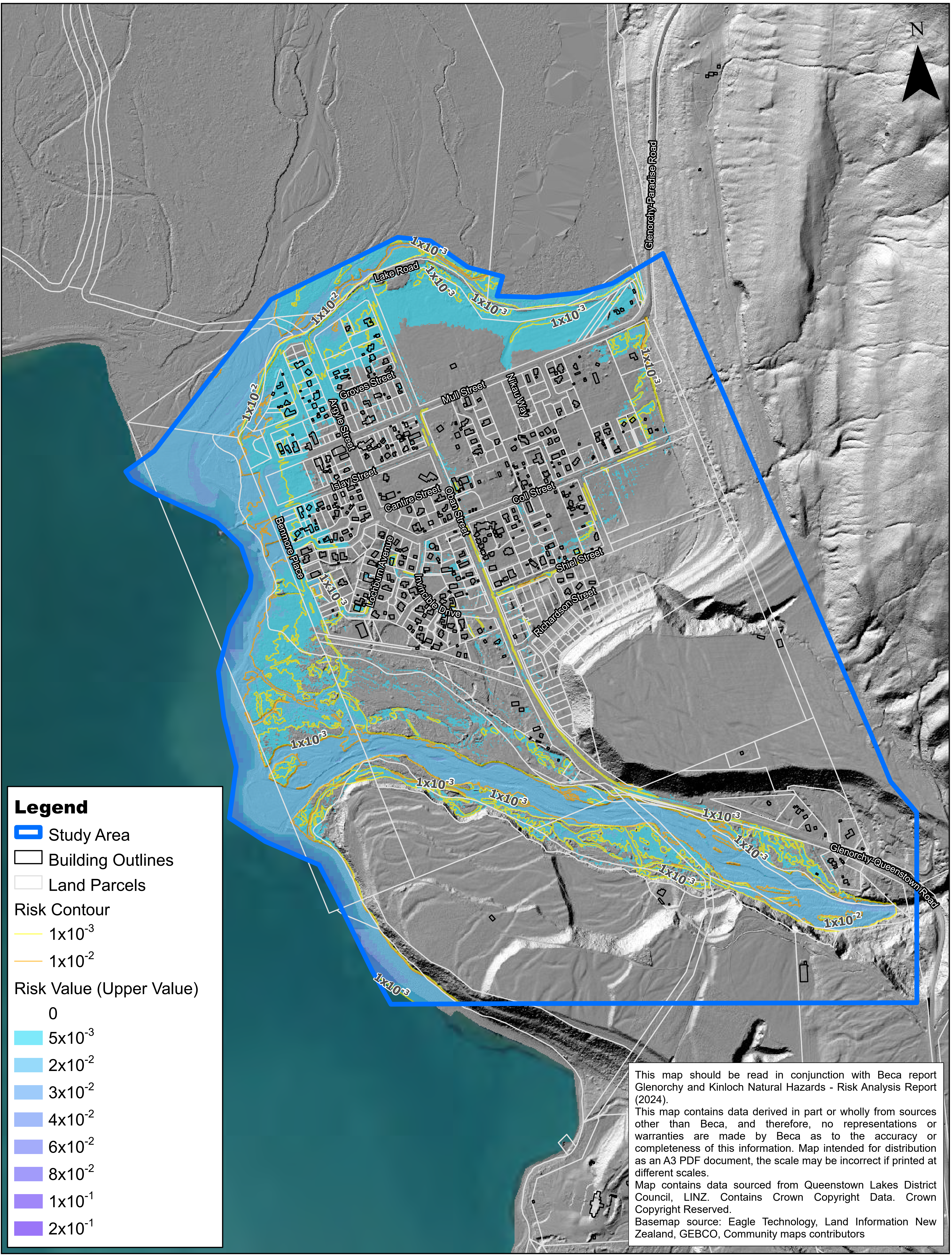
0 200
Metres

Revision	0.1
Status	Final
Author	ZT825
Verifier	BDJ2
Date	26/08/2024

Rees/Dart Flooding
Annual Property Risk
Combined Scenario
Kinloch

Beca

Project	Glenorchy Kinloch Natural Hazard RA
Client	Otago Regional Council
Discipline	GIS
Drawing Number	GIS-3160904-08-002-02



Legend

▬ Study Area

☐ Building Outlines

☐ Land Parcels

Risk Contour

— $1x10^{-3}$

— $1x10^{-2}$

Risk Value (Upper Value)

0

🟦 $5x10^{-3}$

🟦 $2x10^{-2}$

🟦 $3x10^{-2}$

🟦 $4x10^{-2}$

🟪 $6x10^{-2}$

🟪 $8x10^{-2}$

🟪 $1x10^{-1}$

🟪 $2x10^{-1}$

This map should be read in conjunction with Beca report Glenorchy and Kinloch Natural Hazards - Risk Analysis Report (2024).

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Path: P:\3160904\1-WIP\WG-GIS\01-Map\GlenorchyKinloch_ReportMaps\GlenorchyKinloch_ReportMaps.aprx Map Layout: 08 Quantitative - Combined Risk - APR Flooding Date Printed: 26/08/2024

Map Scale @ A3: 1:8,500

0 200
Metres

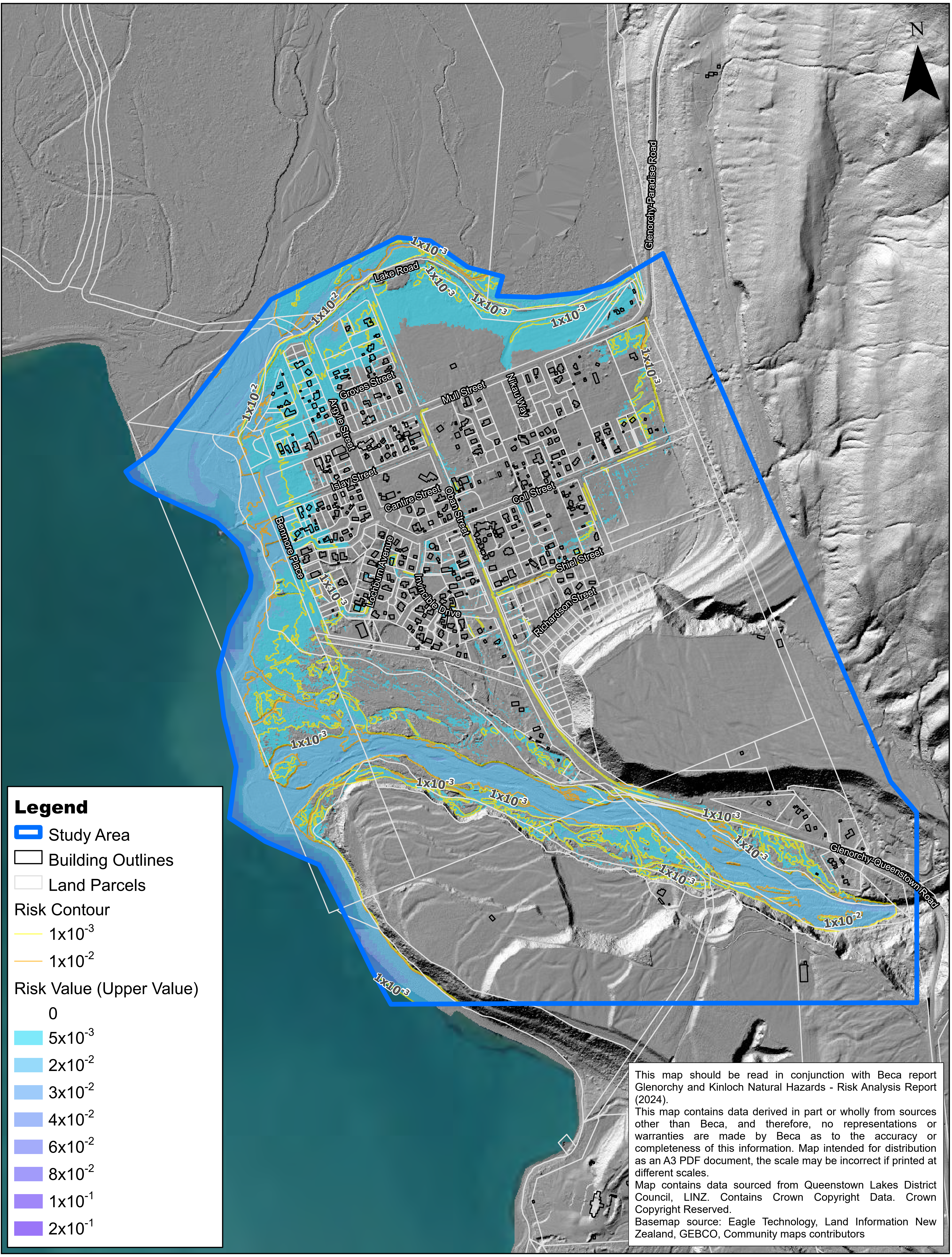
Revision	0.1
Status	Final
Author	ZT825
Verifier	BDJ2
Date	26/08/2024

