Attachment D - Engineering solutions

Beca

Gorge Road Natural Hazards - Engineering Options Report

Prepared for Queenstown Lakes District Council
Prepared by Beca Limited

2 March 2021

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Revision History

Revision Nº	Prepared By	Description	Date
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Document Acceptance

Action	Name	Signed	Date
Prepared by	**Anna Punt**		2 March 2021
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on behalf of	Beca Limited		

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, near Gorge Road in Queenstown. This area is known to be susceptible to natural hazards including debris flows, rockfall, liquefaction and flooding.

Beca Limited (Beca) was previously commissioned by QLDC to undertake a review of natural hazards affecting this area. The intention of this work was 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 report *Natural Hazards Affecting Gorge Road, Queenstown* (reference NZ1-16638194-3 2.0, 12 November 2020) provides a review of natural hazards in the study area, along with quantitative life and property risk assessments from debris flow and rockfall. The report provided Annual Individual Fatality Risk (AIFR) and Annual Property Risk (APR) contour plans for the study areas, and was peer reviewed by GNS Science. The report identified that the AIFR exceeds published guidance on tolerability for both new and existing developments on some areas of both fans.

Further to the above natural hazards study, Beca has been commissioned by QLDC to assess the potential for reducing life risk from slope stability hazards (debris flow and rockfall) to tolerable levels through physical hazard management options. The findings of this study are detailed in this report.

Concept Engineering Options

Three concept engineering options have been considered for each fan, which would potentially reduce the life risk posed by the debris flow and rockfall hazards. The options include:

Debris flow channels or bunds which are designed to allow debris to be directed to safe run-out locations. Channels are generally designed to accommodate peak debris flow rates, with straight morphologies and no sharp corners that may impede flow.

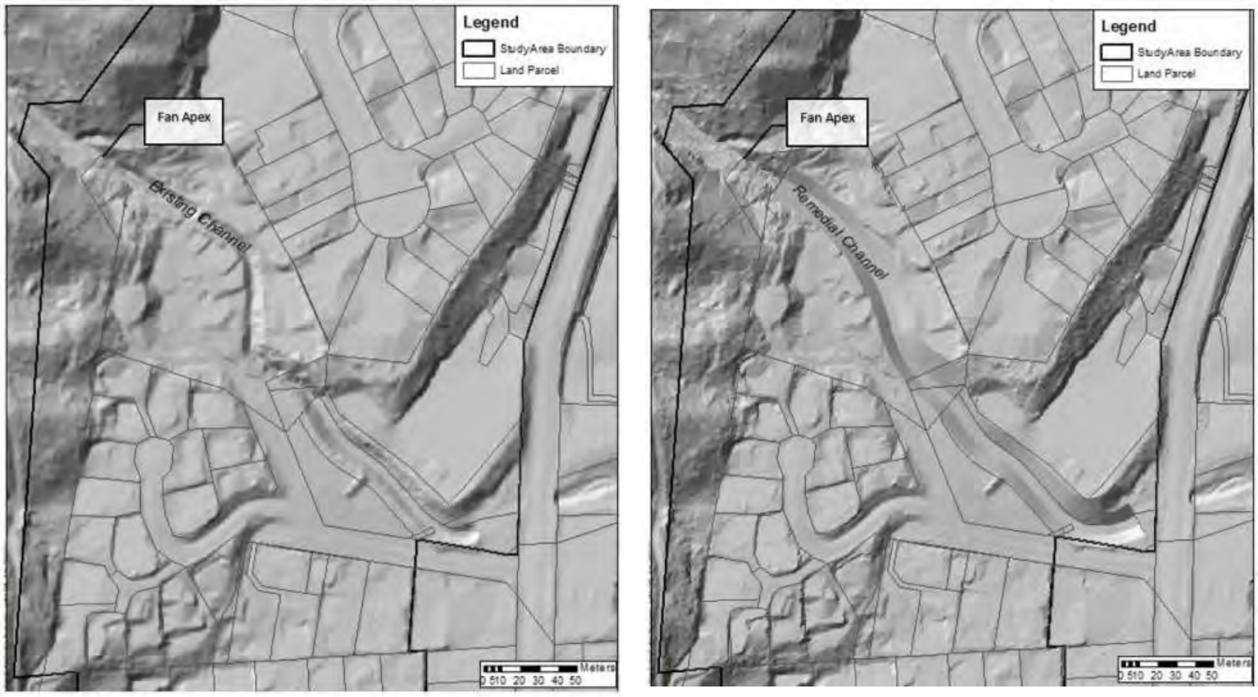
Debris flow fences consisting of flexible ring net barriers constructed across the channel to resist the dynamic and static loads of debris flows. The barriers work to trap debris and can be installed at several levels along the channel to increase retention capacity. Positioning debris flow fences upstream of the fan apex would allow some debris to be trapped before entering the fans.

Rockfall barrier fences consisting of a system of steel cables, ground anchors and mesh with high deformation capabilities that are designed to absorb rockfall impact energy. The fences would work to stop rocks released from upslope outcrops impacting the downslope properties.

Brewery Creek Fan – Debris Flow Channel

The debris flow modelling completed under the previous phase of work (Beca, 2020) shows that debris flows would overtop the existing channel at the fan apex and at the bend immediately downstream from the fan apex. Realigning and deepening of the existing channel to smooth the existing bends and increase channel capacity has been considered as the first concept option, with the intention of reducing the risk of debris flows overtopping the channel.

The channel redesign considered the maximum modelled debris flow discharge, flow height, and flow velocity at the fan apex for a representative 50 - 200 year return period event ('small' event). High-level concept sizing indicates that a 17m wide and 4m deep channel is required to achieve the specified flow capacity. The proposed channel is designed to accommodate peak flow rates and to minimise debris flow overtopping during a design event.



Comparison of the morphology of the existing Brewery Creek channel (left) and the proposed modified channel (right).

Brewery Creek Fan – Debris Flow Fences

Two broadly equivalent debris flow fence solutions have been considered. The options include the Gebrugg U-shaped and V-shaped valley models, based on cross-sectional profiles at the fan apex and approximately 200m upstream. An example of a similar fence is included below.

Example of a debris flow fence in a stream channel. The fence works to trap large debris and slow flow velocities.

Brewery Creek Fan – Rockfall Fences and Mesh

The Beca (2020) report identified areas on Brewery Creek Fan where rockfall trajectories were modelled as reaching the residential properties. Positioning rockfall fences parallel to the transmission line route beneath the source outcrops would intercept most falling rocks before they reached the developed areas. Fence lengths and the required design heights and impact ratings were assessed in accordance with MBIE (2016). An example of a similar rockfall fence is shown below, with design details of the fences in the below table.

Example of a rockfall fence, designed to retain the majority of rocks.

Draped rockfall TECCO mesh was considered for the cliff outcrops immediately behind the business zone on Industrial Place where rockfall modelling suggests rocks would accumulate at the base of the outcrops. The length and anticipated height of the outcrops requiring meshing is summarised in the below table.

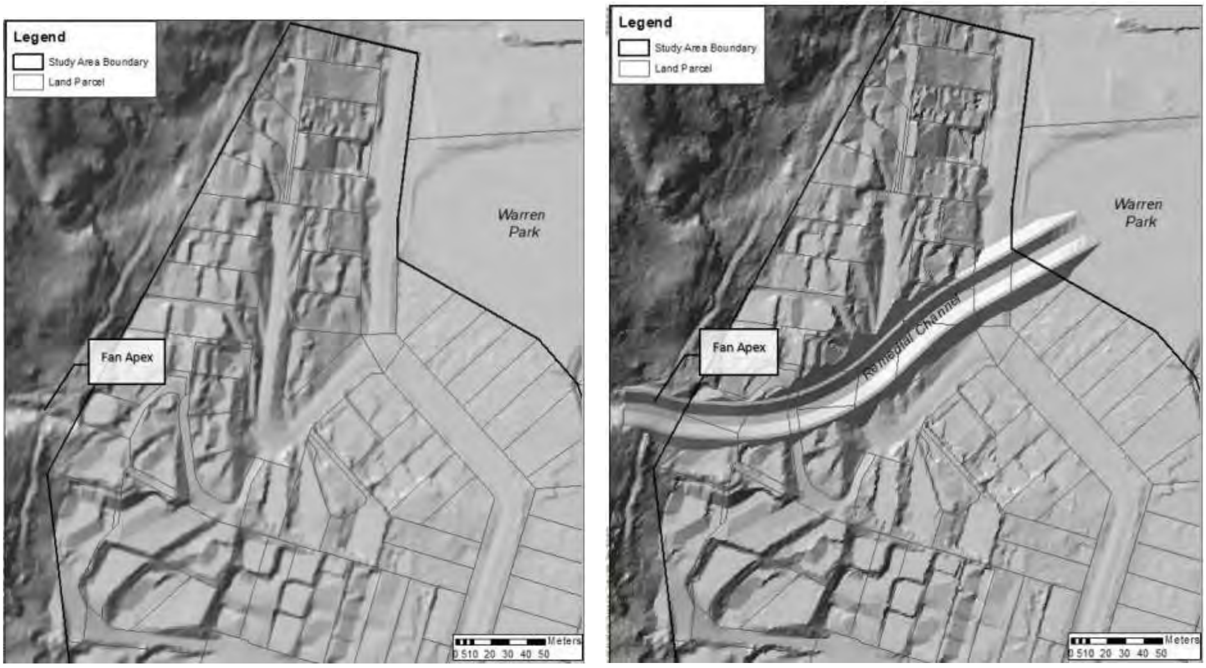
Summary of the dimensions and design ratings of rockfall protection considered for Brewery Creek Fan

Model location	Method	Design height (m)	Design rating (kJ)	Length (m)
True Left	Fence	3.0	300	125
True Right	Fence	3.0	300	115
True Left	Draped Mesh	4.0	N/A	205

Reavers Fan – Debris Flow Channel Construction

Reavers Creek currently has no open channel from the fan apex. Debris flow modelling completed under the previous phase of work suggests that debris flows would overtop the culvert and flow across the residential properties immediately downslope. Construction of a debris flow channel would reduce channel overtopping and overland flow. The route impacts ten residential properties and involves four road-crossings.

Concept design of the debris flow channel considered the maximum flow discharge, flow height, and flow velocity at the fan apex as modelled for a representative 100 - 2,500 year return period (‘small’ event) debris flow. High-level concept sizing indicates that a channel 17m wide and 4m deep would be required to accommodate peak flow. The proposed channel is shown with respect to the existing fan surface below.



Comparison of the morphology of the existing Reavers Fan surface (left) and the proposed remedial channel (right).

Reavers Fan – Debris Flow Fences

A debris flow solution has been developed to concept design level. The option considers a cross-sectional profile at the fan apex and approximately 200m upstream.

Reavers Fan – Rockfall Fences

As with Brewery Creek Fan, positioning rockfall fences parallel to the transmission line route behind the residential properties would stop most rocks before they entered the study area. The required fence lengths, design heights, and impact ratings were assessed in accordance with MBIE (2016) and are outlined below.

Summary of the dimensions and design ratings of rockfall protection considered for Reavers Fan

Model location	Method	Design height (m)	Design rating (kJ)	Length (m)
True Left	Fence	3.0	400	255
True Right	Fence	4.0	1000	185

Engineering Option Effectiveness

Life Risk Assessment Process

Quantitative life risk assessments have been carried out for each of the mitigation options detailed above, in order to assess the effectiveness of the engineering options considered. The process followed is identical to that conducted in the Beca (2020) report, which should be referred to for full details of the life risk assessment process.

A quantitative assessment of life risk posed by debris flow and rockfall hazards has been carried out for the mitigation options. **AIFR is the probability that an individual most at risk 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). The output of the life risk assessment are a series of values which are presented as probabilities.

Debris Flow Life Risk Assessment Process

The life risk assessment process detailed in the November 2020 Beca report involved assessing the risk for three debris flow magnitudes at each fan, based on a range of annual probabilities. These debris flow events are referred to as small (with a shorter return period/higher annual probability), medium, and large (longer return period/lower annual probability).

The AIFR from debris flow was assessed as the summed total of the risk from the individual magnitude events, using a zone based approach[1].

Rockfall Life Risk Assessment Process

Three risk zones were generated for the AIFR calculation based on the released rocks' final resting position[2].

AIFR Results and Tolerability

There are currently no national guidelines for determining tolerable limits to life risk in New Zealand. Life risk tolerability guidelines for slope stability are provided for Australia by AGS (2007), with a maximum recommended AIFR of 1×10^{-4} (1 in 10,000) for existing slopes/developments, and 1×10^{-5} (1 in 100,000) for new slopes/developments. The value of 1×10^{-4} saw widespread application on Christchurch's Port Hills following the 2010-11 Canterbury Earthquakes and is widely considered to be the boundary of tolerable life risk.

AIFR values determined through the Beca studies exceed published guidance on risk tolerability for both new and existing developments on some areas of both fans before considering any engineering options. The following comments can be made regarding risk tolerability with engineering options in place, with respect to the AGS (2007) guidelines:

- Channel and debris fence options:
  - The 'small' events can be largely mitigated with the options considered.
  - Engineering options have limited effect on risk posed by 'medium' and 'large' events.
  - Risks **fall outside tolerability guidance** for existing developments for zones 1 & 2 (upper fans).
  - Risks **fall outside tolerability guidance** for new developments in zones 1 to 3 (mid and upper fans).
  - Reavers Fan Channel – risk transfer means that some properties previously assessed as having tolerable risk would become **intolerable**.
- Rockfall fences and mesh:
  - Risk reduced to **tolerable** for existing developments for all zones on both fans.
  - Risk reduced to **tolerable** for new developments in zone 2 (business) and zone 3 (residential and business) on both fans.
  - Risk still **not tolerable** for new developments in zone 1, and zone 2 (residential).

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[1]Debris flow zones are defined as follows:

- Zone 1 occupies the area susceptible to all three magnitude events.
- Zone 2 is the area susceptible to both a medium and a large event.
- Zone 3 is the area susceptible to a large event.
- Zone 4 occupies the area between the cut off extents of the models (depth <1m and velocity <2m/s), and the maximum extent of the model run out for the largest size event.

[2]Rockfall zones are defined as:

- Zone 1 - greater than 10% of released rocks came to rest.
- Zone 2 - 1-10% of released rocks came to rest.
- Zone 3 - 0-1% of released rocks came to rest.

The above changes in AIFR apply to a single engineering option being considered. While calculations have not been run on the effect of engineering options being considered together (i.e. channels and debris flow fences), any improvements would be anticipated to be approximately half an order of magnitude (i.e. from 5×10^{-3} to 1×10^{-3}) for the upper zones. A reduction in AIFR of these magnitudes is not sufficient to bring risk to a tolerable level.

Cost Estimates

Order of magnitude capital cost estimates have been prepared for the three mitigation options considered for Brewery Creek and Reavers Fans assuming installation in accordance with the relevant codes, standards and manufacturer's instructions. Capital cost estimates are listed in millions of New Zealand dollars (NZ$) below and are exclusive of GST.

Estimate of construction costs for the three mitigation options (NZD).

Estimate Summary		Brewery Creek Fan			Reavers Fan		
	Range	Low -35% $M	Mid 100% $M	High +50% $M	Low -35% $M	Mid 100% $M	High +50% $M
1.0	Debris Flow Channels	1.04	**1.60**	2.4	2.52	**3.88**	5.82
2.0	Debris Flow Barriers	0.79	**1.22**	1.83	0.9	**1.39**	2.09
3.0	Rockfall Fence and Ground Mesh	0.69	**1.07**	1.61	0.55	**0.86**	1.29

Maintenance and land acquisition costs are not included in the above estimates. If these are taken in to account, total costs could be significantly greater, particularly in the case of the Reavers Fan channel option. Taking additional costs such as land acquisition, road designation removal and relocation and road construction costs into account, the total cost for the Reavers Fan channel for example could be in the order of five times greater than the capital cost estimates.

Conclusions

This study has considered three engineering measures at both Brewery Creek and Reavers Fans, with the aim of reducing the life risk resulting from debris flow and rockfall to tolerable levels. The study found that of the engineering options considered, only rockfall fences and mesh are capable of reducing rockfall AIFR to tolerable levels for the majority of the properties potentially affected by rockfall.

Debris flow channels and fences were dimensioned to mitigate the risk from a small sized event. More extensive engineering options have not been assessed, as the size and extent of these options would be prohibitive, and the mitigation likely ineffective (i.e. it would likely not be possible to contain the volume of material released in a large debris flow event with existing technology within the available space). Designing mitigating controls for a small, more frequent event is in line with the approach undertaken elsewhere to reduce debris flow hazards, for example at Mt Cook. The reduction in AIFR from the debris flow channels and fences is negligible for anything other than a small sized event.

Rockfall fence and mesh cost estimates are in the order of $1M for each fan. The debris flow channel and fence options were also costed, with estimates ranging from $1M to $6M, however the benefit of these options is limited, as the risk to life remains outside published tolerability guidelines.

1 Introduction

1.1 Background

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, near Gorge Road in Queenstown, as shown in Figure 1. This area is known to be susceptible to natural hazards including debris flows, rockfall, liquefaction and flooding.

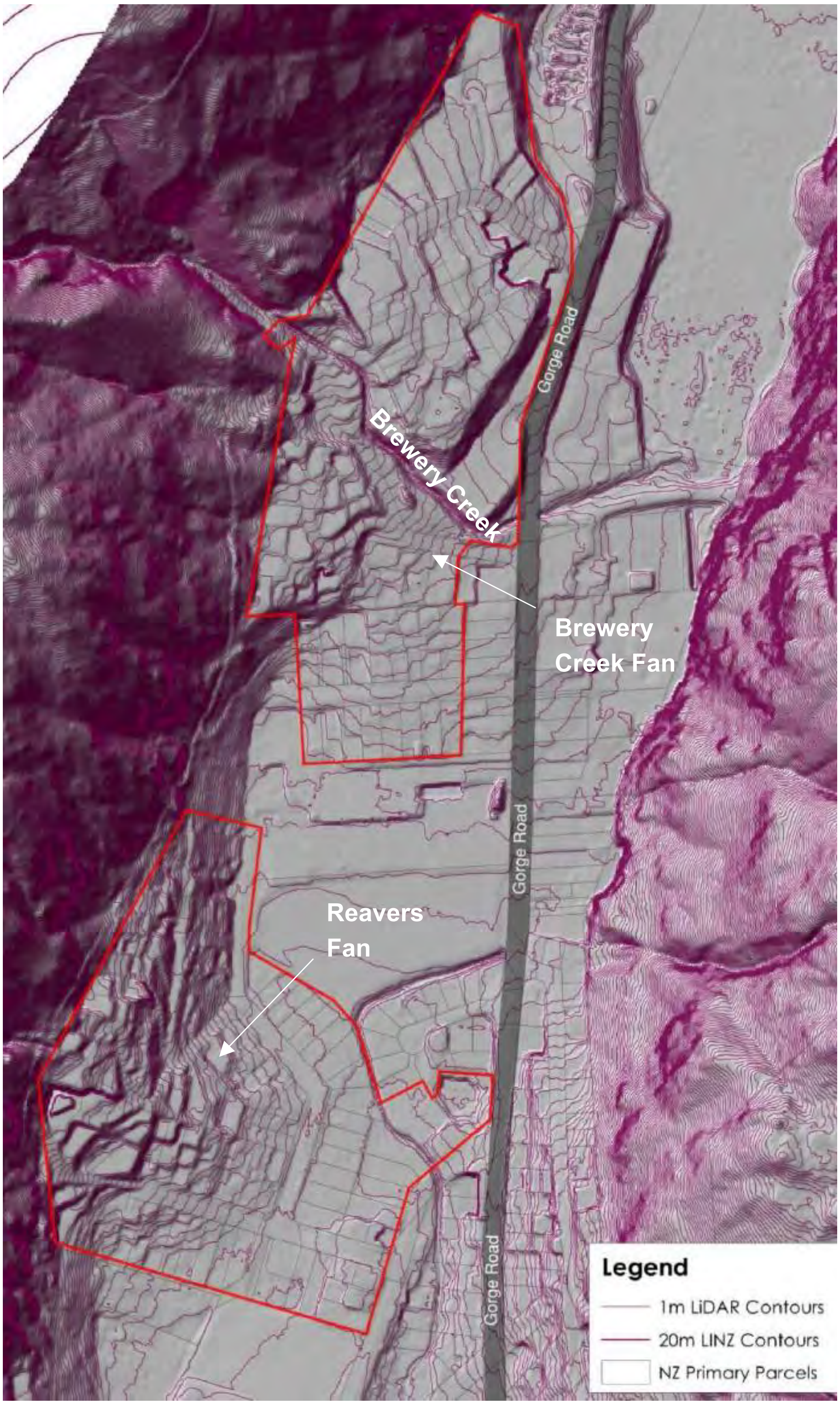


Figure 1 - Gorge Road study assessment areas (outlined in red)

1.2 Previous Studies

Beca Limited (Beca) was previously commissioned by QLDC to undertake a review of natural hazards affecting this area. The intention of this work was 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 report *Natural Hazards Affecting Gorge Road, Queenstown* (reference NZ1-16638194-3 2.0, 12 November 2020) provides a review of natural hazards in the study area, along with quantitative life and property risk assessments from debris flow and rockfall. The report provided Annual Individual Fatality Risk (AIFR) and Annual Property Risk (APR) slope stability contour plans for the study areas, and was peer reviewed by GNS Science.

The report identified that the risk to life (AIFR) exceeds published guidance on tolerability for both new and existing developments on some areas of both fans.

1.3 Scope of Study

Further to the above natural hazards study, Beca has been commissioned by QLDC to assess the potential for reducing life risk from slope stability hazards (debris flow and rockfall) to tolerable levels through physical hazard management options. The scope includes the following:

- Development of up to three engineering options each for Brewery Creek Fan and Reavers Fan, including rockfall and debris flow protection measures.
  - Workshop with QLDC to agree the high level engineering options.
  - Provision of conceptual sketches of the mitigation options for each catchment including approximate sizing and outlining post-event fate of debris with consideration to downstream effects.
  - Assessment of the effectiveness of the mitigation options, through running updated debris flow and rockfall models, and assessing the stormwater implications.
- Updating AIFR assessment to illustrate the reduction in risk from the engineering options.
- Estimates of high level cost for construction of the mitigation options.
- Commentary on maintenance and long-term functionality of the mitigation options.
- Provision of advice on the ability of the property-specific mitigation measures to effectively reduce debris flow and rockfall risk.

The effect of mitigation options on APR are not considered under the current scope of work.

The findings of this study are detailed in this report.

2 Concept Engineering Options

Three concept engineering options have been considered for each fan, which would potentially reduce the life risk posed by the debris flow and rockfall hazards. The concept options are detailed in this section, with the associated effect on AIFR included in Section 3. The options include:

- Debris flow channel construction or modification.
- Debris flow fence construction.
- Rockfall fences and mesh.

The proposed options were agreed with QLDC at a workshop on 8 July 2020, and are outlined below at a high level with addition details in the following sections. Concept sketches are provided in Appendices A, B, and C respectively. Case studies outlining the application of similar mitigation techniques are provided in Appendix D.

2.1 Scale of Engineering Measures Considered

The debris flow channels and debris flow fence options considered below have been designed to accommodate 'small' events (see Section 3), with return periods ranging from 50 years (Brewery Creek Fan) to 100 years (Reavers Fan). More extensive engineering options have not been assessed, as the size and extent of these options would be prohibitive, and the mitigation likely ineffective (i.e. it would not be possible to contain the volume of material released in a large debris flow event within the available space). This approach is in line with that undertaken elsewhere to reduce debris flow hazards, for example at Mt Cook (Skermer et al, 2002), where debris flow channelisation measures were designed for a small event, while acknowledging the residual risk from larger events.

This study considers area-wide engineering works that reduce the risk to multiple properties, and the associated effect of these measures on AIFR. Adopting property specific mitigation measures would have some associated complexities, including consideration of:

- Spatial limitations in constructing the proposed measures within an individual property boundary.
- Whether the proposed measures reduce risk to a tolerable level.
- If effective mitigation measures are economically feasible at an individual property scale.
- If the proposed measures would result in a transfer of risk to other properties.
- The cost of protection may fall disproportionally onto upslope or "frontline" properties.
- Controls and standards would need to be in place to prevent "ad hoc" development of measures that may be incompatible with adjacent properties.
- The risk that varying standards of protection are developed and approved, even if designed and permitted under professional advice.
- Complexities and costs associated with processing applications and ensuring consistency of standards.

Some mitigation options such as rockfall fences may be feasible at a property level. However debris flows are unlikely to satisfy the above considerations, due to the fluid nature of the flow and the potential for debris to be redirected elsewhere, as well as the scale of the engineering measures required for mitigation.

2.2 Options Summary

2.2.1 Debris flow channels

Debris flow channels or bunds are designed to allow debris to be directed to safe run-out locations. Channels are generally designed to accommodate peak flow rates of debris flow events, with straight morphologies and no sharp corners that may impede flow. Deflection bunds are essentially built up channel banks designed to deflect flows away from critical areas. An example of a deflection bund at Mt Cook village is shown in Figure 2.

The existing Brewery Creek channel may be further modified and realigned to accommodate modelled debris flow events while a new channel may be excavated across Reavers Fan.

Figure 2 - Example of a debris flow deflection bund installed at Aoraki/Mount Cook Village (source GNS Science, 2017)

2.2.2 Debris flow fences

Debris flow fences consist of flexible ring net barriers constructed across the channel that are designed to resist the dynamic and static debris loads, as shown in Figure 3. The barriers work to trap debris and can be installed at several levels along the channel to increase retention capacity. Positioning debris flow fences upstream of the fan apex would allow debris to be trapped before entering the fans. Maintenance tracks would be required to allow clearing of the debris fences following flood events.

The design approach includes basal openings in the fences, which allow debris through during the early stages of an event, trapping debris within the downstream fences first for easier maintenance. The upper fences progressively fill once the lower fence is at capacity and channel avulsion occurs, blocking the basal openings. Water and smaller debris will pass through the fence and remain channelised. Once each fence is retaining its full capacity further debris passes over it.

Figure 3 - Example of a debris flow protection fence installed within a stream channel. The fence works to trap large debris and slow flow velocities.

2.2.3 *Rockfall barrier fences*

Rockfall barrier fences consisting of a system of steel cables and anchors with high deformation capacities that are designed to absorb energy associated with impact from rockfall debris, as shown below. The fences would work to stop rocks released from upslope outcrops impacting the downslope residential and business properties.

Figure 4 - Example of a rockfall protection fence.

2.3 Brewery Creek Fan

2.3.1 Channel realignment

The debris flow modelling completed under the previous phase of work (Beca, 2020) shows that debris flows would overtop the existing channel at the fan apex and at the bend immediately downstream from the fan apex. Realigning and deepening of the existing channel to smooth the existing bends and increase channel capacity has been considered as the first concept option, with the intention of reducing the risk of debris flows overtopping the channel.

The existing channel was modified in approximately 2015 following previous debris flows and is currently designed to accommodate a 100 year return period debris flow event (1% Average Exceedance Probability, AEP). The existing box culvert at the Brewery Creek/Gorge Road intersection is designed to accommodate a 40 year return period flood (i.e. excluding debris) (2.5% AEP) under current climate conditions.

Resizing of the channel considered the maximum modelled debris flow discharge, flow height, and flow velocity at the fan apex for a representative 50 - 200 year return period event ('small' event, as detailed in Section 3) as modelled under the previous phase of work. A peak flow rate of $135m^3/s$ with average velocity of 3m/s was adopted for concept design. A detailed description of the methodology for resizing the channel, along with concept design drawings are included in Appendix A – Debris Flow Channel .

High-level concept sizing indicates that a 17.0m wide and 4.0m deep channel is required to achieve the specified flow capacity. The proposed channel morphology is designed to accommodate peak flow rates and to minimise debris flow overtopping during a design event. The proposed channel is compared to the existing channel morphology in Figure 5 and comprises the following parameters:

- Cross-sectional area $44m^2$
- Length 301m
- Channel volume $13,244m^3$
- Bank grade of 1v:1.5h.
- Earthworks are estimated to involve a cut volume of around $11,000m^3$ and fill volume of around $450m^3$.

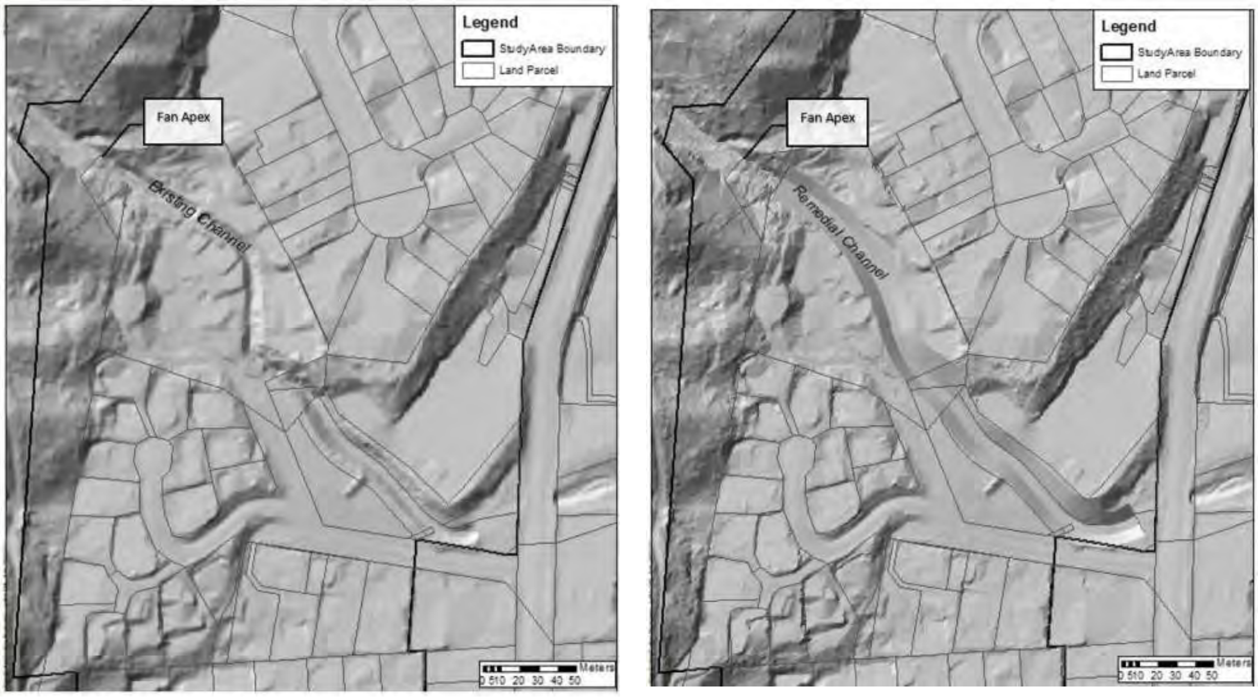


Figure 5 - Comparison of the morphology of the existing Brewery Creek channel (left) and the proposed modified channel (right).

The channel dimensions required to accommodate the 200 - 2500 year and 2500 - 10,000 year return period events ('medium' and 'large' events, as detailed in Section 3) are not achievable in the space available.

2.3.2 Debris flow fences

Two broadly equivalent debris flow fence concept solutions have been proposed by specialist supplier Geobrugg based on data provided by Beca. The options considered the Gebrugg U-shaped and V-shaped valley models (termed UX and VX by Geobrugg), based on cross-sectional profiles at the fan apex and approximately 200m upstream. Sizing was based on the following parameters:

- Release volume of 5650m^3
- Peak discharge of 135m^3/s at the fan apex (as modelled for the representative 50 - 200-year return period ('small' event)).

Geobrugg proposed a series of debris flow fences to reach the required design capacity. Details of the adopted design methodology and concept design sketches are provided in Appendix B – Debris Flow Fence. Details of the two options are summarised in Table 1.

Table 1 - Debris fence options for Brewery Creek Fan

Option	Fence type and location	Height (m)	Top width (m)	Basal width (m)	Total retention volume (m^3)
Option 1	UX – fan apex	6.0	20.0	13.0	1480
	VX – 50m upstream from fan apex	8.0	12.0	6.0	1440
	VX – 110m upstream from fan apex	8.0	12.0	6.0	1440
			Total retained volume Option 1 (m^3)		4,360
Option 2	UX – fan apex	6.0	20.0	13.0	1480
	VX – 50m upstream from fan apex	6.0	12.0	6.0	900
	VX – 100m upstream from fan apex	6.0	12.0	6.0	900
	VX – 150m upstream from fan apex	8.0	12.0	6.0	1440
			Total retained volume Option 2 (m^3)		4,720

2.3.3 Rockfall Fences

The Beca (2020) report identified areas on Brewery Creek Fan where rockfall trajectories were modelled as reaching the residential properties during the previous phase of work. The modelled trajectories are shown for the Brewery Creek study area in Figure 6. Positioning rockfall fences parallel to the transmission line beneath the source outcrops would intercept most falling rocks before they reached the developed areas. The transmission line construction track additionally acts as an informal catch bench to trap debris and could provide an access route to clean out debris following a rockfall event. Fence lengths and the required design heights and impact ratings were assessed in accordance with MBIE (2016) and are outlined in Table 2. Proposed fence locations and detailed descriptions of the methodology for sizing of the fences is presented in Appendix C – Rockfall.

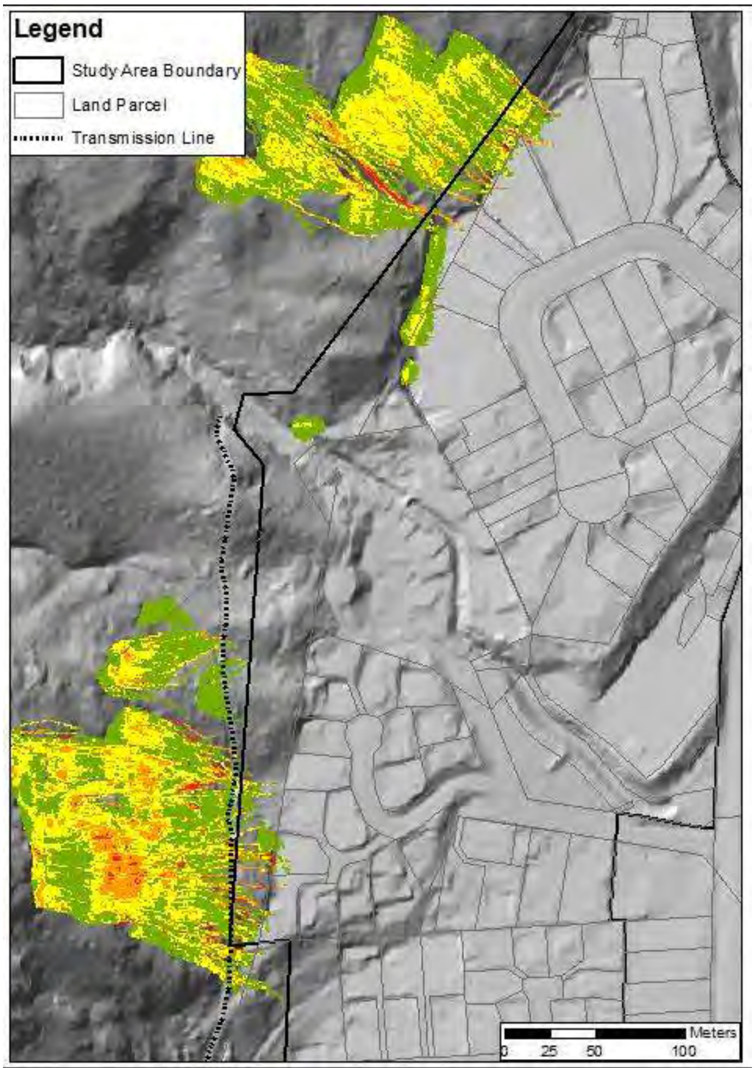


Figure 6 - Modelled rockfall trajectories shown with respect to the Brewery Creek study area, transmission line, and existing property boundaries.

Rockfall draped TECCO mesh is proposed for the cliff outcrops immediately behind the business zone on Industrial Place where the rockfall modelling suggest that the rocks would accumulate at the base of the outcrops. Meshing with a basal opening would allow for the controlled accumulation of debris at the base of the slope. The length and anticipated height of the outcrops requiring meshing is summarised in Table 2 and is based on a visual assessment of the outcrops made during the site visit, and dimensions visible in the 1m DEM. Plans showing locations of the proposed fences and mesh, along with generic supplier draped mesh concept sketches are included in Appendix C – Rockfall.

Table 2 - Summary of the dimensions and design ratings of rockfall protection considered for Brewery Creek Fan

Model location	Method	Design height (m)	Design rating (kJ)	Length (m)
True Left	Fence	3.0	300	125
True Right	Fence	3.0	300	115
True Left	Draped Mesh	4.0	N/A	205

2.4 Reavers Fan

2.4.1 Channel development

Reavers Creek currently has no open channel downstream of the fan apex, beyond which water is transported by a 375mm-500mm diameter culvert (with a design ARI of between 10 and 15 years for rainfall only) to its discharge point into Horne Creek east of Robins Road. Debris flow modelling completed under previous phases of work suggests that debris flows would overtop the culvert and flow across the residential properties immediately downslope. Construction of a debris flow channel would reduce channel overtopping and overland flow. Channel alignment options were limited by the requirement to transport debris to a suitable retention basin, rather than into Horne Creek which is not capable of transmitting large volumes of debris. The proposed alignment therefore extends from the fan apex to Warren Park which is intended to act as a retention area to contain the debris flow if required. The route affects ten residential properties and involves four road-crossings. Details of the road crossings, and re-routing of access roads have not been developed at this stage and the fate of the existing culvert would need to be assessed at detailed design if this option were to be considered further.

Concept design of the debris flow channel considered the maximum flow discharge, flow height, and flow velocity at the fan apex as modelled for a representative 100 - 2,500 year return period ('small' event) debris flow, as detailed in Section 3. A peak flow rate of 259m^3/s with average velocity of 6m/s was adopted for channel sizing. A detailed description of the channel sizing methodology, along with concept design drawings are included in Appendix A – Debris Flow Channel .

High-level concept sizing indicates that a channel 17.0m wide and 4.0m deep channel would be required to accommodate peak flow. The channel is shown with respect to the existing fan surface in Figure 7.

