Attachment C: Executive Summary

Beca

Natural Hazards Affecting Gorge Road, Queenstown

Prepared for Queenstown Lakes District Council
Prepared by Beca Limited

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Executive Summary

Introduction

Queenstown Lakes District Council (QLDC) is undertaking a review of the Queenstown Lakes District Plan, which includes considering changes to land use in the Brewery Creek and Reavers Lane areas, located near Gorge Road, Queenstown. This area is known to be susceptible to natural hazards including debris flows, rockfall, liquefaction and flooding.

As part of this process, Beca Limited (Beca) has been commissioned to undertake a review of natural hazards affecting this area. The intention of this work is to provide a greater understanding of the level of risk posed by natural hazards to allow QLDC to make informed decisions relating to land use planning.

Beca's work has been conducted in two phases, as summarised below:

- An initial review of natural hazards in the Gorge Road area, including debris flow, rockfall, liquefaction and flooding. A qualitative assessment of risk to property from debris flow and rockfall was also undertaken. This work was summarised in the report titled *Natural Hazards Affecting Gorge Road, Queenstown* (Beca, 2019).
- A second phase of work extends the original qualitative property risk study to include a quantification of both life risk and property risk.

This report sets out all phases of work undertaken by Beca to date relating to natural hazards in the Gorge Road area, and provides Annual Individual Fatality Risk (AIFR) and Annual Property Risk (APR) contour plans for the study areas. GNS Science are providing peer review of the study.

Site Characterisation

Setting

The study area comprises two alluvial fans located approximately 1km north of Queenstown centre.

Brewery Creek Fan is occupied by residential properties in the southern and western limits, to the south of Brewery Creek. To the north of Brewery Creek, the fan is occupied by industrial and service activities. Reavers Fan is the smaller and steeper of the two fans and is predominantly occupied by residential properties, with some properties in the upper fan used for commercial visitor accommodation.

History

Urban development on both fans commenced in the 1950s. There are no historical reports of debris flow events having impacted property on Reavers Fan. There are two documented historic debris flow and flood events in the Brewery Creek catchment, in May 1986 and November 1999. The 1999 event resulted in debris covering parts of the fan surface and extending over Gorge Road.

There are no records of rockfall events having impacted buildings on either fan in the reviewed data sources, although there is evidence of isolated rockfall having occurred.

Slope Stability Risk Assessment

The annual risk to life (AIFR) and property (APR) from debris flow and rockfall hazards have been assessed quantitively. The resulting risk values are presented as probabilities which can be expressed in a number of ways, as shown in the below table.

Ways of expressing risk probabilities (after GNS Science, 2012b).

Probability 1 in… (per year)	Is the same as (per year)	Is the same as (per year)	Is the same as (per year)	Is the same as (over lifetime)*	Is the same as (over building life)†
1,000	10^{-3}	0.001	0.1%	8%	5%
10,000	10^{-4}	0.0001	0.01%	0.8%	0.5%
100,000	10^{-5}	0.00001	0.001%	0.08%	0.05%
1,000,000	10^{-6}	0.000001	0.0001%	0.008%	0.005%

*Based on average New Zealand life expectancy of approximately 80 years, from 2008 mortality and population data.
†Based on minimum building design life of 50 years in accordance with the New Zealand Building Code.

Slope Stability Life Risk Assessment

A quantitative assessment of life risk posed by debris flow and rockfall hazards has been carried out for the study area. **AIFR is the probability that an <u>individual most at risk</u> is killed in any one year as a result of debris flow or rockfall.** The methodology adopted to assess this follows the Australian Geomechanics Society (AGS) Guidelines for Landslide Risk Management (2007).

An estimate of AIFR can be developed from:

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

Where:

$P_{(H)}$ is the annual probability of a hazard (debris flow or rockfall) occurring.

$P_{(S:H)}$ is the spatial probability that, given the hazard has occurred, the resulting debris traverses a location that could be occupied by the person most at risk.

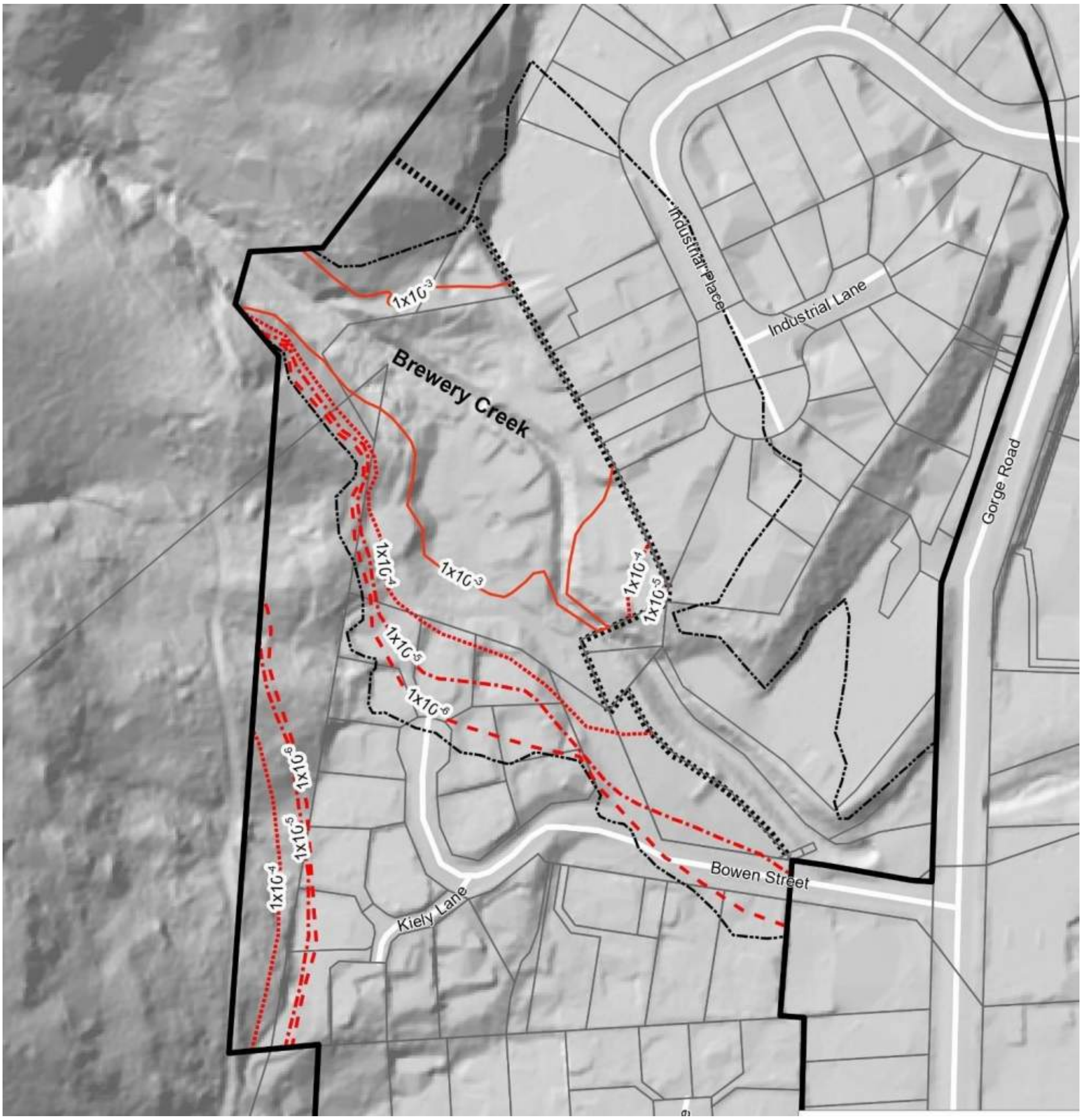
$P_{(T:S)}$ is the temporal spatial probability incorporating the proportion of the time the person most at risk is present and allowing for the possibility that there may be enough warning of the hazard to allow self-evacuation.