Joint Scenario
Annual Property Risk
Combined Scenario
Glenorchy

Project	Glenorchy Kinloch Natural Hazard RA
Client	Otago Regional Council
Discipline	GIS
Drawing Number	GIS-3160904-08-003-01

GIS@beca.com

Path: P:\316\3160904\1-WIP\WG-GIS\01-Map\GlenorchyKinloch_ReportMaps\GlenorchyKinloch_ReportMaps.aprx Map Layout: 08 Quantitative - Combined Risk - APR Flooding Date Printed: 26/08/2024



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Map Scale @ A3: 1:8,500

0 200
Metres

Revision	0.1
Status	Final
Author	ZT825
Verifier	BDJ2
Date	26/08/2024

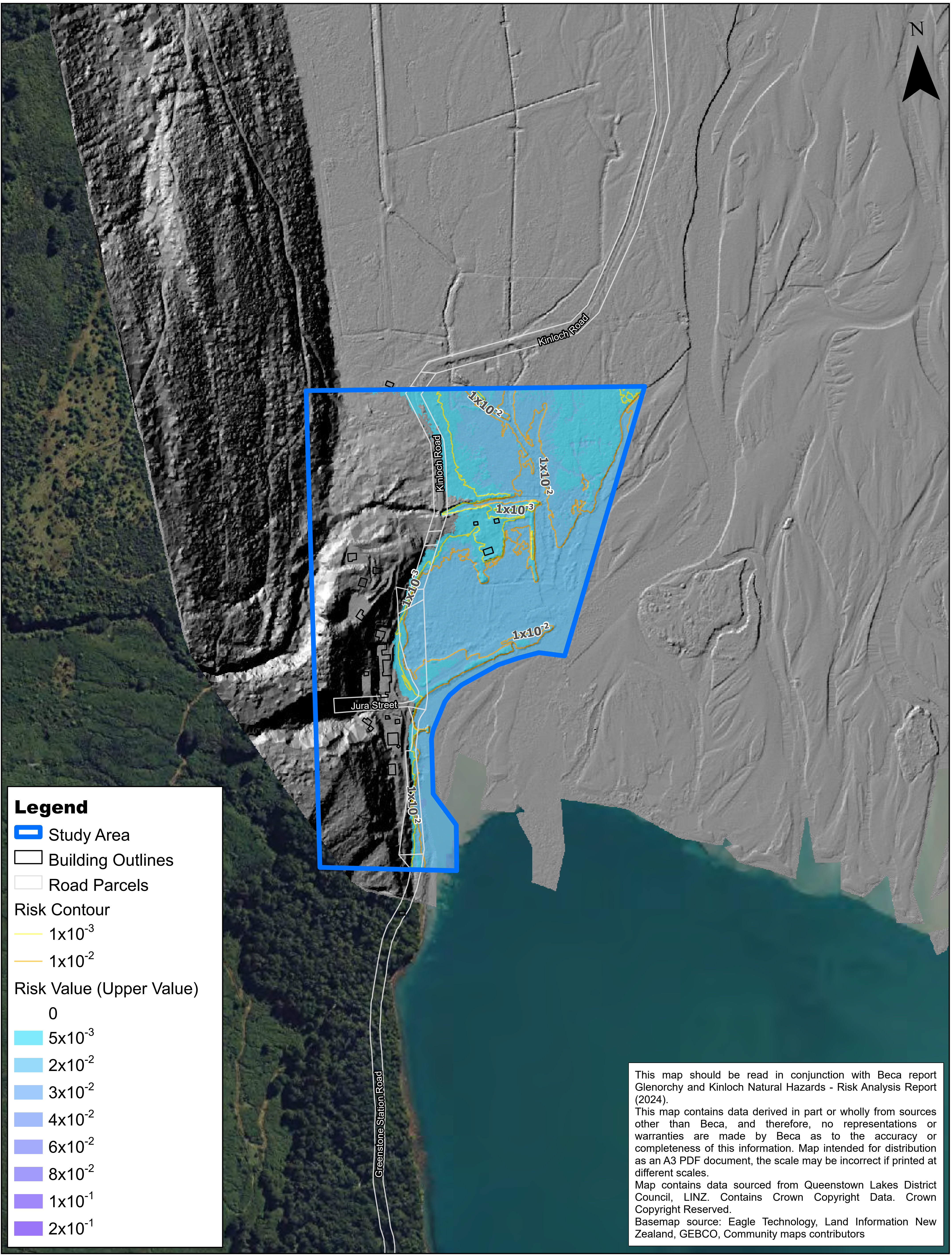
Lake Flood
Annual Property Risk
Combined Scenario
Glenorchy

Beca

Project	Glenorchy Kinloch Natural Hazard RA
Client	Otago Regional Council
Discipline	GIS
Drawing Number	GIS-3160904-08-004-01

GIS@beca.com

Path: P:\316\3160904\1-WIP\WG-GIS\01-Map\GlenorchyKinloch_ReportMaps\GlenorchyKinloch_ReportMaps.aprx Map Layout: 08 Quantitative - Combined Risk - APR Flooding Date Printed: 26/08/2024