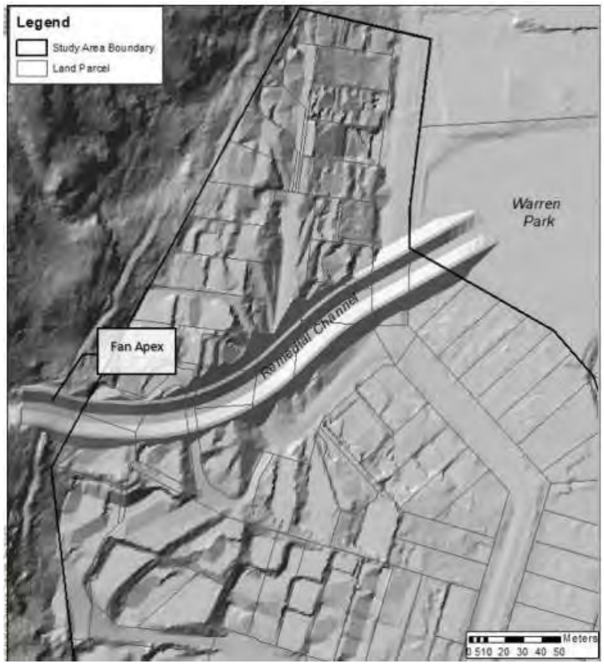


Figure 7 - Comparison of the morphology of the existing Reavers Fan surface (left) and the proposed remedial channel (right)

The parameters of the remedial channel are as follows:

- Cross-sectional area 44m^2
- Length 280m
- Channel volume 12,364m^3.
- Bank grade of 1v:1.5h.

- Earthworks are estimated to involve a cut volume of 9,756m^3 and fill volume of 9,480m^3.
- The channel has a depth of 2.5m below the existing ground level and is surrounded by 1.5m high bunds, resulting in a total channel depth of 4.0m.

Channel dimensions required to accommodate the modelled peak flows rates of the 2,500 – 6,700 and 6,700 - 20,000-year return period events ('medium' and 'large' events, as detailed in Section 3) were not assessed as the flow rates as anticipated to be too high to accommodate within a mitigation channel.

2.4.2 Debris Flow Fence

A debris flow solution has been developed to concept design level by Geobrugg based on data provided by Beca. The option considers a cross-sectional profile at the fan apex and approximately 200m upstream. Sizing considered the UX- and VX- debris flow fence options and was based on the following parameters:

- Release volume 5550m^3
- Peak discharge 259m^3/s at the fan apex (modelled for the representative 100-2,500 year return period ('small' event) debris flow model).

Geobrugg proposed a series of debris flow fences to reach the required design capacity. The use of multiple fences allows debris to pass the top barriers and accumulate first in the downstream barrier which allows for easier maintenance. Water and smaller debris would continue through the fences and into the culvert at the fan apex, however the culvert capacity equates to an Average Recurrence Interval (ARI) of between 10 and 15 years for a flood event, and as such is not capable of transporting the volume of water associated with a small debris flow event without overflow occurring. Details of the adopted design methodology and concept design sketches are provided in Appendix B – Debris Flow Fence. Details of the option are summarised in Table 3.

Table 3 - Debris fence options for Reavers Fan

Fence type and location	Height (m)	Top width (m)	Basal width (m)	Total retention volume (m^3)
UX – fan apex	10.0	25.0	12.0	4,620
VX – 70m upstream apex	4.0	11.5	5.0	330
VX – 100m upstream apex	4.0	11.5	5.0	330
			Total retained volume (m^3)	5,280

2.4.3 Rockfall Fences

Source outcrops with modelled rockfall trajectories reaching the residential properties were identified on the true-left and true-right sides of Reavers Fan from the RAMMS:Rockfall models completed under the previous phase of work, as shown in Figure 8 (Beca, 2020). Positioning rockfall fences parallel to the transmission line behind the residential properties would stop rocks before they entered the fan. The transmission line additionally acts as an informal catch bench to trap rocks and could allow for access to clean out the fences following a rockfall event. The required fence lengths, design heights, and impact ratings were assessed in accordance with MBIE (2016) and are outlined in Table 4. A plan showing locations of the proposed fences, along with the methodology for sizing of the fences are presented in Appendix C – Rockfall.

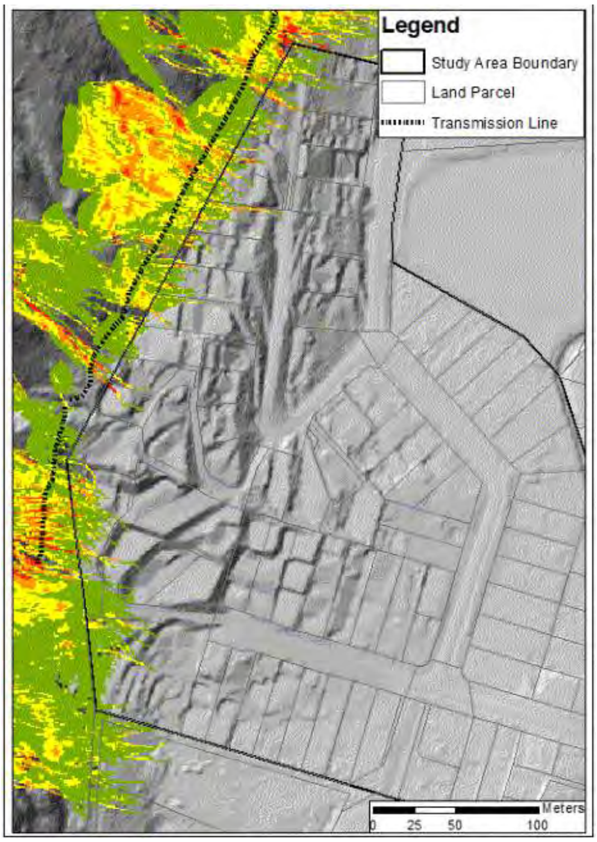


Figure 8 - Modelled rockfall trajectories shown with respect to the Reavers Fan study area, transmission line, and existing property boundaries.

Table 4 - Summary of the dimensions and design ratings of rockfall protection considered for Reavers Fan

Model location	Method	Design height (m)	Design rating (kJ)	Length (m)
True Left	Fence	3	400	255
True Right	Fence	4	1000	185

3 Engineering Option Effectiveness

3.1 Quantitative Life Risk Assessment Process

Quantitative life risk assessments have been carried out for each of the mitigation options detailed in Section 2 in order to assess the effectiveness of the proposed options. The process followed is identical to that described in the Beca (2020) report. The Beca (2020) report should be referred to for full details of the life risk assessment process, a summary of which is provided below.

A quantitative assessment of life risk posed by debris flow and rockfall hazards has been carried out for the mitigation options. **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.

The above parameters are determined from the following sources:

- Annual probability of a hazard ($P_{(H)}$) – literature review, historical information, field investigations and radiocarbon dating.
- Spatial probability ($P_{(S:H)}$) – runout distances, depths, velocities (for debris flow) and bounce height and impact pressures (rockfall) are assessed using RAMMS (Rapid Mass Movement System) debris flow and rockfall modelling software.
- Temporal spatial probability ($P_{(T:S)}$) – is a function of the time the person most at risk is present (TIMARP), and the ability of that person to evacuate (probability of self-evacuation, P_{SE}).
- Vulnerability ($V_{(D:T)}$) – for debris flow, this is linked to the ability of debris to enter a building, and is based on the outputs of the RAMMS models.

The spatial probability ($P_{(S:H)}$) and vulnerability are the parameters that potentially change when engineering mitigation options involving interception are considered. All other parameters remain the same as for the original (unmitigated) AIFR assessment.

AIFR has been re-assessed for each of the proposed options for both fans. Combined debris flow and rockfall AIFR values have not been reassessed for this stage of the project.

The output of the life risk assessment are a series of values which are presented as probabilities which can be expressed in a series of ways, as shown in Table 5 where each subsequent row represents a change of an order of magnitude.

Table 5 - Ways of expressing risk probabilities (after GNS Science, 2012).

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)*
1,000	10^{-3}	0.001	0.1%	8%
10,000	10^{-4}	0.0001	0.01%	0.8%
100,000	10^{-5}	0.00001	0.001%	0.08%
1,000,000	10^{-6}	0.000001	0.0001%	0.008%

*Based on average New Zealand life expectancy of approximately 80 years, from 2008 mortality and population data.

The results of the quantitative life risk assessment for the concept engineering options are included in the following subsections. AIFR tolerability is discussed in Section 3.4.

3.1.1 Debris Flow AIFR Process

The life risk assessment process detailed in the November 2020 Beca report involved assessing the risk for three debris flow magnitudes at each fan, based on a range of annual probabilities. These debris flow events are referred to as small (with a shorter return period/higher annual probability), medium and large (longer return period/lower annual probability). A time range was provided for each return period based on confidence in the available data. The associated return periods for each size event are outlined in Table 6.

Table 6 - AIFR return periods and associated probabilities for three magnitude classes

Fan	Parameter	Small event		Medium event		Large event	
		Min	Max	Min	Max	Min	Max
Brewery Creek Fan	Return period (years)	50	200	200	2,500	2,500	10,000
	Annual probability	0.02	0.005	0.005	0.0004	0.0004	0.0001
Reavers Fan	Return period (years)	100	2,500	2,500	6,700	6,700	20,000
	Annual probability	0.01	0.0004	0.0004	0.00015	0.00015	0.00005

For each of the resulting RAMMS models, cut-off parameters for debris flow velocity (2m/s) and depth (1m) were applied to the models, with any areas beyond this discounted. The AIFR from debris flow was then assessed as the summed total of the risk from the individual magnitude events, using a zone based approach, where:

- Zone 1 occupies the area susceptible to all three magnitude events.
- Zone 2 is the area susceptible to both a medium and a large event.
- Zone 3 is the area susceptible to a large event.
- The lower risk zone (Zone 4) occupies the area between the cut off extents of the models described above, and the maximum extent of the model run out for the largest size event.

The extents of the debris flow risk zones from the previous Beca study are shown in Figure 10. Risk zone extent maps have not been regenerated as part of this study due to marginal difference between zone extents, as detailed in the following sections.

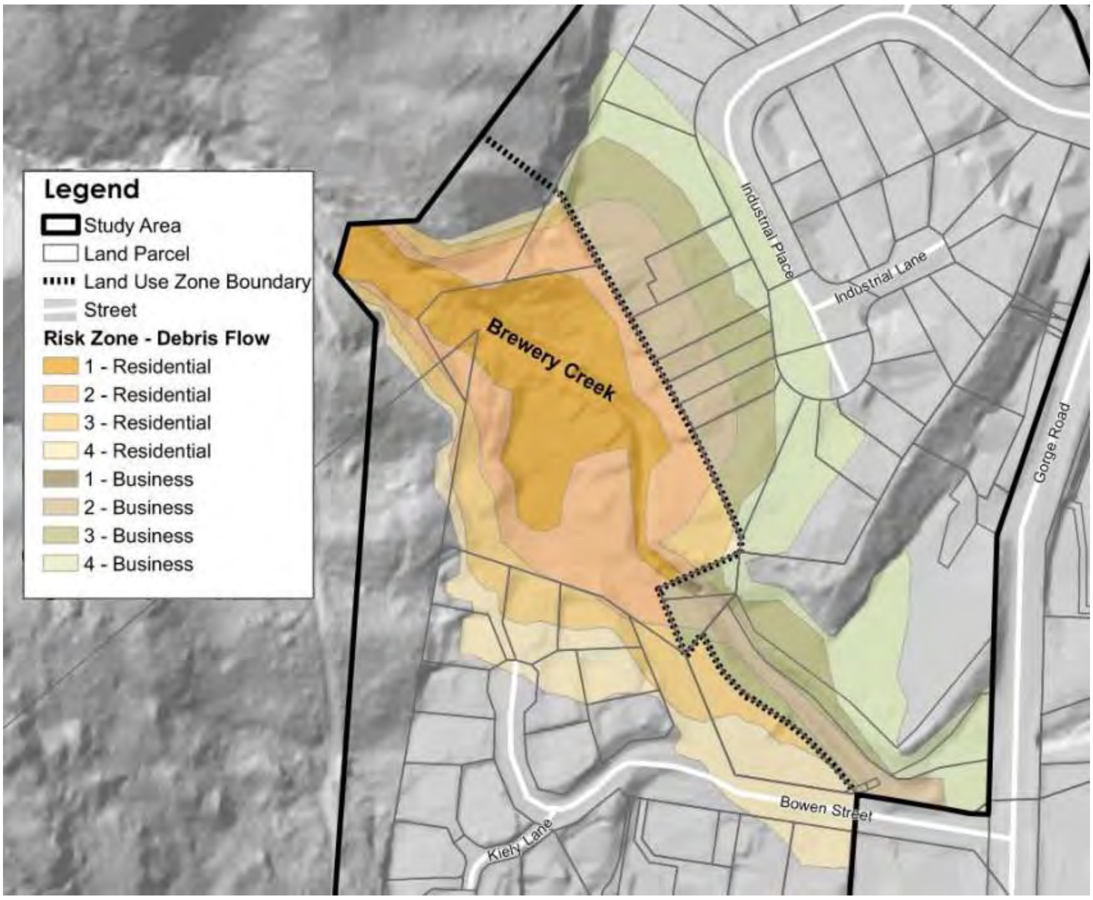


Figure 9 - Brewery Creek Fan debris flow risk zones from Beca (2020) study

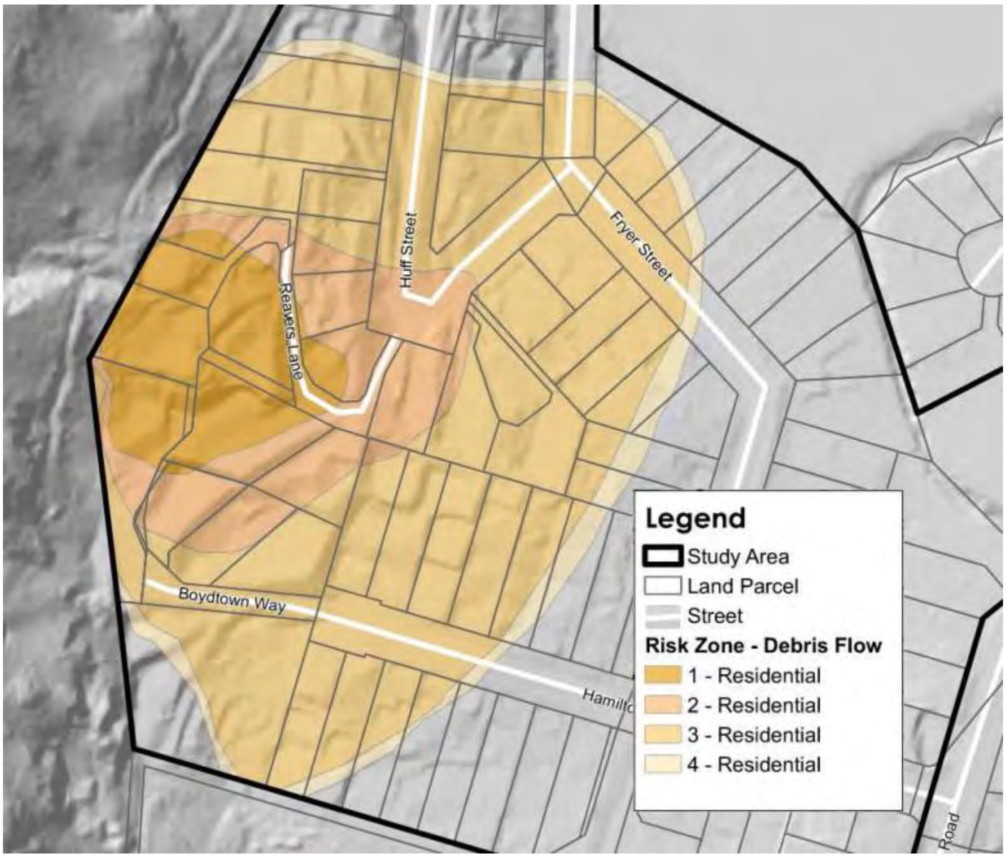


Figure 10 - Reavers Fan debris flow risk zones from Beca (2020) study

3.1.2 Rockfall AIFR Process

The rockfall AIFR was derived from rockfall trajectories modelled using the 3-dimensional statistical software RAMMS:ROCKFALL. Outcrops identified from field mapping and the DEM and considered capable of releasing rocks into the study area were used in the models. Three risk zones were generated for the AIFR calculation based on the final resting position of the released rocks and defined as follows:

- Zone 1 - greater than 10% of modelled released rocks came to rest.
- Zone 2 - 1-10% of modelled released rocks came to rest.
- Zone 3 - 0-1% of modelled released rocks came to rest.

Rockfall risk zones from the Beca (2020) study are shown in Figure 11 and Figure 12. Risk zone maps have not been regenerated as part of this study due to marginal difference between zone extents.

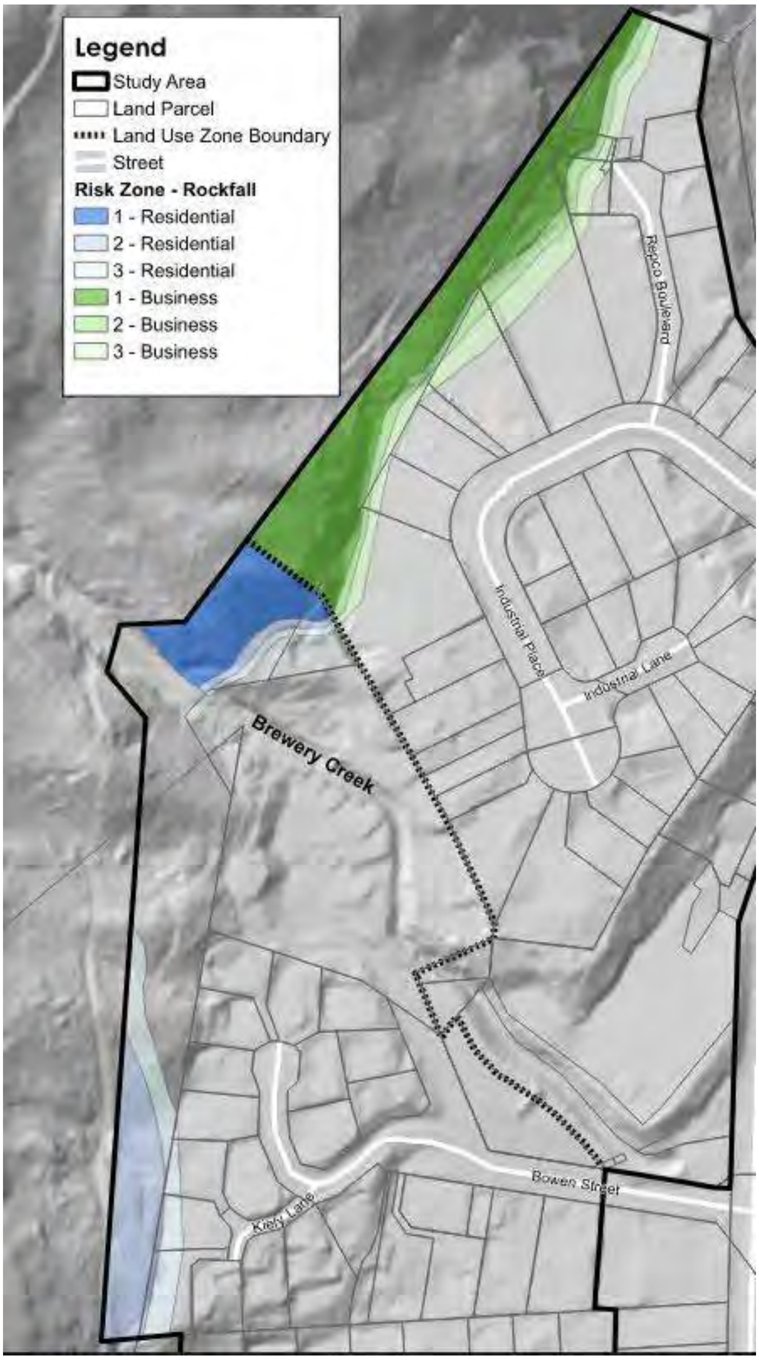


Figure 11 - Brewery Creek Fan rockfall risk zones from the Beca (2020) study

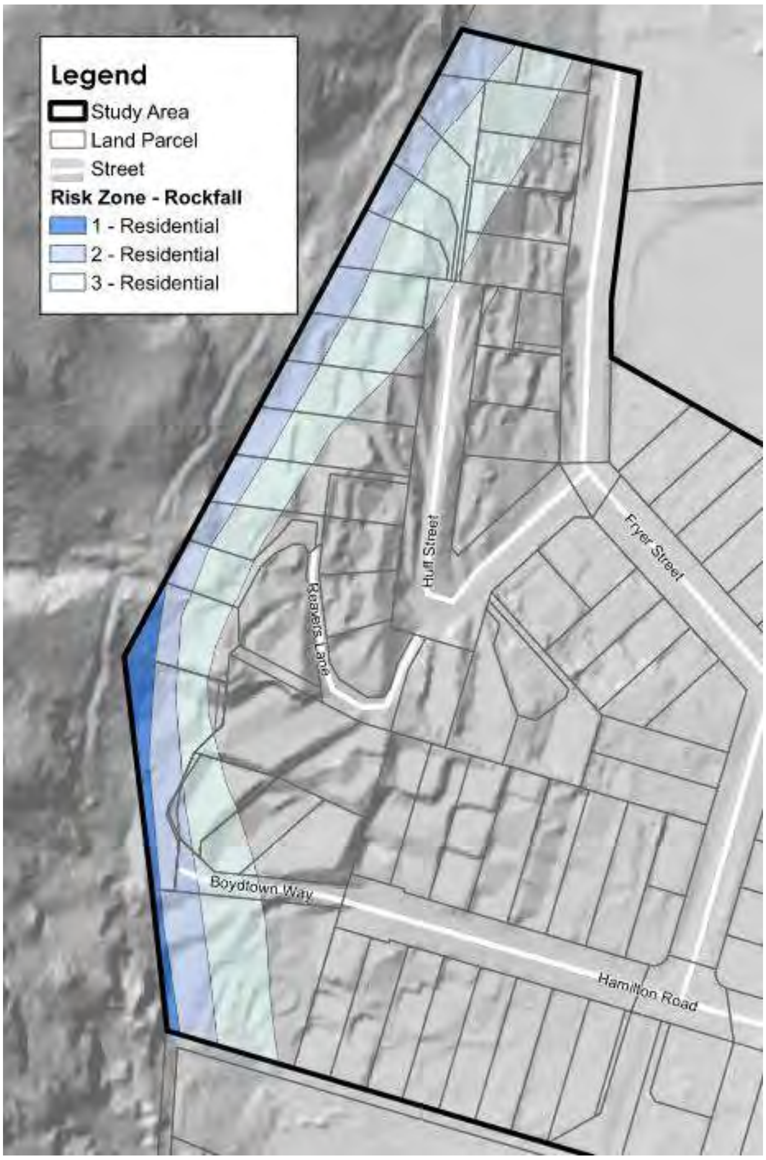


Figure 12 - Reavers Fan rockfall risk zones from the Beca (2020) study

The annual probability of a rockfall occurring and number of individual rocks involved was assessed for three triggering events:

- Small rockfall with a non-seismic trigger (predominantly heavy rainfall or gradual weathering effects), with a return period of 1 year (annual probability of 1.0) and releasing between 1 and 10 rocks.
- Seismically triggered rockfall from a far-field earthquake with a return period of 100 years (annual probability of 0.01) and releasing between 10 and 100 rocks (analogous to an Alpine Fault event).
- Seismically triggered rockfall from a large near-field earthquake with a return period of 500 years (annual probability of 0.002) and releasing between 100 and 1,000 rocks (analogous to a near field fault rupture).

3.2 Brewery Creek Fan AIFR

3.2.1 Channel Resizing and Realignment Option

The channel option detailed in Section 2.3.1 has been dimensioned to retain the volume of debris released in a 'small' event. The RAMMS debris flow models have been re-run with the proposed resized and realigned channel. The model outputs are shown in Figure 13 and in full in Appendix E – Revised Debris Flow Modelling, and indicate:

- The channel largely retains the debris from a small event, with some overspill in the order of 1m to 2m depth in the site at 21 Bowen Street. This is due to the dogleg in the channel, which despite being smoothed out, would still result in some channel overtopping.
- The medium and large events show very little difference in flow extents between the existing and proposed channels:
  - The medium event lateral flow extents reduce by approximately 5m in the business zone. The residential zone extents are broadly comparable with both the existing and proposed channels (i.e. there is negligible improvement with the proposed channel).
  - The large event lateral flow extents reduce by approximately 10m in the business zone, and 5m to 10m in the residential zone.
  - Changes in the debris flow extents are related to local topography and the location of bank overtopping. The models indicate that the debris flows first flows into the residential zone, and then, as the channel backs up, flows into the business zone. The channel mitigation options reduces back up within the channel, subsequently there is a greater reduction in the debris flow extents within the business zone.
- The large event model shows debris reaching the culvert at Gorge Road at the eastern boundary of the study area, at depths of approximately 2m to 3m within the channel. Large events in this order of magnitude would have the potential to block the culvert and overtop Gorge Road. As noted in Section 2.3.1, the existing culvert is understood to be designed to accommodate a 40 year return period flood event, and as such the water alone associated with the large event would result in overtopping of the road at this location.

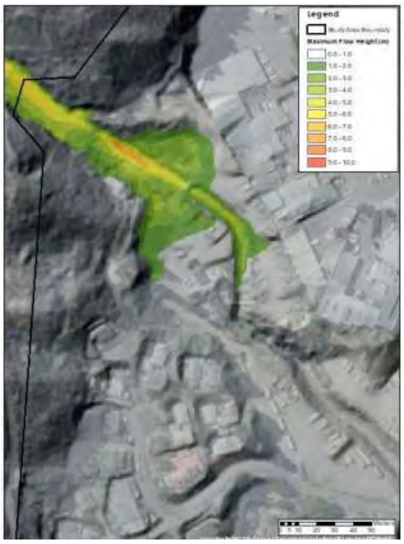
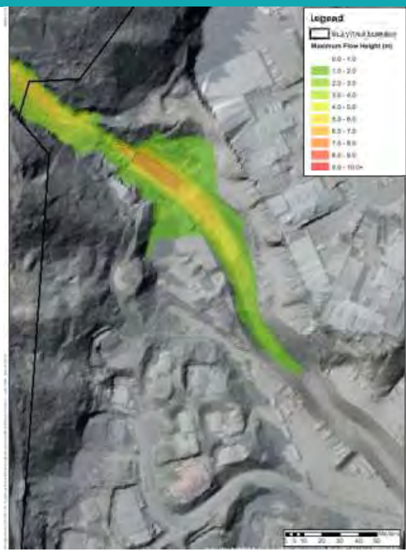
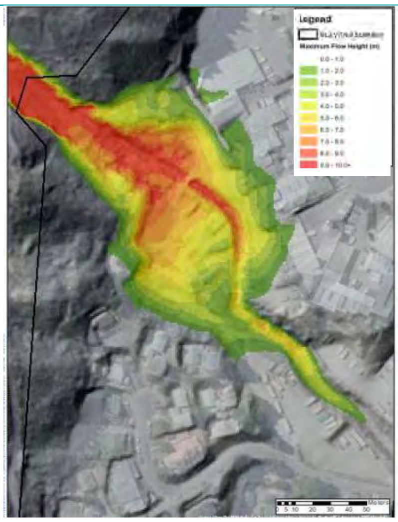
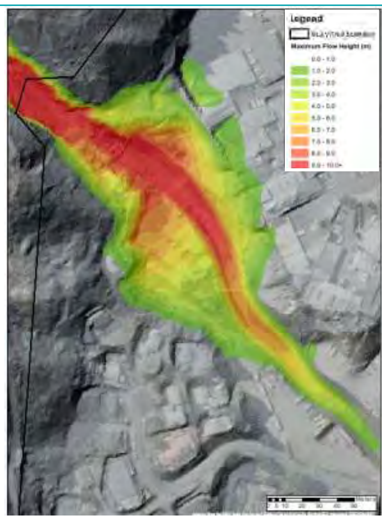
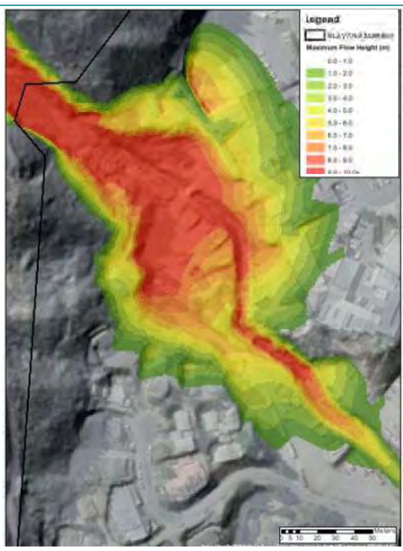
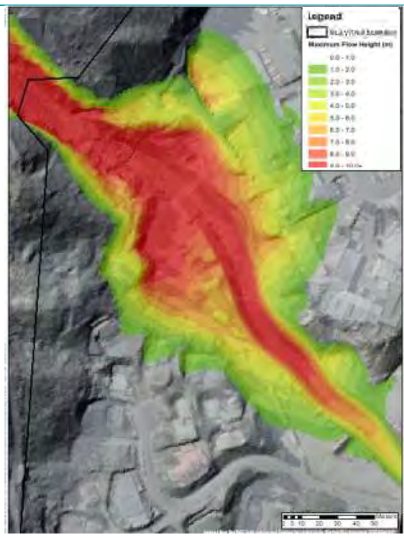
The spatial probability and vulnerability parameters for the small events have been updated based on the outputs of the RAMMS models. The vulnerability parameter classification is a function of the average depth and velocities from the RAMMS models within the affected area and has been updated based on the classification applied in the previous study.

The resulting changes to the AIFR are shown in Table 7. The values show an improvement in AIFR of less than half an order of magnitude for both the residential and business areas for Zone 1 (upper fan). The AIFR for the lower zones has not reduced, as improvement gained by the channel realignment for the larger events is negligible. Full AIFR calculations are shown in Appendix F – AIFR Calculations.

Table 7 - AIFR values comparing the current situation with the channel realignment option for Brewery Creek Fan

	Residential		Business	
	AIFR existing	AIFR channel upgrade	AIFR existing	AIFR channel upgrade
Zone 1	3.1×10^{-3}	1.3×10^{-3}	1.2×10^{-3}	5.0×10^{-4}
Zone 2	9.1×10^{-4}	9.1×10^{-4}	3.4×10^{-4}	3.4×10^{-4}
Zone 3	9.6×10^{-5}	9.6×10^{-5}	3.6×10^{-5}	3.6×10^{-5}
Zone 4	4.8×10^{-6}	4.8×10^{-6}	1.9×10^{-6}	1.9×10^{-6}

Figure 13 - Summary of modelled debris flow extents for Brewery Creek Fan

Return Period (years)	Initial Model with existing topography	Revised model with mitigation channel
50 – 200 (Small event)		
200 – 2500 (Medium event)		
2,500 – 10,000 (Large event)		

3.2.2 Debris Flow Fence Option

The debris flow fence option detailed in Section 2.2.2 has been designed to retain the volume of debris released in a small event. The RAMMS debris flow models have been re-run considering the effect of the fences, with details and results included in Appendix E – Revised Debris Flow Modelling, and summarised in Figure 14. As it is not possible in RAMMS to run models with mitigation options like debris fences in place, the models run include:

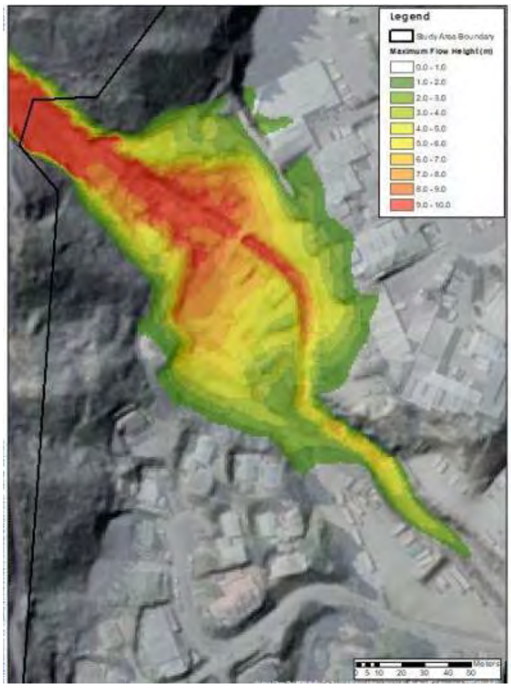
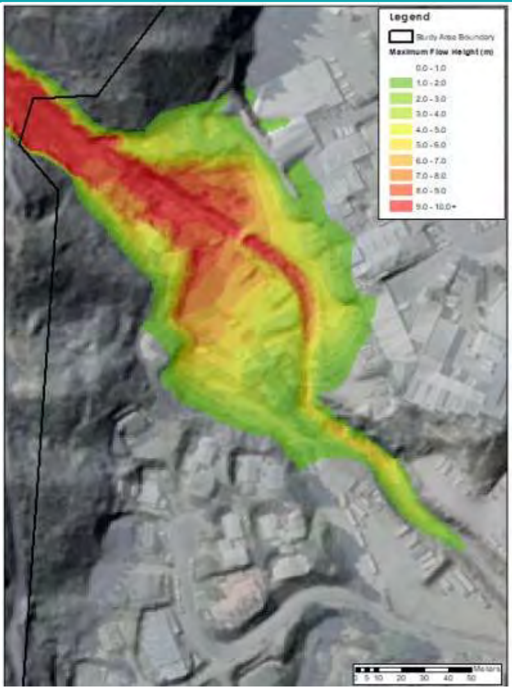
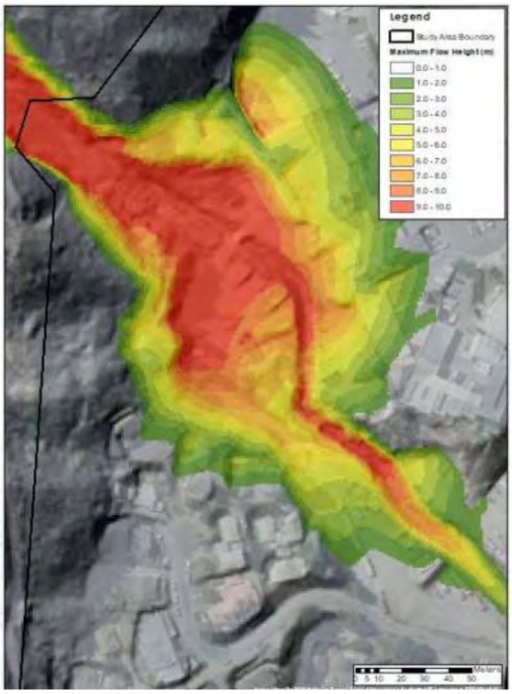
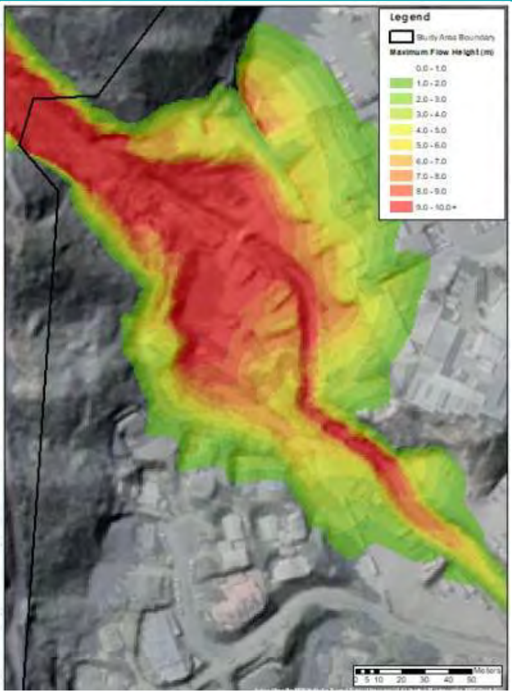
- Medium event less the volume of the small event, to assess any improvement in the medium event extents from the debris fences.
- Large event less the volume of the small event, to assess any improvement in the large event extents from the debris fences.

The model outputs show:

- The medium and large events show very little difference in flow extents with or without the debris flow fences.
  - The medium event extents are almost identical with or without debris flow fences, with the exception of a strip of land approximately 45m in length and 20m in width adjacent to 47a Industrial Place, which is not covered in debris >1m depth with the debris fences in place.
  - The large event extents are similar both with and without the debris fences, with small pockets less than 5m in width not affected by debris greater than 1m depth with the debris fences in place.
  - The large event model extents do not reach the study area boundary.

The spatial probability and vulnerability parameters for the small events have been updated based on the outputs of the RAMMS models. The vulnerability parameter classification is a function of the average depth and velocities from the RAMMS models within the affected area, and has been updated based on the classification applied in the previous study.

Figure 14 - Comparison of the initial debris flow extent modelled for Brewery Creek fan and that simulating the effects of the debris flow fences.

Return Period (years)	Initial Model with exisitng topography	Revised model with debris flow fences
200 – 2,500 (Medium event)		
2,500 – 10,000 (Large event)		

The resulting changes to the AIFR are shown in Table 8 and in full in Appendix F – AIFR Calculations. These values are the same as for the channel option, due to the vulnerability classification resulting in similar values based on the RAMMS outputs, showing a reduction in AIFR of less than half an order of magnitude (e.g. from 3×10^{-3} to 1×10^{-3}, see Section 3.1) for both the residential and business areas in Zone 1 (upper fan). The AIFR for the medium and large events has not reduced, as improvement gained by the channel realignment for the larger events is negligible.

Table 8 - AIFR values comparing the current situation with the debris fence option for Brewery Creek Fan

	Residential		Business	
	AIFR existing	AIFR debris fences	AIFR existing	AIFR debris fences
Zone 1	3.1×10^{-3}	1.3×10^{-3}	1.2×10^{-3}	5.0×10^{-4}
Zone 2	9.1×10^{-4}	9.1×10^{-4}	3.4×10^{-4}	3.4×10^{-4}
Zone 3	9.6×10^{-5}	9.6×10^{-5}	3.6×10^{-5}	3.6×10^{-5}
Zone 4	4.8×10^{-6}	4.8×10^{-6}	1.9×10^{-6}	1.9×10^{-6}

3.2.3 Rockfall Fence Option

The rockfall fence option detailed in Section 2.3.3 has been designed to retain 95% of released rocks, based on velocities and bounce heights obtained from the RAMMS:Rockfall models.

AIFR has been updated based on modification of the spatial probability parameter, which incorporates the probability of travel ($P_{(T)}$), or the probability that a single fallen rock rolls far enough down the hill to reach the person most at risk. This parameter has been reduced by 95% to allow for the removal of 95% of the rocks using the rockfall fence option.

AIFR values for the current situation and with the fence option in place are summarised in Table 9 and shown in full in Appendix F – AIFR Calculations. The residential values apply to both Brewery Creek and Reavers Fans. The values show an improvement in AIFR of up to two orders of magnitude (e.g. from 4×10^{-5} to 4×10^{-7}, see Section 3.1)) for the three rockfall zones.