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

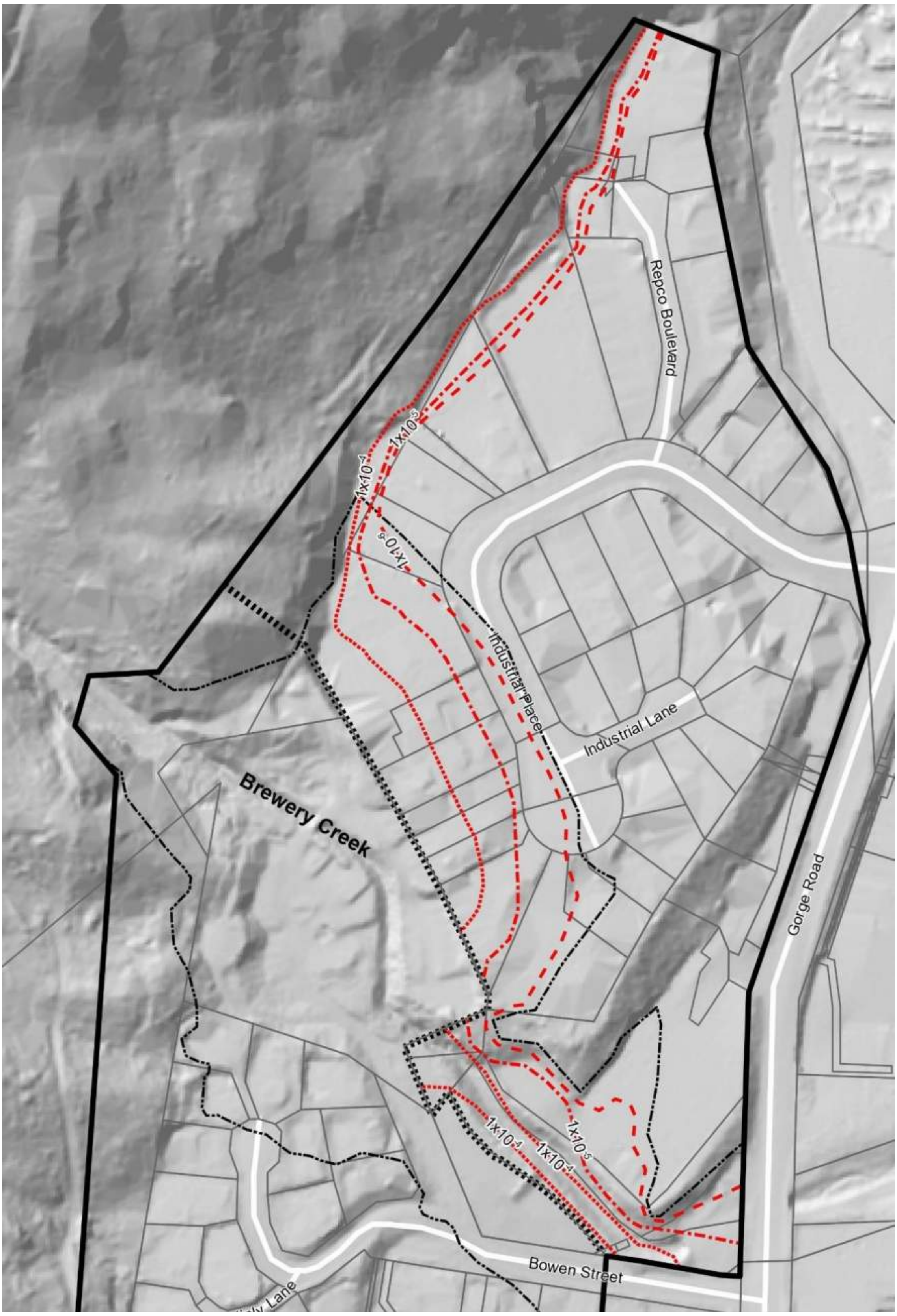
AIFR has been assessed for both fans based upon field mapping, ground investigation, historical events and numerical modelling.

Debris flow and rockfall risk are evaluated differently and separately but are then summed to provide a combined slope stability risk, presented as slope stability risk zone maps in this report.

