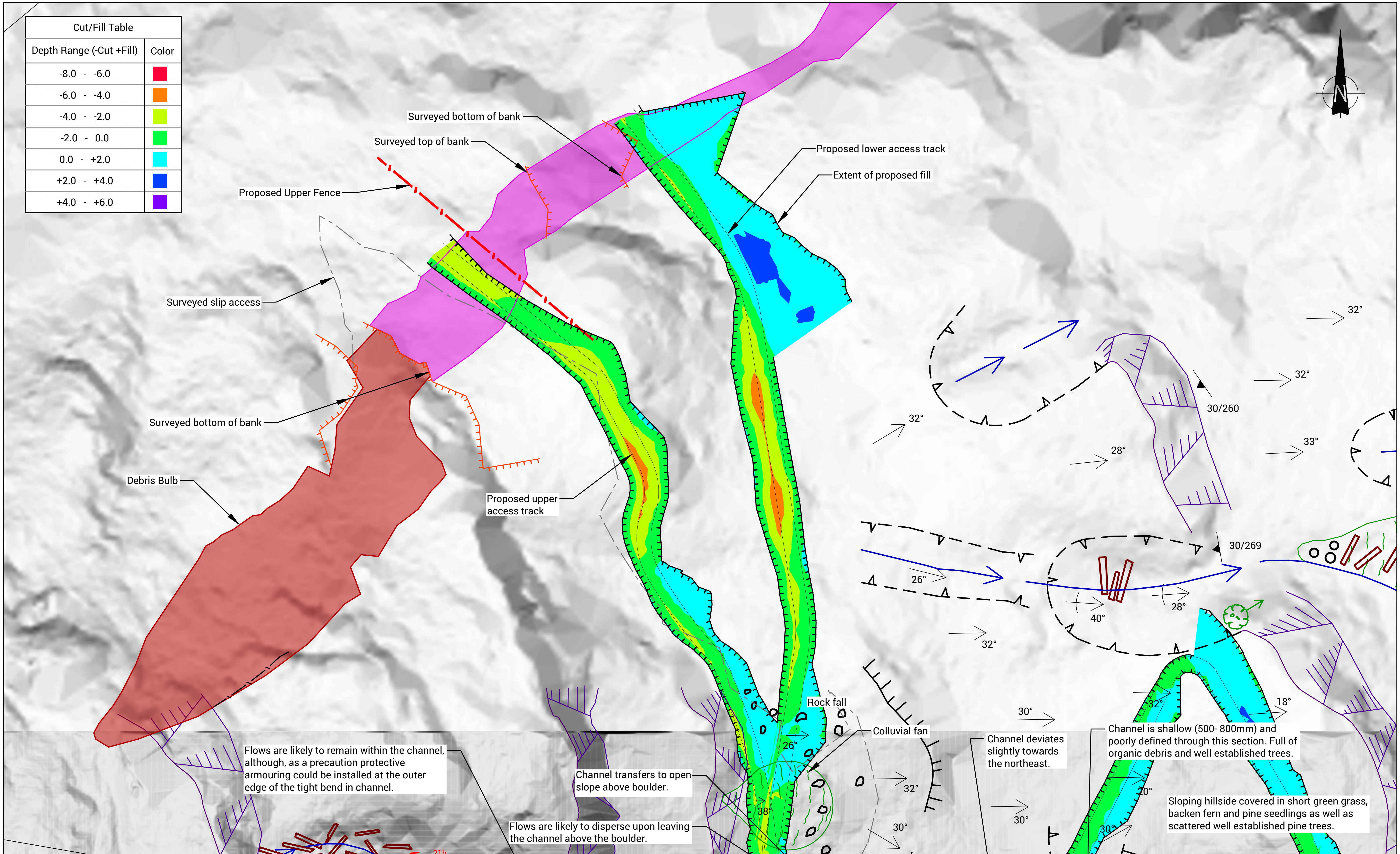
Appendix B: Earthworks and Geomorphic Plan

Cut/Fill Table

Depth Range (-Cut +Fill)	Color
-8.0 - -6.0	
-6.0 - -4.0	
-4.0 - -2.0	
-2.0 - 0.0	
0.0 - +2.0	
+2.0 - +4.0	
+4.0 - +6.0	



Notes:
1. These drawings have been prepared for the benefit of Skyline Enterprises Limited with respect to the particular brief given to us and it may not be relied upon in other contexts or for any other purpose without our prior review and agreement.
2. See Figure 2 for legend.