Table 9 - AIFR values comparing the current situation with the rockfall fence option

	Residential Zone		Business Zone	
	AIFR existing	AIFR fence	AIFR existing	AIFR fence
Zone 1	7.4×10^{-4}	3.7×10^{-5}	1.3×10^{-3}	1.4×10^{-5}
Zone 2	2.3×10^{-4}	1.1×10^{-5}	4.1×10^{-4}	4.5×10^{-6}
Zone 3	1.7×10^{-5}	8.6×10^{-7}	3.1×10^{-5}	3.7×10^{-7}

3.2.4 Rockfall Mesh Option

The rockfall draped TECCO mesh option has been designed to control rockfall from the cliff outcrops immediately behind the business zone of Brewery Creek Fan. Any resulting rocks would undergo controlled failure and would accumulate at the base of the mesh at the toe of the outcrops. Is has been assumed that all rocks would be retained, and as a result the AIFR for these outcrops would be reduced to insignificant. Modelling conducted for the outcrops further upslope as part of the previous phase of work did not indicate rocks would reach the properties in the business zone.

3.3 Reavers Fan

3.3.1 Channel Development Option

The channel development option detailed in Section 2.4.1 has been designed to retain the volume of debris released in a small event. The RAMMS debris flow models have been re-run with the proposed resized and realigned channel as summarised in Appendix E – Revised Debris Flow Modelling.

The model outputs are shown in Figure 15 and` indicate:

- The channel almost entirely retains the debris released in a small event, with some spillage onto the road at the intersection of Huff Street and Fryer Street, in the order of 1m to 2m depth.
- The medium and large events show overall a reduction in the flow extents when comparing the current situation and proposed channel.
- The medium and large events result in a transfer of risk, due to the channel redirecting the debris flow. Some properties that were previously only marginally affected by debris flows would become inundated.
  - The medium event is almost retained within the channel, affecting two properties outside those that would need to be removed for the construction of the channel.
  - The large event extents are reduced to the south east by up to approximately 45m when compared with the existing situation, although generally in the order of 10m to 20m.
  - Models for the existing topography do not show any debris reaching the study boundary, however the medium and large events show a transfer of risk, both to the properties surrounding the channel, and in terms of debris reaching Warren Park to the north east of the study area boundary.
  - Not all areas properties would be affected by the redirection of the debris flow and transfer of risk. Some properties are shown as being inundated in the large event both with the existing topography and with the proposed channel in place.

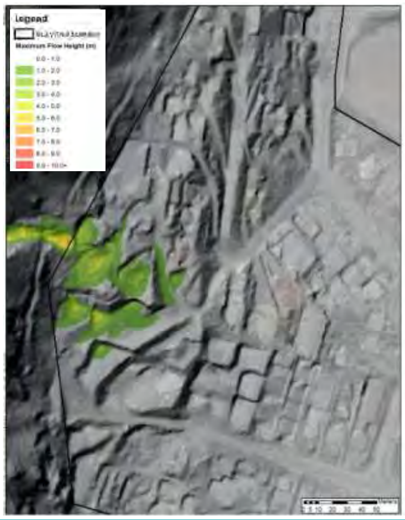
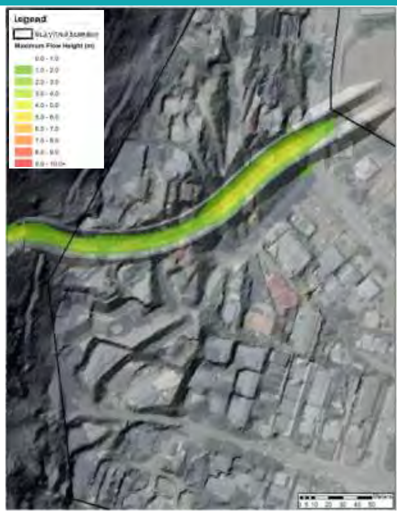
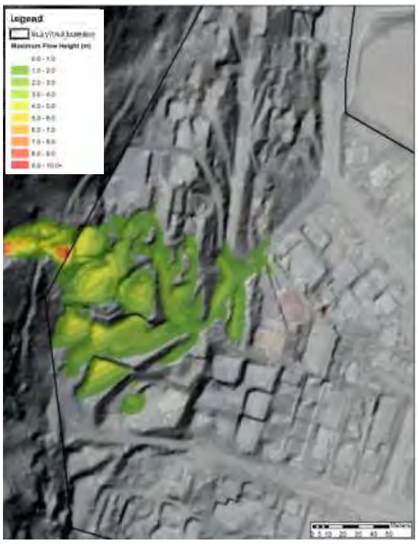
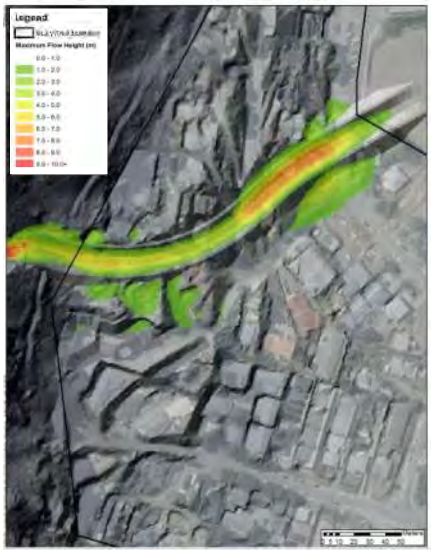
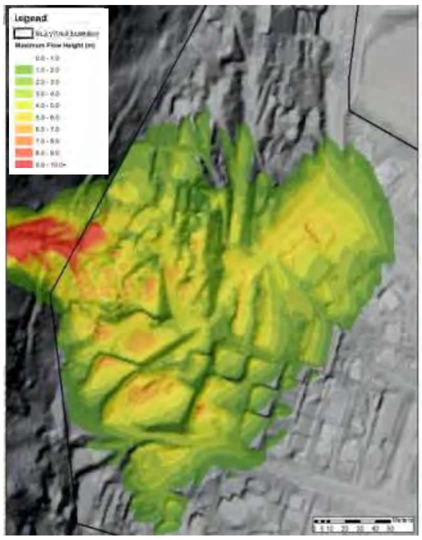
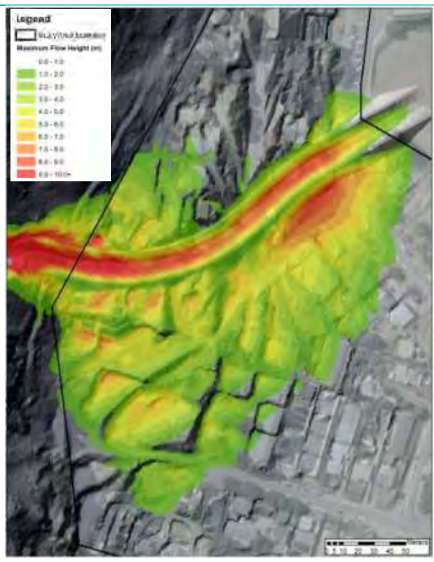
The spatial probability and vulnerability parameters for the small events have been updated based on the outputs of the RAMMS models. The vulnerability parameter classification is a function of the average depth and velocities from the RAMMS models within the affected area and has been updated based on the classification applied in the previous study.

The resulting changes to the AIFR are summarised in Table 10 and shown in full in Appendix F – AIFR Calculations. The values show a reduction in AIFR of approximately an order of magnitude for Zone 1 (from 1×10^{-3} to 1×10^{-4}), and a marginal reduction for Zone 2. Unlike for Brewery Creek Fan, AIFR for Zone 2 is reduced due to decreased vulnerability, as a result of changing depth and velocity parameters.

Table 10 - AIFR values comparing the current situation with the proposed channel option for Reavers Fan

Residential		
	AIFR existing	AIFR channel upgrade
Zone 1	1.0×10^{-3}	1.4×10^{-4}
Zone 2	1.4×10^{-4}	1.1×10^{-4}
Zone 3	4.3×10^{-5}	4.3×10^{-5}
Zone 4	2.2×10^{-6}	2.2×10^{-6}

Figure 15 - Summary of modelled debris flow extents on Reavers Fan

Return Period (years)	Initial Model with existing topography	Revised model with mitigation channel
100-2,500 (Small event)		
2,500 – 6,700 (Medium event)		
6,700 – 20,000 (Large event)		

It should be highlighted that the extents of the risk zones for the Reavers Fan channel option are significantly changed in comparison with the other mitigation options and Brewery Creek Fan. This is evident in Figure 15, and is due to the channel significantly affecting the spatial extents of debris flows. For all other options the risk zone extents reduce to varying levels as a result of the mitigation options, but the general locations are not significantly altered.

3.3.2 Debris Flow Fence Option

The debris flow fence option detailed in Section 2.2.2 has been designed to retain the volume of debris released in a small event. The RAMMS debris flow models have been re-run considering the effect of the fences, as shown in Appendix E – Revised Debris Flow Modelling and summarised in Figure 16. As it is not possible in RAMMS to run models with mitigation options like debris fences in place, the models run include:

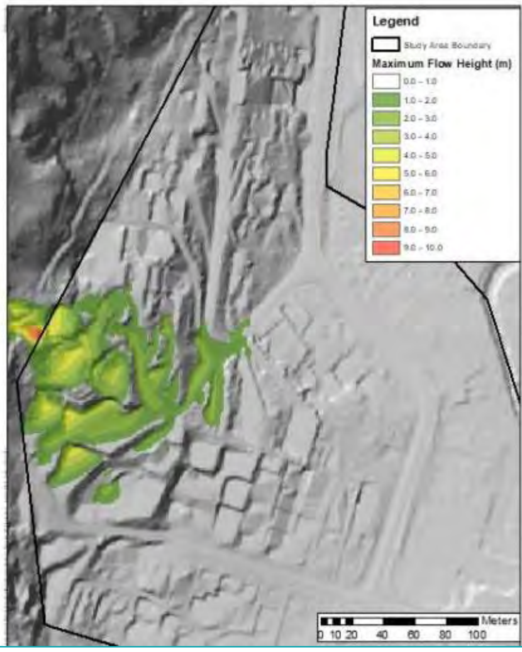
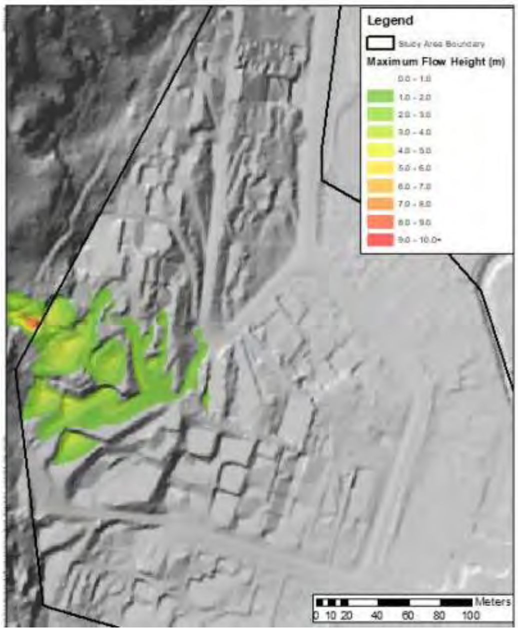
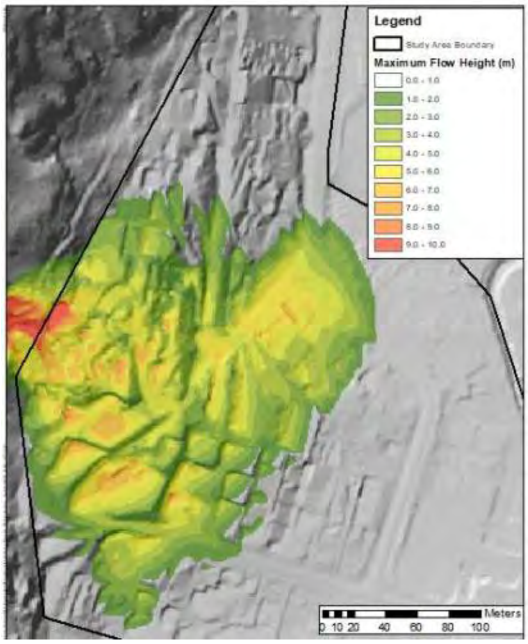
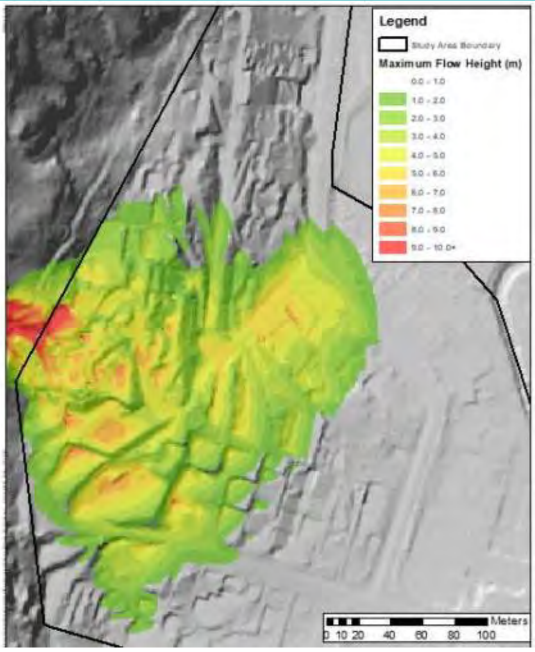
- Medium event less the volume of the small event, to assess any improvement in the medium event extents from the debris fences.
- Large event less the volume of the small event, to assess any improvement in the large event extents from the debris fences.

The model outputs show:

- The medium and large events show very little difference in flow extents comparing with or without the debris flow fences.
  - The medium event extents are less than without debris flow fences, typically in the order of 25m.
  - The large event extents are almost identical both with and without the debris fences, with small bands in the order of 8m width not affected by debris greater than 1m depth with the debris fences in place.
  - None of the models shows debris reaching the study area boundary with the debris fence option.

The spatial probability and vulnerability parameters for the small events have been updated based on the outputs of the RAMMS models. The vulnerability parameter classification is a function of the average depth and velocities from the RAMMS models within the affected area and has been updated based on the classification applied in the previous study.

Figure 16 - Comparison of the initial debris flow extent modelled for Reavers Fan and that simulating the effects of the debris flow fences.

Return Period (years)	Initial Model with exisitng topography	Revised model with debris flow fences
2,500 – 6,700 (Medium event)		
6,700 – 20,000 (Large event)		

The resulting changes to the AIFR are summarised in Table 11 and shown in full in Appendix F – AIFR Calculations. The values show a reduction in AIFR of just under an order of magnitude for Zone 1 (from 1 x 10^{-3} to 2 x 10^{-4}), with no improvement for Zones 2 and 3.

Table 11 - AIFR values comparing the current situation with the debris fence option for Reavers Fan

Residential		
	AIFR existing	AIFR debris fence
Zone 1	1.0×10^{-3}	1.8×10^{-4}
Zone 2	1.4×10^{-4}	1.4×10^{-4}
Zone 3	4.3×10^{-5}	4.3×10^{-5}
Zone 4	2.2×10^{-6}	2.2×10^{-6}

3.3.3 Rockfall Fence Option

The rockfall fence option detailed in Section 2.4.3 has been designed to retain 95% of released rocks, based on velocities and bounce heights obtained from the RAMMS:Rockfall models.

AIFR values for the current situation and with the fence option in place are summarised in Table 12 and shown in full in Appendix F – AIFR Calculations. The residential values are the same for both Brewery Creek and Reavers Fans. The values show an improvement in AIFR of less than two orders of magnitude for the three rockfall zones. No areas of rockfall mesh are proposed for Reavers Fan.

Table 12 - AIFR values comparing the current situation with the rockfall fence option at Reavers Fan

Residential Zone		
	AIFR existing	AIFR fence
Zone 1	7.4×10^{-4}	3.7×10^{-5}
Zone 2	2.3×10^{-4}	1.1×10^{-5}
Zone 3	1.7×10^{-5}	8.6×10^{-7}

3.4 AIFR Tolerability

3.4.1 Tolerability Guidelines

There are currently no national guidelines for determining tolerable limits to life risk in New Zealand. Life risk tolerability guidelines for slope stability are provided for Australia by AGS (2007), with a maximum recommended AIFR of 1×10^{-4} (1 in 10,000) for existing slopes/developments, and 1×10^{-5} (1 in 100,000) for new slopes/developments. A discussion on existing guidance is included in the Beca (2020) report. The AGS (2007) guidelines would apply to the study area as follows:

- Existing slopes / developments in accordance with AGS are those slopes and structures which are not part of a recognisable landslide and have demonstrated non-failure performance over a period of 10-20 years.
  - This definition would generally apply to existing properties on Brewery Creek and Reavers Fans, and as such the maximum tolerable risk of 1×10^{-4} would apply.
- New slopes / developments in accordance with AGS include any new structures or changes to existing slopes or structures. The exceptions to this are:

- Where changes to an existing slope results in a vertical cut of less than 1m, it may be considered an existing slope.
- Where changes to an existing structure do not increase the building footprint or result in an overall change in footing loads, it may be considered an existing development.
- Aside from the above exceptions, the tolerable risk for any new structures or slopes on Brewery Creek and Reavers Fans would therefore be 1 x 10^{-5}.

3.4.2 Effect of Engineering Options on AIFR

AIFR values determined through the previous and current Beca studies exceed published guidance on risk tolerability for both new and existing developments on some areas of both fans before considering any engineering options. Table 13 shows highest AIFR values (i.e. Zone 1 values) with each of the engineering options in place for both fans.

Table 13 - Highest slope stability AIFR values for the Gorge Road study area with engineering options in place

Location	Debris flow channel		Debris flow fences		Rockfall fences	
	Existing	Proposed	Existing	Proposed	Existing	Proposed
Brewery Creek Fan Residential Zone	3.1 x 10^{-3}	1.3 x 10^{-3}	3.1 x 10^{-3}	1.3 x 10^{-3}	7.4 x 10^{-4}	3.7 x 10^{-5}
Brewery Creek Fan Business Zone	1.2 x 10^{-3}	5.0 x 10^{-4}	1.2 x 10^{-3}	5.0 x 10^{-4}	2.9 x 10^{-4}	1.4 x 10^{-5}
Reavers Creek Fan	1.0 x 10^{-3}	1.4 x 10^{-4}	1.0 x 10^{-3}	1.8 x 10^{-4}	7.4 x 10^{-4}	3.7 x 10^{-5}

The following comments can be made regarding risk tolerability with engineering options in place, with respect to AGS (2007) guidelines:

- Channel and debris fence options:
  - The ‘small’ events can be largely mitigated with the options considered.
  - Engineering options have limited effect on risk posed by ‘medium’ and ‘large’ events.
  - Risks **fall outside tolerability guidance** for existing developments for zones 1 & 2 (upper fans).
  - Risks **fall outside tolerability guidance** for new developments in zones 1, 2 or 3 (middle and upper fans).
  - Reavers Fan Channel – risk transfer means that some properties previously assessed as having tolerable risk would become **intolerable**.
- Rockfall fences and mesh:
  - Risk reduced to **tolerable** for existing developments for all zones on both fans.
  - Risk reduced to **tolerable** for new developments in zone 2 (business) and zone 3 (residential and business) on both fans.

The above changes in AIFR apply to a single engineering option being considered. While calculations have not been run on the effect of engineering options being considered together (i.e. channels and debris flow fences), any improvements would be anticipated to be approximately half an order of magnitude (e.g. from 5 x 10^{-3} to 1 x 10^{-3}) for the upper zones. A reduction in AIFR of these magnitudes is not sufficient to bring risk to a tolerable level.

4 Cost Estimates

Order of magnitude capital cost estimates have been prepared for the three mitigation options proposed for Brewery Creek and Reavers Lane assuming installation in accordance with the relevant codes, standards and manufacturer's instructions. Cost estimates are listed in millions of New Zealand dollars (NZ$) in Table 14 and are exclusive of GST. Estimates are based on "Concept Design" information and are subject to an estimate range of approximately -35% to +50% to reflect the current market conditions and allowance for unknown risks. The estimate assumes traditional procurement with fully designed and competitively tendered measure and value tenders from at least three suitable selected tenderers however does not consider the programme for construction. Specific clarifications, assumptions, exclusions and items of cost risks are outlined in Appendix F – Cost Estimate.

Table 14 - Estimate of Construction Costs for the three mitigation options listed as millions of NZD.

Estimate Summary		Brewery Creek Fan			Reavers Fan		
	Range	Low -35% $M	Mid 100% $M	High +50% $M	Low -35% $M	Mid 100% $M	High +50% $M
1.0	Debris Flow Channels	1.04	**1.60**	2.4	2.52	**3.88**	5.82
2.0	Debris Flow Barriers	0.79	**1.22**	1.83	0.9	**1.39**	2.09
3.0	Rockfall Fence and Ground Mesh	0.69	**1.07**	1.61	0.55	**0.86**	1.29

The cost estimate does not include allowances for the following items which would be required for the mitigation channel option:

- Land purchase and negotiations
  - 10 residential properties require demolition/removal for Reavers Fan debris flow channel.
  - 1 relocatable building would need to be repositioned to allow for Brewery Creek Fan debris flow channel.
- Costs associated with the demolition/ removal of the residential properties
- Major road and associated services re-alignment on Reavers Fan and/or allowance for any bridge, culvert or tunnels required for the mitigation channel.
- Consenting costs.
- Costs associated with ground improvements, removal of any contaminated materials that may be present (asbestos etc), obstructions or de-watering.
- Maintenance and operational costs.

5 Maintenance

5.1 Debris flow channel

Debris flow channels do not require regularly scheduled maintenance however should be checked for debris accumulation and scour damage following flood and/or high rainfall events. Following a debris flow event, any accumulated debris should be removed and the design capacity of the channel restored.

5.2 Debris flow fences

Debris flow fences are recommended to be inspected twice per year, generally corresponding to seasonal changes. Additional maintenance inspections should be undertaken if the structures become loaded following a debris flow event.

The standard inspections would involve assessing the following:

- Inspection of all fence components for corrosion, signs of wear, and/or deformation, including any damage or problems with anchors such as that caused by active ground movements, heavy scouring, and/or side erosion.
  - Brake rings should be replaced when more than 50% of the maximum elongation has been reached.
  - Wire rope clamps should be retightened approximately six months after installation.
- Removal of any vegetation from around the structure and clearing out any debris from immediately behind the fence in order to avoid blockages of the basal opening.
  - Generally, emptying the nets from upstream is more maintenance-friendly and should always be the aim during project planning.

Fences should also be inspected as soon as possible following any debris flow event in order to assess the amount of debris trapped by the system and any damage or wear to componentry. Debris trapped behind the fence should be removed as soon as possible after the event in order to restore the system capacity. Access roads to the debris fences will need to be formed and maintained to allow ongoing access to maintenance vehicles.

5.3 Rockfall

Rockfall fences generally have an assumed working life of 25 years under normal environmental conditions and without rock impact. In-ground anchors are generally expected to have a design life of not less than 50 years.

The MBIE (2016) recommended maintenance schedule for rockfall fences involves;

- Regularly scheduled maintenance every 1 to 5 years depending on the anticipated rockfall frequency and corrosivity of the environment. Inspections should involve the following activities:
  - Removal of accumulated debris within the fence and vegetation local to the fence area
  - Inspection of mechanical components including checking the tension of clamped connections
  - Checking the state of corrosion protection
  - Inspection and cleaning of any drainage works
- Visual inspection of potential rockfall sources every 5 to 10 years, or as warranted following a rainfall or other trigger event. Inspections should assess whether there have been any changes in condition to the source, such as loosening or movement of blocks.
- Inspection of fences following triggering or potentially triggering event(s). The assessment should include the following checks;

- Assessment all components for damage
- Removal of any debris trapped within the fence
- Repair or replacement of any damaged component as required to return the structure to the intended design capacity.

6 Conclusions

This study has considered three engineering measures at both Brewery Creek and Reavers Fans, with the aim of reducing the AIFR due to debris flow and rockfall to tolerable levels. The study found that of the engineering options considered, only rockfall fences and mesh are capable of reducing rockfall AIFR to tolerable levels for the majority of the properties affected. Debris flow channels and fences were sized to mitigate the risk from a small sized event, as any larger engineering works were not considered feasible. The reduction in AIFR from the debris flow channels and fences is negligible for anything other than a small sized event.

Rockfall fence and mesh capital cost estimates are in the order of $1M for each fan. The debris flow channel and fence options were also costed, with capital estimates ranging from $1M to $6M, however the benefit of these options is limited as detailed above and life risk remains outside published guidelines of tolerability.

This study has considered broad scale engineering works and their effect on AIFR. Property-specific measures have not been considered and caution is required in adopting such measures with regard to transfer of risk from one property to another. This applies in particular with debris flows due to the fluid nature of the flow and the potential for it to be redirected elsewhere. Additionally, large scale engineering works have not proven effective in reducing the risk from debris flow to tolerable levels, and as such property-specific measures would be even less likely to do so.

In addition to the natural hazard risk assessment work conducted by Beca, QLDC are in the process of conducting further work to inform the District Plan review, including loss modelling, community consultation, socio-economic assessments, and notification.

7 Applicability

This report is solely for our Client's use for the purpose for which it is intended in accordance with the agreed scope of work. It may not be disclosed to any person other than the Client and 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.

This report must be read in its entirety and no portion of it should be relied on without regard to the report as a whole, especially the assumptions, limitations and disclaimers set out in the estimate notes and elsewhere in the report.

While Beca believes that the use of the assumptions in the report are reasonable for the purposes of this study, Beca makes no assurances with respect to the accuracy of such assumptions and some may vary significantly due to unforeseen events and circumstances.

In preparing the cost estimates, Beca has relied on the accuracy, completeness and currency of the information provided, therefore is not responsible for the information provided, and has not sought to independently verify it. To the extent that the information is inaccurate or incomplete, the opinions expressed by Beca may no longer be valid and should be reviewed.

8 References

Beca (2020). Natural Hazards Affecting Gorge Road, Queenstown, Report prepared by Beca for Queenstown Lakes District Council; Report reference NZ1-16638194-3 2.0, Christchurch, New Zealand.

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Skermer, N., Rawlings, G. and Hurley, A. (2002). Debris Flow Defences at Aoraki Mount Cook Village, New Zealand. Quarterly Journal of Engineering Geology and Hydrogeology, 35, 19-24. 2002.

Xiong, M et al (2016). Effectiveness of debris flow mitigation strategies in mountainous regions. Progress in Physical Geography: Earth and Environment. Volume 40, Issue 6 p768-793. Surface water runoff reduction is also noted as beneficial in reduction sediment erosion and therefore debris flow risk, alongside channel capacity improvements, bank upgrades and levee construction (Golder, 2019).

A

Appendix A – Debris Flow Channel Design

Introduction

Beca Ltd (Beca) is undertaking a natural hazards study on the Gorge Road area, in particular rock fall and debris flow. This study includes understanding the scale and risk of these hazards and includes exploring options for engineering mitigation of the hazards.

For engineering mitigation of debris flow hazards, the most feasible option is considered to be construction of a flow path (created by constructing an open channel, bunding or combination of the two) to a safe runout location.

This memo describes the high-level concept design of flow paths as engineering mitigation for the small event for the each of Brewery Creek and Reavers Fan debris flows.

Information Used

Model results

The following information was provided from the 2-dimensional probabilistic modelling of debris flow movements using RAMMS:DEBRIS FLOW. This modelling is described in more detail in Beca's report *Natural Hazards Affecting Gorge Road, Queenstown* (reference NZ1-16638194-3 2.0, 12 November 2020).

Table A1 - Debris flow events

Location	Event	Peak flow, Q (m^3/s)
Brewery Creek Fan	Small	135
	Medium	1489
	Large	3,177
Reavers Fan	Small	259
	Medium	714
	Large	5,710

The return periods (and probability) of these events have been assessed as follows:

- Brewery Creek Fan
  - Small events with a return period in the order of 50 to 200 years (annual probability of 0.02 to 0.005).
  - Moderate event with a return period between 200 and 2,500 years (annual probability of 0.005 to 0.0004).
  - Large event with a return period of between 2,500 and 10,000 years (annual probability of 0.0004 to 0.0001).
- Reavers Fan
  - Small event with a return period ranging from 100 to 2,500 years (annual probability of 0.01 to 0.0004).
  - Moderate event with a return period of between 2,500 and 6,700 years (annual probability of 0.0004 to 0.00015).
  - Large event with a return period of between 6,700 and 20,000 years (annual probability of 0.00015 to 0.00005).

LiDAR

A ground surface model (1m digital elevation model or DEM) from the Otago Regional Council Otago - Queenstown 2016 LiDAR[3] , was used in developing the concepts. This is the same LiDAR DEM as was used for the debris flow modelling with no engineering mitigation.

Site Visit

A site visit was carried out on 8 June 2020 (by Kate Purton, with Anna Punt and Paul Horrey), to understand the existing topography, features and development.

High-level concept

Key design parameters

The channels were sized based on the small events (refer Table A1) for both debris flows. Key parameters are summarised in Table A2.

Table A2 - Key parameters

Location	Event	Peak flow, Q (m^3/s)	Average velocity (m/s)
Brewery	Small	135	3
Reavers	Small	259	6

Channel routes

For Brewery Creek Fan, the proposed route generally follows the existing channel, but with smoothing of the existing sharp corners, and ends at Gorge Road. This would affect existing properties.

For Reavers Fan, the proposed route is through existing properties, crossing the existing roads in four locations, ending at Warren Park. Typical details for road crossings, or options for closing of roads and re-routing of access, have not been developed at this stage.

[3] 1m DEM created from the Otago - Queenstown LiDAR captured for Otago Regional Council by Aerial Surveys in March and April 2016. https://data.linz.govt.nz/layer/99115-otago-queenstown-lidar-1m-dem-2016/metadata/

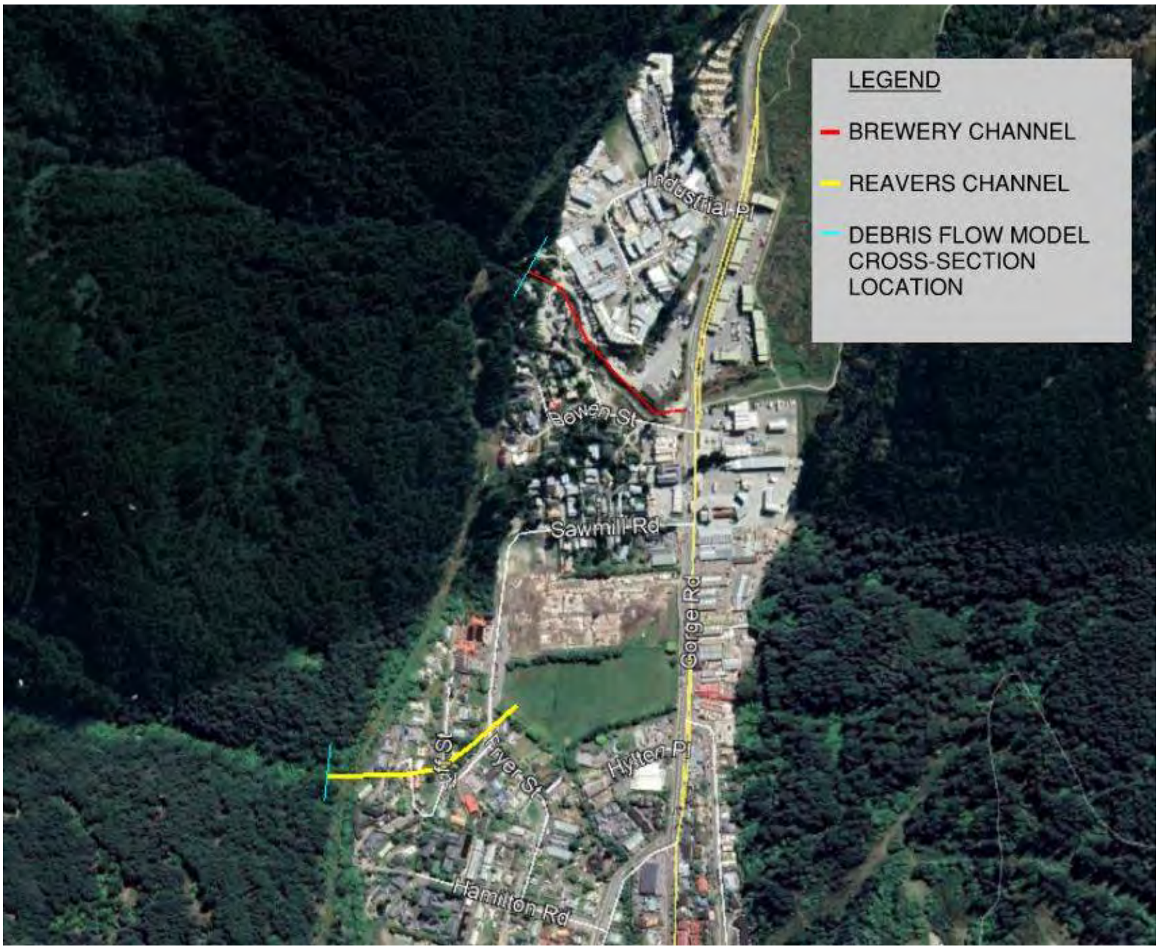


Figure A1 - Plan of channel routes

Channel sizing

Debris flow equations

The high-level concept sizing of the channels was carried out using equations for debris flows from DeLeon, A. A. and Jeppson R.W. (1982)[4], as set out below.

- Reynolds number as a function of velocity:

  $R_e = 10 V$

- Chezy coefficient as a function of Reynolds number:

  $C = 1.02 R_e^{0.52}$

- Flow as a function of Chezy coefficient (C) above, channel area (A), wetted perimeter (P), hydraulic gradient (S) which equals channel slope for normal flow:

  $$Q^2 = \frac{A^3 S C^2}{P}$$

The velocity was taken from the debris flow model results provided at the upstream end of the proposed channel (refer Figure A1). Channel dimensions were estimated and iterated to achieve the required flow.

[4] DeLeon, A. A. and Jeppson R.W. (1982), "*Hydraulics and Numerical Solutions of Steady-State but Spatially Varied Debris Flow*". Reports. Paper 515.

Two sensibility checks were carried out:

- The selected channel area was cross-checked against the area of the channel from the debris flow model results (at the upstream end of the proposed channel – refer Figure A1).
- The resulting velocity was calculated from the flow and area (V=Q/A) and checked against the velocity from the debris flow model results.

Table A3 – Comparison of area and velocity

Location	Flow (m^3/s)	**Approximate cross-sectional area from debris flow model (m^2)**	Selected channel area (m^2)	Debris flow model average velocity v = Q/A (m/s)	**Selected channel average velocity v= Q/A (m/s)**
Brewery Creek	135	60	44	2.25	3
Reavers	259	34	44	7.62	6.2

Manning's Equation

Another approach for sizing channels for debris flow is to multiply the flow by a factor of 3 to 5 and use Manning's equation to size the channel.

The capacities of the design channel sizes were also checked using Manning equation, and Manning's equation was found to give a capacity 3.8 times greater for Brewery Creek and 1.8 times greater for Reavers Fan. This provides some confirmation for Brewery Creek but implies Reavers Fan might be slightly too small.

Sizes adopted

The high-level concept designs are shown in Figures A2 and A3 below (all dimensions in metres).

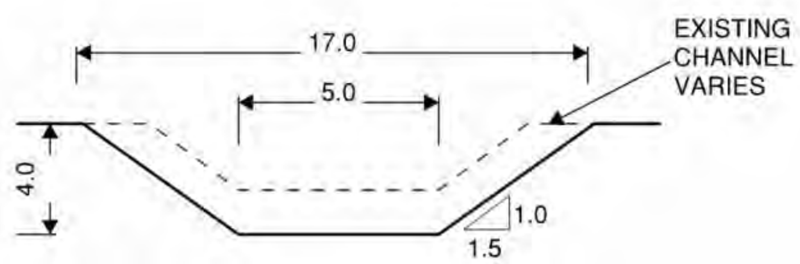


Figure A2 - Brewery Creek channel (modification to existing channel)

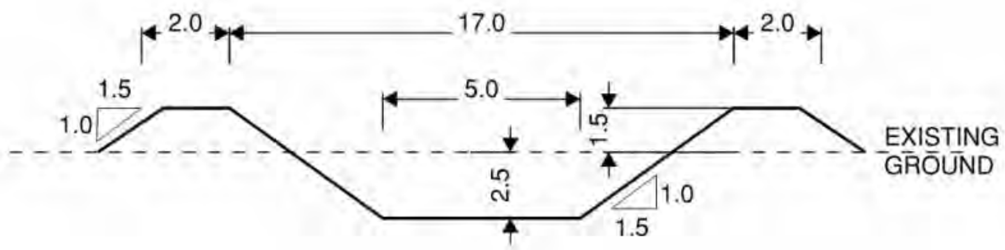


Figure A3 - Reavers Fan channel (new channel)

Design Testing in RAMMS:DEBRIS FLOW Model

Editing surface

The ground surface model was edited, using the civil modelling software 12d, to include channels and bunds as shown in Figures A1, A2 and A3 above, tying into the existing ground. Plans and cross-sections of the ground surface model are outlined in the concept sketches overleaf.

Modelling

The RAMMS:DEBRIS FLOW 2-dimension model was then re-run with the edited ground surface including the channels and bunds. Refer to Beca's report *Natural Hazards Affecting Gorge Road, Queenstown* (reference NZ1-16638194-3 2.0, 12 November 2020) for details of the modelling and results.

Limitations

It is important to note that this was a very high-level assessment for the purposes of understanding the potential feasibility of using channels as engineering mitigation option for small events.

If this option is to be advanced (at either location) then more research and design will be required.

Drawing Plotted: 25 Feb 2021 3:39 p.m.

No.	Revision	By	Chk	Appd	Date
1	FINAL				

Drawing Originator: Beca

Original Scale (A1) 1:500	Design	K.PURTON	06.10.20	Approved For Construction* N/A
Reduced Scale (A3) 1:1000	Drawn	P.ROWE	30.11.20	
	Dsg Verifier	G.LEVY	11.11.20	
	Dwg Check	A.PUNT	30.11.20	Date

* Refer to Revision 1 for Original Signature

Client: QUEENSTOWN LAKES DISTRICT COUNCIL

Project: GORGE ROAD ENGINEERING OPTIONS

Title: BREWERY CREEK FAN PROPOSED CHANNEL (PLAN VIEW)

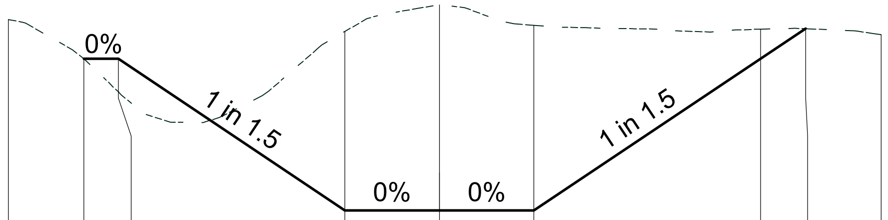
Discipline: CIVIL WATER

Drawing No. 3209881-A001 Rev. 1

Document No. 3209881-A001.DWG

DO NOT SCALE

IF IN DOUBT ASK.