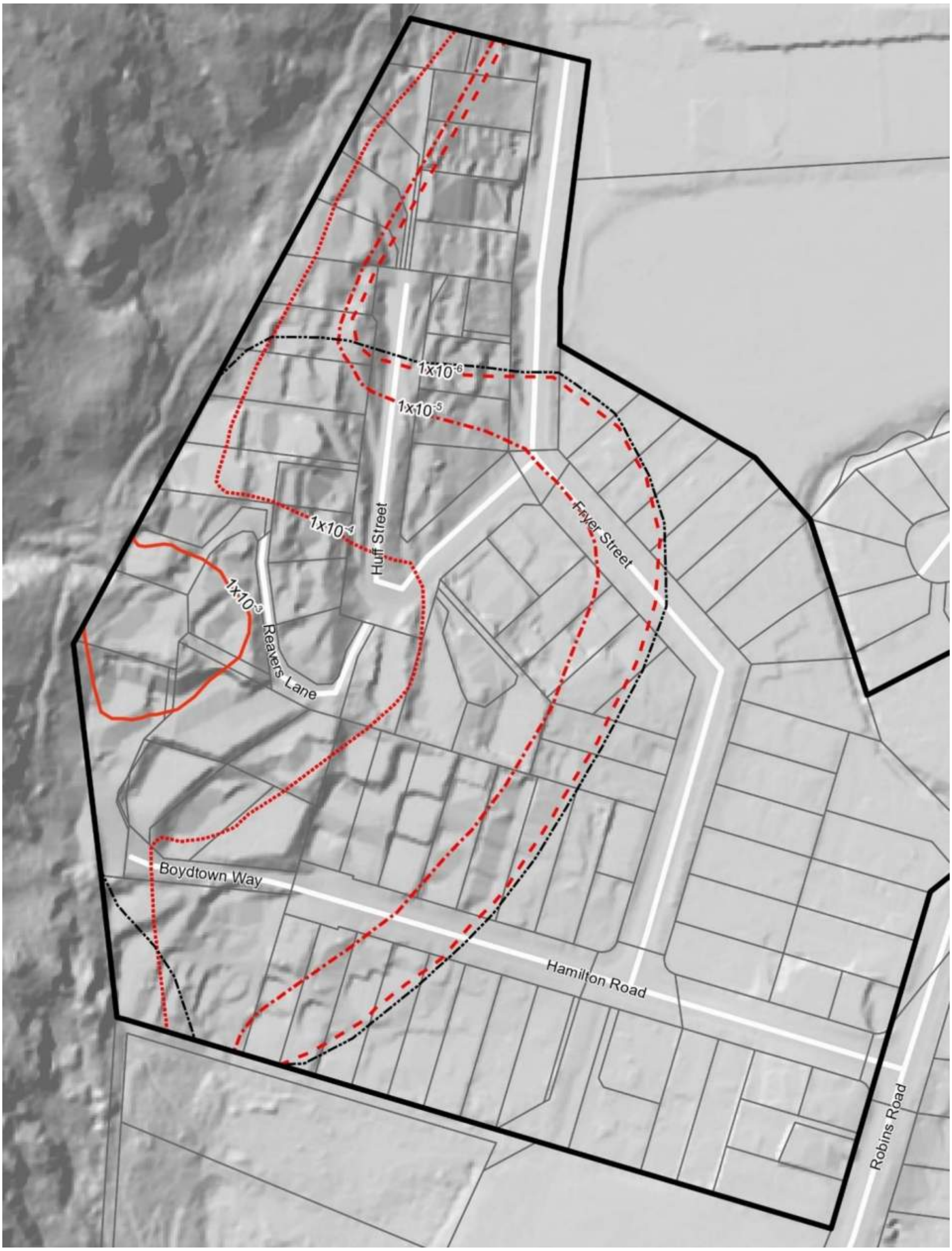
AIFR contours were then developed for combined debris flow and rockfall risk, using average AIFR values for the current (forested) situation. The resulting AIFR contour plans are shown below, with contours ranging from 10^{-3} to 10^{-6}.



AIFR contours Brewery Creek Fan – Residential Zone. Extract from drawing J013 – Appendix J. Refer to Appendix for full drawing.



AIFR contours Brewery Creek Fan – Business Zone. Extract from drawing J014 – Appendix J. Refer to Appendix for full drawing.



AIFR contours Reavers Fan. Extract from drawing J015 – Appendix J. Refer to Appendix for full drawing.

Climate Change Impacts on Slope Stability

The AIFR assessment for debris flow is based on historical rainfall data. An indicative sensitivity analysis was conducted to assess the likely effect of climate change on debris flow AIFR. The results indicated an increase in AIFR of just under one order of magnitude between current climate conditions and the most extreme climate change scenario for the year 2090.

It is anticipated that the effect of climate change on rockfall would be considerably less significant than for debris flow as climate triggers do not dominate the rockfall risk profile.

Slope Stability Property Risk Assessment

The risk of property damage was assessed qualitatively in the first phase of this natural hazards study. The most recent scope of work, as reported below, supersedes the property risk assessment provided in the Beca 2019 report.

A quantitative assessment of APR posed by the debris flow and rockfall hazards has been carried out for the study area. **APR is the annual probability of total property loss (relating to permanent structures) as a result of the hazards occurring**, on the assumption that the site is developed. The methodology adopted follows the AGS Guidelines for Landslide Risk Management (2007).

An estimate of APR can be developed from:

$$APR = P_{(H)} \times P_{(S:H)} \times P_{(T:S)} \times V_{(Prop:S)} \times E.$$

Where:

$P_{(H)}$ is the annual probability of a hazard (debris flow or rockfall) occurring.

$P_{(S:H)}$ is the spatial probability of impact (by debris flow or rockfall) on the property, taking into account the travel distance and travel direction.

$P_{(T:S)}$ is the temporal spatial probability. For houses and other buildings (i.e. fixed elements), P(T:S) = 1.0