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Map Scale @ A3: 1:5,000

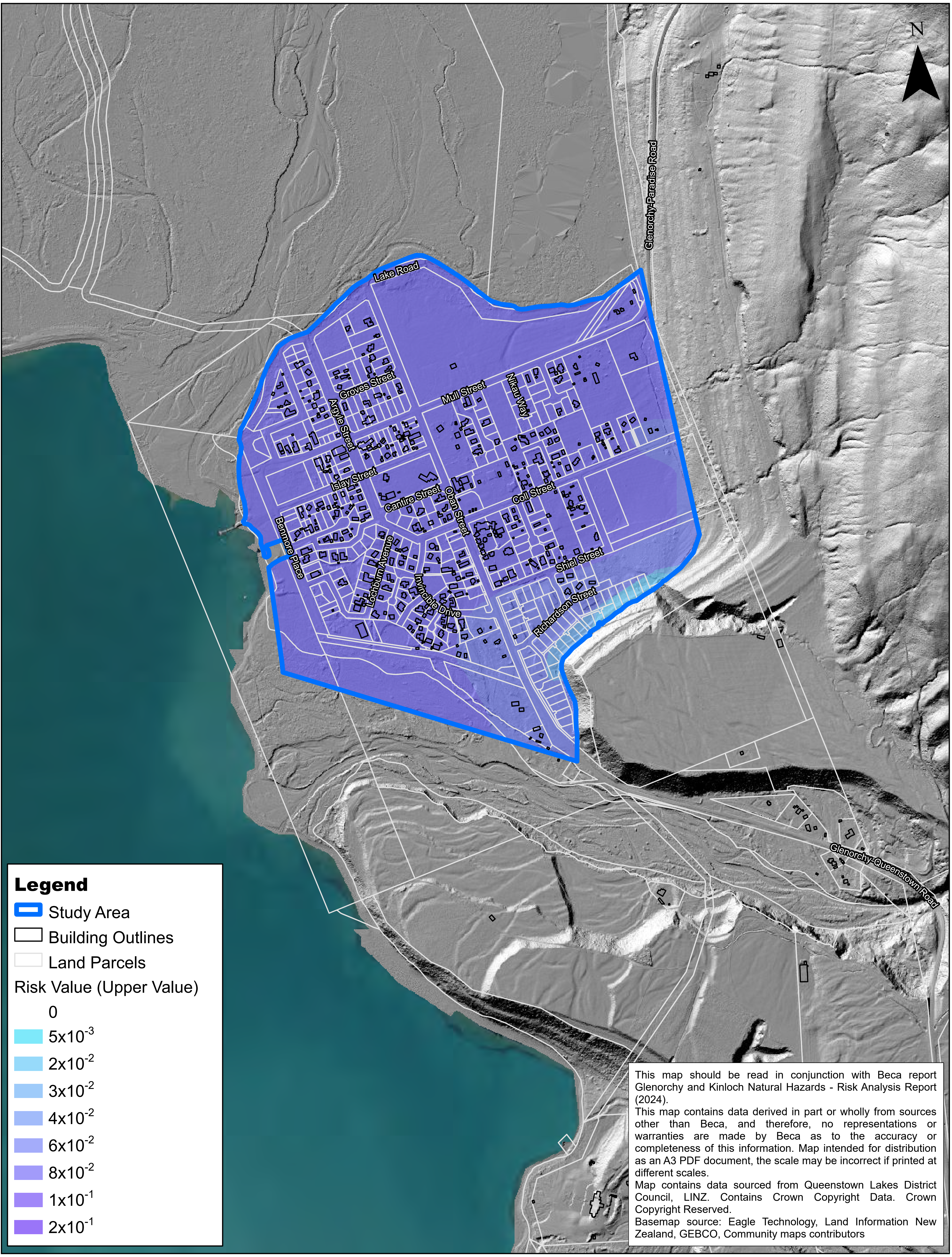
0 200
Metres

Revision	0.1
Status	Final
Author	ZT825
Verifier	BDJ2
Date	26/08/2024

Lake Flood
Annual Property Risk
Combined Scenario
Kinloch

Beca

Project	Glenorchy Kinloch Natural Hazard RA
Client	Otago Regional Council
Discipline	GIS
Drawing Number	GIS-3160904-08-004-02



This map should be read in conjunction with Beca report Glenorchy and Kinloch Natural Hazards - Risk Analysis Report (2024).
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Map Scale @ A3: 1:8,500

0 200
Metres

Revision	0.1
Status	Final
Author	ZT825
Verifier	BDJ2
Date	26/08/2024

Liquefaction
Annual Property Risk
Combined Scenario
Glenorchy

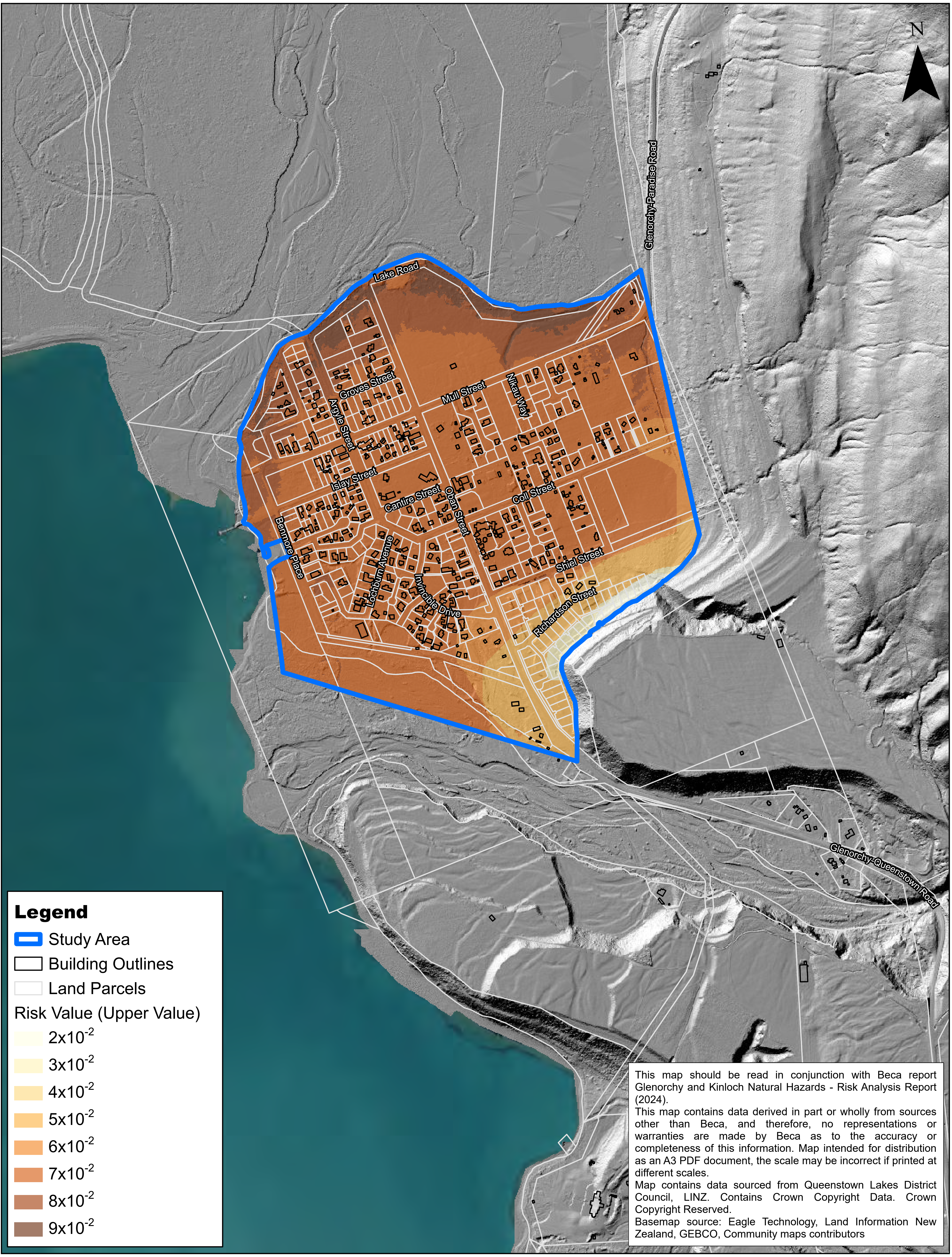
Beca

Project	Glenorchy Kinloch Natural Hazard RA
Client	Otago Regional Council
Discipline	GIS
Drawing Number	GIS-3160904-09-001-01

GIS@beca.com

Path: P:\316\3160904\1-WIP\WG-GIS\01-Map\GlenorchyKinloch_ReportMaps\GlenorchyKinloch_ReportMaps.aprx Map Layout: 09 Quantitative - Combined Risk - APR Liquefaction Date Printed: 26/08/2024

GIS@beca.com



This map should be read in conjunction with Beca report Glenorchy and Kinloch Natural Hazards - Risk Analysis Report (2024).
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Path: P:\3160904\1-WIP\WG-GIS\01-Map\GlenorchyKinloch_ReportMaps\GlenorchyKinloch_ReportMaps.aprx Map Layout: 10 Quantitative - Cumulative Risk Date Printed: 26/08/2024