H.A.D (m) 357.2

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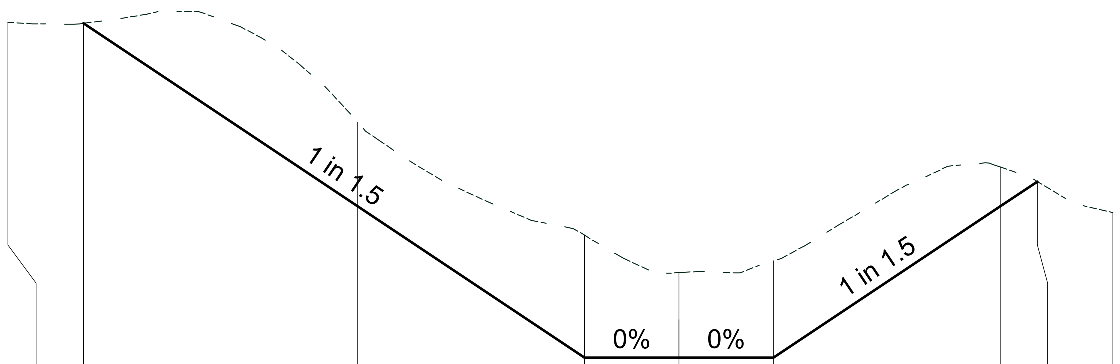
A - A'



H.A.D (m) 335.2

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EXISTING SURFACE LEVEL	345.09	345.07	342.45	339.46	338.47	338.79	341.27	340.88	340.06
OFFSET	-17.76	-15.76	-8.50	-2.50	0.00	2.50	8.50	9.48	11.48

B - B'

ORIGINAL DRAWING IN COLOUR

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No.	Revision	By	Chk	Appd	Date
1	FINAL				

Drawing Originator: Beca

Original Scale (A1) 1:100
Reduced Scale (A3) 1:200

Design	K.PURTON	06.10.20
Drawn	P.ROWE	30.11.20
Dsg Verifier	G.LEVY	11.11.20
Dwg Check	A.PUNT	30.11.20

Approved For Construction* N/A
Date
* Refer to Revision 1 for Original Signature

Client: QUEENSTOWN LAKES DISTRICT COUNCIL

Project: GORGE ROAD ENGINEERING OPTIONS

Title: BREWERY CREEK FAN PROPOSED CHANNEL SECTIONS

Discipline: CIVIL WATER

Drawing No. 3209881-A002 Rev. 1

Document No. 3209881-A002.DWG

Drawing Plotted: 21 Jan 2021 9:55 a.m.

ORIGINAL DRAWING IN COLOUR

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No.	Revision	By	Chk	Appd	Date
1	FINAL				

Drawing Originator: Beca

Original Scale (A1) 1:500	Design	K.PURTON	06.10.20	Approved For Construction* N/A
	Drawn	P.ROWE	30.11.20	
Reduced Scale (A3) 1:1000	Dsg Verifier	G.LEVY	11.11.20	
	Dwg Check	A.PUNT	30.11.20	Date

* Refer to Revision 1 for Original Signature

Client: QUEENSTOWN LAKES DISTRICT COUNCIL

Project: GORGE ROAD ENGINEERING OPTIONS

Title: REAVERS FAN PROPOSED CHANNEL (PLAN VIEW)

Discipline: CIVIL WATER

Drawing No. 3209881-A003 Rev. 1

Document No. 3209881-A003.DWG

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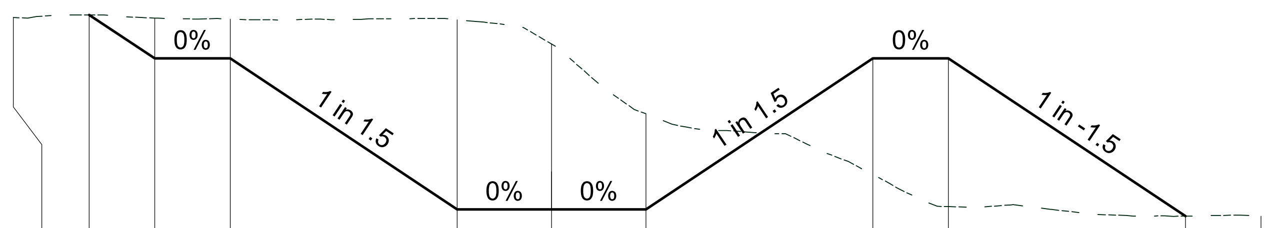
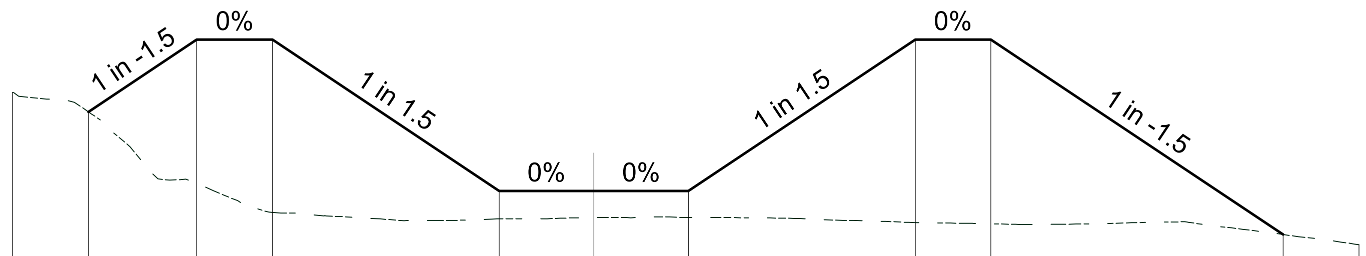
Drawing Plotted: 25 Feb 2021 3:52 p.m.



H.A.D (m) 363.1

CUT / FILL		0.00	1.07	1.04	5.03	4.39	2.54	-3.08	-3.93	0.00	
EXISTING SURFACE LEVEL	369.47	369.54	369.46	369.43	369.41	368.77	366.92	365.31	364.46	364.21	364.20
OFFSET	-14.24	-12.24	-10.50	-8.50	-2.50	0.00	2.50	8.50	10.50	16.77	18.77

SECT A - A'



H.A.D (m) 324.1

CUT / FILL		0.00	-3.80	-4.57	-0.74	-0.71	-0.71	-4.84	-4.87	0.00	
EXISTING SURFACE LEVEL	329.16	328.65	326.76	325.99	325.82	325.85	325.85	325.72	325.69	325.41	325.13
OFFSET	-15.37	-13.37	-10.50	-8.50	-2.50	0.00	2.50	8.50	10.50	18.23	20.23

SECT B - B'

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ORIGINAL DRAWING IN COLOUR

FOR INFORMATION
NOT FOR CONSTRUCTION

No.	Revision	By	Chk	Appd	Date
1	FINAL				

Drawing Originator: Beca

Original Scale (A1) 1:100	Design	K.PURTON	06.10.20	Approved For Construction*
Reduced Scale (A3) 1:200	Drawn	P.ROWE	30.11.20	N/A
	Dsg Verifier	G.LEVY	11.11.20	
	Dwg Check	A.PUNT	30.11.20	Date

* Refer to Revision 1 for Original Signature

Client: QUEENSTOWN LAKES DISTRICT COUNCIL

Project: GORGE ROAD ENGINEERING OPTIONS

Title: REAVERS FAN PROPOSED CHANNEL SECTIONS

Discipline: CIVIL WATER

Drawing No. 3209881-A004 Rev. 1

Document No. 3209881-A004.DWG

DO NOT SCALE

IF IN DOUBT ASK.

B

Appendix B – Debris Flow Fences

Debris Flow Fence Sizing Methodology

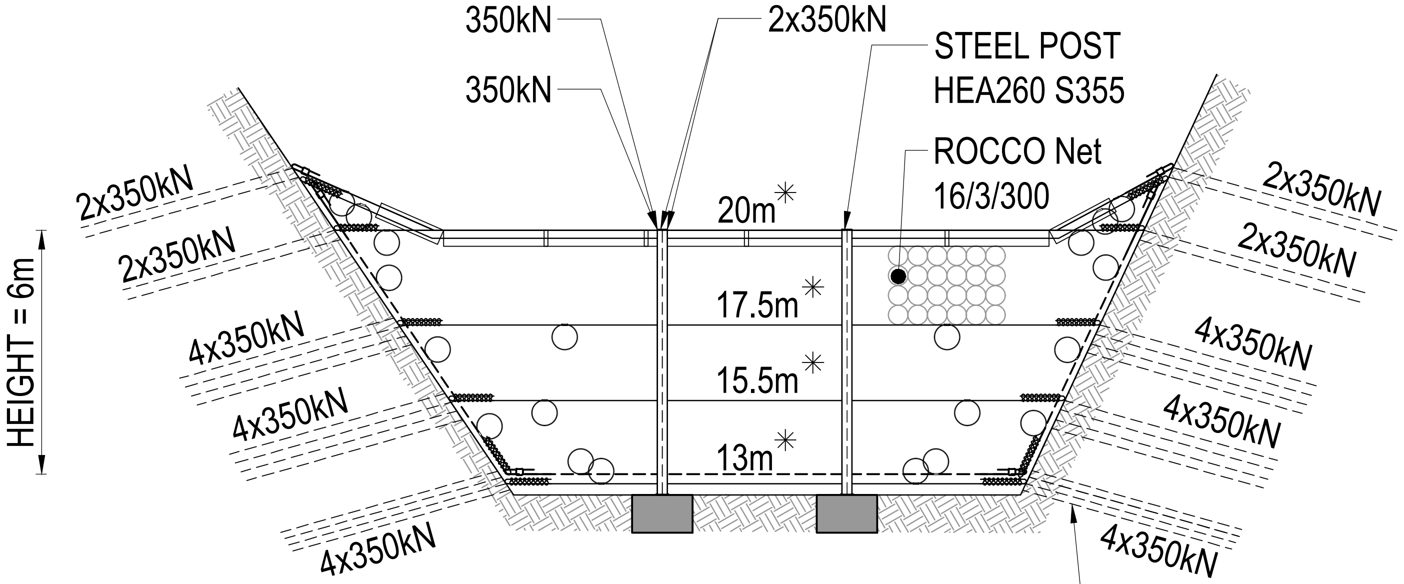
Debris flow fence solutions were sized for the Brewery Creek and Reavers fan catchments considering the results of the representative small return period debris flow events as modelled under Phases 1 and 2.

The following input parameters were supplied to Geobrugg:

- Debris flow density of 200kg/m^3, consistent with that used in the RAMMS:Debris Flow models.
- Release area volumes of 5650 m^3 for Brewery Creek Fan and 5550m^3 for Reavers Fan as derived from the representative small return period event modelled in RAMMS:Debris Flow.
- Number of surges = 1, as determined from time plots outlining the modelled peak flow over time in the representative RAMMS:Debris Flow model.
- Peak discharges of 135 m^3/s for Brewery Creek Fan and 260m^3/s for Reavers Fan as determined for cross-sectional profiles across the fan apex from the representative RAMMS:Debris Flow model.
- Peak flow velocity of 5m/s for Brewery Creek Fan and 10m/s for Reavers as determined from the cross-sectional profiles across the fan apexes in the representative RAMMS:Debris Flow model.
- Dry-Coulomb type friction (μ) of 0.2 for Brewery Creek Fan and 0.22 for Reavers Fan, consistent with that used in the RAMMS:Debris Flow models.
- Channel geometries were approximated from the field survey completed under Phases 1 and 2 and the 1m Hillshade model. The following dimensions were supplied:
  - **Brewery Creek Fan**
    - Cross-section location at the fan apex
      - Base width = 13 m
      - Upper width (i.e. top of U) = 20 m
      - Height = 6m
    - ~100m upstream of the fan apex
      - Base width = 6 m
      - Upper width (i.e. top of U) = 12 m
      - Height = 8m
  - **Reavers Fan**
    - Cross-section location at the fan apex
      - Base width = 12 m
      - Upper width (i.e. top of U) = 25 m
      - Height = 10m
    - ~100m upstream of channel mouth
      - Base width = 5 m
      - Upper width (i.e. top of U) = 18 m
      - Height = 8m

Concept designs of the debris flow barriers are included below. Geobrugg have assumed 1.5m basal openings for the upper barriers and 1.0m for the lowest barrier.

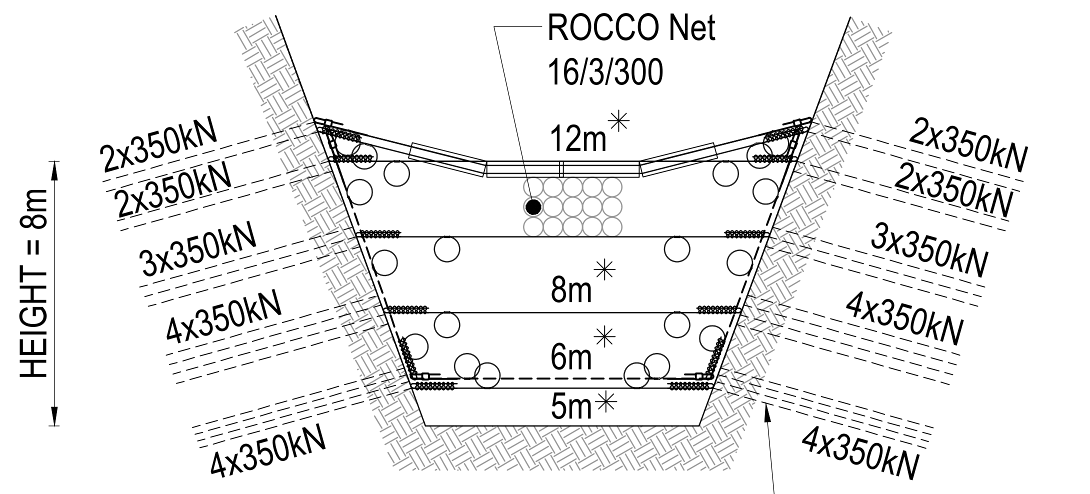
Drawing Plotted: 25 Feb 2021 4:27 p.m.



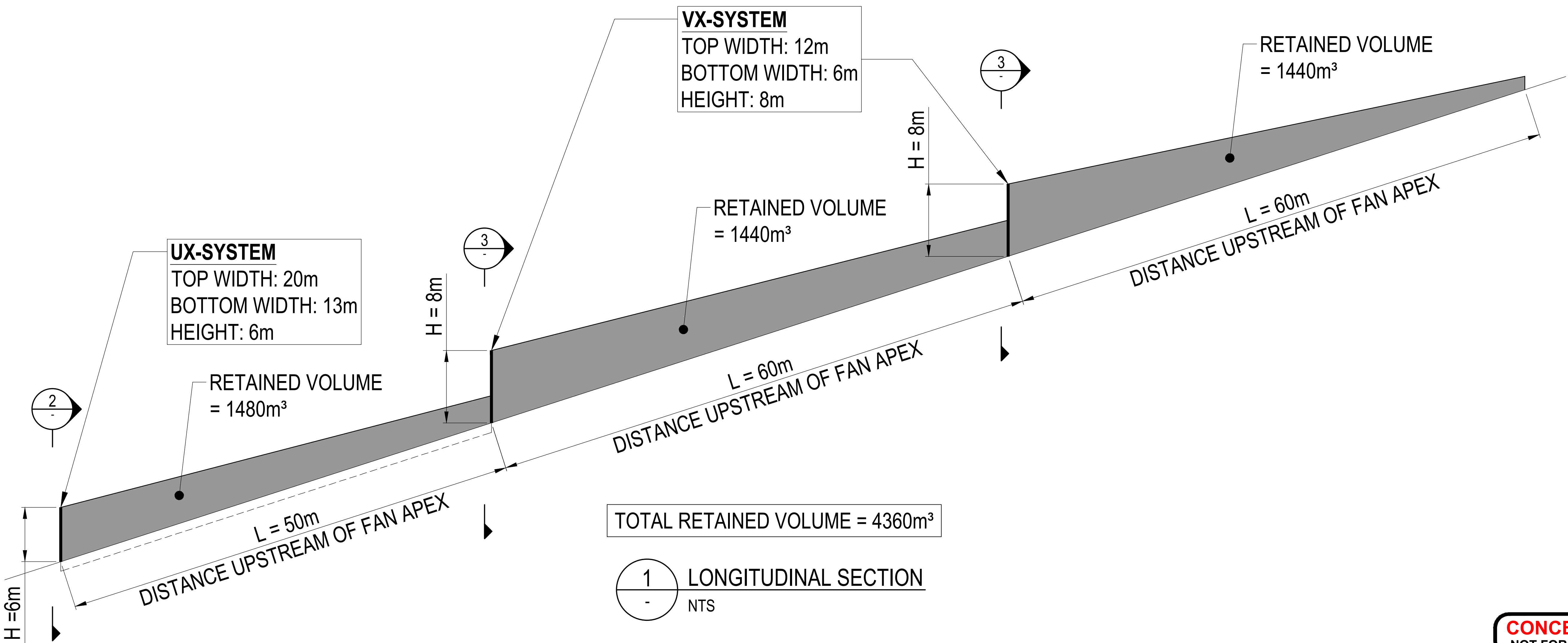
2 SECTION
NTS

LEGEND

✳ WIDTH



3 SECTION
NTS



TOTAL RETAINED VOLUME = 4360m³

1 LONGITUDINAL SECTION
NTS

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CONCEPT DESIGN
NOT FOR CONSTRUCTION

No.	Revision	By	Chk	Appd	Date
1	FINAL	JRO	AP	PH	01.21

Drawing Originator: Beca

Original Scale (A1) NTS	Design	S. BARRETT	12.20	Approved For Construction* N/A
Reduced Scale (A3) NTS	Drawn	J. OCAMPO	12.20	
	Dsg Verifier	A. PUNT	12.20	
	Dwg Check	P. HORREY	01.21	Date

* Refer to Revision 1 for Original Signature

Client: QUEENSTOWN LAKES DISTRICT COUNCIL

Project: GORGE ROAD ENGINEERING OPTIONS

Title: BREWERY CREEK FAN, DEBRIS FENCE OPTION 1

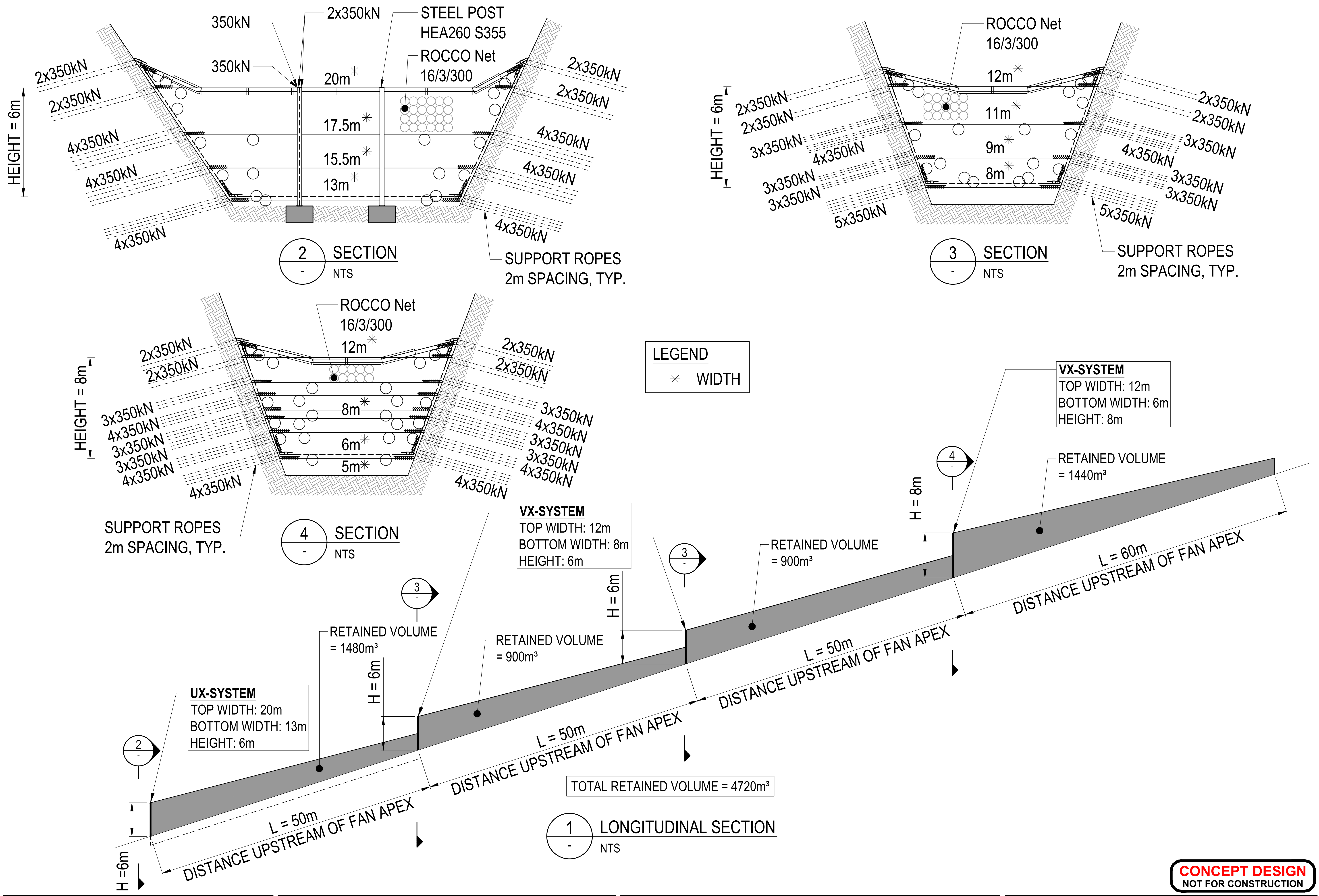
Discipline: GEOTECHNICAL

Drawing No. 3209881-B001 Rev. 1

Document No. 3209881-B001.DWG

DO NOT SCALE

IF IN DOUBT ASK.



No.	Revision	By	Chk	Appd	Date
1	FINAL	JRO	AP	PH	01.21

Drawing Originator: Beca

Original Scale (A1)	NTS	Design	S. BARRETT	12.20	Approved For Construction*
Reduced Scale (A3)	NTS	Drawn	J. OCAMPO	12.20	N/A
		Dsg Verifier	A. PUNT	12.20	
		Dwg Check	P. HORREY	01.21	Date

* Refer to Revision 1 for Original Signature

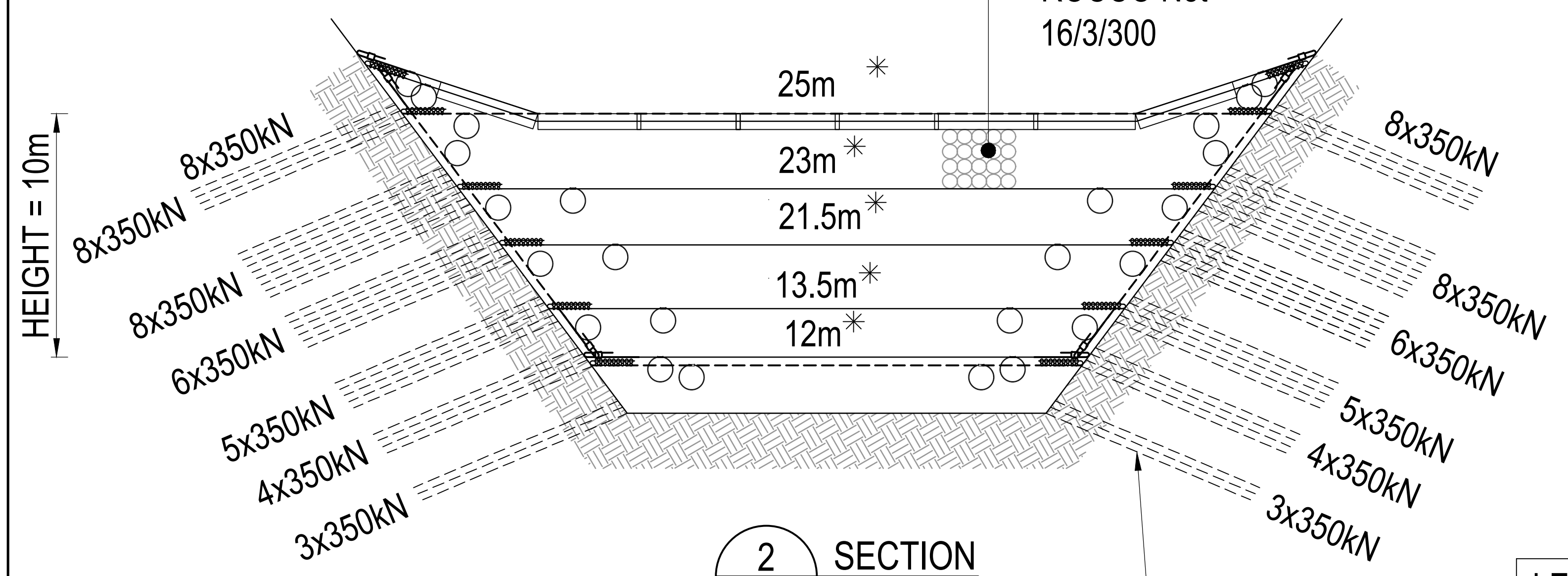
Client: QUEENSTOWN LAKES DISTRICT COUNCIL

Project: GORGE ROAD ENGINEERING OPTIONS

Title: BREWERY CREEK FAN, DEBRIS FENCE OPTION 2

Discipline: GEOTECHNICAL

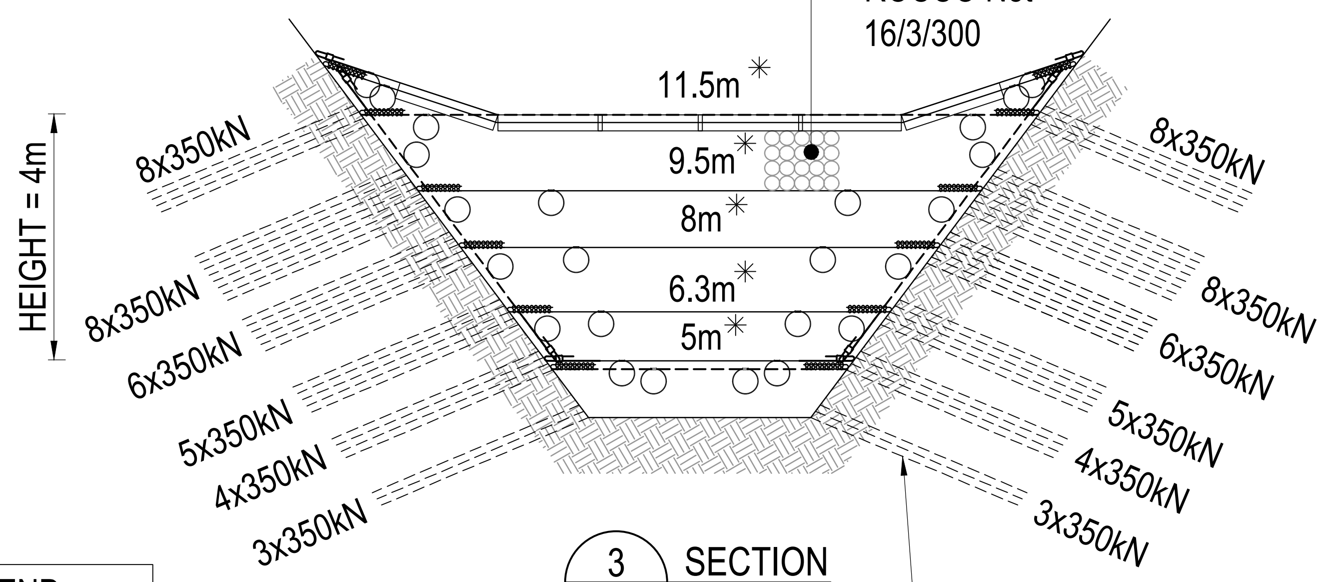
Drawing No.: 3209881-B002 — Rev.: 1



2 SECTION
NTS

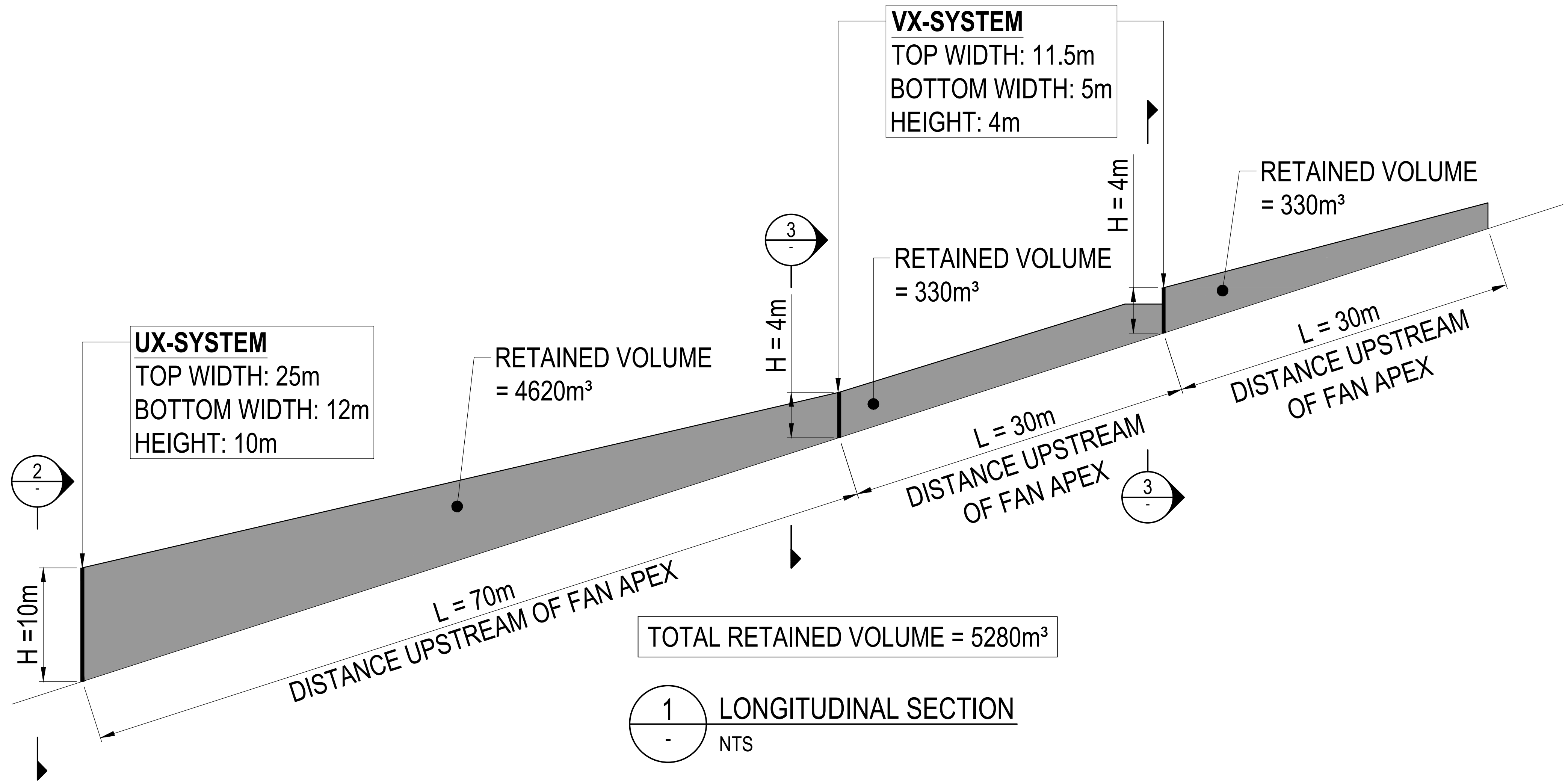
SUPPORT ROPES
2m SPACING, TYP.

LEGEND	
✳	WIDTH



3 SECTION
NTS

SUPPORT ROPES
2m SPACING, TYP.



TOTAL RETAINED VOLUME = 5280m³

1 LONGITUDINAL SECTION
NTS

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CONCEPT DESIGN
NOT FOR CONSTRUCTION

No.	Revision	By	Chk	Appd	Date
1	FINAL	JRO	AP	PH	01.21

Drawing Originator: Beca

Original Scale (A1) NTS	Design	S. BARRETT	12.20	Approved For Construction*
Reduced Scale (A3) NTS	Drawn	J. OCAMPO	12.20	N/A
	Dsg Verifier	A. PUNT	12.20	
	Dwg Check	P. HORREY	01.21	Date

* Refer to Revision 1 for Original Signature

Client: QUEENSTOWN LAKES DISTRICT COUNCIL

Project: GORGE ROAD ENGINEERING OPTIONS

Title: REAVERS FAN, DEBRIS FENCE

Discipline: GEOTECHNICAL

Drawing No.: 3209881-B003 Rev.: 1

Document No. 3209881-B003.DWG

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C

Appendix C – Rockfall

Rockfall Fences

Locations of the rockfall fences were assessed from the rockfall trajectories modelled using RAMMS:Rockfall under Phases 1 and 2 of this study and outlined in Beca's report *Natural Hazards Affecting Gorge Road, Queenstown* (reference NZ1-16638194-3 2.0, 12 November 2020). The proposed fence lengths were determined from the extent over which the modelled rockfall trajectories entered the study area. An additional 20m was added to the length at each end where the local topography and outcrop orientations suggest that rockfall trajectories may continue outside of that modelled.

Fence heights and impact ratings were determined for the study in accordance with MBIE (2016) which outlines design guidelines for passive rockfall protection structures. The assessment adopted a Maximum Energy Level (MEL) design condition. The fence height and impact rating calculations were as follows:

- Fence heights were calculated based on the following equation (MBIE, 2016)

  Fence height (m) = Q95 jump height (m) + boulder radius (m) + clearance height (m)

  - Where:
    - The 95th percentile (Q95) jump height of rockfall trajectories passing the proposed rockfall fence was determined using the 'Barrier Plot' tool in RAMMS:Rockfall. A Barrier Plot was constructed along the proposed length of the rockfall fence and summarises the statistical distribution of the jump heights of rocks intersecting the barrier.
    - Boulder radius and clearance height (equal to the boulder radius) were adopted from the input parameters of the RAMMS:Rockfall modelling conducted during the previous phase of work. Modelling utilised the 'Real_Flat_1.8' rock shape with dimensions of 1.8m*1.5m*1.0m. A boulder radius of 0.75m was selected as the design parameter based on review of the RAMMS rockfall modelling trajectories, showing the primary boulder rotation axis was 1.5m diameter, giving a boulder radius of 0.75m.

- The impact design rating of the fence was determined from:

  Fence rating (MEL) = Q95 kinetic energy (SEL, kJ) * 3

  - Where:
    - The 95th percentile kinetic energy was determined from the Barrier plot placed along the proposed location of the rockfall fence. The plot summarises the statistical distribution of kinetic energies of rocks intersecting or passing through the barrier plot.
    - The 95th percentile kinetic energy of boulders intersecting the proposed fence location is equivalent to the Service Energy Level (SEL), which is multiplied by three to determine the MEL in accordance with MBIE (2016).

The resulting fence design parameters are shown in Table C1. Concept designs of the rockfall fence options, including ranges in the fence length, height, and design ratings, are outlined below.

Table C1 - Rockfall fence design parameters

Fan	Location (bank)	Q95 Jump height (m)	Q95 Kinetic Energy (kJ)	Boulder radius (m)	Design height (m)	Design rating (kJ)	Length (m)
Brewery	True Left	1.1	88	0.75	3	300	125
Brewery	True Right	1.0	79	0.75	3	300	115
Reavers	True Left	1.2	111	0.75	2.7	400	255
Reavers	True Right	2.3	303	0.75	3.8	1000	185

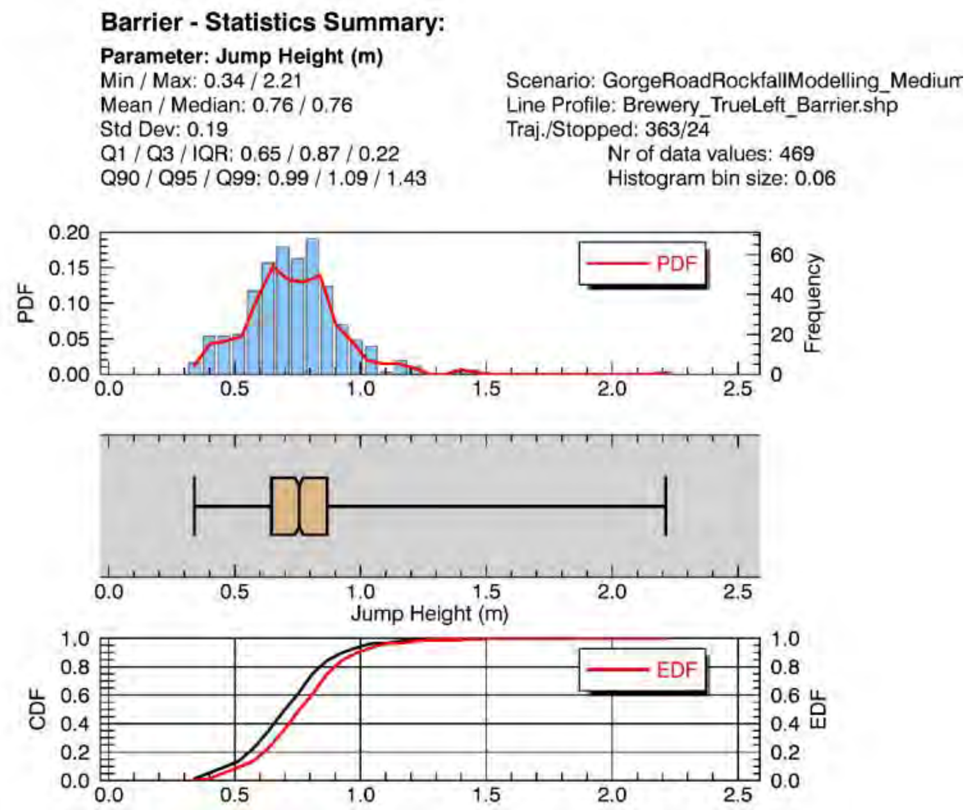


Figure C 1 - Barrier plot showing bounce heights of modelled rockfall trajectories intersecting the proposed location of the rockfall fence on the hillslope to the true left of Brewery Creek (drawing 3209881-C001).