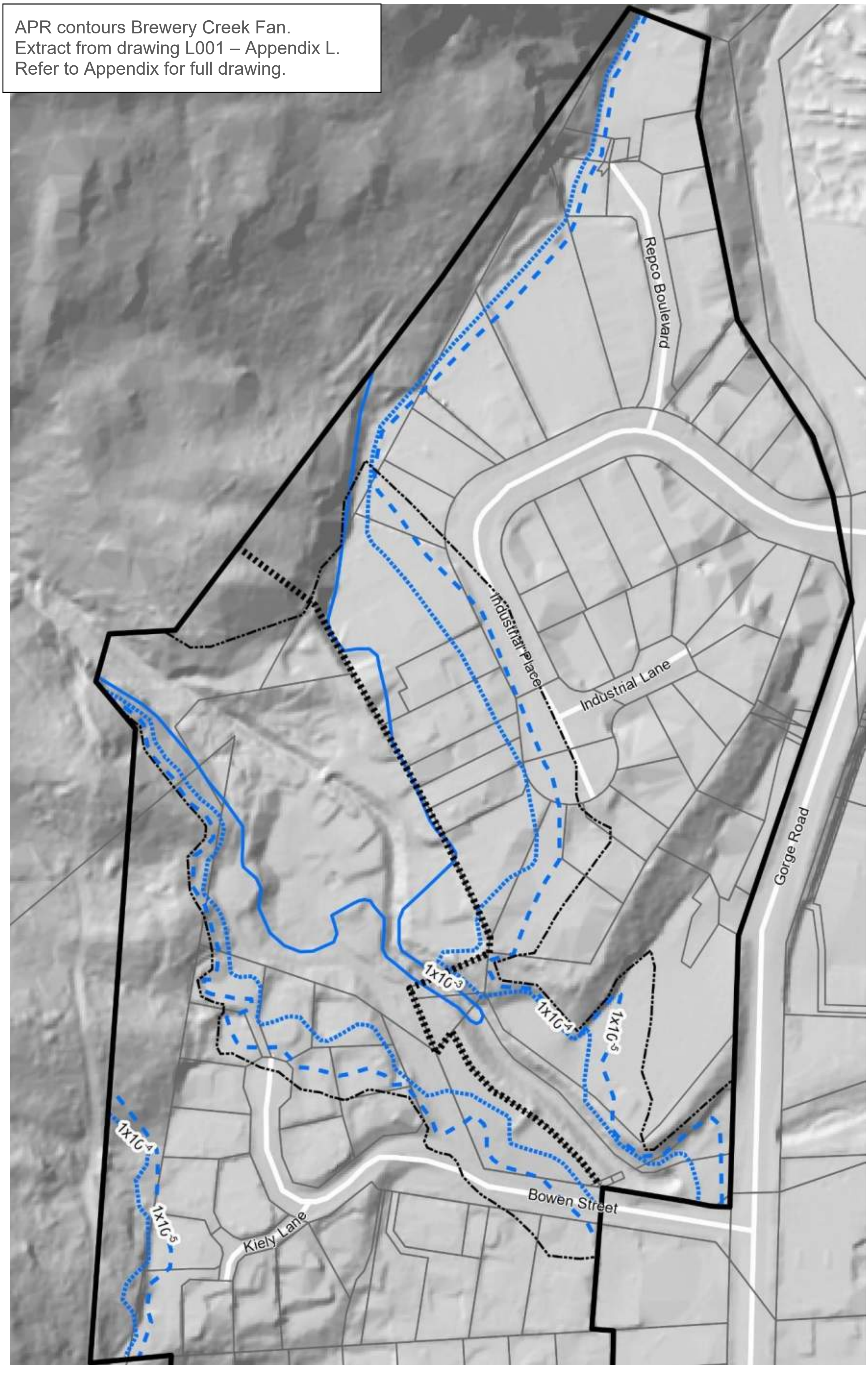
$V_{(D:T)}$ is the vulnerability of the property to the spatial impact (or expected proportion of property value lost in the event of impact).

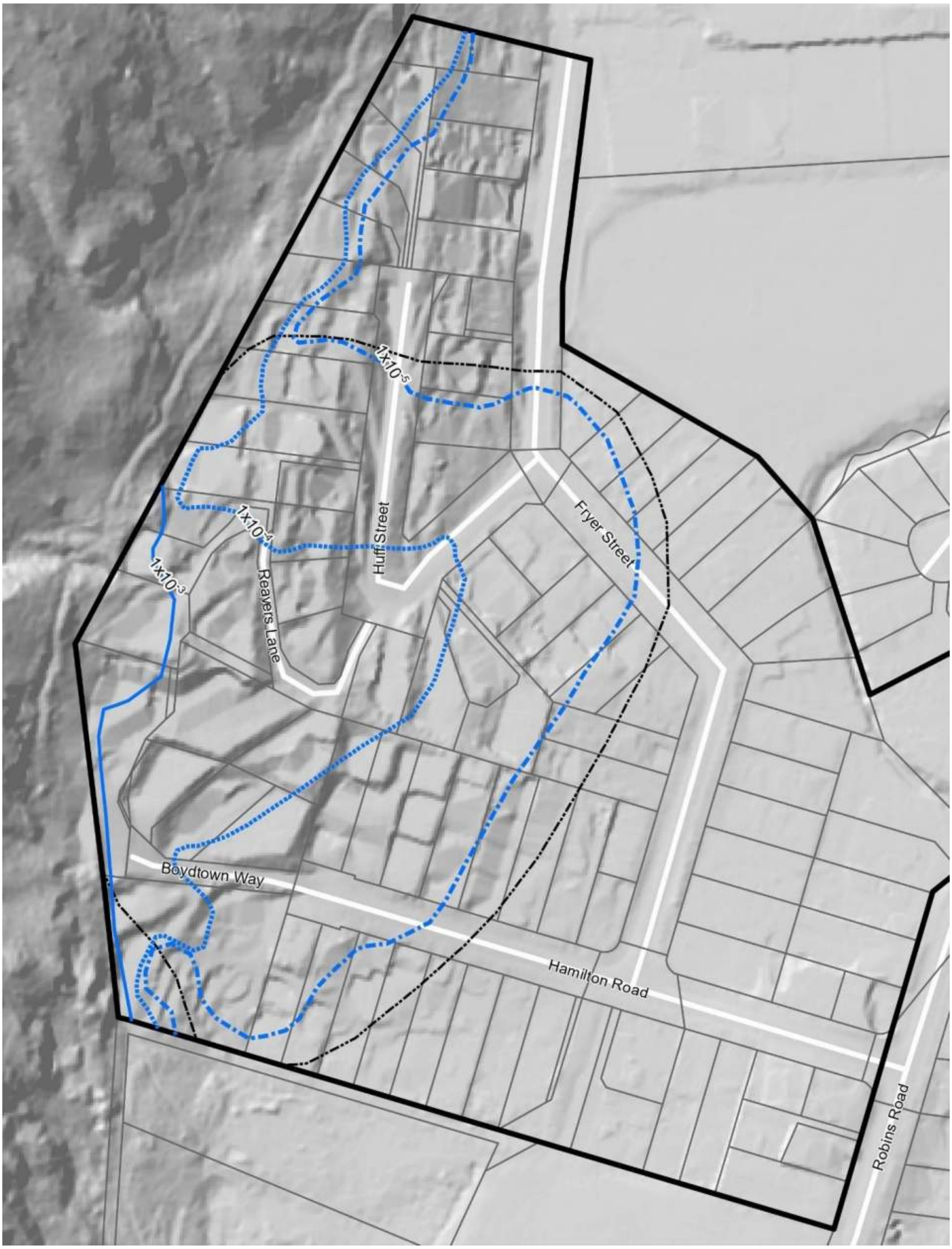
E is the value of the element at risk (e.g. the replacement value of the property).

APR has been assessed utilising the annual and spatial probability parameters from in the AIFR assessment, along with vulnerability parameters obtained from the loss modelling software RiskScape (https://www.riskscape.org.nz/), provided by GNS Science.