Map Scale @ A3: 1:8,500

0 200
Metres

Revision	0.1
Status	Final
Author	ZT825
Verifier	BDJ2
Date	26/08/2024

Liquefaction and Joint Flooding
Annual Property Risk
Cumulative Scenario
Glenorchy

Beca

Project	Glenorchy Kinloch Natural Hazard RA
Client	Otago Regional Council
Discipline	GIS
Drawing Number	GIS-3160904-10-001-01

H

Appendix H – Quantitative Risk Level Maps

Legend

- Study Area
- Building Outlines
- Land Parcels

Risk Category

- 🟩 Acceptable Risk
- 🟨 Tolerable Risk
- 🟥 Significant Risk

This map should be read in conjunction with Beca report Glenorchy and Kinloch Natural Hazards - Risk Analysis Report (2024).
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Path: P:\316\3160904\1-WIP\WG-GIS\01-Map\GlenorchyKinloch_ReportMaps\GlenorchyKinloch_ReportMaps.aprx Map Layout: 11 Quantitative - Flood Risk Categories Date Printed: 26/08/2024

Map Scale @ A3: 1:8,500

0 200
Metres

Revision	0.1
Status	Final
Author	ZT825
Verifier	BDJ2
Date	26/08/2024

Buckler Burn Flooding
Annual Individual Fatality Risk
Combined Scenarios
Glenorchy

Beca

Project	Glenorchy Kinloch Natural Hazard RA
Client	Otago Regional Council
Discipline	GIS
Drawing Number	GIS-3160904-11-001-01

GIS@beca.com

Legend

- 🟦 Study Area
- ☐ Building Outlines
- ☐ Land Parcels

Risk Category

- 🟩 Acceptable Risk
- 🟨 Tolerable Risk
- 🟥 Significant Risk

This map should be read in conjunction with Beca report Glenorchy and Kinloch Natural Hazards - Risk Analysis Report (2024).

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Path: P:\316\3160904\1-WIP\WG-GIS\01-Map\GlenorchyKinloch_ReportMaps\GlenorchyKinloch_ReportMaps.aprx Map Layout: 11 Quantitative - Flood Risk Categories Date Printed: 26/08/2024

Map Scale @ A3: 1:8,500

0 200
Metres

Revision	0.1
Status	Final
Author	ZT825
Verifier	BDJ2
Date	26/08/2024

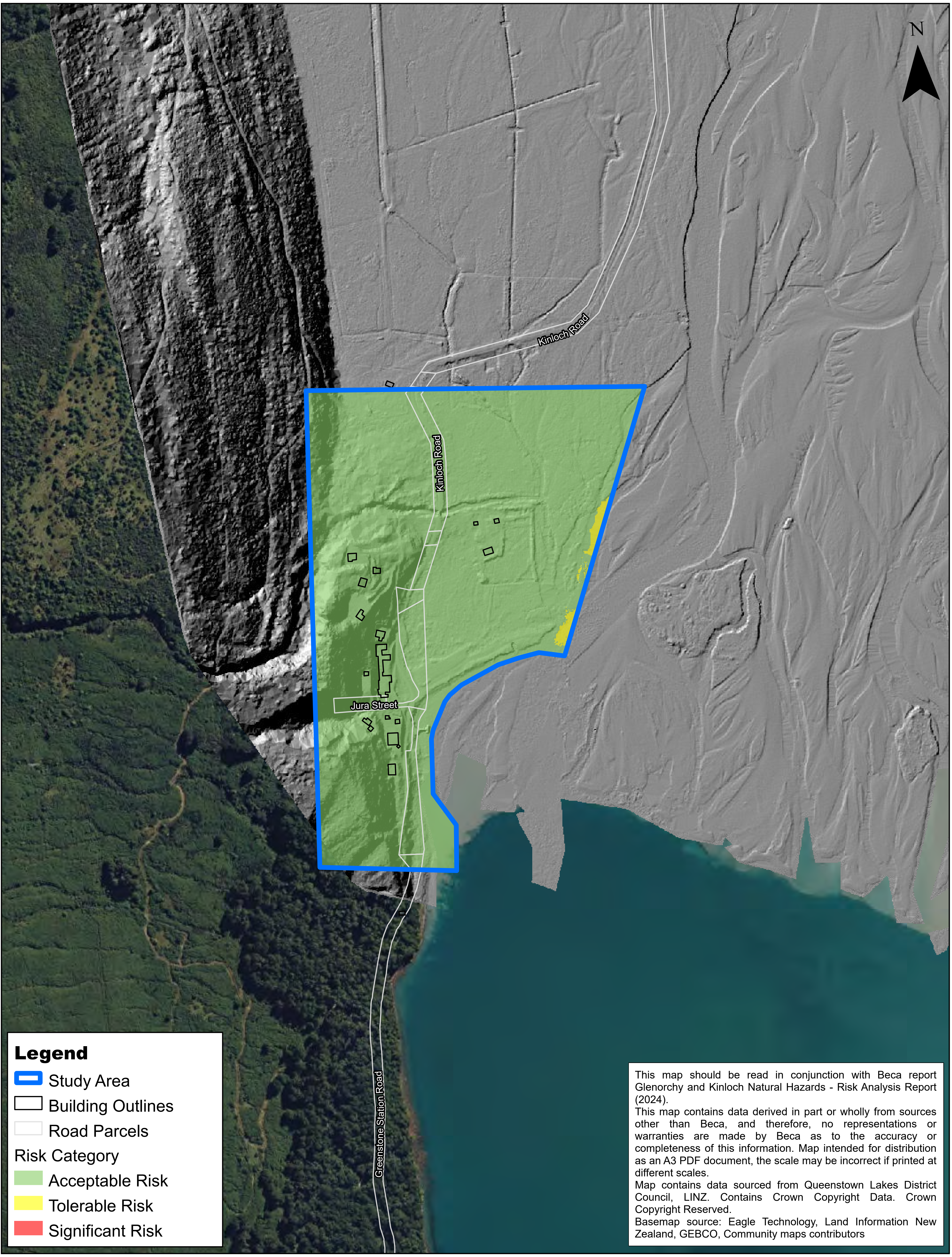
Rees/Dart Flooding
Annual Individual Fatality Risk
Combined Scenarios
Glenorchy

Beca

Project	Glenorchy Kinloch Natural Hazard RA
Client	Otago Regional Council
Discipline	GIS
Drawing Number	GIS-3160904-11-002-01

GIS@beca.com

Path: P:\316\3160904\1-WIP\WG-GIS\01-Map\GlenorchyKinloch_ReportMaps\GlenorchyKinloch_ReportMaps.aprx Map Layout: 11 Quantitative - Flood Risk Categories Date Printed: 26/08/2024



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Map Scale @ A3: 1:5,000

0 200
Metres

Revision	0.1
Status	Final
Author	ZT825
Verifier	BDJ2
Date	26/08/2024

Rees/Dart Flooding
Annual Individual Fatality Risk
Combined Scenarios
Kinloch

Beca

Project	Glenorchy Kinloch Natural Hazard RA
Client	Otago Regional Council
Discipline	GIS
Drawing Number	GIS-3160904-11-002-02

Legend

- 🟦 Study Area
- ☐ Building Outlines
- ☐ Land Parcels

Risk Category

- 🟩 Acceptable Risk
- 🟨 Tolerable Risk
- 🟥 Significant Risk

This map should be read in conjunction with Beca report Glenorchy and Kinloch Natural Hazards - Risk Analysis Report (2024).
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Map Scale @ A3: 1:8,500

0 200
Metres

Revision	0.1
Status	Final
Author	ZT825
Verifier	BDJ2
Date	26/08/2024

Joint Scenario
Annual Individual Fatality Risk
Combined Scenarios
Glenorchy

Beca

Project	Glenorchy Kinloch Natural Hazard RA
Client	Otago Regional Council
Discipline	GIS
Drawing Number	GIS-3160904-11-003-01