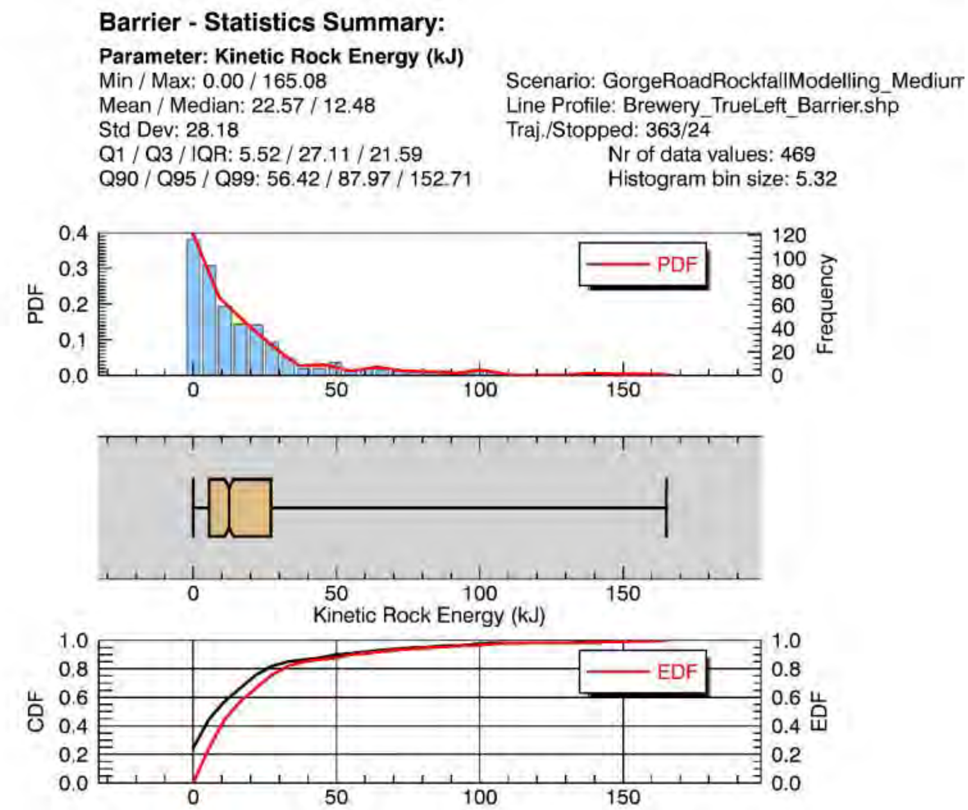


Figure C 2 - Barrier plot showing kinetic energy of modelled rockfall trajectories intersecting the proposed location of the rockfall fence on the hillslope to the true left of Brewery Creek (drawing 3209881-C001).

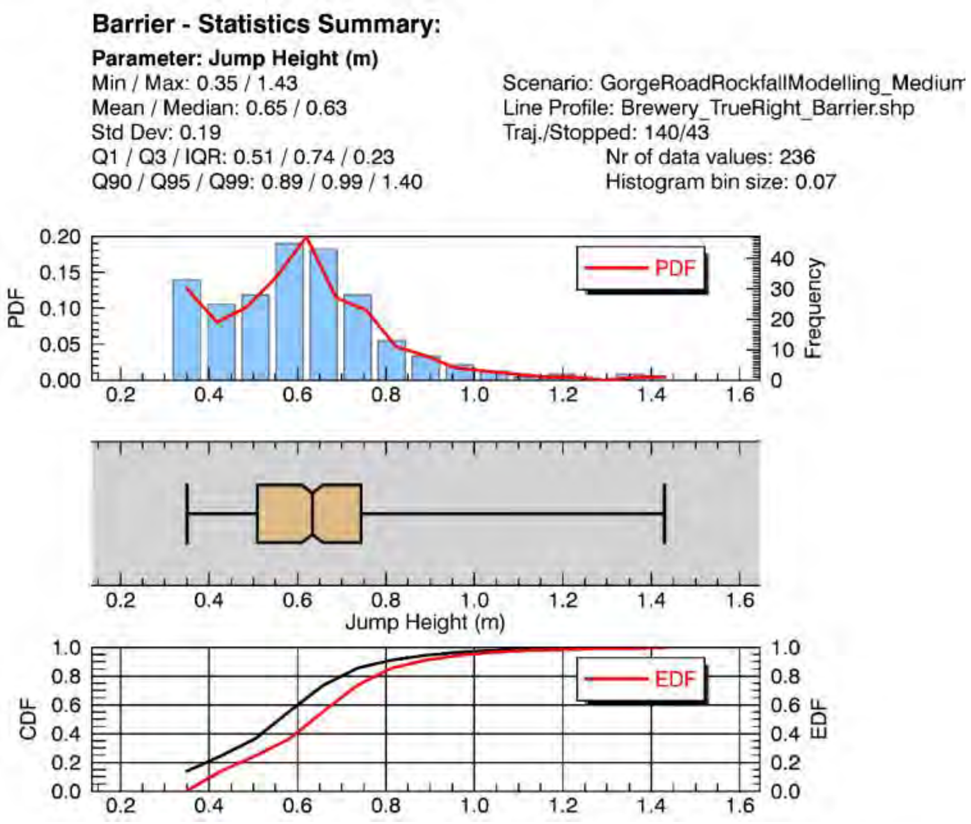


Figure C 3 - Barrier plot showing bounce heights of modelled rockfall trajectories intersecting the proposed location of the rockfall fence on the hillslope to the true right of Brewery Creek (drawing 3209881-C001).

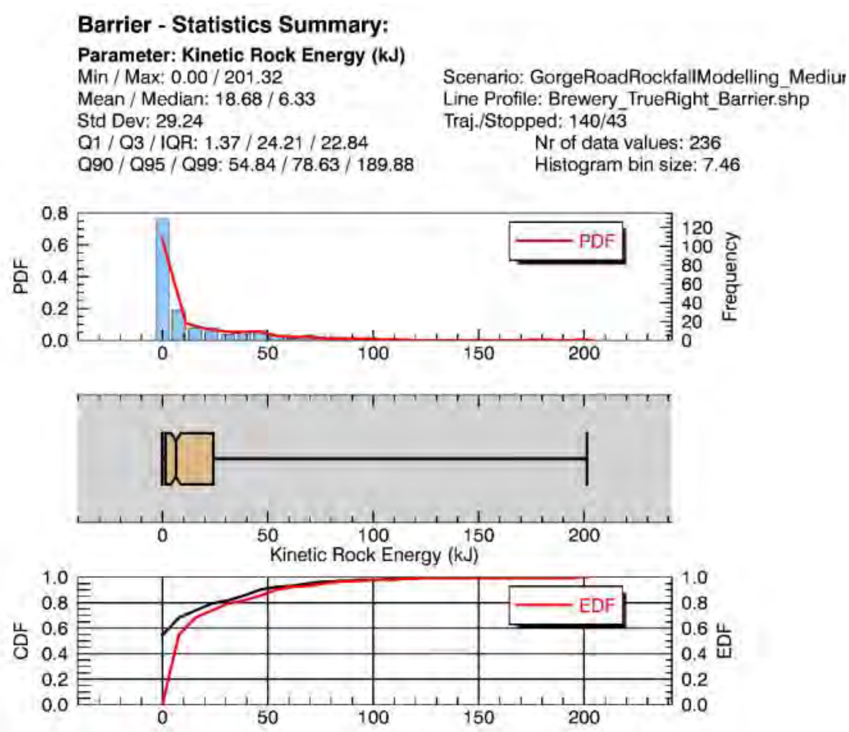


Figure C 4 – Barrier plot showing kinetic energy of modelled rockfall trajectories intersecting the proposed location of the rockfall fence on the hillslope to the true right of Brewery Creek (drawing 3209881-C001).

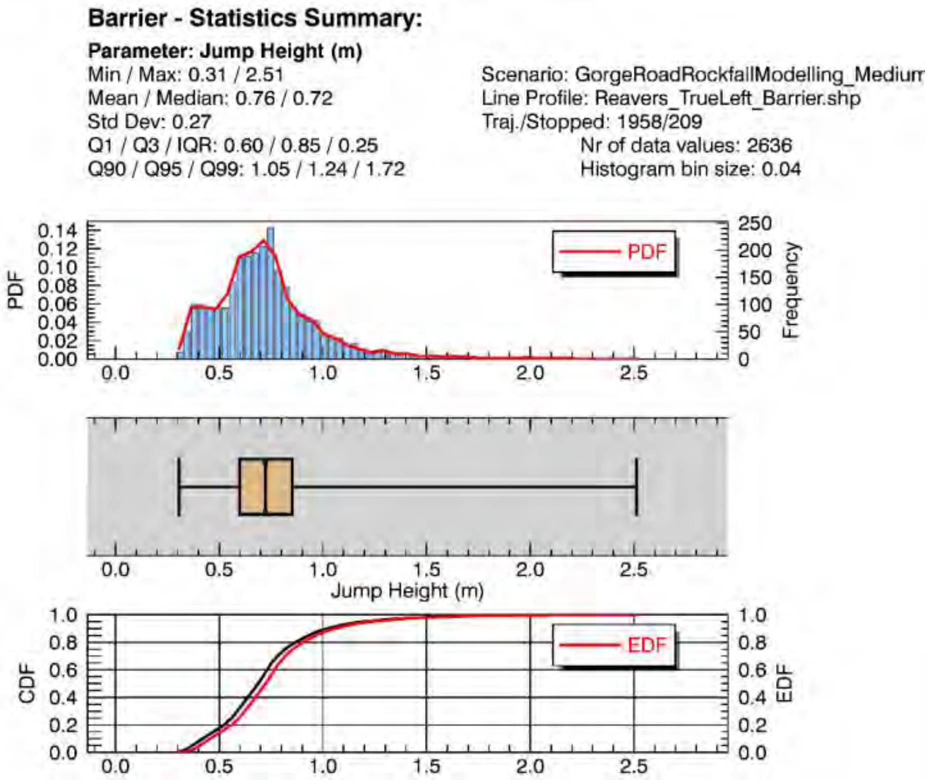


Figure C 5 - Barrier plot showing bounce heights of modelled rockfall trajectories intersecting the proposed location of the rockfall fence on the hillslope to the true left of Reavers fan (drawing 3209881-C002).

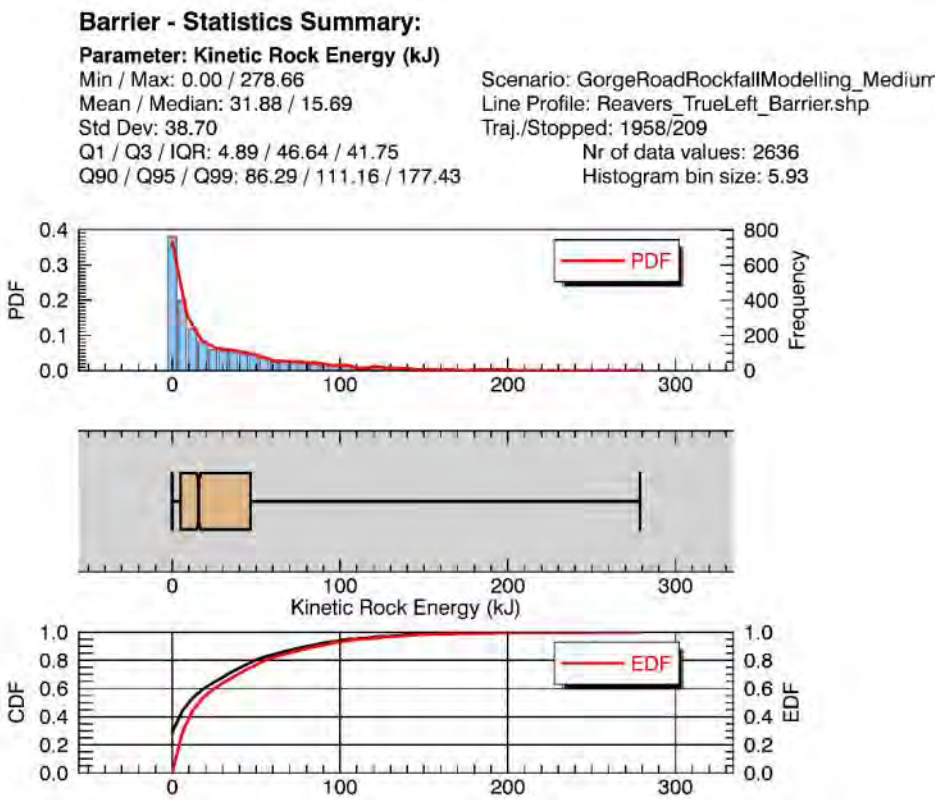


Figure C 6 - Barrier plot showing kinetic energy of modelled rockfall trajectories intersecting the proposed location of the rockfall fence on the hillslope to the true left of Reavers Fan (drawing 3209881-C002).

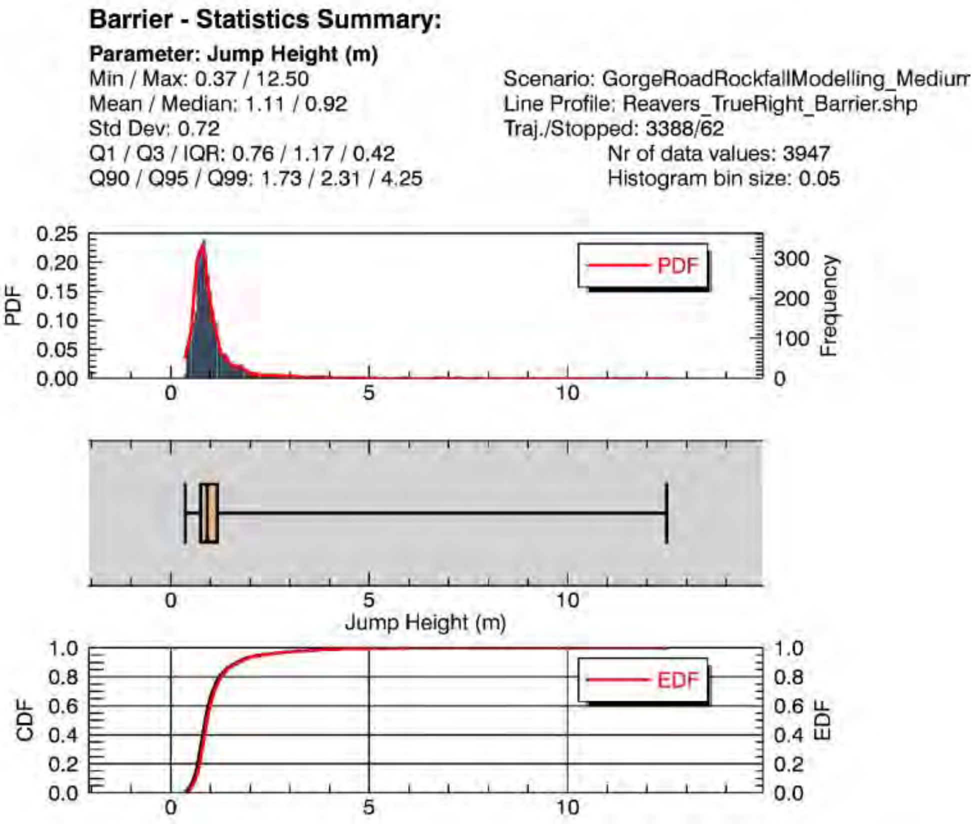


Figure C 7 - Barrier plot showing bounce heights of modelled rockfall trajectories intersecting the proposed location of the rockfall fence on the hillslope to the true left of Reavers Fan (drawing 3209881-C002).

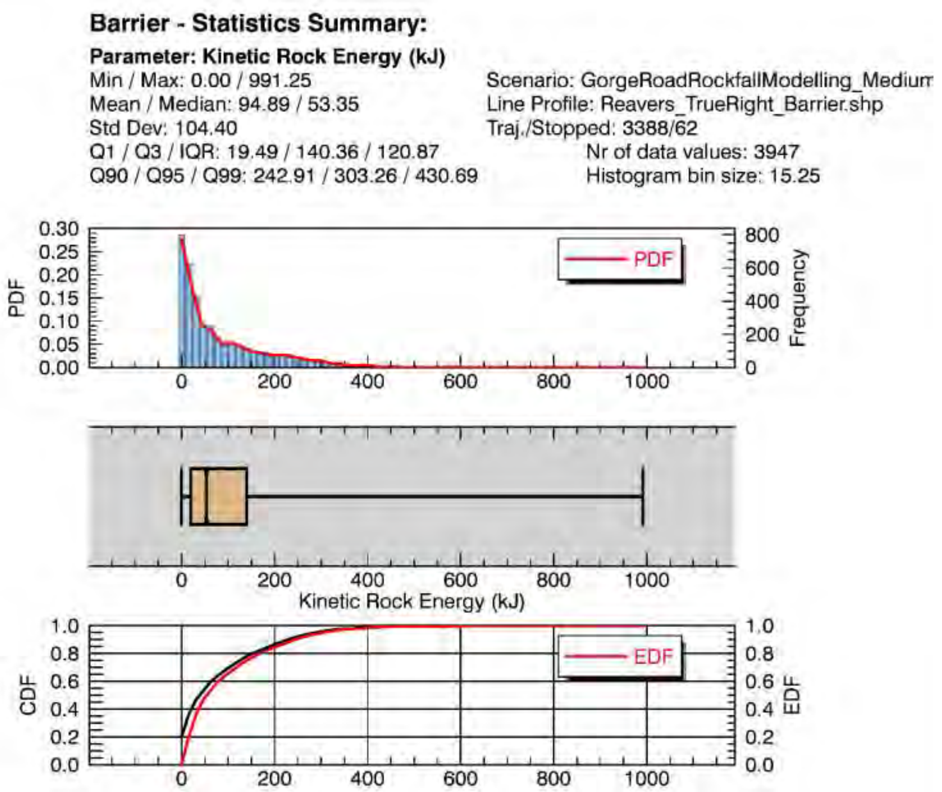
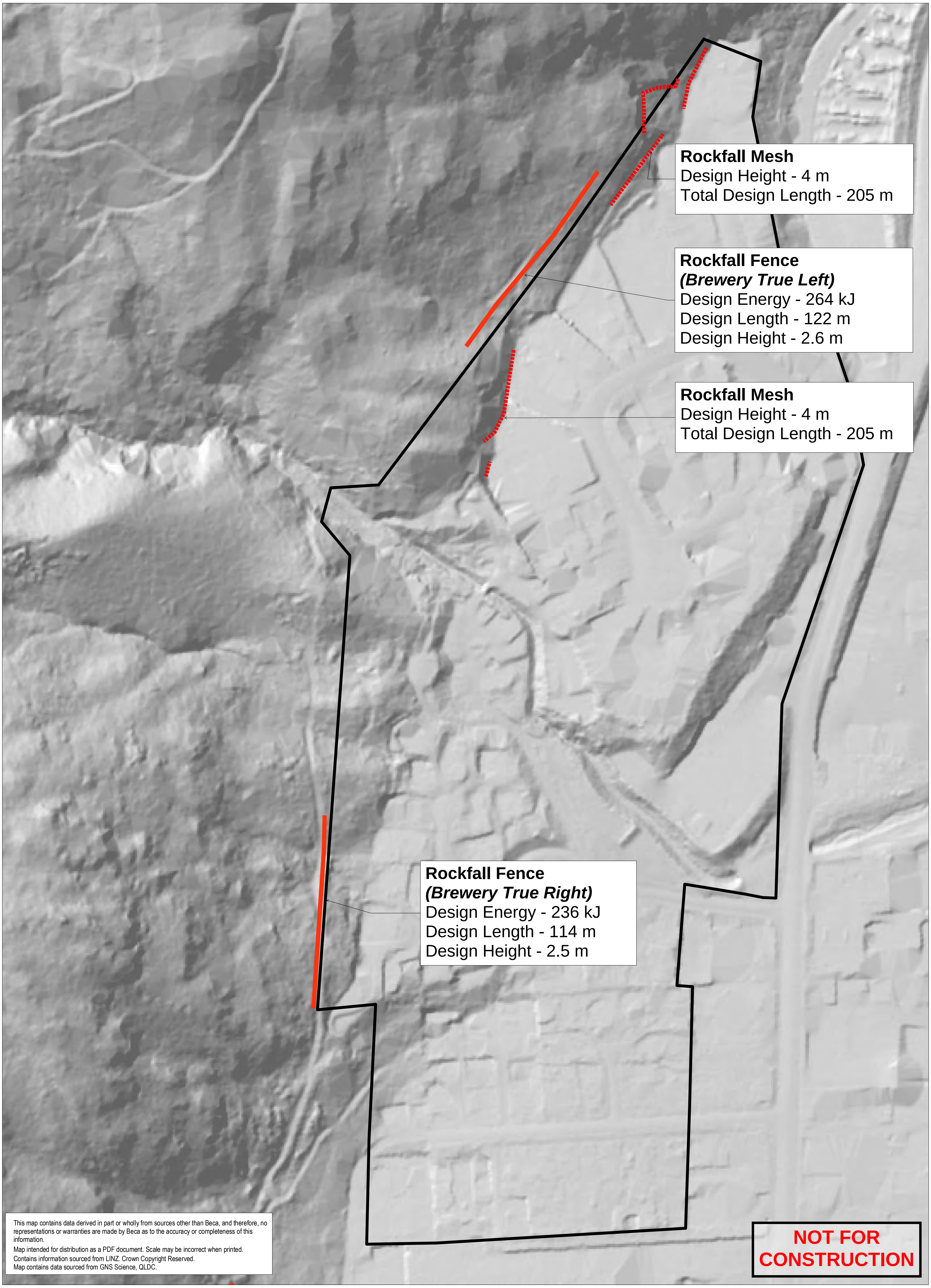


Figure C 8 - Barrier plot showing kinetic energy of modelled rockfall trajectories intersecting the proposed location of the rockfall fence on the hillslope to the true right of Reavers fan (drawing 3209881-C002).



Map Scale @ A3: 1:2,000

0 40 80

Metres

Revision	Author	Verified	Approved	Date
1 - Final	SB	AP	PH	21/01/2021

Title: **Brewery Creek Fan Rockfall Mitigation**

Client: Queenstown Lakes District Council

Project: Natural Hazards Affecting Gorge Road

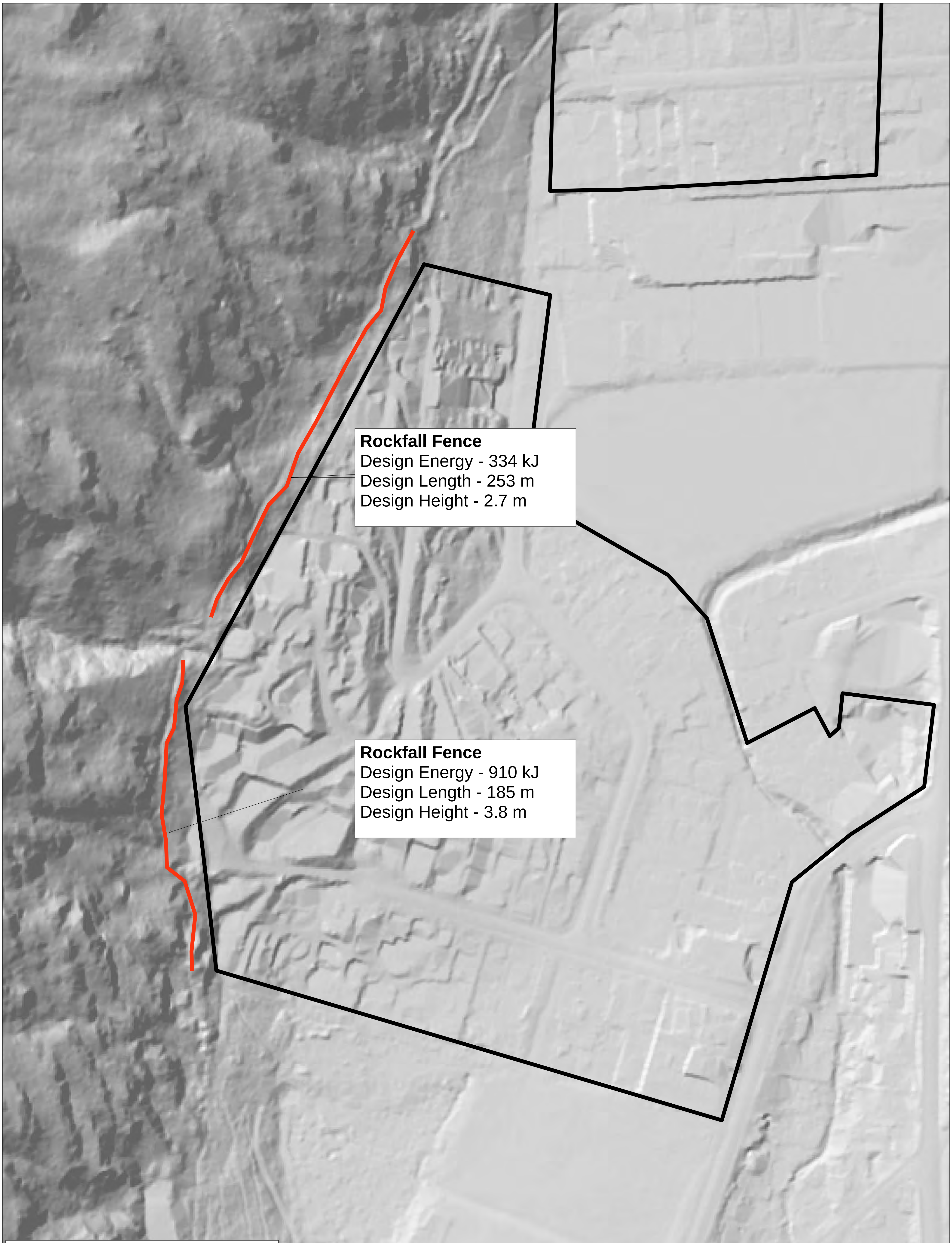
N

Beca

Discipline: GIS

Drawing No: 3209881-C001

File: \\beca.net\projects\320\3209881\200 - Engineering Options\Maps\Working\Working_Brewery_Rockfall.mxd Author: SHB Date: 18/12/2020



NOT FOR CONSTRUCTION

Map Scale @ A3: 1:2,000

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Metres

Revision	Author	Verified	Approved	Date
1 - Final	SB	AP	PH	21/01/2021

Title: Reavers Fan Rockfall Mitigation

Client: Queenstown Lakes District Council

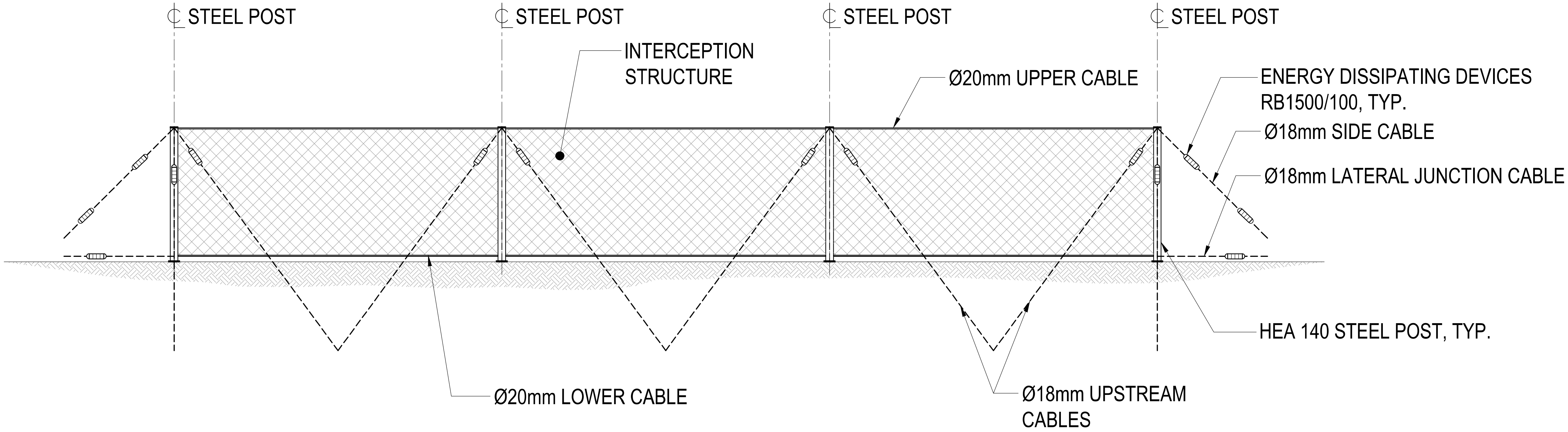
Project: Natural Hazards Affecting Gorge Road

N

Beca

Discipline: GIS

Drawing No: 3209881-C002



1 / - ROCKFALL FENCE TYPICAL ELEVATION

NTS

FAN	MODEL LOCATION	METHOD	DESIGN HEIGHT (m)	DESIGN RATING (kJ)	LENGTH (m)
BREWERY	TRUE LEFT	FENCE	3.0	300	125
BREWERY	TRUE RIGHT	FENCE	3.0	300	115
REAVERS	TRUE LEFT	FENCE	3.0	400	255
REAVERS	TRUE RIGHT	FENCE	4.0	1000	185

NOT FOR CONSTRUCTION

No.	Revision	By	Chk	Appd	Date
1	FINAL - CONCEPT SKETCH	JRO	AP	PH	02.21

Drawing Originator: Beca

Original Scale (A1): NTS
Reduced Scale (A3): NTS

Design	S. BARRETT	12.20	Approved For Construction* N/A
Drawn	J. OCAMPO	12.20	
Dsg Verifier	A. PUNT	12.20	
Dwg Check	P. HORREY	01.21	Date

* Refer to Revision 1 for Original Signature

Client: QUEENSTOWN LAKES DISTRICT COUNCIL

Project: GORGE ROAD ENGINEERING OPTIONS

Title: ROCKFALL FENCE DETAILS

Discipline: GEOTECHNICAL

Drawing No.: 3209881-C003 Rev.: A

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Document No. 3209881-C003.DWG

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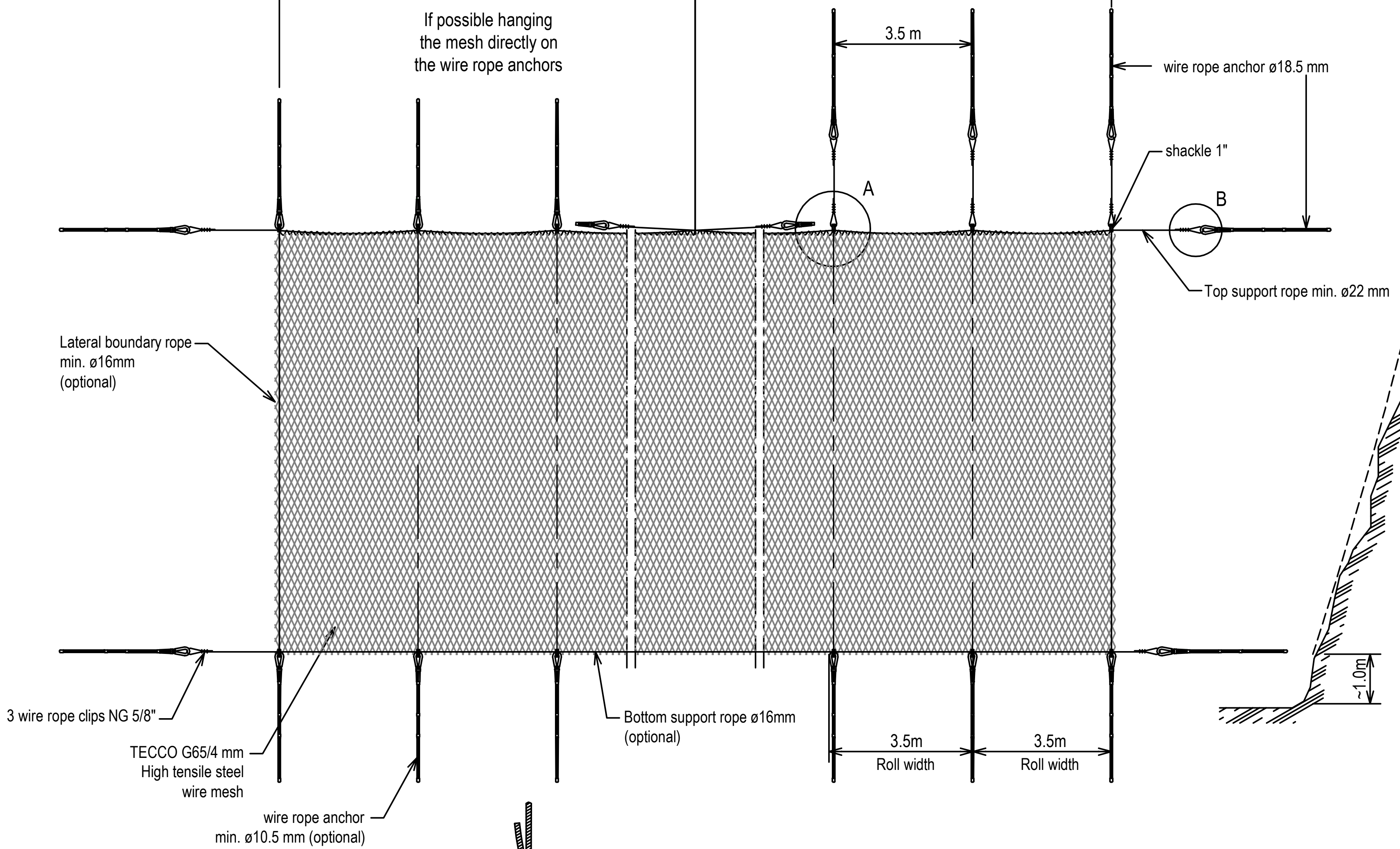
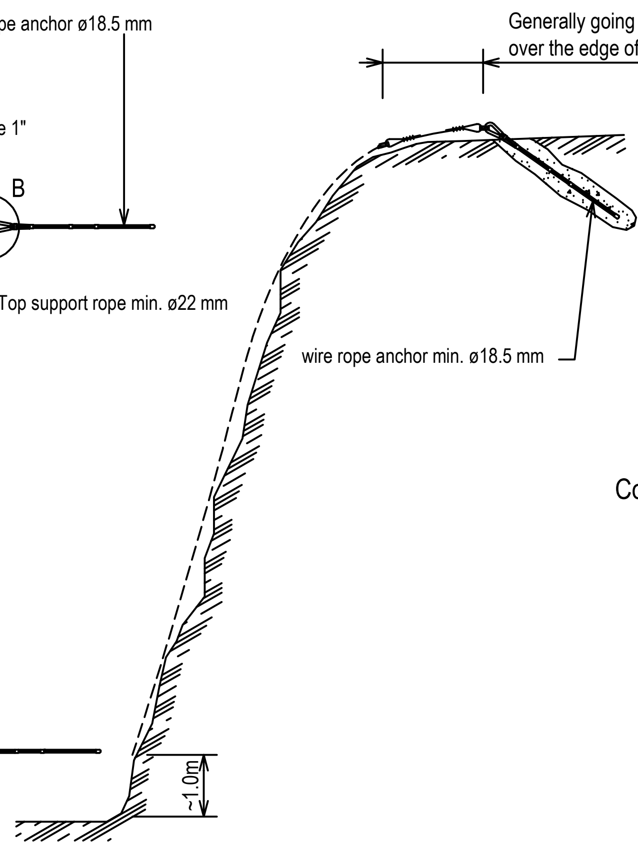


Cross section



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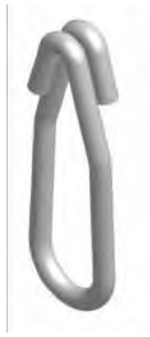

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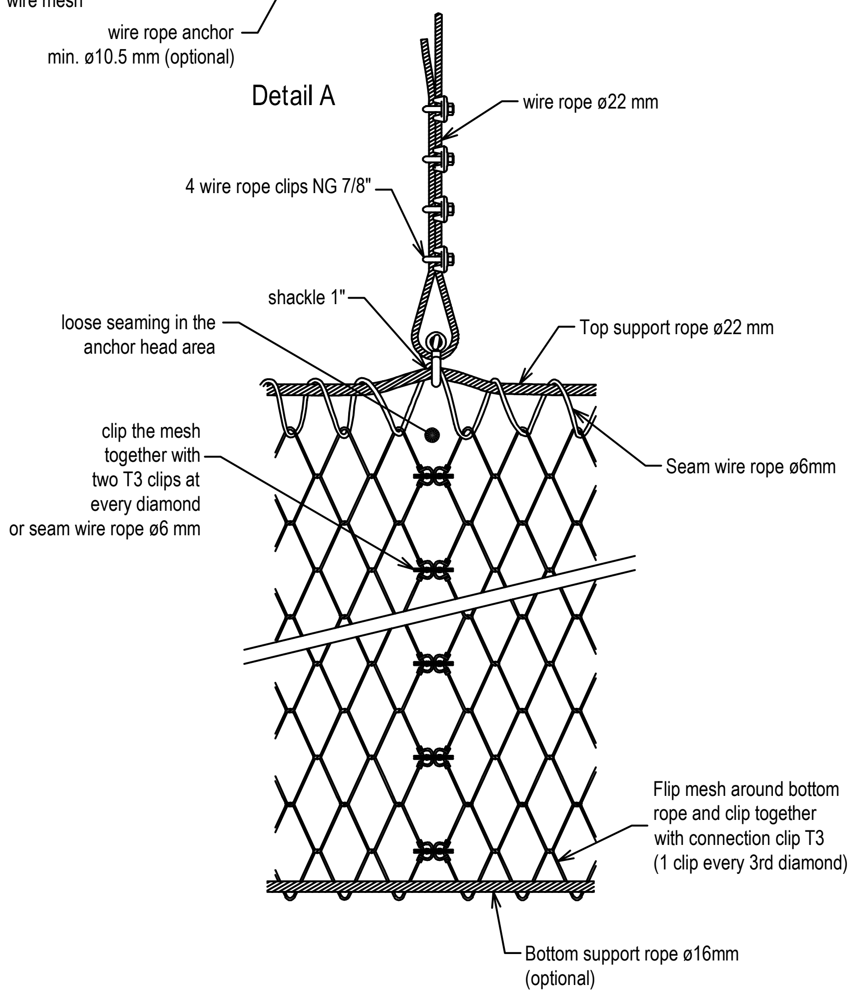
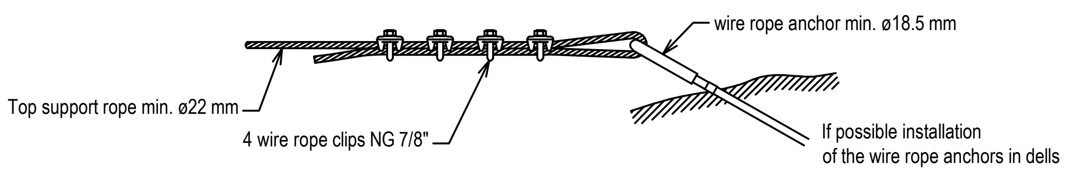


Detail B



NOT FOR CONSTRUCTION

modification:	M:%	substitute for: GS-1042e ed. 10.12.18
-		replaced by:

TECCO rockfall drape
TECCO G65/4 mm
System drawing

drawn	05.02.19	BIH
checked	05.02.19	BIH
edition	05.02.19	ROA1

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GS-1186e

D

Appendix D – Supplier Case Studies

Mitigation Options Case Studies

A series of supplier case studies are presented overleaf, detailing examples of the mitigation options proposed in this report. A brief summary of individual options case studies is detailed below.