APR values for debris flow and rockfall were overlaid to produce combined APR, with values ranging from 10^{-3} to 10^{-6}. The resulting APR values have been contoured as shown in the below plans.

APR contours Brewery Creek Fan.
Extract from drawing L001 – Appendix L.
Refer to Appendix for full drawing.





APR contours Brewery Creek Fan. Extract from drawing L002 – Appendix L. Refer to Appendix for full drawing.

Liquefaction Vulnerability

Cone Penetration Testing (CPT) was undertaken on the distal (lower) margins of the Brewery Creek and Reavers alluvial fans to inform liquefaction assessment, which considered a total of 17 CPTs conducted by Beca and others. This information was used to inform the liquefaction susceptibility analysis using the Boulanger and Idriss (2014) methodology. Vertical settlement during a 1/500 year Mw 6.5 earthquake (equivalent to a 0.41g peak ground acceleration) ranged from less than 30mm to 320mm across the study area.

Liquefaction hazard has been assessed based on the vulnerability of damage to land during a design seismic event, in accordance with MBIE (2017). Liquefaction damage is possible for the distal areas of both Brewery Creek and Reavers Fans, and unlikely for the upper fans. The liquefaction vulnerability plan is included in Appendix M – Liquefaction Vulnerability, with extracts shown overleaf for Brewery Creek and Reavers Fan.

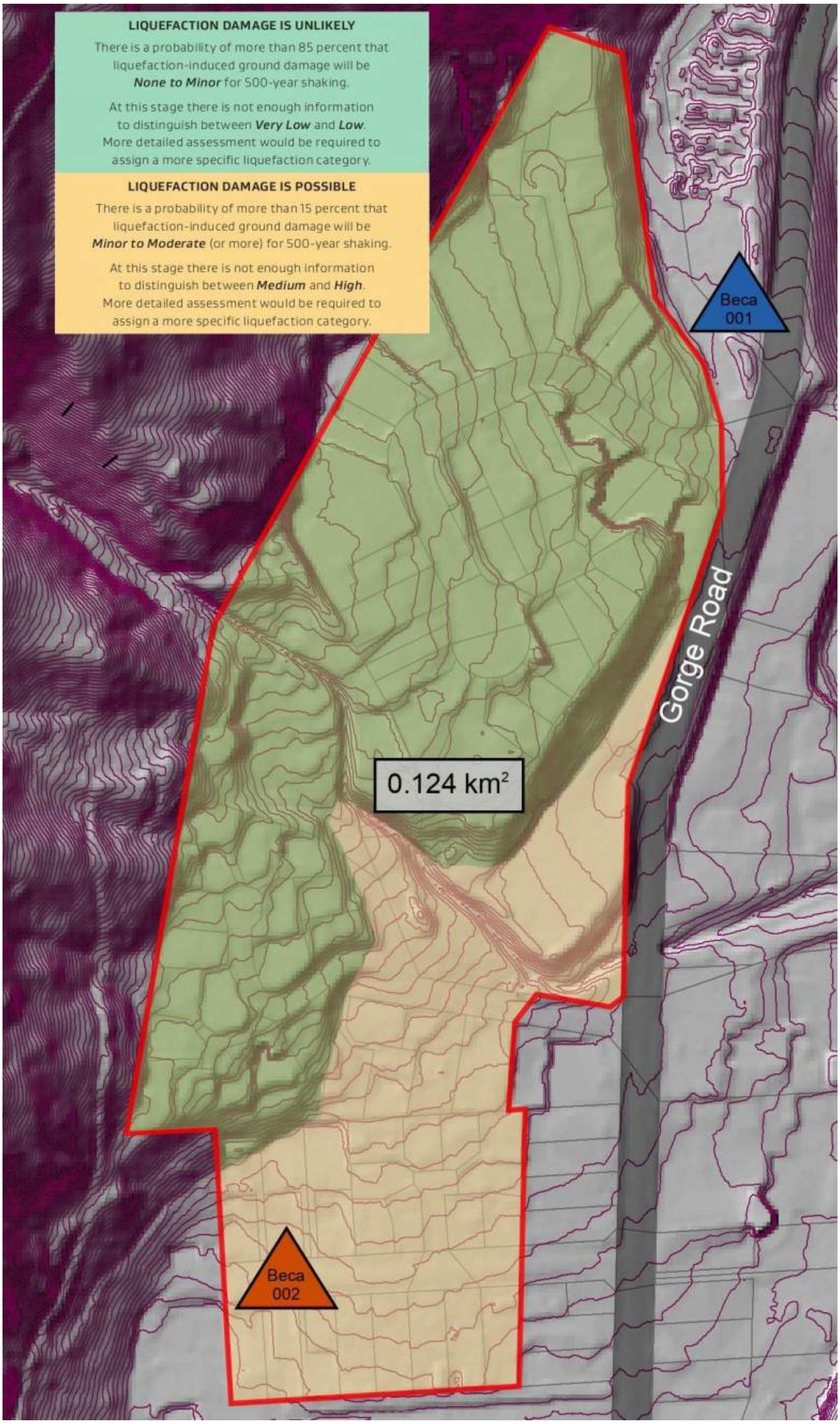
Flooding

An assessment of flood hazard to property has been undertaken for the study area. Beca has updated the previous QLDC flood models to include the ability to consider surface flow (2D). The model now includes the stormwater pipe network, stream channels and land surface but with buildings removed.