GIS@beca.com

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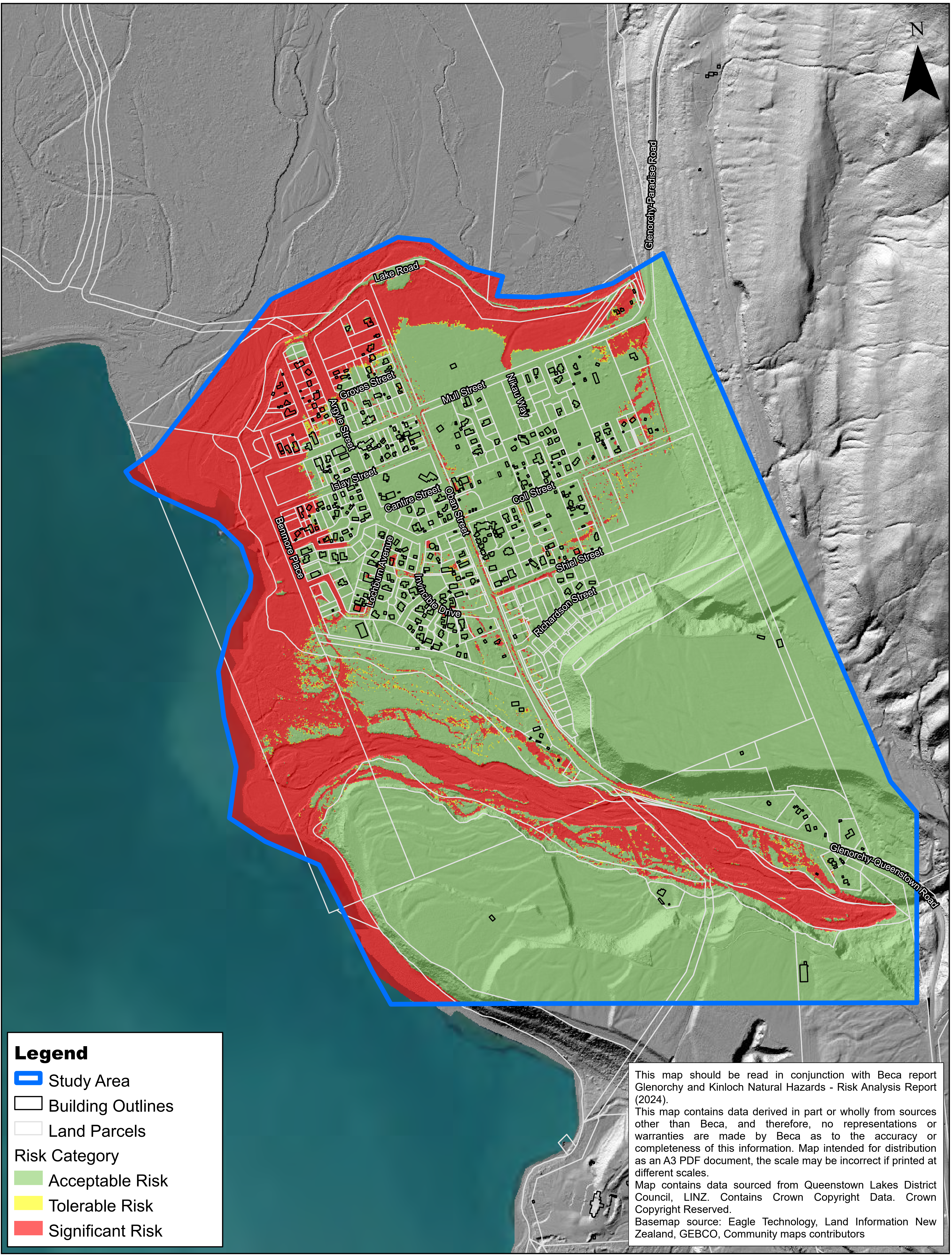

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Map Scale @ A3: 1:8,500

0 200
Metres

Revision 0.1
Status Final
Author ZT825
Verifier BDJ2
Date 26/08/2024

Buckler Burn Flooding
Annual Property Risk
Combined Scenarios
Glenorchy

Beca

Project	Glenorchy Kinloch Natural Hazard RA
Client	Otago Regional Council
Discipline	GIS
Drawing Number	GIS-3160904-11-004-01

GIS@beca.com

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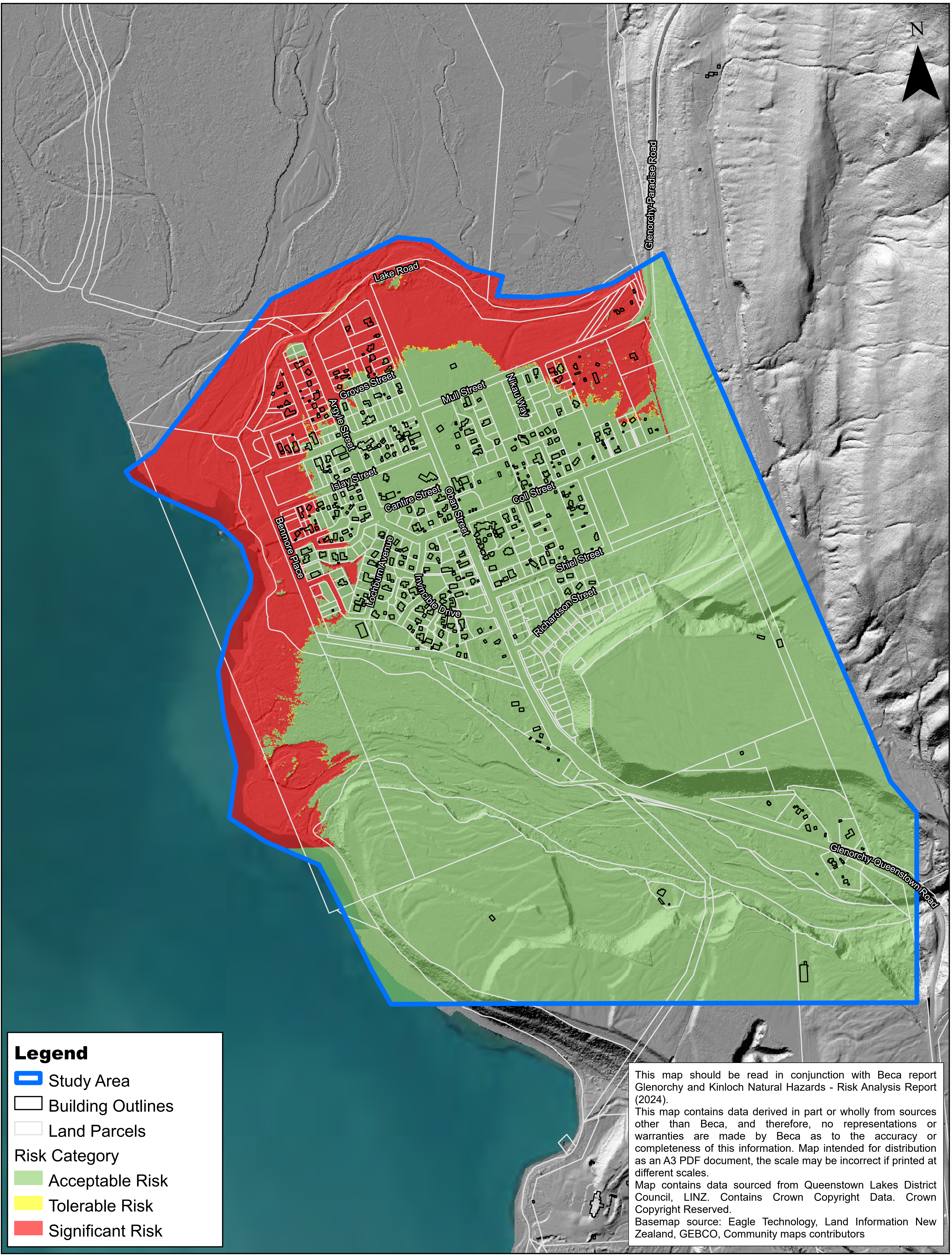