Debris Flow Channels

Debris flow channels are generally considered the preferred approach for debris flow mitigation in order to minimise damage (Xiong et al, 2016; Golder, 2019). Examples in New Zealand of channelised include:

- Construction of flanking dykes within an existing channel to create the debris flow storage volume at Glencoe Stream, Mt Cook village (Skermer et al, 2002). A design debris flow magnitude of 100,000m^3 was adopted, with a peak discharge of 280m^3/s. These works allowed for zoning allocation leading to controlled development on the fan.
- Excavation of the existing channels, deflection levees and training levees have been proposed as the preferred engineering options for three priority channels in Roxburgh, following the 2017 debris flow events (Golder, 2019). As the primary driver for these works was in relation to the SH8 crossing, the proposed options considered a design of 1/100 year event to meet the NZ Transport Agency requirements.

Debris Flow Fences

Several debris flow fences have been installed to date in New Zealand, with hundred installed globally (Geobrugg, personal communications, 2021). Examples in New Zealand include:

- Four fences in separate locations along the SH1/Coastal Pacific Rail as part of the 2016 Kaikoura earthquake recovery
  - 4m high, VX debris flow barrier, combined with ring mesh tail for easier clearing and reduced maintenance.
  - 2m high, 10m long VX modified debris flow barrier with ring mesh tail.
  - 3.5m high debris flow barrier with 150kN/m^2 load capacity.
  - 3.5m high, 126m long debris flow barrier.
- VX debris flow barrier at SH65 near Shenandoah (below).

- Additional smaller barriers currently under construction at Transmission Gully north of Wellington.

Rockfall fences

Rockfall fences have been installed extensively in New Zealand to reduce rockfall risk. A residential example from Whakatane of similar height and capacity to the Brewery and Reavers Fan options is included in Appendix D.

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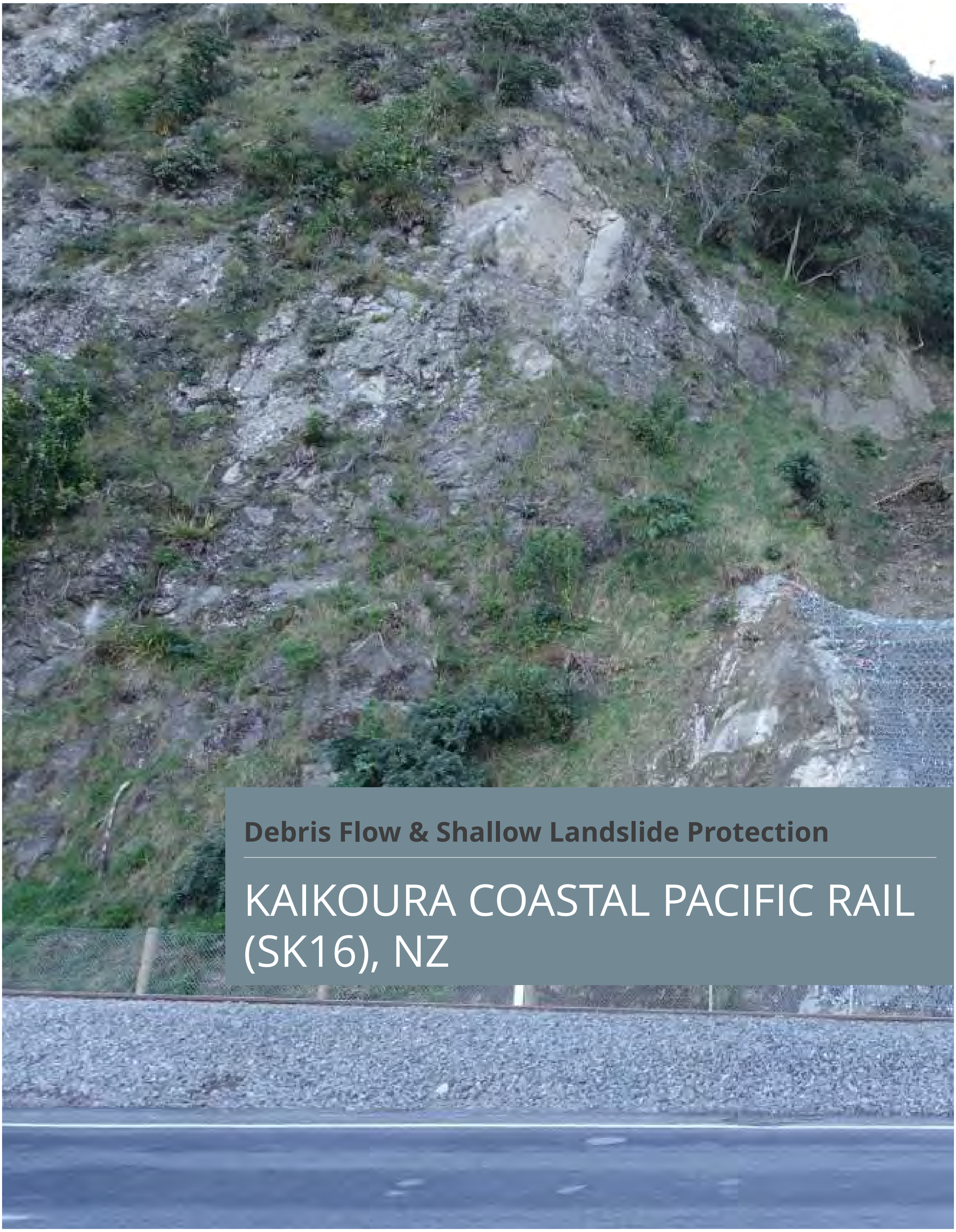

Debris Flow & Shallow Landslide Protection

KAIKOURA COASTAL PACIFIC RAIL (SK16), NZ

KAIKOURA COASTAL PACIFIC RAIL (SK16)

Debris Flow & Shallow Landslide Protection

Project	Kaikoura Coastal Pacific Rail (SK16)
Place	Peketa Kaikoura
Country/Region	New Zealand
Year of installation	2019
Customer	KiwiRail
Contractor	Rock Control
Initial situation	The Kaikoura M7.8 Earthquake caused widespread damage to the road and rail corridor for 20 km North and South of the Kaikoura township. Over 40 major slips inundated the road and rail with more than 750'000 m³ of material from source zones up to 500 m above sea level. The highly fractured Grey Wacke meant frequent future rockfalls and debris loads were expected. The high rockfall and debris load frequency created the requirement for a Geohazard Solution that attenuated the energy to a manageable level and then guided the material down to a catchment area. Space was limited due to the proximity of the Coastal Pacific rail line. The SK16 site is a narrow, incised catchment that extends about 150 m above road/rail level. The slope angle is about 50-55 degrees.
Description	A 10 meters wide VX080-H2 debris flow barrier was modified to include a 12 meters 16/3/300 ROCCO ring net tail. This system enabled the rockfall and debris energy to be attenuated and guided down to a catchment area at the toe of the slope for easier clearing and reduced maintenance. Additional support ropes were also installed across the channel to minimise deflection onto the railway. The installation required abrasion protection on the top ropes due to the potential of it being overtopped in above design large events. TECCO® G65/3 was used as a secondary mesh as a robust solution was required to avoid puncturing failures from the high frequency of smaller high-velocity rocks.
Protected object	Railway
Systems	VX, TECCO® G65/3, Special Solutions
Corrosion protection	GEOBRUGG SUPERCOATING®
System height	2.0 m
System length	2 m - 10 m
Retention capacity	n/a m³

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Looking South - VX080-H2 debris flow barrier with 16/3/300 ROCCO® ringnet tail.

Looking upslope - VX080-H2 debris flow barrier with 16/3/300 ROCCO ringnet tail. Note abrasion protection on the top ropes.

Looking upslope - VX080-H2 debris flow barrier with 16/3/300 ROCCO® ringnet tail under construction.

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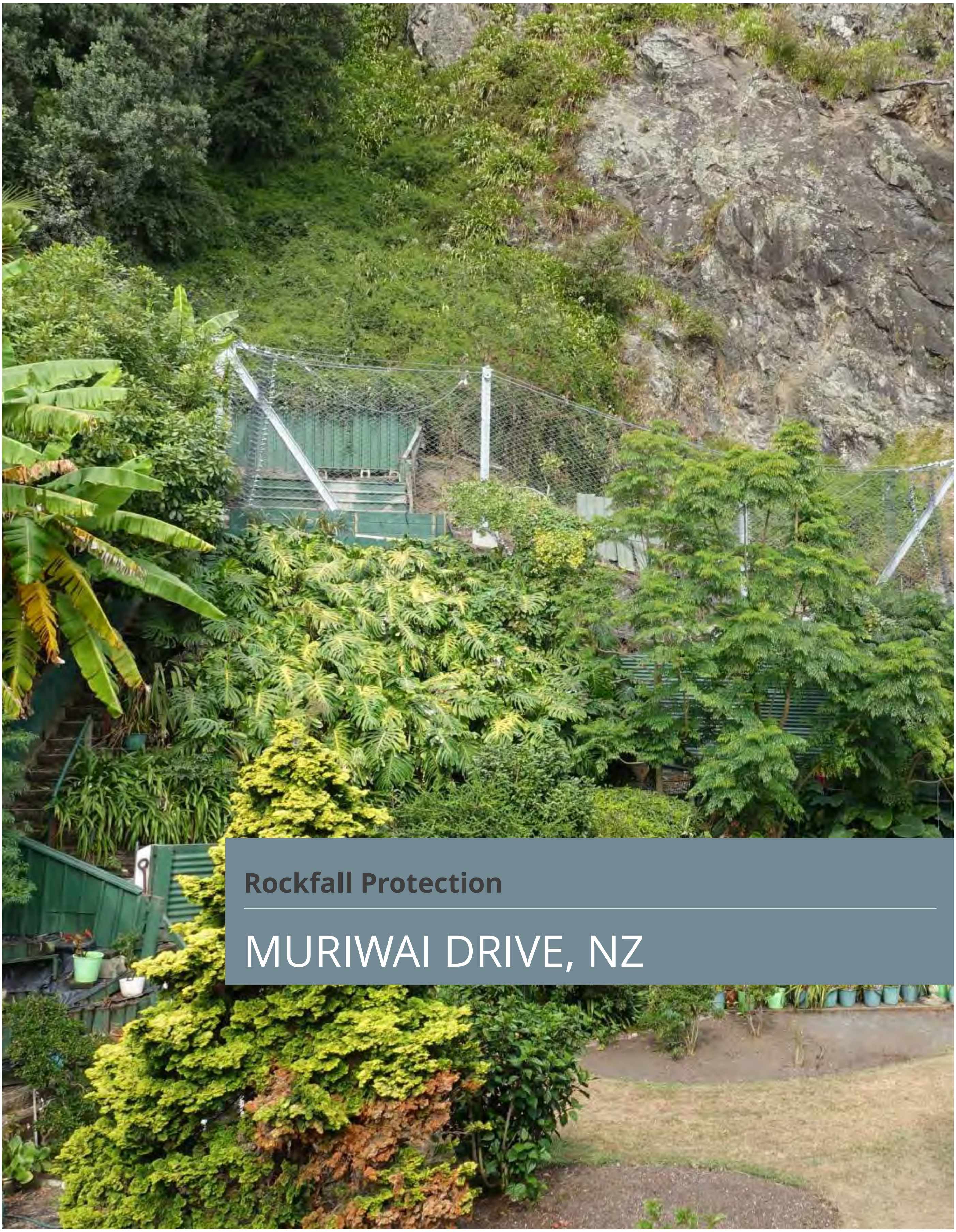

Rockfall Protection

MURIWAI DRIVE, NZ

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MURIWAI DRIVE

Rockfall Protection

Project	Muriwai Drive
Location	Whakatane
Country/Region	New Zealand
Year of installation	2019
Customer	Private
Contractor	Rock Control, www.rockcontrol.co.nz
Initial situation	A rock and tree fall hazard on an existing property created the requirement for a custom rockfall barrier. The site was narrow (17 m wide), had difficult access and no flat alignments.
Description	The system selected was a 16 m long, 3 m high GBE-1000A-R with pressure posts, drag nets and a gap fill kit. Below is a list of custom features: Fixed Post - no upslope anchors due to proximity of alignment to property boundary Pressure Posts - no lateral anchors meant barrier could be installed over full property width Drag Nets - enabled the shorter barrier to have the required deflection to absorb the 1000 kJ energy event Gap Fill Kit - enabled the barrier to contour the difficult alignment
Protected object	Building
Systems	GBE-1000A-R
Corrosion protection	GEOBRUGG SUPERCOATING®, GEOBRUGG ULTRACOATING®
Energy absorption capacity	1000 kJ
System height	3.0 m
System length	16 m

Close up of post base - note drag net and proximity to property boundary

Looking north - fence allignment and gap fill kit

E

Appendix E – Revised Debris Flow Modelling

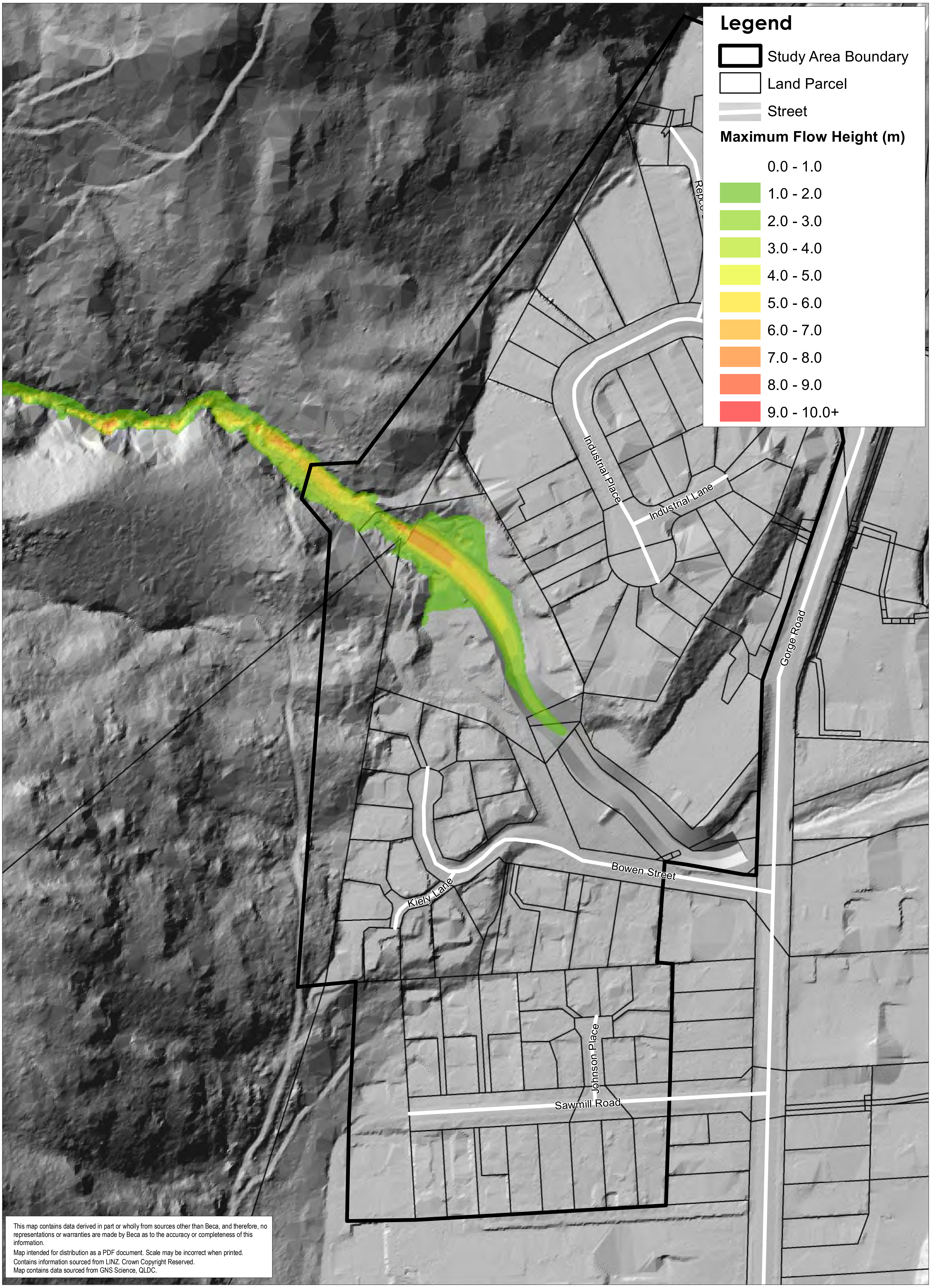
Revised Debris Flow Models

Selected debris flow models used in the initial AIFR calculations were re-run using the 1m Hillshade DEM modified to incorporate the morphology of the debris flow mitigation channels, as summarised in Table E 1. Modelling aimed capture changes in the flow paths, heights, and velocities of the debris flows compared to the initial modelling for representative return period ranges. The DEM was modified in 12d using the channel dimensions identified from concept design and summarised in Appendix A – Debris Flow Channel Design. The remainder of the input parameters were kept consistent with the initial modelling.

Table E 1 - Summary of debris flow models re-run to consider the debris flow mitigation channel

Fan	Return Period Range (years)	Scenario	Peak Flow	Time since release (seconds)
Brewery Creek Fan	50 - 200	Release Area 2 1m release depth 1m erosion depth 5,650m^3 release volume	135.38 m^3/s over ~20m wide area	105
	200 - 2,500	Release Area 3 4m release depth 2m erosion depth 74,200m^3 release volume	1488.54m^3/s over ~30m wide area	65
	2,500 – 10,000	Release Area 5 5m release depth 2m erosion depth 163,000m^3 release volume	3176.67 m^3/s over ~35m wide area	55
Reavers Fan	100 – 2500	Release Area 1 1m release depth 1m erosion depth 5560m^3 release volume	263.54m^3/s over ~17m wide area.	70
	2,500 – 6,700	Release Area 1 3m release depth 1m erosion depth 16,685m^3 release volume	714.59/s over ~20m wide area	55
	6,700 – 20,000	Release Area 5 5m release depth 2m erosion depth 98,330m^3 release volume	5709.52m^3/s over ~35m wide area	55

Results of the initial and revised modelling are shown in Appendix E – Revised Debris Flow Modelling.



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Map Scale @ A3: 1:2,000

0 40 80

Metres

Revision	Author	Verified	Approved	Date
1 - Final	SB	AP	PH	21/01/2021

Title:

Brewery Creek
Debris Flow Channel Modelling
Scenario 2: 50-200 yr Forested Source Area

Client: Queenstown Lakes District Council

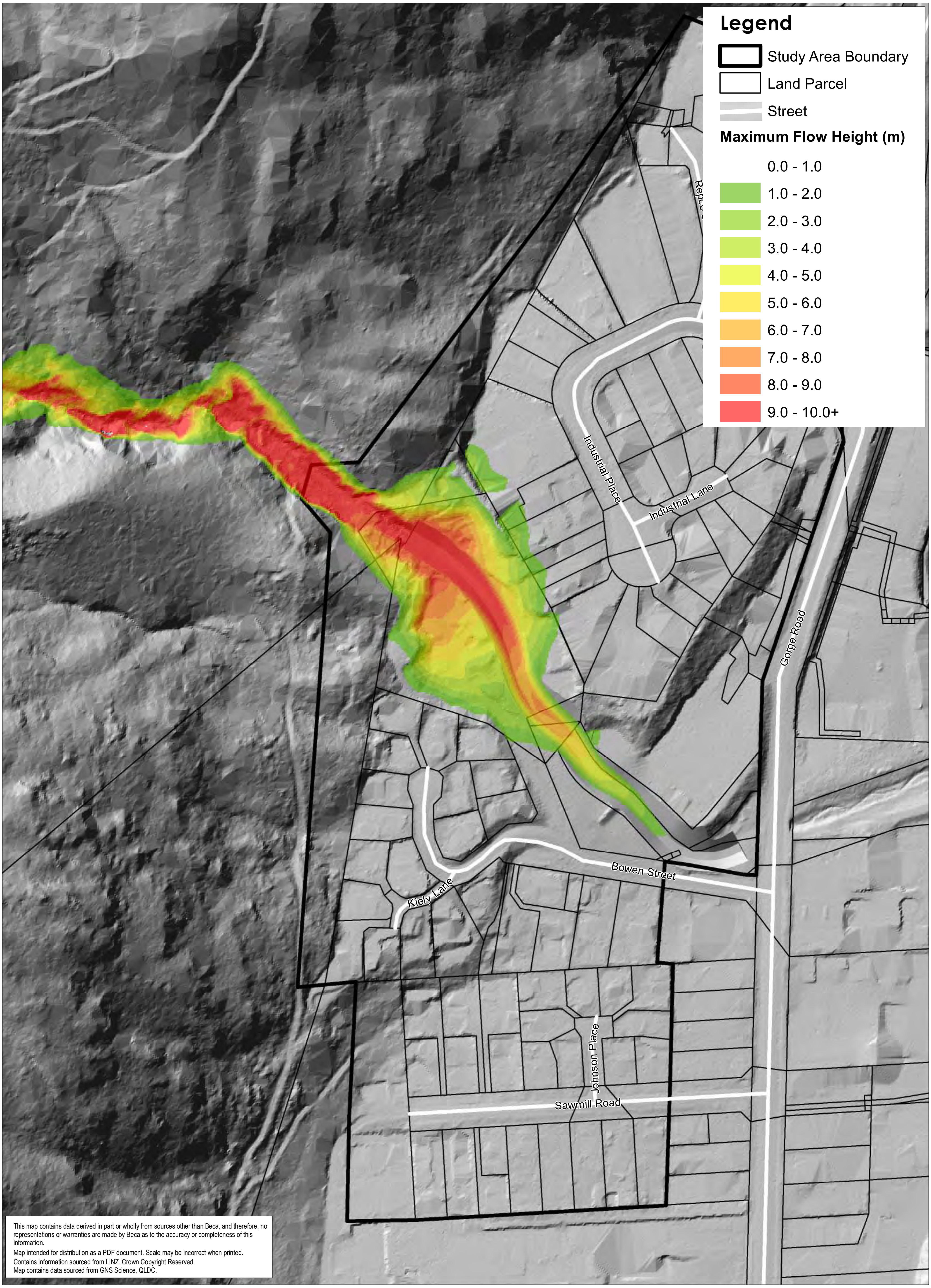
Project: Natural Hazards Affecting Gorge Road

N

Beca

Discipline: GIS

Drawing No: 3209881-E001



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Map Scale @ A3: 1:2,000
0 40 80
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Revision	Author	Verified	Approved	Date
1 - Final	SB	AP	PH	21/01/2021

Title: Brewery Creek
Debris Flow Channel Modelling
Scenario 1: 200-2,500 yr
Forested Source Area

Client: Queenstown Lakes District Council

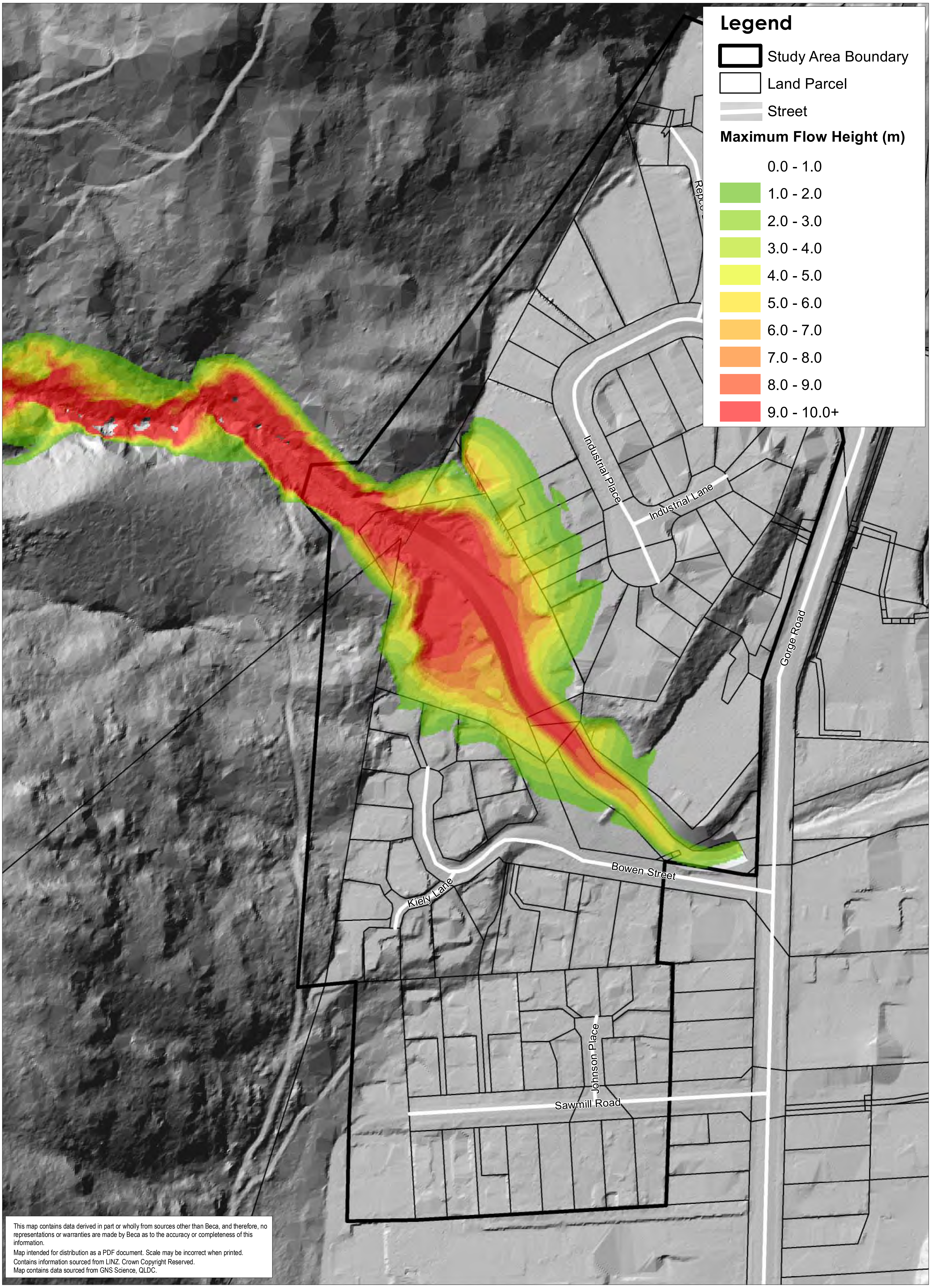
Project: Natural Hazards Affecting Gorge Road

N

Beca

Discipline: GIS

Drawing No: 3209881-E002



GIS@beca.com

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Map Scale @ A3: 1:2,000

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Metres

Revision	Author	Verified	Approved	Date
1 - Final	SB	AP	PH	21/01/2021

Title: Brewery Creek
Debris Flow Channel Modelling
Scenario 1: 2,500-10,000 yr
Forested Source Area

Client: Queenstown Lakes District Council

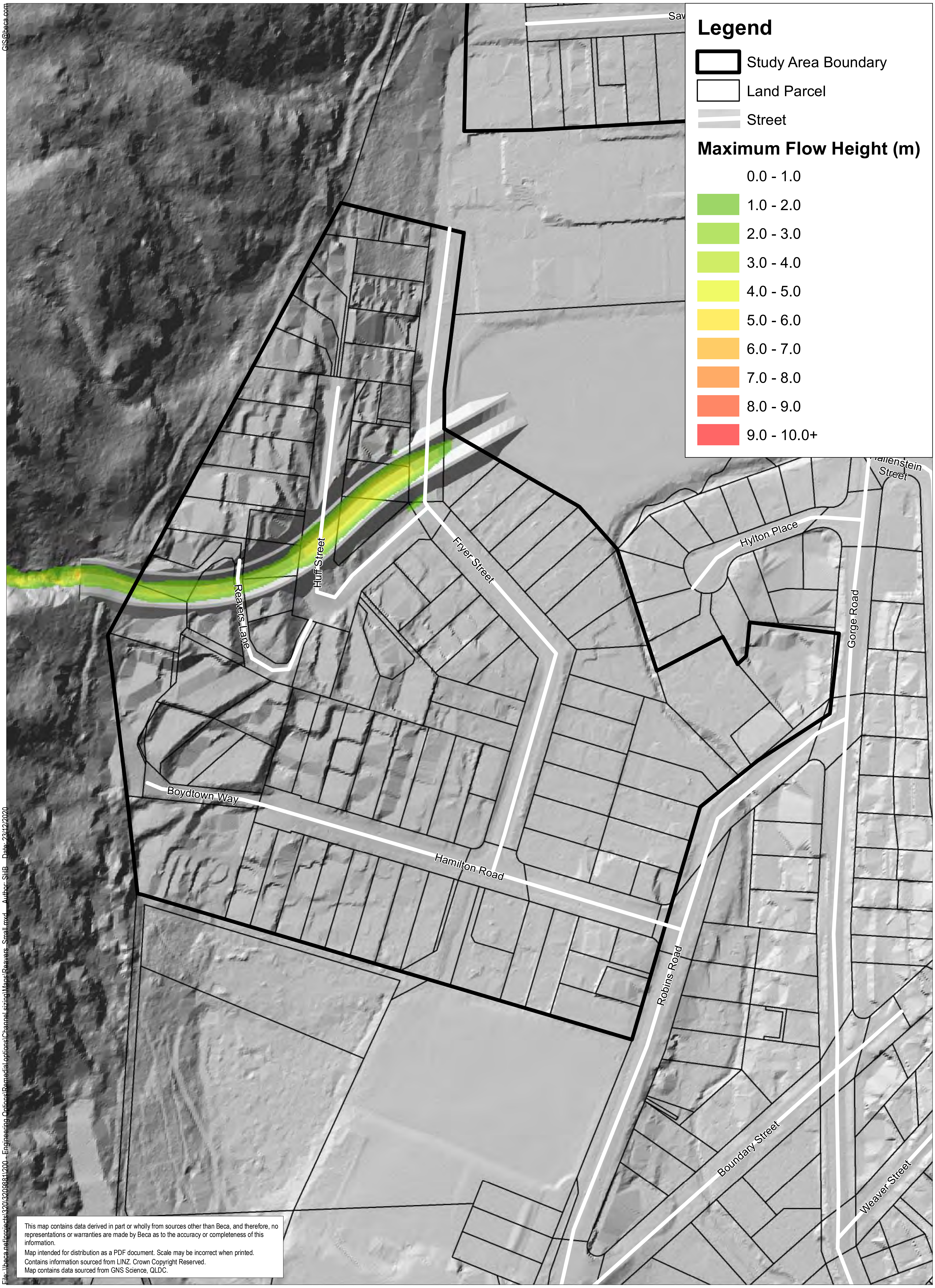
Project: Natural Hazards Affecting Gorge Road

N

Beca

Discipline: GIS

Drawing No: 3209881-E003



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GIS@beca.com

Map Scale @ A3: 1:2,000
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Metres

Revision	Author	Verified	Approved	Date
1 - Final	SB	AP	PH	21/01/2021

Title:
Reavers Creek
Debris Flow Channel Modelling
Scenario 1: 100-2500 yr
Forested Source Area

Client: Queenstown Lakes District Council

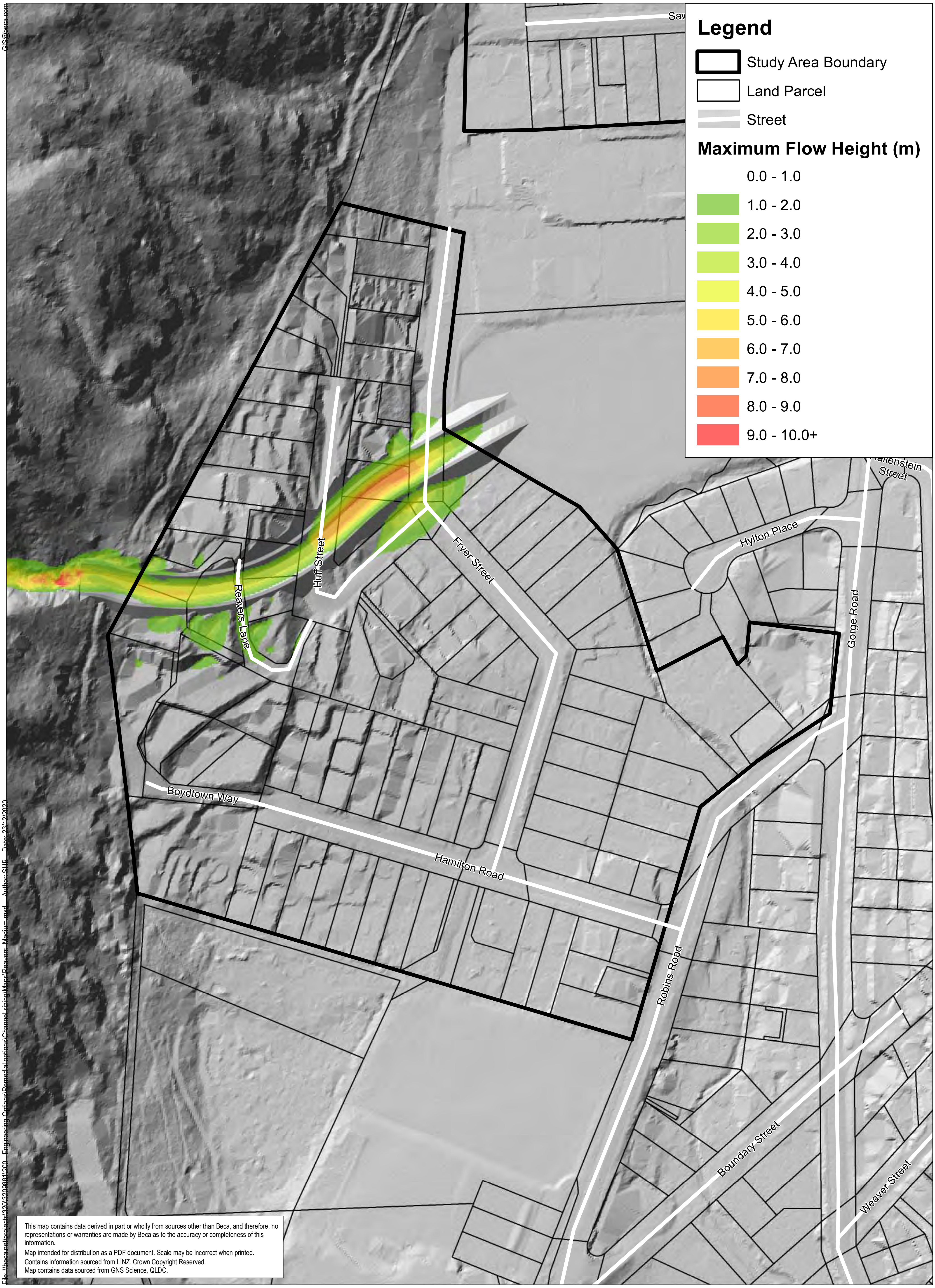
Project: Natural Hazards Affecting Gorge Road

N

Beca

Discipline: GIS

Drawing No: 3209881-E004



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Revision	Author	Verified	Approved	Date
1 - Final	SB	AP	PH	21/01/2021

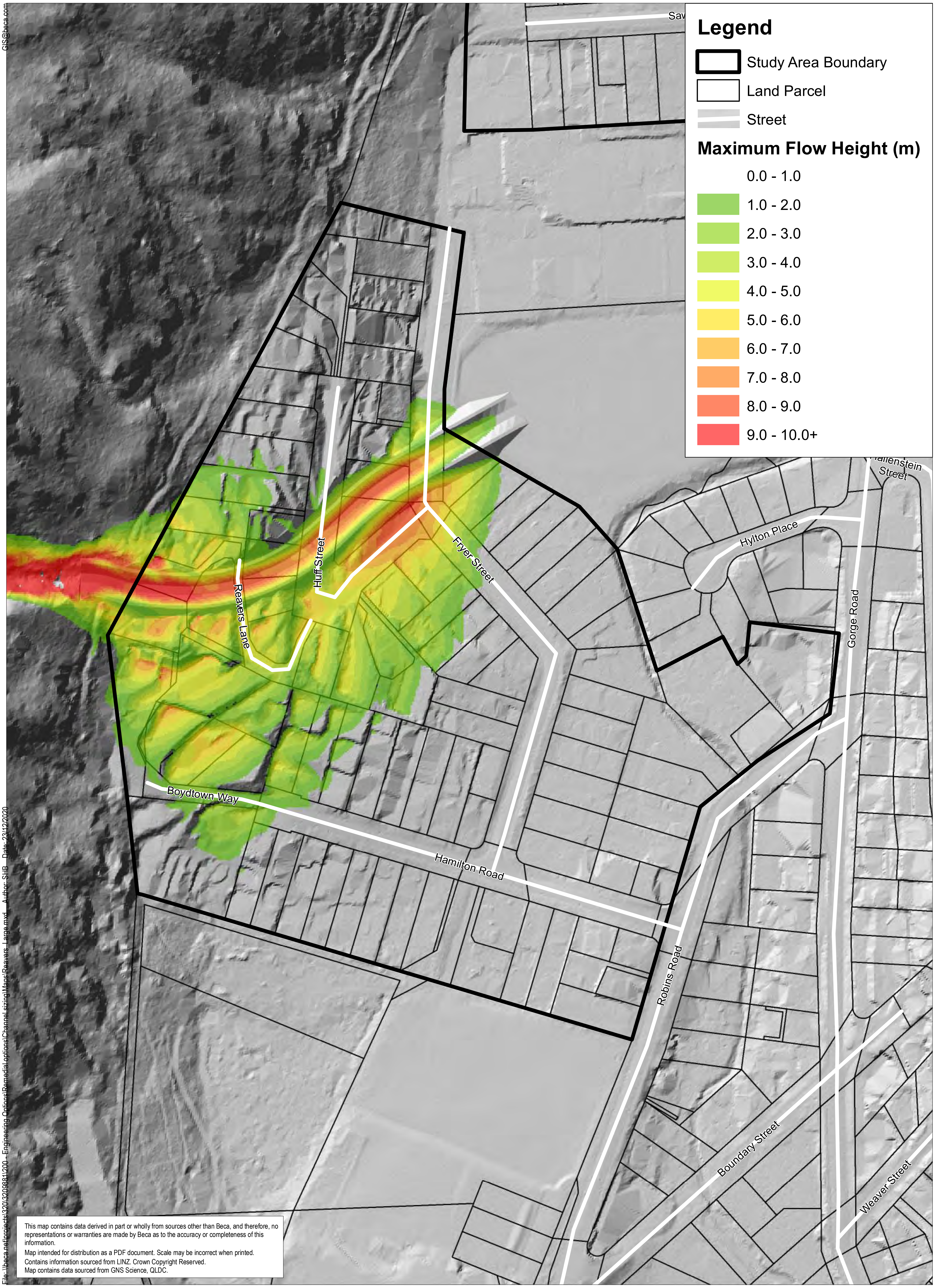
Title: Reavers Creek
Debris Flow Channel Modelling
Scenario 2: 2,500-6,700 yr
Forested Source Area