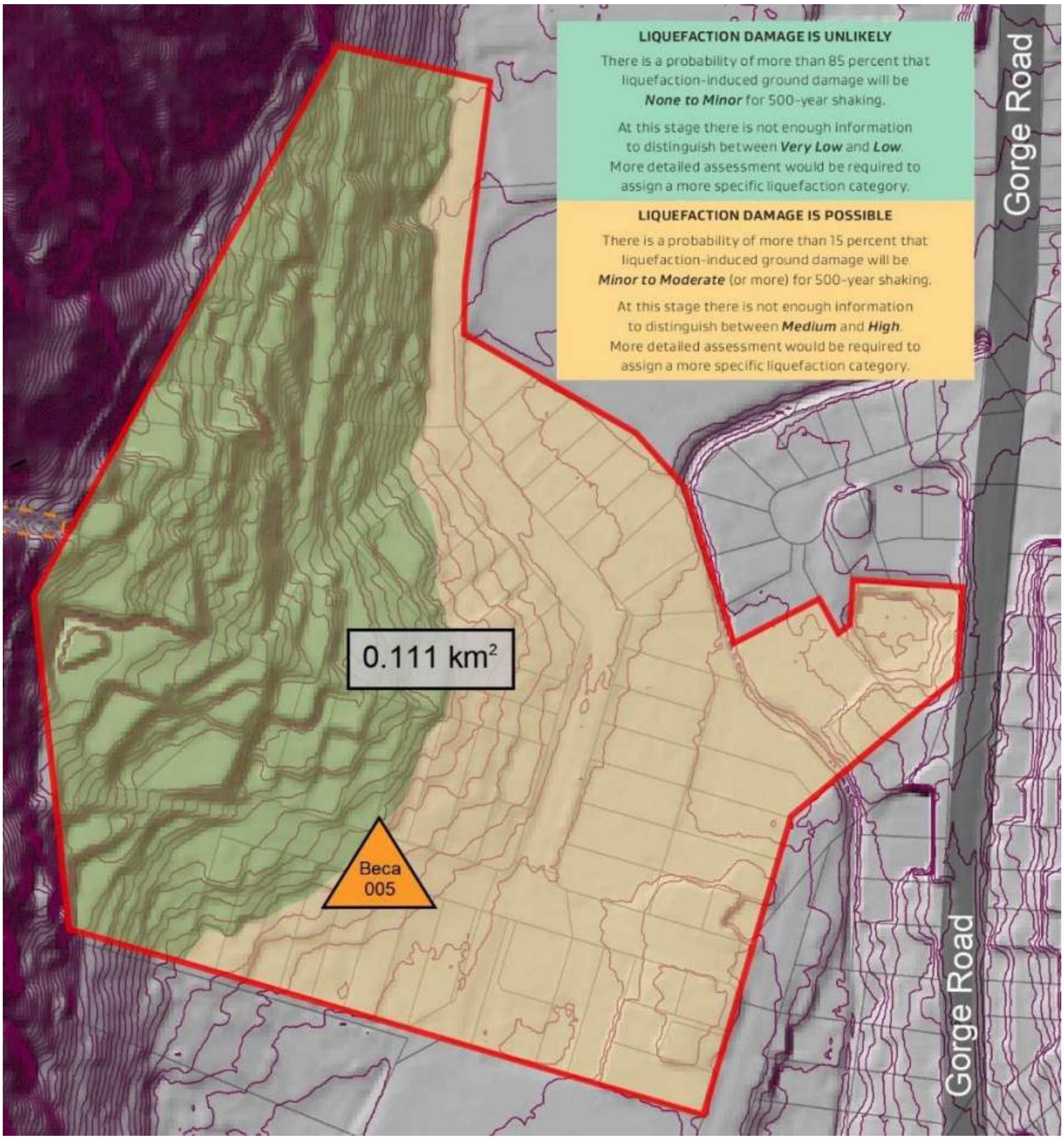
The engineered channel downstream of the Brewery Creek Fan apex has the capacity to convey a 100-year flow from the Brewery Creek catchment. No overflow occurs from Brewery Creek channel until it reaches the wetlands north of the Creek. Minor flooding is indicated from a small catchment south of Brewery Creek which is not conveyed by the pipe network. This flow travels south towards Sawmill Road/Fryer Street and on towards the Ngai Tahu development site (former Wakatipu High School).

The intake structure at Reavers Creek is shown to be unable to contain the flood water from a 100-year event, resulting in overflow across the fan surface at depths of 100mm-200mm, even without considering entrained debris. The flood water is not confined to the roading network and finds its way across private property. Flooding in the lower part of the fan is caused by Horn Creek. The Robins Road bridge cannot convey the full 100-year flow causing an increase in water level upstream of this point and flooding into the Creeksyde Holiday Park.

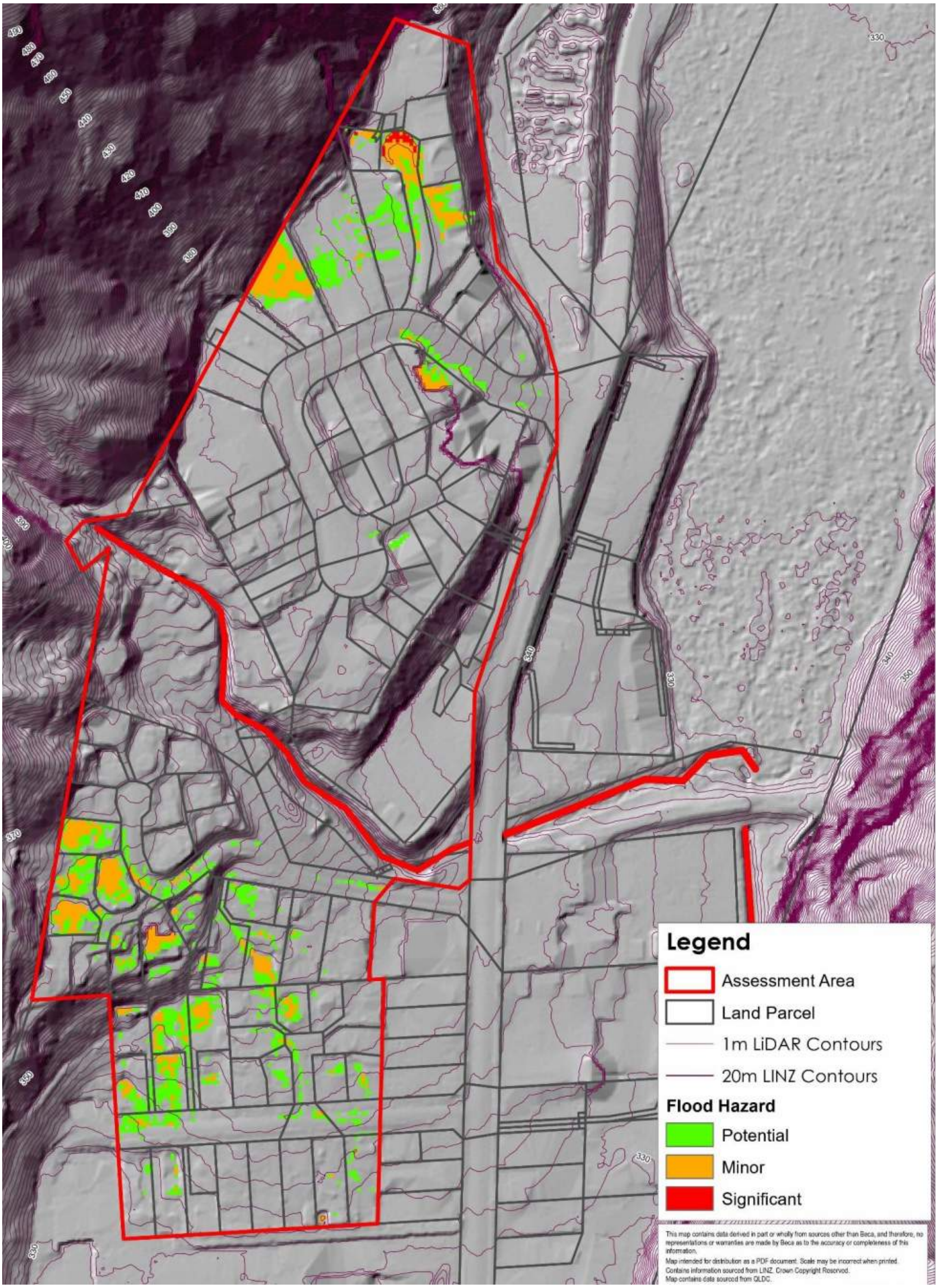
The flood modelling does not allow for debris flows which have the ability to change the course of the flood water depending on the size of debris moved by the flood waters. Flood maps and flood hazard maps are included in Appendix N – Flood Maps. Extracts of the flood hazard maps for a 100 year ARI event are shown in the following pages.