Legend

🟦 Study Area

☐ Building Outlines

☐ Land Parcels

Risk Category

🟩 Acceptable Risk

🟨 Tolerable Risk

🟥 Significant Risk

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Map Scale @ A3: 1:8,500

0 200
Metres

Revision 0.1
Status Final
Author ZT825
Verifier BDJ2
Date 26/08/2024

Rees/Dart Flooding
Annual Property Risk
Combined Scenarios
Glenorchy

Beca

Project Glenorchy Kinloch Natural Hazard RA
Client Otago Regional Council
Discipline GIS
Drawing Number GIS-3160904-11-005-01

GIS@beca.com

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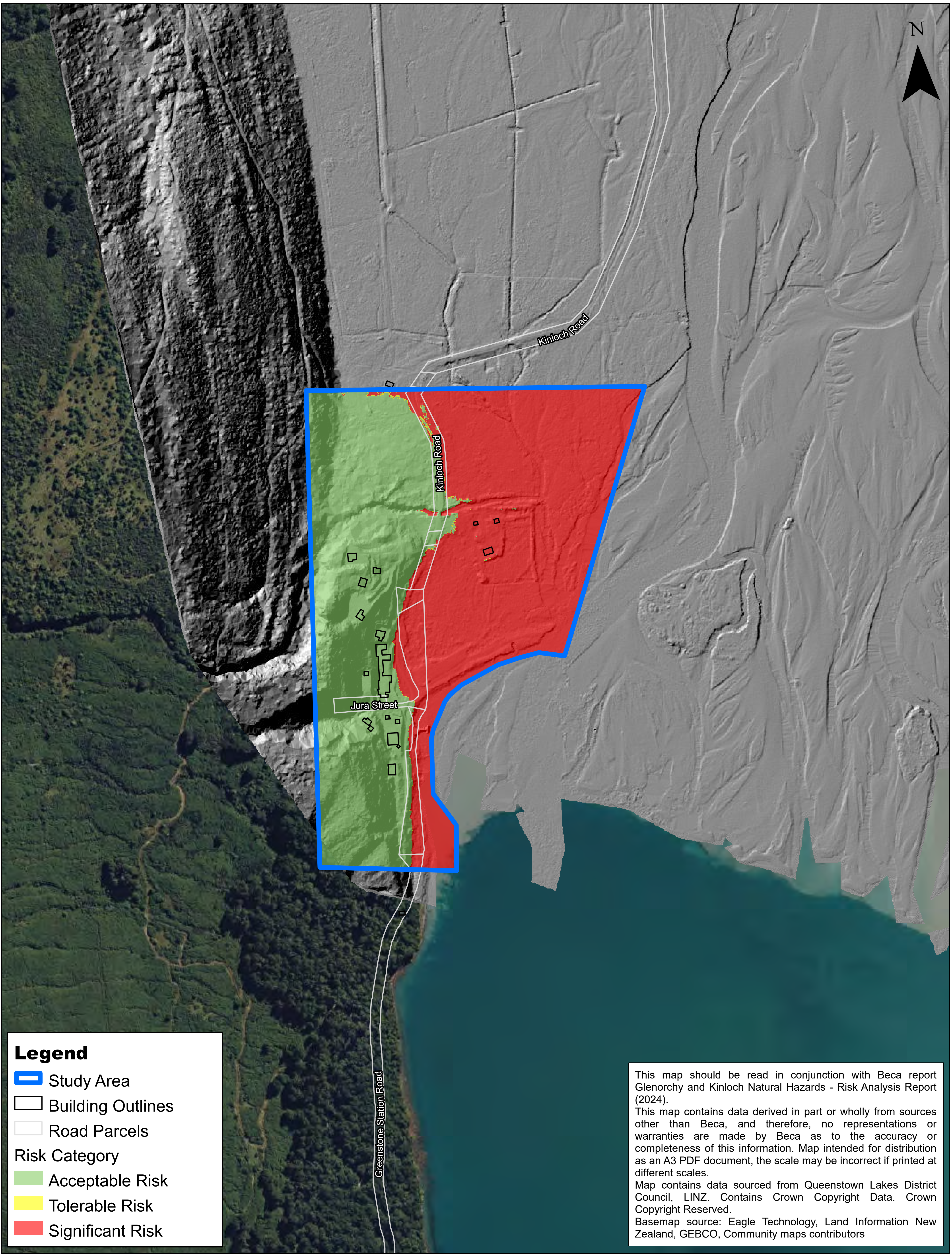

Legend

- 🟦 Study Area
- □ Building Outlines
- □ Road Parcels

Risk Category

- 🟩 Acceptable Risk
- 🟨 Tolerable Risk
- 🟥 Significant Risk

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Map Scale @ A3: 1:5,000

0 200
Metres

Revision	0.1
Status	Final
Author	ZT825
Verifier	BDJ2
Date	26/08/2024

Rees/Dart Flooding
Annual Property Risk
Combined Scenarios
Kinloch

Beca

Project	Glenorchy Kinloch Natural Hazard RA
Client	Otago Regional Council
Discipline	GIS
Drawing Number	GIS-3160904-11-005-02

GIS@beca.com

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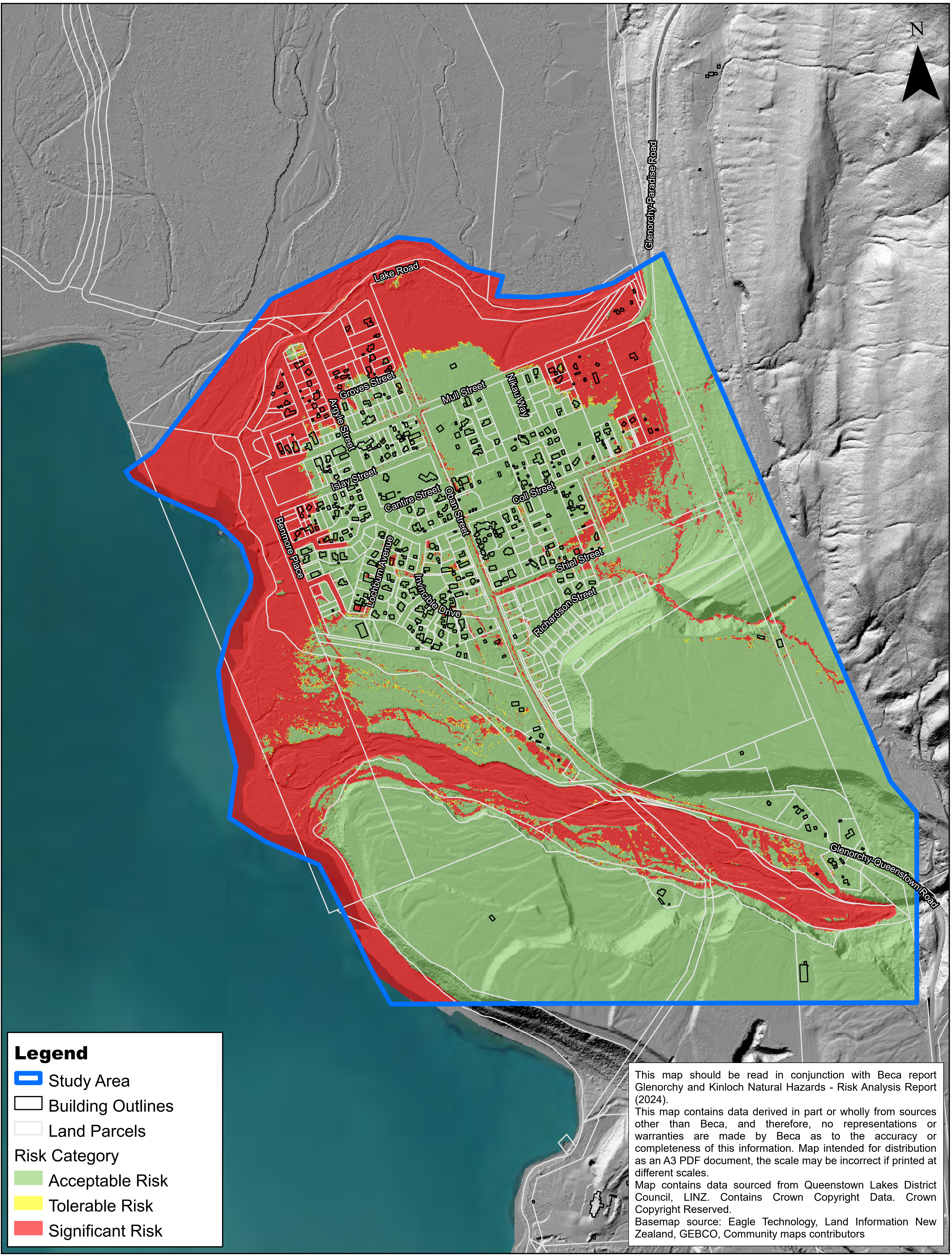