Client: Queenstown Lakes District Council

Project: Natural Hazards Affecting Gorge Road

Discipline: GIS

Drawing No: 3209881-E005



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0 40 80
Metres

Revision	Author	Verified	Approved	Date
1 - Final	SB	AP	PH	21/01/2021

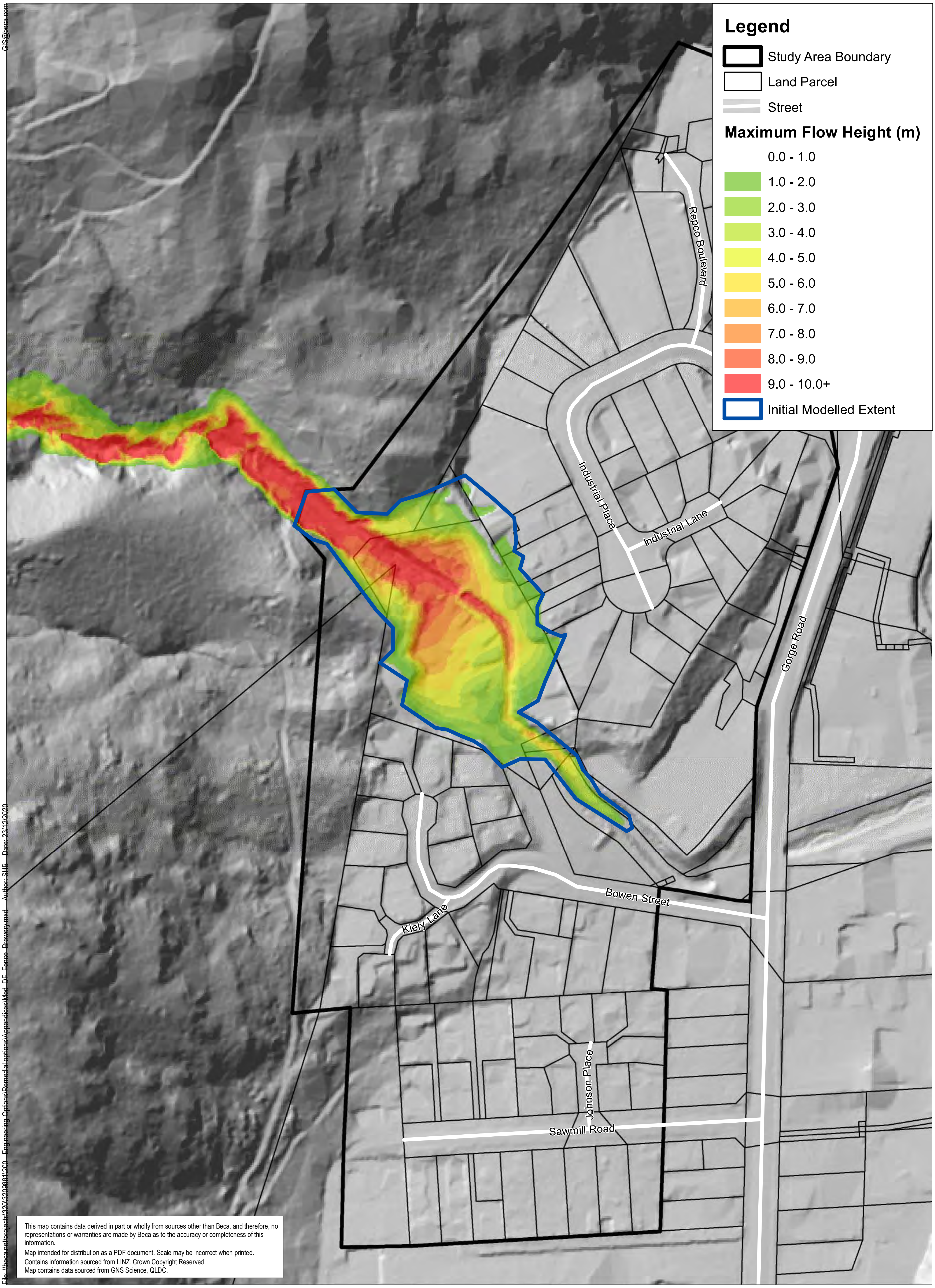
Title: Reavers Creek
Debris Flow Channel Modelling
Scenario 1: 6,700-20,000 yr
Forested Source Area

Client: Queenstown Lakes District Council

Project: Natural Hazards Affecting Gorge Road

Discipline: GIS

Drawing No: 3209881-E006



GIS@beca.com

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Map Scale @ A3: 1:2,000

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Metres

Revision	Author	Verified	Approved	Date
1 - Final	SB	AP	PH	21/01/2021

Title:

Brewery Creek
Debris Flow Fence Modelling
Scenario 1: 200-2,500 yr
Forested Source Area

Client: Queenstown Lakes District Council

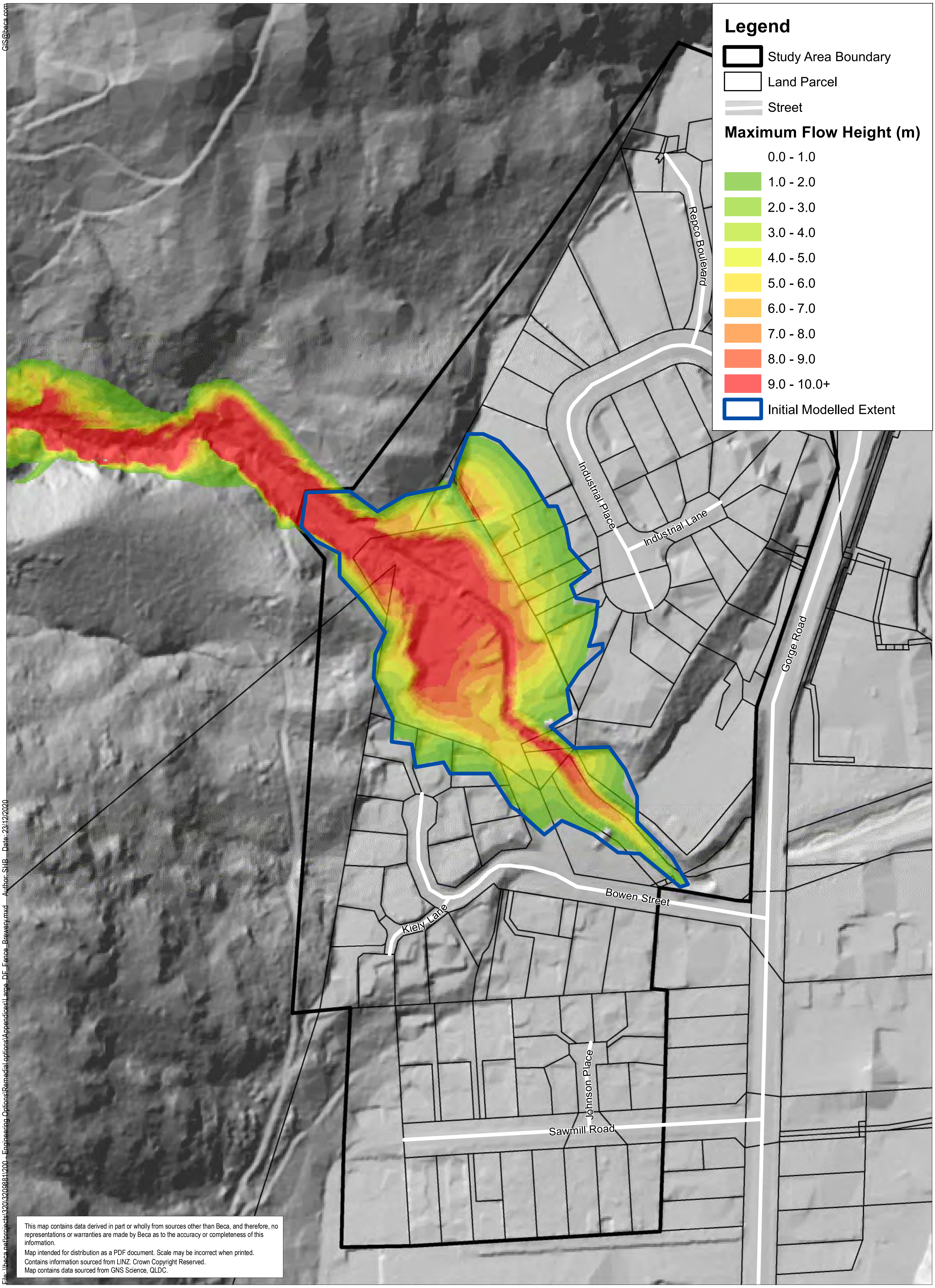
Project: Natural Hazards Affecting Gorge Road

N

Beca

Discipline: GIS

Drawing No: 3209881-E007



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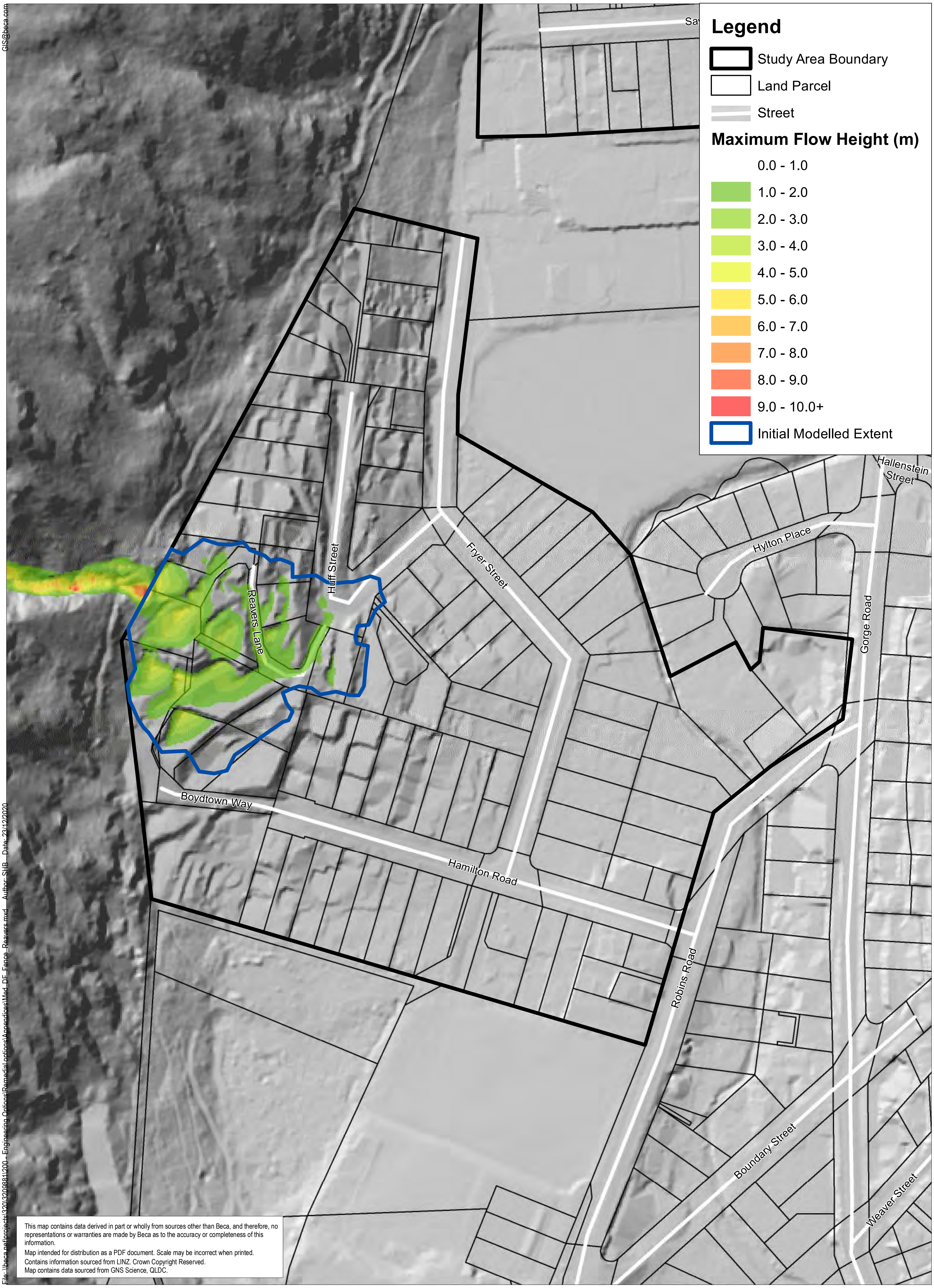
	1 - Final	SB	AP	PH	21/01/2021		Project: Natural Hazards Affecting Gorge Road	Beca	Drawing No: 3209881-E008



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Revision	Author	Verified	Approved	Date
1 - Final	SB	AP	PH	21/01/2021

Title: Reavers Creek
Debris Flow Fence Modelling
Scenario 1: 2,500-6,700 yr
Forested Source Area

Client: Queenstown Lakes District Council

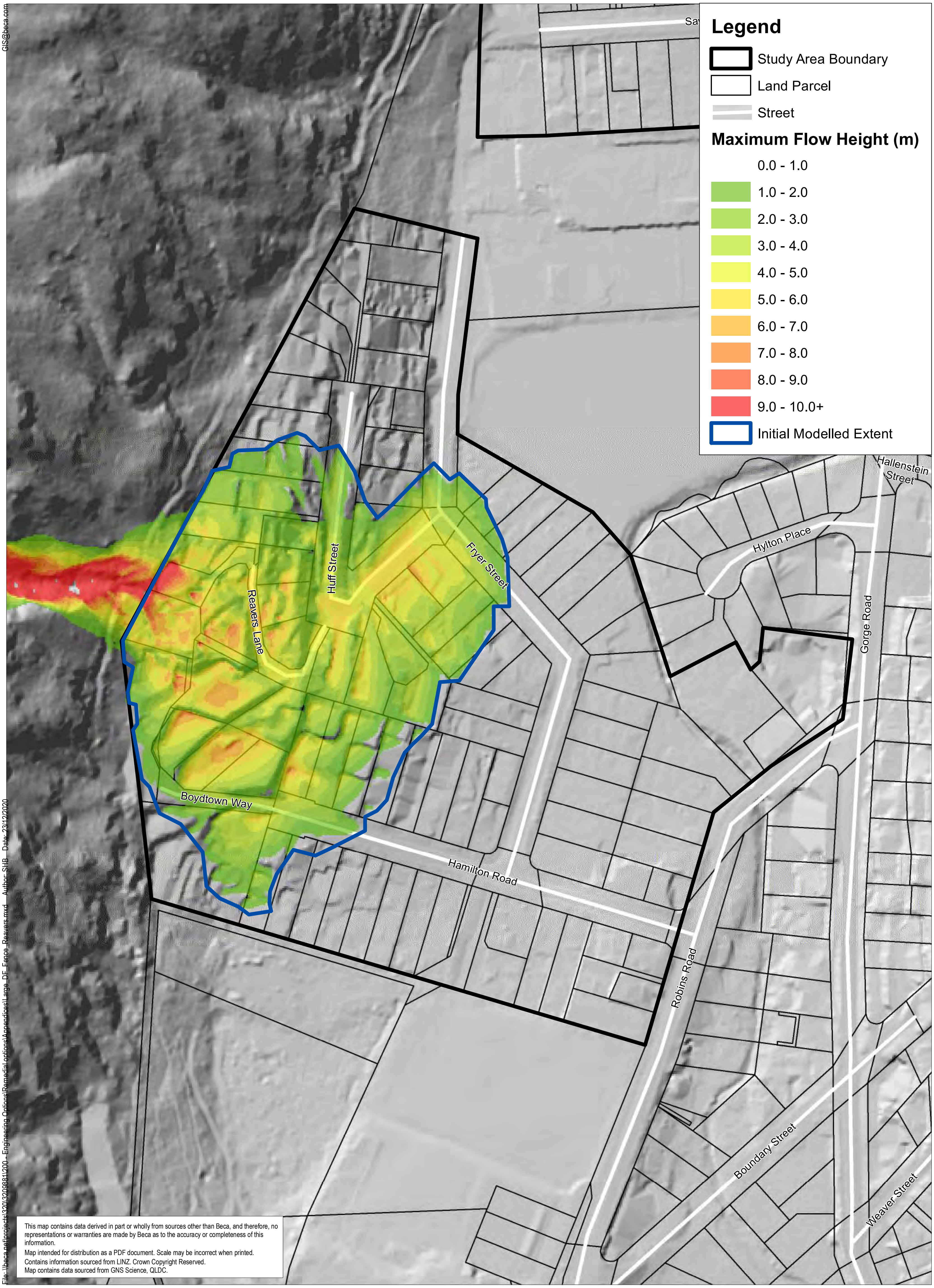
Project: Natural Hazards Affecting Gorge Road

N

Beca

Discipline: GIS

Drawing No: 3209881-E009



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Map Scale @ A3: 1:2,000

0 40 80

Metres

Revision	Author	Verified	Approved	Date
1 - Final	SB	AP	PH	21/01/2021

Title: Reavers Creek
Debris Flow Fence Modelling
Scenario 2: 6,700-20,000 yr
Forested Source Area

Client: Queenstown Lakes District Council

Project: Natural Hazards Affecting Gorge Road

N

Beca

Discipline: GIS

Drawing No: 3209881-E010

F

Appendix F – AIFR Calculations

Annual Individual Fatality Risk (AIFR) Assessment Worksheet

Location: Brewery Creek Fan, Queenstown
Failure mode: Debris flow - channel option
Consequence: Death
Element at risk: Individual most at risk
Date: 23-Dec-20
Status: Final

Hazard	Hazard zone	Failure magnitude (refer debris flow modelling scenarios for definitions, see tab 2)	Annual probability of failure P(H) (1) Lower P(H)	Lower 1 in x years	Upper P(H)	Upper 1 in x years	Probability of travel (P(S:H)) (2)	Probability of self evacuation, P(se) Lower	Probability of self evacuation, P(se) Upper	Temporal spatial probability (P(T:S)) (3) Planning zone	Occupancy	Time "individual most at risk present)	Lower	Upper	Vulnerability (4)	AIFR Minimum AIFR	AIFR Minimum AIFR Residential	AIFR Minimum AIFR Business	AIFR Average AIFR	AIFR Average AIFR Residential	AIFR Average AIFR Business	AIFR Maximum AIFR	AIFR Maximum AIFR Residential	AIFR Maximum AIFR Business
Debris flow		Small, more frequent event	0.005	200	0.02	50	0.0	0.5	0.7	Residential	Inside	80%	0.24	0.4	0	0.0E+00	0.0E+00		0.0E+00	0.0E+00		0.0E+00	0.0E+00	
Brewery			0.005	200	0.02	50	0.0	0.6	0.8	Residential	Outside	10%	0.02	0.04	0	0.0E+00			0.0E+00			0.0E+00		
			0.005	200	0.02	50	0.0	0.5	0.7	Business	Inside	27%	0.081	0.135	0	0.0E+00		0.0E+00	0.0E+00		0.0E+00	0.0E+00		0.0E+00
			0.005	200	0.02	50	0.0	0.6	0.8	Business	Outside	7%	0.014	0.028	0	0.0E+00			0.0E+00			0.0E+00		
		Medium	0.0004	2500	0.005	200	1.0	0.3	0.5	Residential	Inside	80%	0.4	0.56	0.8	1.3E-04	1.4E-04		1.0E-03	1.2E-03		2.2E-03	2.5E-03	
	1		0.0004	2500	0.005	200	1.0	0.4	0.6	Residential	Outside	10%	0.04	0.06	0.9	1.4E-05			1.2E-04			2.7E-04		
			0.0004	2500	0.005	200	1.0	0.3	0.5	Business	Inside	27%	0.135	0.189	0.8	4.3E-05		5.3E-05	3.5E-04		4.3E-04	7.6E-04		9.5E-04
			0.0004	2500	0.005	200	1.0	0.4	0.6	Business	Outside	7%	0.028	0.042	0.9	1.0E-05			8.5E-05			1.9E-04		
		Large, less frequent event	0.0001	10000	0.0004	2500	1.0	0.1	0.3	Residential	Inside	80%	0.56	0.72	0.9	5.0E-05	5.6E-05		1.4E-04	1.6E-04		2.6E-04	2.9E-04	
			0.0001	10000	0.0004	2500	1.0	0.2	0.4	Residential	Outside	10%	0.06	0.08	1.0	6.0E-06			1.8E-05			3.2E-05		
			0.0001	10000	0.0004	2500	1.0	0.1	0.3	Business	Inside	27%	0.189	0.243	0.9	1.7E-05		2.1E-05	4.9E-05		6.1E-05	8.7E-05		1.1E-04
			0.0001	10000	0.0004	2500	1.0	0.2	0.4	Business	Outside	7%	0.042	0.056	1.0	4.2E-06			1.2E-05			2.2E-05		
																AIFR	**2.0E-04**	**7.4E-05**	AIFR	**1.3E-03**	**5.0E-04**	AIFR	**2.8E-03**	**1.1E-03**
Debris flow		Small, more frequent event	0.005	200	0.02	50	0.0	0.5	0.7	Residential	Inside	80%	0.24	0.4	0.5	0.0E+00	0.0E+00		0.0E+00	0.0E+00		0.0E+00	0.0E+00	
Brewery			0.005	200	0.02	50	0.0	0.6	0.8	Residential	Outside	10%	0.02	0.04	0.6	0.0E+00			0.0E+00			0.0E+00		
			0.005	200	0.02	50	0.0	0.5	0.7	Business	Inside	27%	0.081	0.135	0.5	0.0E+00		0.0E+00	0.0E+00		0.0E+00	0.0E+00		0.0E+00
			0.005	200	0.02	50	0.0	0.6	0.8	Business	Outside	7%	0.014	0.028	0.6	0.0E+00			0.0E+00			0.0E+00		
		Medium	0.0004	2500	0.005	200	0.8	0.4	0.6	Residential	Inside	80%	0.32	0.48	0.8	8.2E-05	9.1E-05		6.9E-04	7.7E-04		1.5E-03	1.7E-03	
	2		0.0004	2500	0.005	200	0.8	0.5	0.7	Residential	Outside	10%	0.03	0.05	0.9	8.6E-06			7.8E-05			1.8E-04		
			0.0004	2500	0.005	200	0.8	0.4	0.6	Business	Inside	27%	0.108	0.162	0.8	2.8E-05		3.4E-05	2.3E-04		2.9E-04	5.2E-04		6.4E-04
			0.0004	2500	0.005	200	0.8	0.5	0.7	Business	Outside	7%	0.021	0.035	0.9	6.0E-06			5.4E-05			1.3E-04		
		Large, less frequent event	0.0001	10000	0.0004	2500	1.0	0.2	0.4	Residential	Inside	80%	0.48	0.64	0.9	4.3E-05	4.8E-05		1.3E-04	1.4E-04		2.3E-04	2.6E-04	
			0.0001	10000	0.0004	2500	1.0	0.3	0.5	Residential	Outside	10%	0.05	0.07	1.0	5.0E-06			1.5E-05			2.8E-05		
			0.0001	10000	0.0004	2500	1.0	0.2	0.4	Business	Inside	27%	0.162	0.216	0.9	1.5E-05		1.8E-05	4.3E-05		5.3E-05	7.8E-05		9.7E-05
			0.0001	10000	0.0004	2500	1.0	0.3	0.5	Business	Outside	7%	0.035	0.049	1.0	3.5E-06			1.1E-05			2.0E-05		
																AIFR	**1.4E-04**	**5.2E-05**	AIFR	**9.1E-04**	**3.4E-04**	AIFR	**2.0E-03**	**7.4E-04**
Debris flow		Small, more frequent event	0.005	200	0.02	50	0.0	0.5	0.7	Residential	Inside	80%	0.24	0.4	0.5	0.0E+00	0.0E+00		0.0E+00	0.0E+00		0.0E+00	0.0E+00	
Brewery			0.005	200	0.02	50	0.0	0.6	0.8	Residential	Outside	10%	0.02	0.04	0.6	0.0E+00			0.0E+00			0.0E+00		
			0.005	200	0.02	50	0.0	0.5	0.7	Business	Inside	27%	0.081	0.135	0.5	0.0E+00		0.0E+00	0.0E+00		0.0E+00	0.0E+00		0.0E+00
			0.005	200	0.02	50	0.0	0.6	0.8	Business	Outside	7%	0.014	0.028	0.6	0.0E+00			0.0E+00			0.0E+00		
		Medium	0.0004	2500	0.005	200	0.0	0.4	0.6	Residential	Inside	80%	0.32	0.48	0.8	0.0E+00	0.0E+00		0.0E+00	0.0E+00		0.0E+00	0.0E+00	
	3		0.0004	2500	0.005	200	0.0	0.5	0.7	Residential	Outside	10%	0.03	0.05	0.9	0.0E+00			0.0E+00			0.0E+00		
			0.0004	2500	0.005	200	0.0	0.4	0.6	Business	Inside	27%	0.108	0.162	0.8	0.0E+00		0.0E+00	0.0E+00		0.0E+00	0.0E+00		0.0E+00
			0.0004	2500	0.005	200	0.0	0.5	0.7	Business	Outside	7%	0.021	0.035	0.9	0.0E+00			0.0E+00			0.0E+00		
		Large, less frequent event	0.0001	10000	0.0004	2500	0.8	0.3	0.5	Residential	Inside	80%	0.4	0.56	0.9	2.9E-05	3.2E-05		8.6E-05	9.6E-05		1.6E-04	1.8E-04	
			0.0001	10000	0.0004	2500	0.8	0.4	0.6	Residential	Outside	10%	0.04	0.06	1.0	3.2E-06			1.0E-05			1.9E-05		
			0.0001	10000	0.0004	2500	0.8	0.3	0.5	Business	Inside	27%	0.135	0.189	0.9	9.7E-06		1.2E-05	2.9E-05		3.6E-05	5.4E-05		6.8E-05
			0.0001	10000	0.0004	2500	0.8	0.4	0.6	Business	Outside	7%	0.028	0.042	1.0	2.2E-06			7.0E-06			1.3E-05		
																AIFR	**3.2E-05**	**1.2E-05**	AIFR	**9.6E-05**	**3.6E-05**	AIFR	**1.8E-04**	**6.8E-05**
Debris flow		Small, more frequent event	0.005	200	0.02	50	0.0	0.5	0.7	Residential	Inside	80%	0.24	0.4	0.5	0.0E+00	0.0E+00		0.0E+00	0.0E+00		0.0E+00	0.0E+00	
Brewery			0.005	200	0.02	50	0.0	0.6	0.8	Residential	Outside	10%	0.02	0.04	0.6	0.0E+00			0.0E+00			0.0E+00		
			0.005	200	0.02	50	0.0	0.5	0.7	Business	Inside	27%	0.081	0.135	0.5	0.0E+00		0.0E+00	0.0E+00		0.0E+00	0.0E+00		0.0E+00
			0.005	200	0.02	50	0.0	0.6	0.8	Business	Outside	7%	0.014	0.028	0.6	0.0E+00			0.0E+00			0.0E+00		
		Medium	0.0004	2500	0.005	200	0.0	0.4	0.6	Residential	Inside	80%	0.32	0.48	0.8	0.0E+00	0.0E+00		0.0E+00	0.0E+00		0.0E+00	0.0E+00	
	4		0.0004	2500	0.005	200	0.0	0.5	0.7	Residential	Outside	10%	0.03	0.05	0.9	0.0E+00			0.0E+00			0.0E+00		
			0.0004	2500	0.005	200	0.0	0.4	0.6	Business	Inside	27%	0.108	0.162	0.8	0.0E+00		0.0E+00	0.0E+00		0.0E+00	0.0E+00		0.0E+00
			0.0004	2500	0.005	200	0.0	0.5	0.7	Business	Outside	7%	0.021	0.035	0.9	0.0E+00			0.0E+00			0.0E+00		
		Large, less frequent event	0.0001	10000	0.0004	2500	0.8	0.4	0.6	Residential	Inside	80%	0.32	0.48	0.05	1.3E-06	1.5E-06		4.0E-06	4.8E-06		7.7E-06	9.3E-06	
			0.0001	10000	0.0004	2500	0.8	0.5	0.7	Residential	Outside	10%	0.03	0.05	0.1	2.4E-07			8.0E-07			1.6E-06		
			0.0001	10000	0.0004	2500	0.8	0.4	0.6	Business	Inside	27%	0.108	0.162	0.05	4.3E-07		6.0E-07	1.4E-06		1.9E-06	2.6E-06		3.7E-06
			0.0001	10000	0.0004	2500	0.8	0.5	0.7	Business	Outside	7%	0.021	0.035	0.1	1.7E-07			5.6E-07			1.1E-06		
																AIFR	**1.5E-06**	**6.0E-07**	AIFR	**4.8E-06**	**1.9E-06**	AIFR	**9.3E-06**	**3.7E-06**

Annual Individual Fatality Risk (AIFR) Assessment Worksheet

Location: Brewery Creek Fan, Queenstown
Failure mode: Debris flow - fence option
Consequence: Death
Element at risk: Individual most at risk
Date: 23-Dec-20
Status: Final

Hazard	Hazard zone	Failure magnitude (refer debris flow modelling scenarios for definitions, see tab 2)	Annual probability of failure P(H) (1) Lower P(H)	Lower 1 in x years	Upper P(H)	Upper 1 in x years	Probability of travel (P(S:H)) (2)	Probability of self evacuation, P(se) Lower	P(se) Upper	Temporal spatial probability (P(T:S)) (3) Planning zone	Occupancy	Time "individual most at risk present)	Lower	Upper	Vulnerability (4)	AIFR Minimum AIFR	AIFR Minimum AIFR Residential	AIFR Minimum AIFR Business	AIFR Average AIFR	AIFR Average AIFR Residential	AIFR Average AIFR Business	AIFR Maximum AIFR	AIFR Maximum AIFR Residential	AIFR Maximum AIFR Business
Debris flow Brewery	1	Small, more frequent event	0.005	200	0.02	50	0.0	0.5	0.7	Residential	Inside	80%	0.24	0.4	0	0.0E+00	0.0E+00		0.0E+00	0.0E+00		0.0E+00	0.0E+00	
			0.005	200	0.02	50	0.0	0.6	0.8	Residential	Outside	10%	0.02	0.04	0	0.0E+00			0.0E+00			0.0E+00		
			0.005	200	0.02	50	0.0	0.5	0.7	Business	Inside	27%	0.081	0.135	0	0.0E+00		0.0E+00	0.0E+00		0.0E+00	0.0E+00		0.0E+00
			0.005	200	0.02	50	0.0	0.6	0.8	Business	Outside	7%	0.014	0.028	0	0.0E+00			0.0E+00			0.0E+00		
		Medium	0.0004	2500	0.005	200	1.0	0.3	0.5	Residential	Inside	80%	0.4	0.56	0.8	1.3E-04	1.4E-04		1.0E-03	1.2E-03		2.2E-03	2.5E-03	
			0.0004	2500	0.005	200	1.0	0.4	0.6	Residential	Outside	10%	0.04	0.06	0.9	1.4E-05			1.2E-04			2.7E-04		
			0.0004	2500	0.005	200	1.0	0.3	0.5	Business	Inside	27%	0.135	0.189	0.8	4.3E-05		5.3E-05	3.5E-04		4.3E-04	7.6E-04		9.5E-04
			0.0004	2500	0.005	200	1.0	0.4	0.6	Business	Outside	7%	0.028	0.042	0.9	1.0E-05			8.5E-05			1.9E-04		
		Large, less frequent event	0.0001	10000	0.0004	2500	1.0	0.1	0.3	Residential	Inside	80%	0.56	0.72	0.9	5.0E-05	5.6E-05		1.4E-04	1.6E-04		2.6E-04	2.9E-04	
			0.0001	10000	0.0004	2500	1.0	0.2	0.4	Residential	Outside	10%	0.06	0.08	1.0	6.0E-06			1.8E-05			3.2E-05		
			0.0001	10000	0.0004	2500	1.0	0.1	0.3	Business	Inside	27%	0.189	0.243	0.9	1.7E-05		2.1E-05	4.9E-05		6.1E-05	8.7E-05		1.1E-04
			0.0001	10000	0.0004	2500	1.0	0.2	0.4	Business	Outside	7%	0.042	0.056	1.0	4.2E-06			1.2E-05			2.2E-05		
																AIFR	**2.0E-04**	**7.4E-05**	AIFR	**1.3E-03**	**5.0E-04**	AIFR	**2.8E-03**	**1.1E-03**
Debris flow Brewery	2	Small, more frequent event	0.005	200	0.02	50	0.0	0.5	0.7	Residential	Inside	80%	0.24	0.4	0.5	0.0E+00	0.0E+00		0.0E+00	0.0E+00		0.0E+00	0.0E+00	
			0.005	200	0.02	50	0.0	0.6	0.8	Residential	Outside	10%	0.02	0.04	0.6	0.0E+00			0.0E+00			0.0E+00		
			0.005	200	0.02	50	0.0	0.5	0.7	Business	Inside	27%	0.081	0.135	0.5	0.0E+00		0.0E+00	0.0E+00		0.0E+00	0.0E+00		0.0E+00
			0.005	200	0.02	50	0.0	0.6	0.8	Business	Outside	7%	0.014	0.028	0.6	0.0E+00			0.0E+00			0.0E+00		
		Medium	0.0004	2500	0.005	200	0.8	0.4	0.6	Residential	Inside	80%	0.32	0.48	0.8	8.2E-05	9.1E-05		6.9E-04	7.7E-04		1.5E-03	1.7E-03	
			0.0004	2500	0.005	200	0.8	0.5	0.7	Residential	Outside	10%	0.03	0.05	0.9	8.6E-06			7.8E-05			1.8E-04		
			0.0004	2500	0.005	200	0.8	0.4	0.6	Business	Inside	27%	0.108	0.162	0.8	2.8E-05		3.4E-05	2.3E-04		2.9E-04	5.2E-04		6.4E-04
			0.0004	2500	0.005	200	0.8	0.5	0.7	Business	Outside	7%	0.021	0.035	0.9	6.0E-06			5.4E-05			1.3E-04		
		Large, less frequent event	0.0001	10000	0.0004	2500	1.0	0.2	0.4	Residential	Inside	80%	0.48	0.64	0.9	4.3E-05	4.8E-05		1.3E-04	1.4E-04		2.3E-04	2.6E-04	
			0.0001	10000	0.0004	2500	1.0	0.3	0.5	Residential	Outside	10%	0.05	0.07	1.0	5.0E-06			1.5E-05			2.8E-05		
			0.0001	10000	0.0004	2500	1.0	0.2	0.4	Business	Inside	27%	0.162	0.216	0.9	1.5E-05		1.8E-05	4.3E-05		5.3E-05	7.8E-05		9.7E-05
			0.0001	10000	0.0004	2500	1.0	0.3	0.5	Business	Outside	7%	0.035	0.049	1.0	3.5E-06			1.1E-05			2.0E-05		
																AIFR	**1.4E-04**	**5.2E-05**	AIFR	**9.1E-04**	**3.4E-04**	AIFR	**2.0E-03**	**7.4E-04**
Debris flow Brewery	3	Small, more frequent event	0.005	200	0.02	50	0.0	0.5	0.7	Residential	Inside	80%	0.24	0.4	0.5	0.0E+00	0.0E+00		0.0E+00	0.0E+00		0.0E+00	0.0E+00	
			0.005	200	0.02	50	0.0	0.6	0.8	Residential	Outside	10%	0.02	0.04	0.6	0.0E+00			0.0E+00			0.0E+00		
			0.005	200	0.02	50	0.0	0.5	0.7	Business	Inside	27%	0.081	0.135	0.5	0.0E+00		0.0E+00	0.0E+00		0.0E+00	0.0E+00		0.0E+00
			0.005	200	0.02	50	0.0	0.6	0.8	Business	Outside	7%	0.014	0.028	0.6	0.0E+00			0.0E+00			0.0E+00		
		Medium	0.0004	2500	0.005	200	0.0	0.4	0.6	Residential	Inside	80%	0.32	0.48	0.8	0.0E+00	0.0E+00		0.0E+00	0.0E+00		0.0E+00	0.0E+00	
			0.0004	2500	0.005	200	0.0	0.5	0.7	Residential	Outside	10%	0.03	0.05	0.9	0.0E+00			0.0E+00			0.0E+00		
			0.0004	2500	0.005	200	0.0	0.4	0.6	Business	Inside	27%	0.108	0.162	0.8	0.0E+00		0.0E+00	0.0E+00		0.0E+00	0.0E+00		0.0E+00
			0.0004	2500	0.005	200	0.0	0.5	0.7	Business	Outside	7%	0.021	0.035	0.9	0.0E+00			0.0E+00			0.0E+00		
		Large, less frequent event	0.0001	10000	0.0004	2500	0.8	0.3	0.5	Residential	Inside	80%	0.4	0.56	0.9	2.9E-05	3.2E-05		8.6E-05	9.6E-05		1.6E-04	1.8E-04	
			0.0001	10000	0.0004	2500	0.8	0.4	0.6	Residential	Outside	10%	0.04	0.06	1.0	3.2E-06			1.0E-05			1.9E-05		
			0.0001	10000	0.0004	2500	0.8	0.3	0.5	Business	Inside	27%	0.135	0.189	0.9	9.7E-06		1.2E-05	2.9E-05		3.6E-05	5.4E-05		6.8E-05
			0.0001	10000	0.0004	2500	0.8	0.4	0.6	Business	Outside	7%	0.028	0.042	1.0	2.2E-06			7.0E-06			1.3E-05		
																AIFR	**3.2E-05**	**1.2E-05**	AIFR	**9.6E-05**	**3.6E-05**	AIFR	**1.8E-04**	**6.8E-05**
Debris flow Brewery	4	Small, more frequent event	0.005	200	0.02	50	0.0	0.5	0.7	Residential	Inside	80%	0.24	0.4	0.5	0.0E+00	0.0E+00		0.0E+00	0.0E+00		0.0E+00	0.0E+00	
			0.005	200	0.02	50	0.0	0.6	0.8	Residential	Outside	10%	0.02	0.04	0.6	0.0E+00			0.0E+00			0.0E+00		
			0.005	200	0.02	50	0.0	0.5	0.7	Business	Inside	27%	0.081	0.135	0.5	0.0E+00		0.0E+00	0.0E+00		0.0E+00	0.0E+00		0.0E+00
			0.005	200	0.02	50	0.0	0.6	0.8	Business	Outside	7%	0.014	0.028	0.6	0.0E+00			0.0E+00			0.0E+00		
		Medium	0.0004	2500	0.005	200	0.0	0.4	0.6	Residential	Inside	80%	0.32	0.48	0.8	0.0E+00	0.0E+00		0.0E+00	0.0E+00		0.0E+00	0.0E+00	
			0.0004	2500	0.005	200	0.0	0.5	0.7	Residential	Outside	10%	0.03	0.05	0.9	0.0E+00			0.0E+00			0.0E+00		
			0.0004	2500	0.005	200	0.0	0.4	0.6	Business	Inside	27%	0.108	0.162	0.8	0.0E+00		0.0E+00	0.0E+00		0.0E+00	0.0E+00		0.0E+00
			0.0004	2500	0.005	200	0.0	0.5	0.7	Business	Outside	7%	0.021	0.035	0.9	0.0E+00			0.0E+00			0.0E+00		
		Large, less frequent event	0.0001	10000	0.0004	2500	0.8	0.4	0.6	Residential	Inside	80%	0.32	0.48	0.05	1.3E-06	1.5E-06		4.0E-06	4.8E-06		7.7E-06	9.3E-06	
			0.0001	10000	0.0004	2500	0.8	0.5	0.7	Residential	Outside	10%	0.03	0.05	0.1	2.4E-07			8.0E-07			1.6E-06		
			0.0001	10000	0.0004	2500	0.8	0.4	0.6	Business	Inside	27%	0.108	0.162	0.05	4.3E-07		6.0E-07	1.4E-06		1.9E-06	2.6E-06		3.7E-06
			0.0001	10000	0.0004	2500	0.8	0.5	0.7	Business	Outside	7%	0.021	0.035	0.1	1.7E-07			5.6E-07			1.1E-06		
																AIFR	**1.5E-06**	**6.0E-07**	AIFR	**4.8E-06**	**1.9E-06**	AIFR	**9.3E-06**	**3.7E-06**