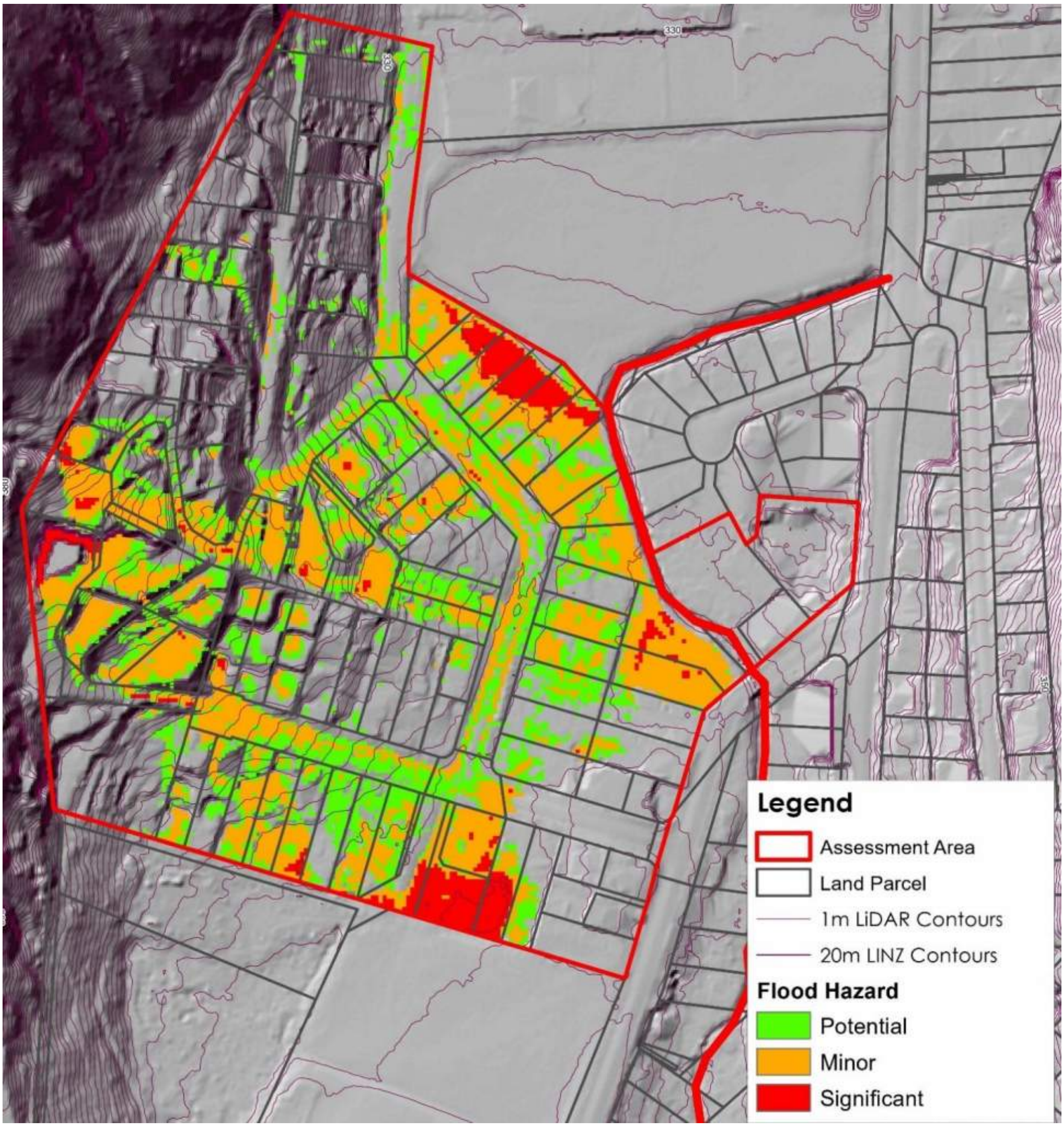
Liquefaction Vulnerability Brewery Creek Fan. Extract from drawing M001 – Appendix M. Refer to Appendix for full drawing and legend.



Liquefaction Vulnerability Reavers Fan. Extract from drawing M001 – Appendix M. Refer to Appendix for full drawing and legend.