Legend

- 🟦 Study Area
- ☐ Building Outlines
- ☐ Land Parcels

Risk Category

- 🟩 Acceptable Risk
- 🟨 Tolerable Risk
- 🟥 Significant Risk

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Map Scale @ A3: 1:8,500

0 200
Metres

Revision 0.1
Status Final
Author ZT825
Verifier BDJ2
Date 26/08/2024

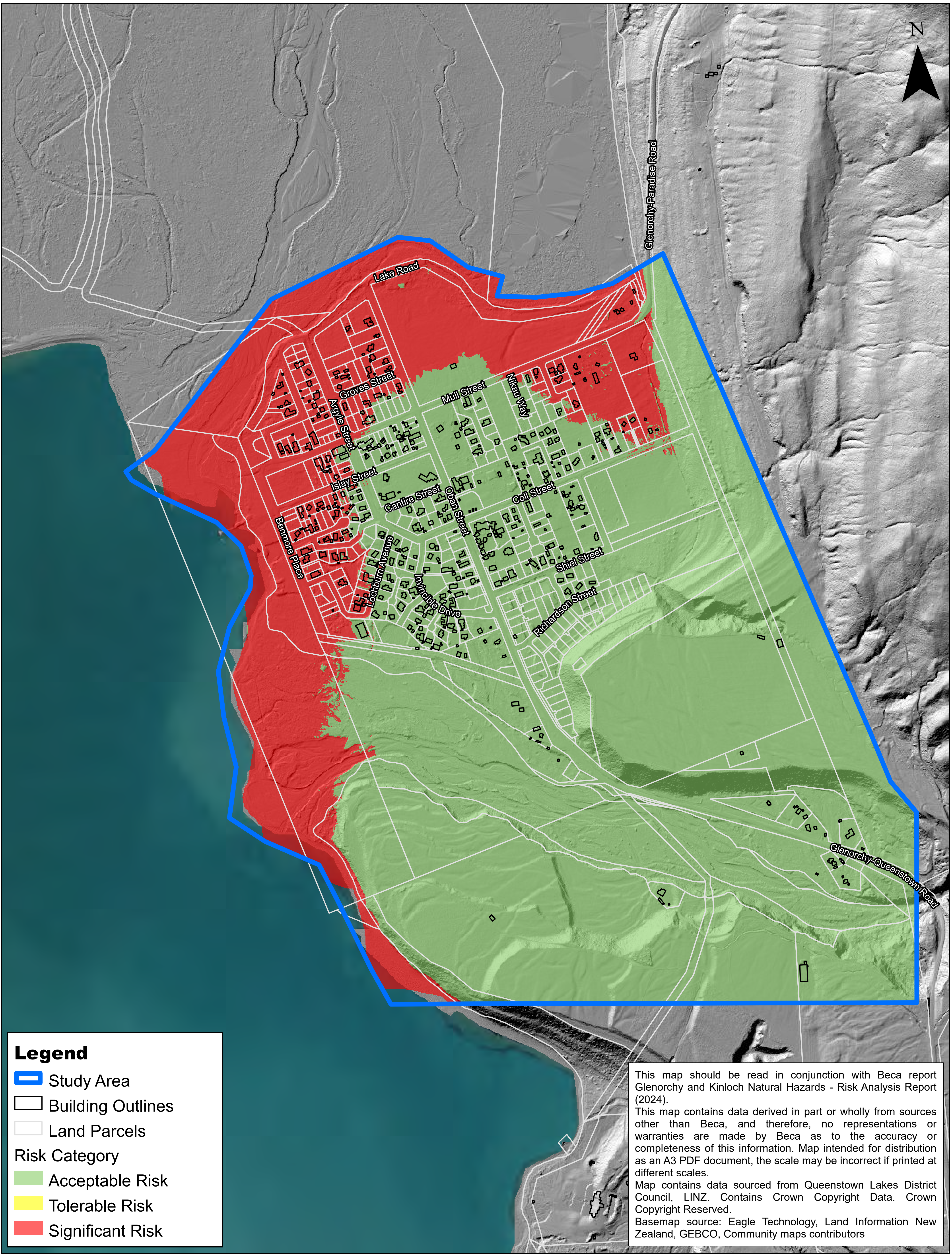
Joint Scenario
Annual Property Risk
Combined Scenarios
Glenorchy

Beca

Project Glenorchy Kinloch Natural Hazard RA
Client Otago Regional Council
Discipline GIS
Drawing Number GIS-3160904-11-006-01

GIS@beca.com

Path: P:\316\3160904\1-WIP\WG-GIS\01-Map\GlenorchyKinloch_ReportMaps\GlenorchyKinloch_ReportMaps.aprx Map Layout: 11 Quantitative - Flood Risk Categories Date Printed: 26/08/2024