Annual Individual Fatality Risk (AIFR) Assessment Worksheet

Location: Brewery Creek and Reavers Fans, Queenstown
Failure mode: Rockfall - fence option
Consequence: Death
Element at risk: Individual most at risk
Date: 23-Dec-20
Status: Final

Element at risk width (m)	1
Average boulder width (m)	1
Slope width (m)	1220
P_1 (S:H)	2.5E-03

Hazard	Hazard zone	Failure magnitude class	Annual frequency of rockfall P(H)							Spatial Probability (P(S:H))			Temporal spatial probability (P(T:S))					Vulnerability	AIFR Lower			AIFR Average			AIFR Upper		
					Lower		Upper				Lower	Upper															
			Annual probability of failure	1 in x years	Number of rocks per individual rockfall (N)	Annual frequency of rockfall	Number of rocks per individual rockfall (N)	Annual frequency of rockfall	Probability of Travel (P(T)) *Q5	Probability of Travel (P(T)) original	$P(T) \times P_N(S:H)$		Probability of self evacuation	Planning zone	Occupancy	Time "individual most at risk" present	Temporal spatial probability (P(T:S))		AIFR	AIFR Residential	AIFR Business	AIFR	AIFR Residential	AIFR Business	AIFR	AIFR Residential	AIFR Business
Rockfall		Rockfall - non-seismic trigger	1	1	1	1	10	10	0.005	0.1	1.2E-05	1.2E-04	0.0	Residential	Inside	80%	8.0E-01	0.5	4.9E-06	5.8E-06		2.7E-05	3.1E-05		4.9E-05	5.7E-05	
			1	1	1	1	10	10	0.005	0.1	1.2E-05	1.2E-04	0.0	Residential	Outside	10%	1.0E-01	0.7	8.6E-07			4.7E-06			8.5E-06		
			1	1	1	1	10	10	0.005	0.1	1.2E-05	1.2E-04	0.0	Industrial	Inside	27%	2.7E-01	0.5	1.7E-06		2.3E-06	9.0E-06		1.2E-05	1.6E-05		2.2E-05
			1	1	1	1	10	10	0.005	0.1	1.2E-05	1.2E-04	0.0	Industrial	Outside	7%	7.0E-02	0.7	6.0E-07			3.3E-06			6.0E-06		
	1	Rockfall - far field seismic trigger - 1/100 yr	0.01	100	10	0.1	100	1	0.005	0.1	1.2E-04	1.1E-03	0.0	Residential	Inside	80%	8.0E-01	0.5	4.9E-07	5.6E-07		2.4E-06	2.8E-06		4.4E-06	5.1E-06	
	>10%		0.01	100	10	0.1	100	1	0.005	0.1	1.2E-04	1.1E-03	0.1	Residential	Outside	10%	9.0E-02	0.7	7.7E-08			3.8E-07			6.9E-07		
			0.01	100	10	0.1	100	1	0.005	0.1	1.2E-04	1.1E-03	0.0	Industrial	Inside	27%	2.7E-01	0.5	1.6E-07		2.2E-07	8.2E-07		1.1E-06	1.5E-06		2.0E-06
			0.01	100	10	0.1	100	1	0.005	0.1	1.2E-04	1.1E-03	0.1	Industrial	Outside	7%	6.3E-02	0.7	5.4E-08			2.7E-07			4.8E-07		
		Rockfall - near field seismic trigger 1/500 yr	0.002	500	100	0.2	1000	2	0.005	0.1	1.1E-03	4.6E-03	0.0	Residential	Inside	80%	8.0E-01	0.5	8.7E-07	1.0E-06		2.3E-06	2.6E-06		3.7E-06	4.2E-06	
			0.002	500	100	0.2	1000	2	0.005	0.1	1.1E-03	4.6E-03	0.1	Residential	Outside	10%	9.0E-02	0.7	1.4E-07			3.6E-07			5.8E-07		
			0.002	500	100	0.2	1000	2	0.005	0.1	1.1E-03	4.6E-03	0.0	Industrial	Inside	27%	2.7E-01	0.5	2.9E-07		3.9E-07	7.6E-07		1.0E-06	1.2E-06		1.6E-06
			0.002	500	100	0.2	1000	2	0.005	0.1	1.1E-03	4.6E-03	0.1	Industrial	Outside	7%	6.3E-02	0.7	9.6E-08			2.5E-07			4.0E-07		
																			AIFR	**7.4E-06**	**2.9E-06**	**AIFR**	**3.7E-05**	**1.4E-05**	**AIFR**	**6.6E-05**	**2.6E-05**
Rockfall		Rockfall - non-seismic trigger	1	1	1	1	10	10	0.0025	0.05	6.1E-06	6.1E-05	0.0	Residential	Inside	80%	8.0E-01	0.3	1.5E-06	1.8E-06		8.0E-06	9.7E-06		1.5E-05	1.8E-05	
			1	1	1	1	10	10	0.0025	0.05	6.1E-06	6.1E-05	0.0	Residential	Outside	10%	1.0E-01	0.5	3.1E-07			1.7E-06			3.0E-06		
			1	1	1	1	10	10	0.0025	0.05	6.1E-06	6.1E-05	0.0	Industrial	Inside	27%	2.7E-01	0.3	5.0E-07		7.1E-07	2.7E-06		3.9E-06	4.9E-06		7.1E-06
			1	1	1	1	10	10	0.0025	0.05	6.1E-06	6.1E-05	0.0	Industrial	Outside	7%	7.0E-02	0.5	2.2E-07			1.2E-06			2.1E-06		
		Rockfall - far field seismic trigger - 1/100 yr	0.01	100	10	0.1	100	1	0.0025	0.05	6.1E-05	5.5E-04	0.0	Residential	Inside	80%	8.0E-01	0.3	1.5E-07	1.7E-07		7.3E-07	8.5E-07		1.3E-06	1.5E-06	
	2		0.01	100	10	0.1	100	1	0.0025	0.05	6.1E-05	5.5E-04	0.2	Residential	Outside	10%	8.0E-02	0.5	2.4E-08			1.2E-07			2.2E-07		
	1-10%		0.01	100	10	0.1	100	1	0.0025	0.05	6.1E-05	5.5E-04	0.0	Industrial	Inside	27%	2.7E-01	0.3	4.9E-08		6.6E-08	2.5E-07		3.3E-07	4.4E-07		5.9E-07
			0.01	100	10	0.1	100	1	0.0025	0.05	6.1E-05	5.5E-04	0.2	Industrial	Outside	7%	5.6E-02	0.5	1.7E-08			8.5E-08			1.5E-07		
		Rockfall - near field seismic trigger 1/500 yr	0.002	500	100	0.2	1000	2	0.0025	0.05	5.5E-04	2.3E-03	0.0	Residential	Inside	80%	8.0E-01	0.3	2.6E-07	3.1E-07		6.8E-07	7.9E-07		1.1E-06	1.3E-06	
			0.002	500	100	0.2	1000	2	0.0025	0.05	5.5E-04	2.3E-03	0.2	Residential	Outside	10%	8.0E-02	0.5	4.4E-08			1.1E-07			1.8E-07		
			0.002	500	100	0.2	1000	2	0.0025	0.05	5.5E-04	2.3E-03	0.0	Industrial	Inside	27%	2.7E-01	0.3	8.8E-08		1.2E-07	2.3E-07		3.1E-07	3.7E-07		5.0E-07
			0.002	500	100	0.2	1000	2	0.0025	0.05	5.5E-04	2.3E-03	0.2	Industrial	Outside	7%	5.6E-02	0.5	3.1E-08			7.9E-08			1.3E-07		
								0											**AIFR**	**2.3E-06**	**9.0E-07**	**AIFR**	**1.1E-05**	**4.5E-06**	**AIFR**	**2.0E-05**	**8.1E-06**
Rockfall		Rockfall - non-seismic trigger	1	1	1	1	10	10	0.0005	0.01	1.2E-06	1.2E-05	0.0	Residential	Inside	80%	8.0E-01	0.1	9.8E-08	1.4E-07		5.4E-07	7.4E-07		9.7E-07	1.3E-06	
			1	1	1	1	10	10	0.0005	0.01	1.2E-06	1.2E-05	0.0	Residential	Outside	10%	1.0E-01	0.3	3.7E-08			2.0E-07			3.6E-07		
			1	1	1	1	10	10	0.0005	0.01	1.2E-06	1.2E-05	0.0	Industrial	Inside	27%	2.7E-01	0.1	3.3E-08		5.9E-08	1.8E-07		3.2E-07	3.3E-07		5.8E-07
			1	1	1	1	10	10	0.0005	0.01	1.2E-06	1.2E-05	0.0	Industrial	Outside	7%	7.0E-02	0.3	2.6E-08			1.4E-07			2.6E-07		
		Rockfall - far field seismic trigger - 1/100 yr	0.01	100	10	0.1	100	1	0.0005	0.01	1.2E-05	1.1E-04	0.0	Residential	Inside	80%	8.0E-01	0.1	9.7E-09	1.3E-08		4.9E-08	6.3E-08		8.7E-08	1.1E-07	
	3		0.01	100	10	0.1	100	1	0.0005	0.01	1.2E-05	1.1E-04	0.2	Residential	Outside	10%	8.0E-02	0.3	2.9E-09			1.5E-08			2.6E-08		
	<1%		0.01	100	10	0.1	100	1	0.0005	0.01	1.2E-05	1.1E-04	0.0	Industrial	Inside	27%	2.7E-01	0.1	3.3E-09		5.3E-09	1.6E-08		2.7E-08	2.9E-08		4.8E-08
			0.01	100	10	0.1	100	1	0.0005	0.01	1.2E-05	1.1E-04	0.2	Industrial	Outside	7%	5.6E-02	0.3	2.0E-09			1.0E-08			1.8E-08		
		Rockfall - near field seismic trigger 1/500 yr	0.002	500	100	0.2	1000	2	0.0005	0.01	1.1E-04	4.6E-04	0.0	Residential	Inside	80%	8.0E-01	0.1	1.7E-08	2.3E-08		4.5E-08	5.9E-08		7.3E-08	9.5E-08	
			0.002	500	100	0.2	1000	2	0.0005	0.01	1.1E-04	4.6E-04	0.2	Residential	Outside	10%	8.0E-02	0.3	5.2E-09			1.4E-08			2.2E-08		
			0.002	500	100	0.2	1000	2	0.0005	0.01	1.1E-04	4.6E-04	0.0	Industrial	Inside	27%	2.7E-01	0.1	5.9E-09		9.6E-09	1.5E-08		2.5E-08	2.5E-08		4.0E-08
			0.002	500	100	0.2	1000	2	0.0005	0.01	1.1E-04	4.6E-04	0.2	Industrial	Outside	7%	5.6E-02	0.3	3.7E-09			9.5E-09			1.5E-08		
																			AIFR	**1.7E-07**	**7.4E-08**	**AIFR**	**8.6E-07**	**3.7E-07**	**AIFR**	**1.5E-06**	**6.7E-07**

Annual Individual Fatality Risk (AIFR) Assessment Worksheet

Location: Reavers Fan, Queenstown
Failure mode: Debris flow - channel option
Consequence: Death
Element at risk: Individual most at risk
Date: 23-Dec-20
Status: Final

Hazard	Hazard zone	Failure magnitude (refer debris flow modelling scenarios for definitions, Tab 2)	Annual probability of failure P(H) (1)				Probability of travel (P(S:H)) (2)	Temporal spatial probability (P(T:S)) (3)							Vulnerability (4)	AIFR Lower		AIFR Average		AIFR Upper	
			Lower		Upper			Probability of self evacuation, P(se)													
			P(H)	1 in x years	P(H)	1 in x years		Lower	Upper	Planning zone	Occupancy	Time "individual most at risk present)	Lower	Upper		AIFR	AIFR Residential	AIFR	AIFR Residential	AIFR	AIFR Residential
Debris flow Reavers	1	Small, more frequent event	0.0004	2500	0.01	100	0	0.5	0.7	Residential	Inside	80%	0.24	0.4	0	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
			0.0004	2500	0.01	100	0	0.6	0.8	Residential	Outside	10%	0.02	0.04	0	0.0E+00		0.0E+00		0.0E+00	
		Medium	0.00015	6667	0.0004	2500	1	0.3	0.5	Residential	Inside	80%	0.4	0.56	0.5	3.0E-05	3.4E-05	6.6E-05	7.4E-05	1.1E-04	1.3E-04
			0.00015	6667	0.0004	2500	1	0.4	0.6	Residential	Outside	10%	0.04	0.06	0.6	3.6E-06		8.3E-06		1.4E-05	
		Large, less frequent event	0.00005	20000	0.00015	6667	1	0.1	0.3	Residential	Inside	80%	0.56	0.72	0.9	2.5E-05	2.8E-05	5.8E-05	6.5E-05	9.7E-05	1.1E-04
			0.00005	20000	0.00015	6667	1	0.2	0.4	Residential	Outside	10%	0.06	0.08	1	3.0E-06		7.0E-06		1.2E-05	
																AIFR	**6.2E-05**	**AIFR**	**1.4E-04**	**AIFR**	**2.4E-04**
Debris flow Reavers	2	Small, more frequent event	0.0004	2500	0.01	100	0.00	0.5	0.7	Residential	Inside	80%	0.24	0.4	0.5	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
			0.0004	2500	0.01	100	0.00	0.6	0.8	Residential	Outside	10%	0.02	0.04	0.6	0.0E+00		0.0E+00		0.0E+00	
		Medium	0.00015	6667	0.0004	2500	0.9	0.4	0.6	Residential	Inside	80%	0.32	0.48	0.5	2.2E-05	2.4E-05	5.0E-05	5.5E-05	8.6E-05	9.7E-05
			0.00015	6667	0.0004	2500	0.9	0.5	0.7	Residential	Outside	10%	0.03	0.05	0.6	2.4E-06		5.9E-06		1.1E-05	
		Large, less frequent event	0.00005	20000	0.00015	6667	1	0.2	0.4	Residential	Inside	80%	0.48	0.64	0.9	2.2E-05	2.4E-05	5.0E-05	5.6E-05	8.6E-05	9.7E-05
			0.00005	20000	0.00015	6667	1	0.3	0.5	Residential	Outside	10%	0.05	0.07	1	2.5E-06		6.0E-06		1.1E-05	
																AIFR	**4.8E-05**	**AIFR**	**1.1E-04**	**AIFR**	**1.9E-04**
Debris flow Reavers	3	Small, more frequent event	0.0004	2500	0.01	100	0.00	0.6	0.8	Residential	Inside	80%	0.16	0.32	0.5	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
			0.0004	2500	0.01	100	0.00	0.7	0.9	Residential	Outside	10%	0.01	0.03	0.6	0.0E+00		0.0E+00		0.0E+00	
		Medium	0.00015	6667	0.0004	2500	0	0.4	0.6	Residential	Inside	80%	0.32	0.48	0.8	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
			0.00015	6667	0.0004	2500	0	0.5	0.7	Residential	Outside	10%	0.03	0.05	0.9	0.0E+00		0.0E+00		0.0E+00	
		Large, less frequent event	0.00005	20000	0.00015	6667	0.9	0.3	0.5	Residential	Inside	80%	0.4	0.56	0.9	1.6E-05	1.8E-05	3.9E-05	4.3E-05	6.8E-05	7.6E-05
			0.00005	20000	0.00015	6667	0.9	0.4	0.6	Residential	Outside	10%	0.04	0.06	1	1.8E-06		4.5E-06		8.1E-06	
																AIFR	**1.8E-05**	**AIFR**	**4.3E-05**	**AIFR**	**7.6E-05**
Debris flow Reavers	4	Small, more frequent event	0.0004	2500	0.01	100	0.00	0.7	0.9	Residential	Inside	80%	0.08	0.24	0.5	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
			0.0004	2500	0.01	100	0.00	0.7	0.9	Residential	Outside	10%	0.01	0.03	0.6	0.0E+00		0.0E+00		0.0E+00	
		Medium	0.00015	6667	0.0004	2500	0	0.5	0.7	Residential	Inside	80%	0.24	0.4	0.8	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
			0.00015	6667	0.0004	2500	0	0.5	0.7	Residential	Outside	10%	0.03	0.05	0.9	0.0E+00		0.0E+00		0.0E+00	
		Large, less frequent event	0.00005	20000	0.00015	6667	0.9	0.4	0.6	Residential	Inside	80%	0.32	0.48	0.05	7.2E-07	8.6E-07	1.8E-06	2.2E-06	3.2E-06	3.9E-06
			0.00005	20000	0.00015	6667	0.9	0.5	0.7	Residential	Outside	10%	0.03	0.05	0.1	1.4E-07		3.6E-07		6.8E-07	
																AIFR	**8.6E-07**	**AIFR**	**2.2E-06**	**AIFR**	**3.9E-06**

Annual Individual Fatality Risk (AIFR) Assessment Worksheet

Location: Reavers Fan, Queenstown
Failure mode: Debris flow - fence option
Consequence: Death
Element at risk: Individual most at risk
Date: 23-Dec-20
Status: Final

Hazard	Hazard zone	Failure magnitude (refer debris flow modelling scenarios for definitions, Tab 2)	Annual probability of failure P(H) (1) – Lower		Annual probability of failure P(H) (1) – Upper		Probability of travel (P(S:H)) (2)	Probability of self evacuation, P(se) – Lower	Probability of self evacuation, P(se) – Upper	Temporal spatial probability (P(T:S)) (3) – Planning zone	Occupancy	Time "individual most at risk present)	Lower	Upper	Vulnerability (4)	AIFR Lower		AIFR Average		AIFR Upper	
			P(H)	1 in x years	P(H)	1 in x years										AIFR	AIFR Residential	AIFR	AIFR Residential	AIFR	AIFR Residential
Debris flow Reavers	1	Small, more frequent event	0.0004	2500	0.01	100	0	0.5	0.7	Residential	Inside	80%	0.24	0.4	0	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
			0.0004	2500	0.01	100	0	0.6	0.8	Residential	Outside	10%	0.02	0.04	0	0.0E+00		0.0E+00		0.0E+00	
		Medium	0.00015	6667	0.0004	2500	1	0.3	0.5	Residential	Inside	80%	0.4	0.56	0.8	4.8E-05	5.3E-05	1.1E-04	1.2E-04	1.8E-04	2.0E-04
			0.00015	6667	0.0004	2500	1	0.4	0.6	Residential	Outside	10%	0.04	0.06	0.9	5.4E-06		1.2E-05		2.2E-05	
		Large, less frequent event	0.00005	20000	0.00015	6667	1	0.1	0.3	Residential	Inside	80%	0.56	0.72	0.9	2.5E-05	2.8E-05	5.8E-05	6.5E-05	9.7E-05	1.1E-04
			0.00005	20000	0.00015	6667	1	0.2	0.4	Residential	Outside	10%	0.06	0.08	1	3.0E-06		7.0E-06		1.2E-05	
																AIFR	**8.2E-05**	**AIFR**	**1.8E-04**	**AIFR**	**3.1E-04**
Debris flow Reavers	2	Small, more frequent event	0.0004	2500	0.01	100	0.00	0.5	0.7	Residential	Inside	80%	0.24	0.4	0.5	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
			0.0004	2500	0.01	100	0.00	0.6	0.8	Residential	Outside	10%	0.02	0.04	0.6	0.0E+00		0.0E+00		0.0E+00	
		Medium	0.00015	6667	0.0004	2500	0.9	0.4	0.6	Residential	Inside	80%	0.32	0.48	0.8	3.5E-05	3.8E-05	7.9E-05	8.8E-05	1.4E-04	1.5E-04
			0.00015	6667	0.0004	2500	0.9	0.5	0.7	Residential	Outside	10%	0.03	0.05	0.9	3.6E-06		8.9E-06		1.6E-05	
		Large, less frequent event	0.00005	20000	0.00015	6667	1	0.2	0.4	Residential	Inside	80%	0.48	0.64	0.9	2.2E-05	2.4E-05	5.0E-05	5.6E-05	8.6E-05	9.7E-05
			0.00005	20000	0.00015	6667	1	0.3	0.5	Residential	Outside	10%	0.05	0.07	1	2.5E-06		6.0E-06		1.1E-05	
																AIFR	**6.2E-05**	**AIFR**	**1.4E-04**	**AIFR**	**2.5E-04**
Debris flow Reavers	3	Small, more frequent event	0.0004	2500	0.01	100	0.00	0.6	0.8	Residential	Inside	80%	0.16	0.32	0.5	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
			0.0004	2500	0.01	100	0.00	0.7	0.9	Residential	Outside	10%	0.01	0.03	0.6	0.0E+00		0.0E+00		0.0E+00	
		Medium	0.00015	6667	0.0004	2500	0	0.4	0.6	Residential	Inside	80%	0.32	0.48	0.8	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
			0.00015	6667	0.0004	2500	0	0.5	0.7	Residential	Outside	10%	0.03	0.05	0.9	0.0E+00		0.0E+00		0.0E+00	
		Large, less frequent event	0.00005	20000	0.00015	6667	0.9	0.3	0.5	Residential	Inside	80%	0.4	0.56	0.9	1.6E-05	1.8E-05	3.9E-05	4.3E-05	6.8E-05	7.6E-05
			0.00005	20000	0.00015	6667	0.9	0.4	0.6	Residential	Outside	10%	0.04	0.06	1	1.8E-06		4.5E-06		8.1E-06	
																AIFR	**1.8E-05**	**AIFR**	**4.3E-05**	**AIFR**	**7.6E-05**
Debris flow Reavers	4	Small, more frequent event	0.0004	2500	0.01	100	0.00	0.7	0.9	Residential	Inside	80%	0.08	0.24	0.5	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
			0.0004	2500	0.01	100	0.00	0.7	0.9	Residential	Outside	10%	0.01	0.03	0.6	0.0E+00		0.0E+00		0.0E+00	
		Medium	0.00015	6667	0.0004	2500	0	0.5	0.7	Residential	Inside	80%	0.24	0.4	0.8	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
			0.00015	6667	0.0004	2500	0	0.5	0.7	Residential	Outside	10%	0.03	0.05	0.9	0.0E+00		0.0E+00		0.0E+00	
		Large, less frequent event	0.00005	20000	0.00015	6667	0.9	0.4	0.6	Residential	Inside	80%	0.32	0.48	0.05	7.2E-07	8.6E-07	1.8E-06	2.2E-06	3.2E-06	3.9E-06
			0.00005	20000	0.00015	6667	0.9	0.5	0.7	Residential	Outside	10%	0.03	0.05	0.1	1.4E-07		3.6E-07		6.8E-07	
																AIFR	**8.6E-07**	**AIFR**	**2.2E-06**	**AIFR**	**3.9E-06**

G

Appendix G – Cost Estimate

Introduction

Beca have prepared order of magnitude cost estimates to compare the likely costs of 3 no. options to provide debris retention and protection to Reavers and Brewery Creek Fans at Gorge Road in Queenstown.

These options comprise the following:

Option	Reavers Fan	Brewery Creek Fan
1 – Rockfall Mesh and Fences	Construction of rockfall fences.	Construction of rock retention mesh and rockfall fences.
2 – Debris Flow Barriers	Construction of 3no. new debris flow barriers to unspecified locations along the Reavers Fan stream.	Construction of 3no. new debris flow barriers to unspecified locations along the Brewery Creek Fan stream.
3 – Debris Flow Channels	Forming a new debris channel from the base of Reavers Fan stream to the domain/playground including fencing and signage together with demolition of existing properties and utility services realignment (road re-alignment of roads to suit.	Re-forming/deepening and extending the existing Brewery Creek Fan debris channel including fencing and signage.

Basis of Estimate

Design Documentation

The estimate of the cost of construction works has been allowed only as per the information supplied. All work should be installed in accordance with the relevant codes, standards and manufacturer's instructions as applicable.

The construction programme has not yet been established.

The drawings and supporting information relied upon to generate this concept stage estimate are summarised as follows;

- Rockfall Fences and Meshing plan
- Debris flow barrier cross sections and Geobrugg UX and VX System design data
- Debris flow channel map overlays plans
- Debris flow cut and fill volumes from 12d modelling
- Various emails

The main risks that remain are linked to the preliminary nature of the design – the extent of specific works required for all options cannot be accurately determined without detailed investigation/design, therefore further design development is recommended

1. Access to and around the work areas (plant, material deliveries and general access)
2. Location of debris flow barriers (exact location and methodology to be established)
3. Temporary/enabling works (staging areas, helicopter lay-down size and location, site preparation)
4. Debris flow channel works (extent of affected properties/features/levels, retaining structures, utilities and services)
5. Service/utility upgrades and re-alignment associated with debris flow channels
6. Major road re-alignment and road/channel intersections associated with Reavers Fan
7. Ground stabilisation, retention or contamination remediation/treatment/disposal, unless specifically identified

Procurement

We have assumed current market rates and sums based on a traditional procurement route, ie. Fully designed and competitively tendered measure and value tenders from at least three suitable selected tenderers.

Escalation

It should be noted that escalation allowances are excluded from the current estimate beyond 4th Quarter 2020.

Estimate

Estimate Summary

A detailed cost breakdown has been provided in Table F 1.

Table F 1 – Detailed cost breakdown

			Reavers Fan $	Brewery Creek Fan $	TOTAL $
1.00	**ROCKFALL FENCE AND GROUND MESH**				
1.01	Site clearance and access		45,500	45,500	91,000
1.02	Geobrugg GBE Rockfall Barrier; 500kJ barrier; posts at 10m centres		275,400	259,200	534,600
1.03	Geobrugg GBE1000AR Rockfall Barrier; 1000kJ barrier; posts at 10m centres		314,500	-	314,500
1.04	Geobrugg Tecco Rockfall Mesh		-	486,000	486,000
	Option 1 Sub-Total		**635,400**	**790,700**	**1,426,100**
	Contingency	10%	63,600	79,100	142,700
	P&G	15%	104,900	130,500	235,400
	Margin	6%	48,300	60,100	108,400
	Option 1 TOTAL		**852,200**	**1,060,400**	**1,912,600**
2.00	**DEBRIS FLOW BARRIERS**				
2.01	Access & protection		159,800	170,600	330,400
2.02	Debris Flow Fences - UX System		460,519	246,750	707,269
2.03	Debris Flow Fences - VX System		327,481	411,250	738,731
	Option 2 Sub-Total		**947,800**	**828,600**	**1,776,400**
	Contingency	20%	189,600	165,800	355,400
	P&G	15%	170,700	149,200	319,900
	Margin	6%	78,500	68,700	147,200
	Option 2 TOTAL		**1,386,600**	**1,212,300**	**2,598,900**
3.00	**DEBRIS FLOW CHANNELS**				
3.01	Site clearance and vegetation removal		74,800	31,500	106,300
3.02	Property clearance		50,000	-	50,000

3.03	Utilities re-alignment - PROVISIONAL SUM		350,000	-	350,000
3.04	Building demolition - residential		500,000	35,000	535,000
3.05	Planting along bunds; 3no. shrubs/m²		30,300	40,400	70,700
3.06	Chainlink mesh fencing 2000 high		72,600	64,700	137,300
3.07	Signage - fence mounted		3,200	3,200	6,400
3.08	Excavation and disposal off site		682,900	772,900	1,455,800
3.09	Fill - imported clean fill and large rocks		853,200	38,400	891,600
3.10	Batter sides of excavation		30,300	27,000	57,300
3.11	Bridge adjustments - PROVISIONAL SUM		-	75,000	75,000
	Option 3 Sub-Total		**2,647,300**	**1,088,100**	**3,735,400**
	Contingency	20%	529,500	217,700	747,200
	P&G	15%	476,600	195,900	672,500
	Margin	6%	219,300	90,200	309,500
	Option 3 TOTAL		**3,872,700**	**1,591,900**	**5,464,600**

Please refer to the clarifications, assumptions, exclusions and items of cost risks that are outlined within the body of this estimate report.

Please note that all values within this report and included in the attached estimate details are in New Zealand dollars (NZ$) and are GST exclusive.

In addition to the single point estimated costs, we have also provided an expected estimate range that reflects current market conditions and unknown risks that can impact the project that are difficult to predict or value.

It is important to note that whilst this estimate is an indication of the overall likely cost to be anticipated for the works described, the individual price items will vary (depending on contractor, plant, methodology etc) and should not be relied on in isolation.

Estimate Detail

Due to the current stage of design it has been necessary to make a number of significant assumptions and exclusions which have been identified in this section.

No allowance has been included in our estimates for construction contingency. Construction contingency is a risk contingency to cover the cost of variation claims made by the contractor during the construction phase of the project. This contingency is integral to the estimated outturn cost and is normally separately monitored during the construction phase.

No allowance has been included in our estimate for client scope change risk. Client scope change risk is for use during both design and construction processes to provide for any client driven changes. It is excluded from our estimate and is a separate budget we recommend the client hold, if there is the potential for client scope changes to influence the outturn cost of the project. We would note that the above contingencies do not allow for any client driven scope change.

P&G has been included as a separate line item in the estimate. P&G otherwise known as On-Site Overhead costs covers the cost of on-site overheads such as site supervision / management, site offices, stores, hoardings, amenities, plant, cranes, temporary works etc.

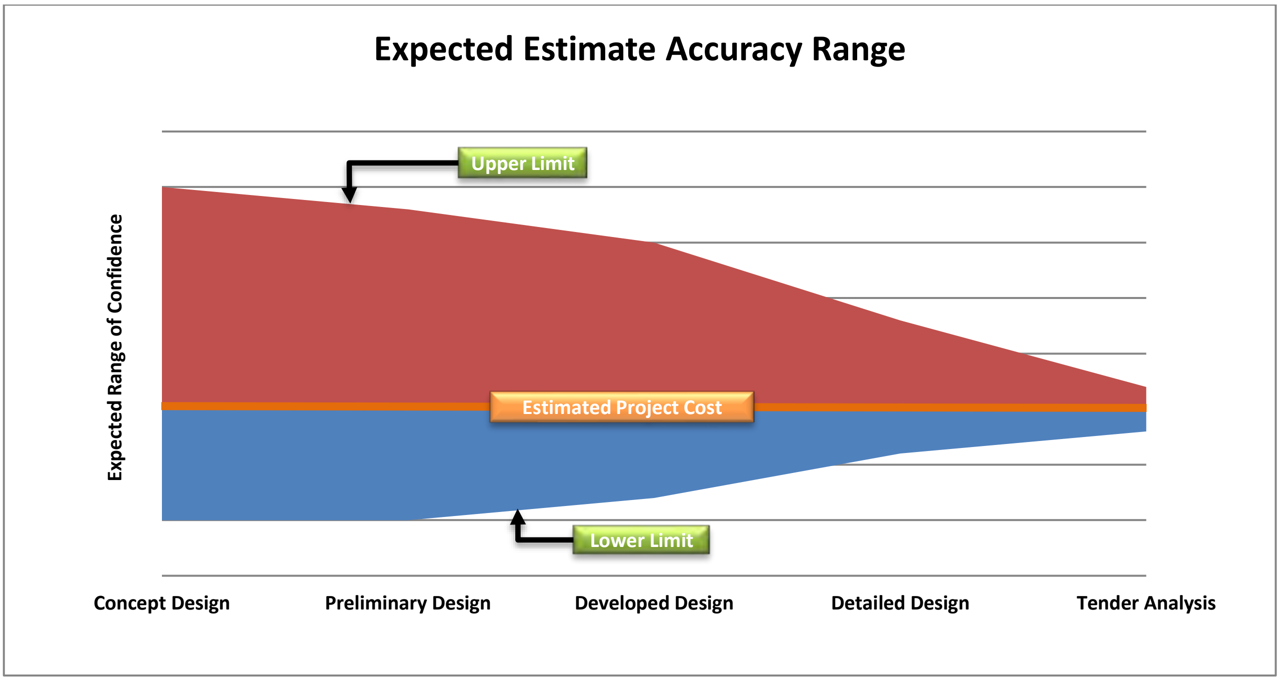
For the purposes of this estimate, contractor’s margin has been added separately to the rates for the measured works. Also referred to as Off-site Overheads and profit (OH&P), this covers the cost of contributions to cover the Main Contractor’s business operational costs, i.e. off-site overhead costs such as executive management, accounts, quality and health & safety systems and company profits.

Lump sum allowances and provisional quantities have been included in with the measured works to cover items that are likely to be encountered as the works proceed. Where provisional quantities have been included.

An estimate contingency has been included at 20% with the exception of the rockfall works which includes a 10% contingency to reflect a lower risk / few assumptions. This is integral to the estimate total and is a general allowance for residual cost risk including price variance, omissions, sundry unmeasured items and assumptions made for construction details not shown based on the current project scope. This is not a project/construction contingency which is expected to be held in addition to this estimating contingency.

Expected Estimate Range

Estimate range is an indication of the degree to which the final cost outcome for a given project will vary from the estimated cost – it is not an additional Contingency. Range is expressed as a +/- percentage range around the point of estimate after the application of contingency, with a stated level of confidence that the actual cost outcome would fall within this range. As the level of project definition increases and the tender date draws nearer, the expected range of the estimate tends to improve, as indicated by a tighter +/- range.



These estimates are based on “Concept Design” information and therefore are currently subject to an estimate range of approximately -35% to +50%, however, options 2 and 3 estimates (debris flow barriers and channels) have been prepared with exceptionally limited information, therefore the scope of work will require further definition in order to achieve a higher degree of accuracy.

This range highlights the following unknown risks that can impact the project that are difficult to predict or value. These risks could include, but are not limited to the following:

- Major fluctuations in the market
- Labour & material shortages
- Health & Safety Hazards
- Unexpected ground and site conditions
- Exceptionally adverse weather
- Methodology

Assumptions, Clarifications & Exclusions

Below we summarise principle notes, assumptions, clarifications and exclusions to the cost estimate:

- Rockfall fence and ground mesh locations assumed uphill of powerline corridor
- Rockfall fence and ground mesh installation assumes unimpeded access along/across powerline firebreak
- Soil matting, seeding, planting and re-surfacing of access tracks for rockfall fence and ground mesh on completion not deemed to be required
- Debris flow barriers pricing based on combination of helicopter transporting small excavator, materials and equipment together with ground-based labour access
- Exact locations of rockfall fence and ground mesh and debris flow barriers to be confirmed
- Disposal of excavated material and vegetation strip for access and debris flow barriers assumed within 25m of excavation

- Potential savings could be realised for re-using excavated materials from channel excavation if deemed to be suitable material
- Reavers Fan utilities re-routing provisional allowance excludes potential upgrades resulting from the works
- A PROVISIONAL ALLOWANCE of $35,000 per debris flow barrier location has been included for working platforms and enabling works
- A PROVISIONAL ALLOWANCE of $350,000 has been included for realignment of utilities crossing Reavers Fan debris flow channel including searching for or discovery of unknown services. Upgrades to utilities to facilitate the channel are excluded (pumping stations, transformers and capacity upgrades etc)
- A PROVISIONAL ALLOWANCE of $75,000 has been included for alterations to the bridge crossing Brewery Creek Fan debris flow channel
- A PROVISIONAL ALLOWANCE of $50,000 has been included for service relocations to properties affected by the Reavers Fan debris flow channel
- The works have been priced on the basis of being undertaken as a single project
- It is assumed that a major road re-alignment and/or bridge, culvert, tunnels may be required to Reavers Fan debris flow channel. The scope and extent of this is currently unknown therefore the cost of these items have been specifically excluded from this estimate
- Debris flow channel bund planting density assumed as three shrubs per square metre
- The contractor shall be responsible for the final locations and methodologies for accessing the debris flow barrier work sites
- 10no. Residential properties demolished/removed to make way for Reavers Fan debris flow channel
- 1no. Relocatable building repositioned to allow for Brewery Creek Fan debris flow channel works
- Elements of cost included within this estimate are based on costs from similar projects and other Beca cost benchmarks
- Contract competitively tendered to minimum of 3no. suitably experienced contractors
- The work will be undertaken by a single 'Main Contractor' through a single contract for the project
- All works will be carried out in a single phase
- All works are carried out during normal daytime working hours
- It is assumed that the contractor will have unobstructed access to the whole site throughout the construction phase
- All base prices are current to 4th Quarter 2020. A construction escalation allowance has not been included
- Option 3 – Road re-alignment to Reavers Fan not designed therefore it is not possible to price for this work.

Exclusions

- Goods and services Tax (GST)
- Land purchase and negotiations
- Professional/consultant and legal fees
- Costs incurred to date
- Consent fees
- Maintenance costs
- Costs associated with ground improvements, contaminated materials (asbestos etc), obstructions or de-watering
- Phasing and staging of the works
- Out of hours work (nights & weekends), fast-track / accelerated programme
- Excavation by hand or restricted access (insufficient for excavator use)
- Cost escalation/increased costs beyond 4th quarter 2020

- Ground/soil stabilisation, remediation, ground/soil retention (retaining works/structures etc except rockfall mesh)
- Planting/landscaping (except for fencing and planting to debris channel berms)
- Bridges, tunnels etc required to Reavers or Brewery Creek Fans debris flow channels
- Road re-alignment required to accommodate debris flow channels
- Traffic management requirements for all options and locations
- Abortive or additional costs due to exceptionally adverse/inclement weather or other natural conditions
- Environmental management plans; including subsequent updates and management
- Excavation in hard rock
- Major roading or utility upgrades
- Water diversions (if required)

General Recommendations

The level of design information currently available for the proposed options is limited, especially for options 2 and 3, therefore it is recommended that the design is developed further to reduce the unknown scope and associated risks and enable the preparation of more detailed and accurate cost estimates.

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