100 Year ARI Flood Hazard Brewery Creek Fan. Extract from drawing N003 – Appendix N. Refer to Appendix for full drawing.



100 Year ARI Flood Hazard Reavers Fan. Extract from drawing N004 – Appendix N. Refer to Appendix for full drawing.

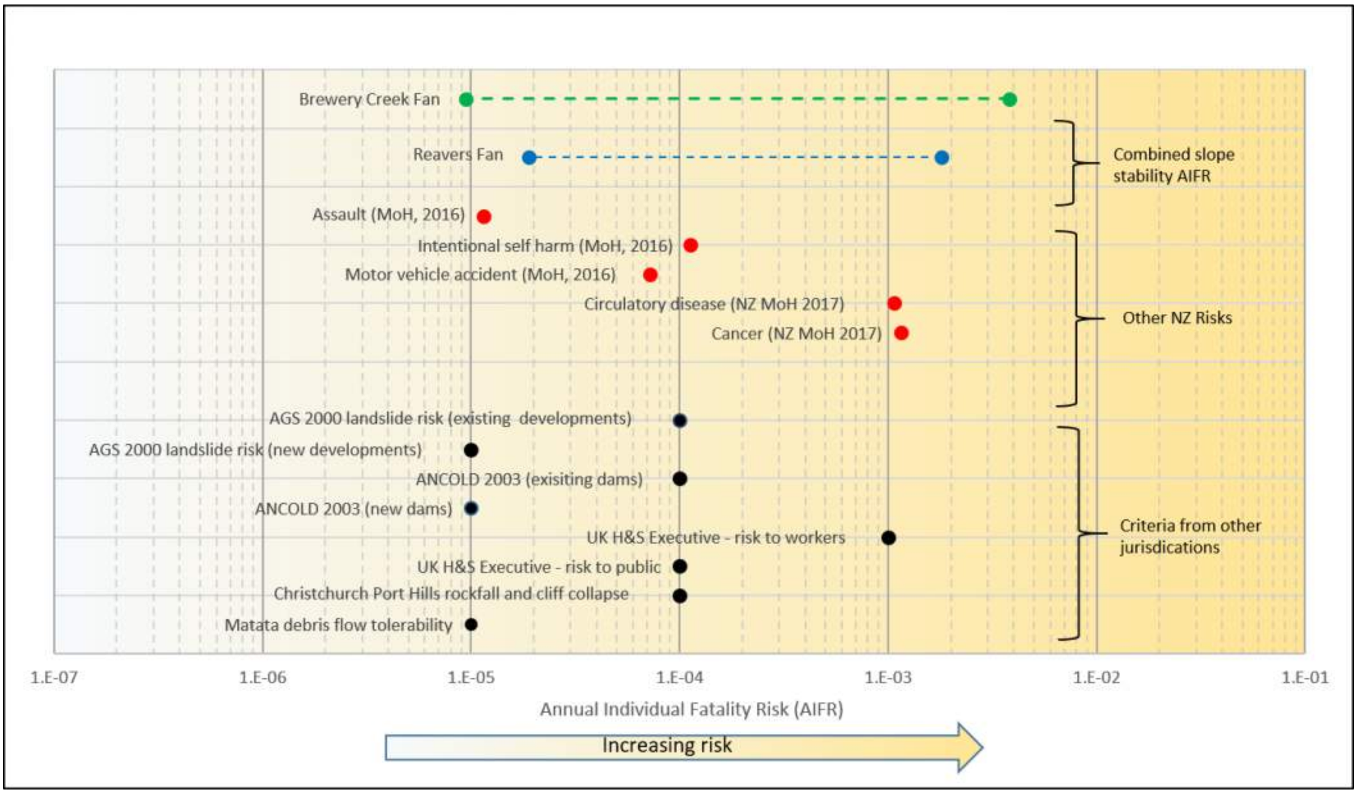
Risk Management

AIFR Tolerability

There are currently no national guidelines for determining tolerable limits to life risk in New Zealand. AIFR tolerability guidelines for slope stability are provided for Australia by AGS (2007), with a maximum recommended AIFR of 1 x 10^{-4} (1 in 10,000) for existing slopes/developments, and 1 x 10^{-5} (1 in 100,000) for new slopes/developments.

The former value saw widespread application on Christchurch's Port Hills following the 2010-11 Canterbury Earthquakes and is widely considered to be the boundary of tolerable risk, e.g. 1.1 x 10^{-4} would not be considered tolerable. A further example of AIFR tolerability precedent in New Zealand is the Awatarariki Fanhead at Matata, where Whakatāne District Council applied 1 x 10^{-5} as the limit of tolerability for all developments, requiring retreat of the developed fan (Campbell et al, 2020). This is more conservative than the AGS and Port Hills approaches.

A comparison of common risks and tolerability limits is shown below, along with combined debris flow and rockfall AIFR for Brewery Creek and Reavers Fans.



Summary of common risks and risk tolerability limits

AIFR values determined through this study exceed published guidance on risk tolerability for both new and existing developments on some areas of both fans. The number of properties exceeding these tolerability guidelines in accordance with AGS (2007) are shown in the below table.

Number of properties with AIFR exceeding tolerable guidelines recommended by AGS (2007)

AIFR	Tolerability (AGS, 2007)	Brewery Creek Fan Residential	Brewery Creek Fan Business	Reavers Fan
> 1 x 10^{-4}	Not tolerable for new or existing slopes/developments	5	12	25
> 1 x 10^{-5}	Not tolerable for new slopes/ developments	10*	14*	41*

*Includes properties >1 x 10^{-4}.

Note 1 – Count includes properties where relevant contour line crosses any part of the property.

Note 2 – Count based on Property Number from QLDC GIS Maps, not Legal Description.

QLDC is investigating future consultation options to assess public tolerability of the risks detailed in this report.

APR Tolerability

Unlike AIFR, no recommendations are made regarding quantitative APR tolerability by AGS (2007), which states '*the regulator is the appropriate authority to set standards for tolerable risk*'.

APR values are not directly comparable to AIFR, and different tolerability levels will likely apply (i.e. people have a different level of tolerance to loss of life compared to loss of buildings).

Quantitative property risk assessment has not been adopted as broadly as quantitative life risk assessment in New Zealand to date. As a result, there are no known examples of precedent in assessing public tolerability to property risk. This may be the result of a lower community tolerance of life risk than property risk, meaning that if life risk tolerability is assessed and actions taken, property risk is also addressed.

A way forward may be to consider AIFR tolerability boundaries initially to define planning zones and then using APR to inform stakeholders of the corresponding property risk.

Hazard Management Options

It has been identified in this report that the risk to life exceeds published guidance on tolerability for both existing and new developments for some properties on Brewery Creek and Reavers Fans. Both planning and physical hazard management options are currently being considered by QLDC areas part of the District Plan review.

A Beca study assessing the potential for reducing life risk from slope stability hazards to tolerable levels through physical hazard management options has been commissioned by QLDC and is currently in progress. The study considers the effectiveness of physical management options (or a combination of options) in reducing the combined risk from debris flow and rockfall. The study is due for completion in late 2020.

Physical options for the management of liquefaction hazard include use of ground improvement techniques and/or foundations specifically designed to resist liquefaction. The latter is usually more cost effective for smaller properties. A map showing where liquefaction is likely and unlikely in the assessment areas has been provided and recommendations made for issuing building consents in line with MBIE Guidance.

Flooding risk management options are being considered as part of the debris flow physical works.