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Map Scale @ A3: 1:8,500

0 200
Metres

Revision 0.1
Status Final
Author ZT825
Verifier BDJ2
Date 26/08/2024

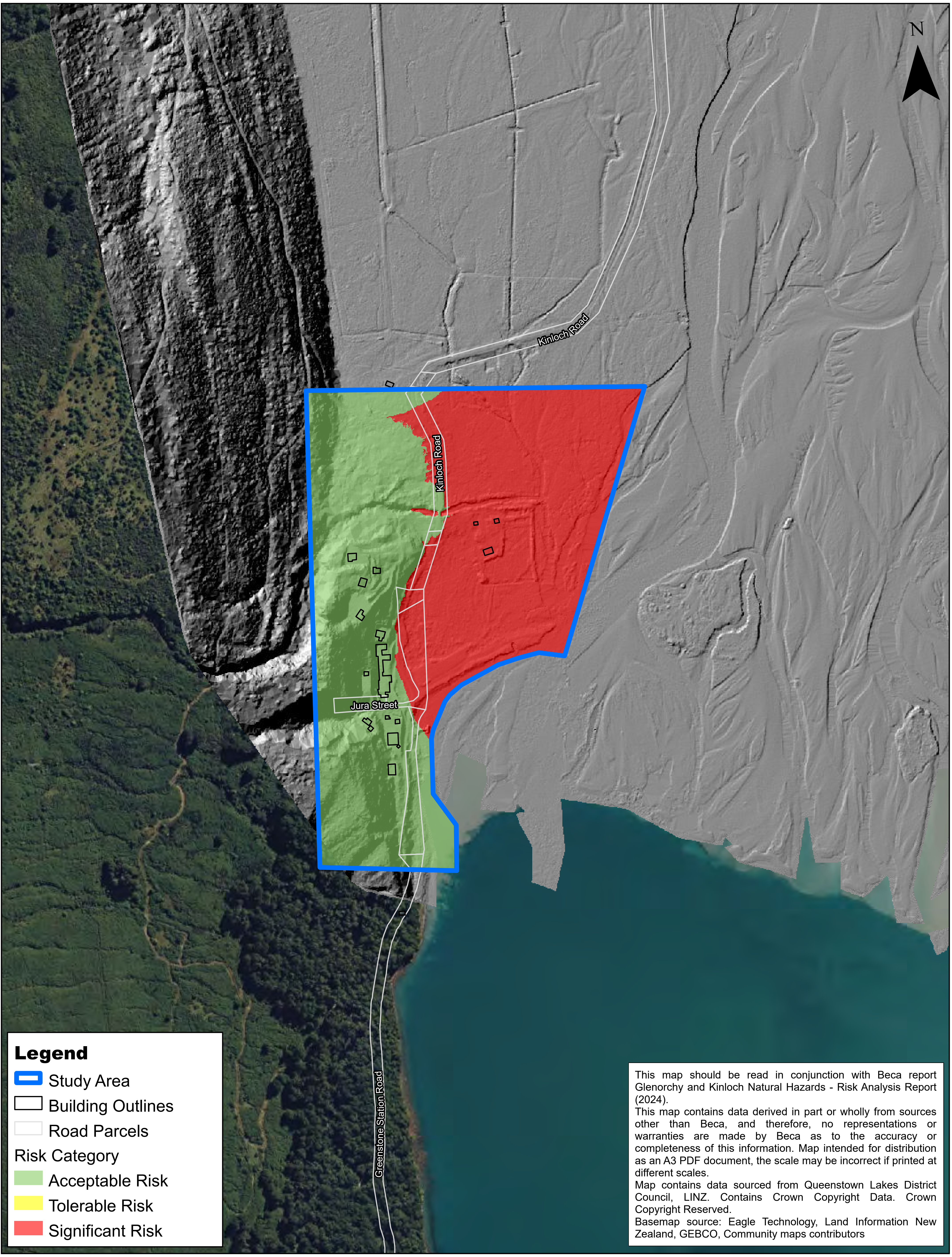
Lake Flood
Annual Property Risk
Combined Scenarios
Glenorchy

Beca

Project Glenorchy Kinloch Natural Hazard RA
Client Otago Regional Council
Discipline GIS
Drawing Number GIS-3160904-11-007-01

GIS@beca.com

Path: P:\316\3160904\1-WIP\WG-GIS\01-Map\GlenorchyKinloch_ReportMaps\GlenorchyKinloch_ReportMaps.aprx Map Layout: 11 Quantitative - Flood Risk Categories Date Printed: 26/08/2024



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Map Scale @ A3: 1:5,000

0 200
Metres

Revision	0.1
Status	Final
Author	ZT825
Verifier	BDJ2
Date	26/08/2024

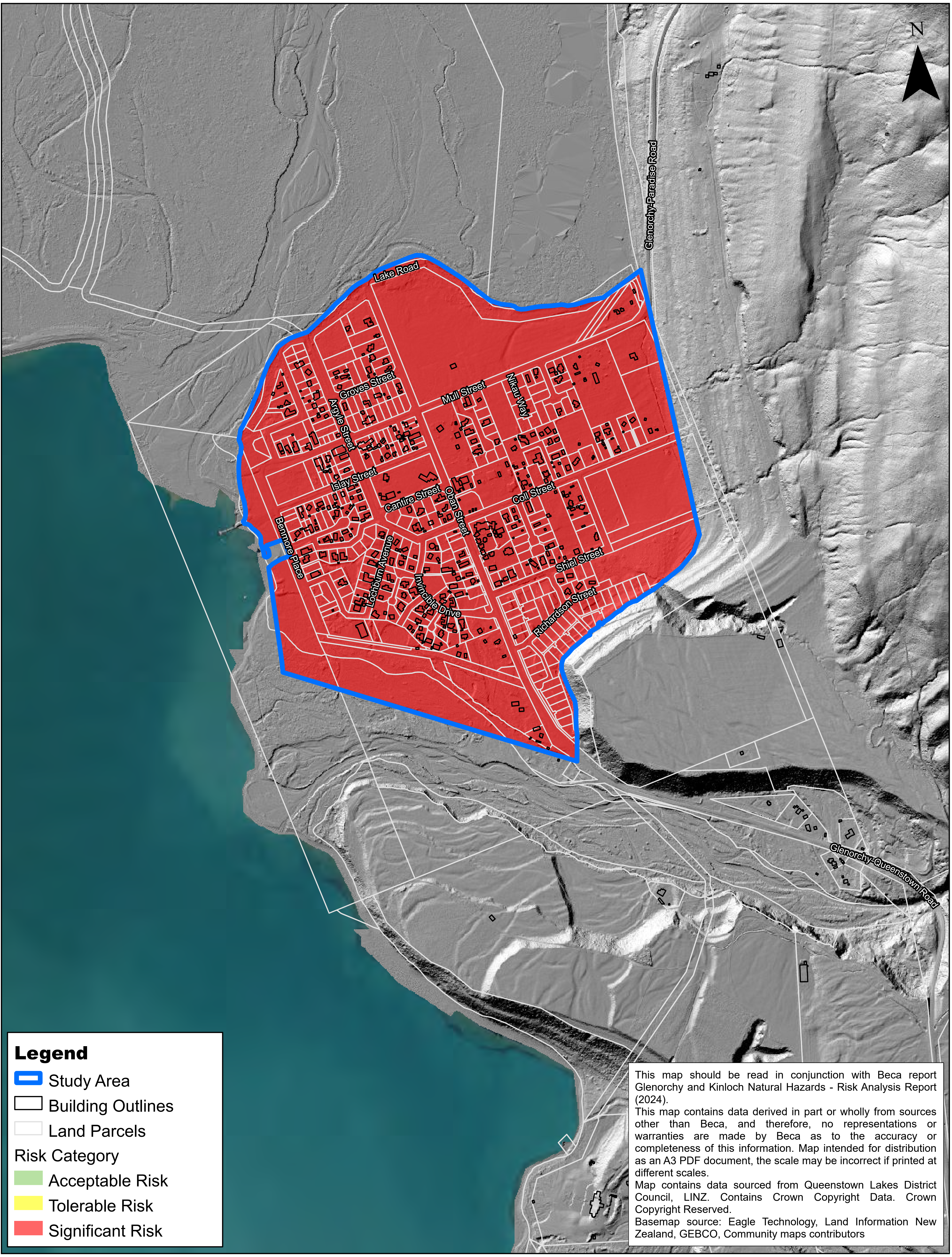
Lake Flood
Annual Property Risk
Combined Scenarios
Kinloch

Beca

Project	Glenorchy Kinloch Natural Hazard RA
Client	Otago Regional Council
Discipline	GIS
Drawing Number	GIS-3160904-11-007-02

GIS@beca.com

Path: P:\316\3160904\1-WIP\WG-GIS\01-Map\GlenorchyKinloch_ReportMaps\GlenorchyKinloch_ReportMaps.aprx Map Layout: 12 Quantitative - Liquefaction Risk Categories Date Printed: 26/08/2024



Legend

- 🟦 Study Area
- ☐ Building Outlines
- ☐ Land Parcels

Risk Category

- 🟩 Acceptable Risk
- 🟨 Tolerable Risk
- 🟥 Significant Risk

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Map Scale @ A3: 1:8,500

0 200
Metres

Revision	0.1
Status	Final
Author	ZT825
Verifier	BDJ2
Date	26/08/2024

Liquefaction
Annual Property Risk
Combined Scenarios
Glenorchy

Beca

Project	Glenorchy Kinloch Natural Hazard RA
Client	Otago Regional Council
Discipline	GIS
Drawing Number	GIS-3160904-12-001-01