SCALE 1:750
0 7.5 15.0 22.5 30.0 37.5 (m)

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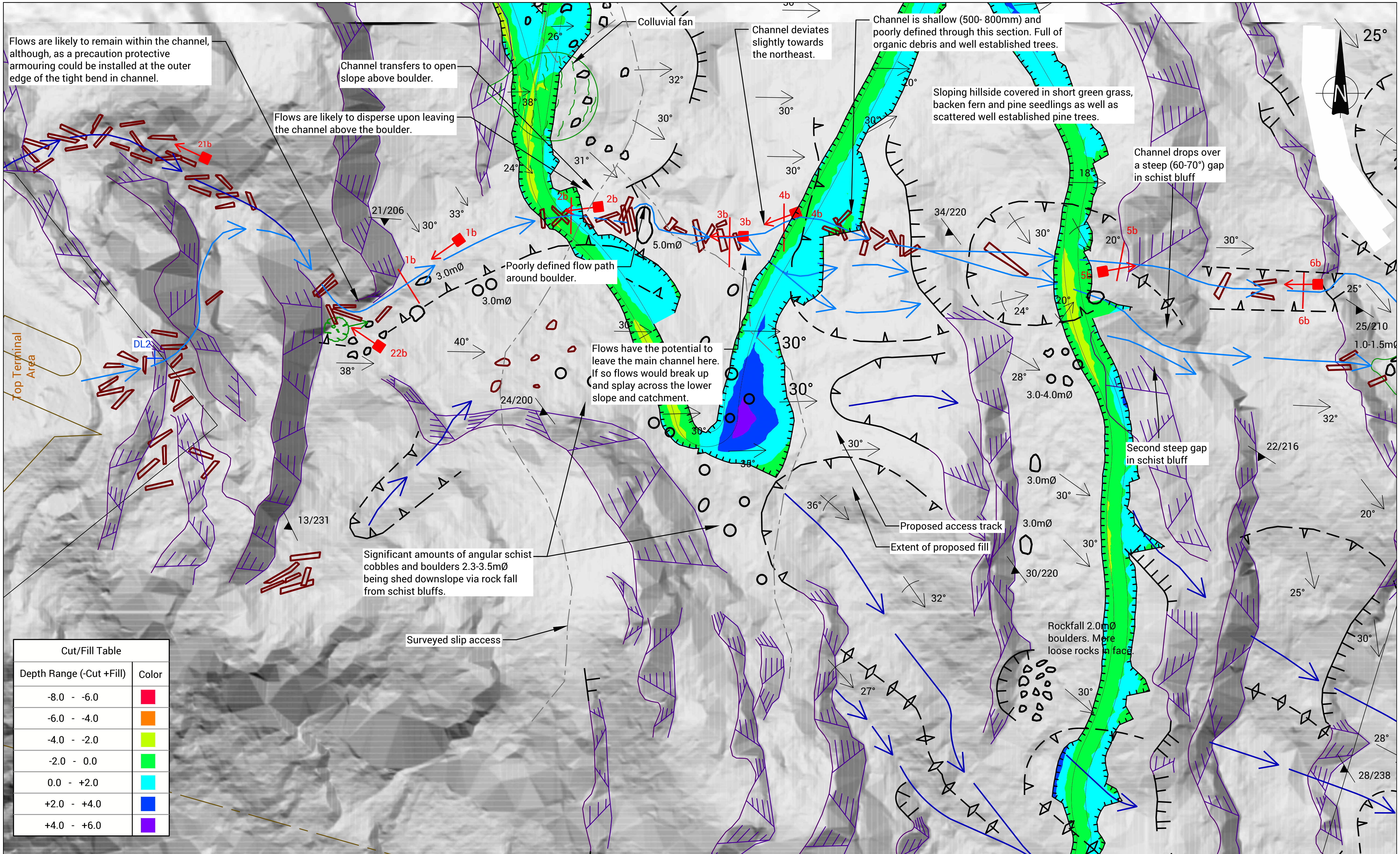
DRAWN	WCG	Apr.24
DRAFTING CHECKED		
APPROVED		

CADFILE: 160073.02_DR.dwg
SCALES (AT A3 SIZE): 1:750
PROJECT No: 160073.03

Skyline Enterprises Ltd
Skyline Debris Removal
Access Track
Geomorphology Plan A

FIG No: Appendix B, Figure 1a
REV. 2



Cut/Fill Table	
Depth Range (-Cut +Fill)	Color
-8.0 - -6.0	red
-6.0 - -4.0	orange
-4.0 - -2.0	yellow-green
-2.0 - 0.0	green
0.0 - +2.0	cyan
+2.0 - +4.0	blue
+4.0 - +6.0	purple

Notes:
1. These drawings have been prepared for the benefit of Skyline Enterprises Limited with respect to the particular brief given to us and it may not be relied upon in other contexts or for any other purpose without our prior review and agreement.
2. See Figure 2 for legend.

SCALE 1:750
0 7.5 15.0 22.5 30.0 37.5 (m)

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APPROVED		
CADFILE: 160073.02_DR.dwg		
SCALES (AT A3 SIZE): 1:750		
PROJECT No: 160073.03		

Skyline Enterprises Ltd

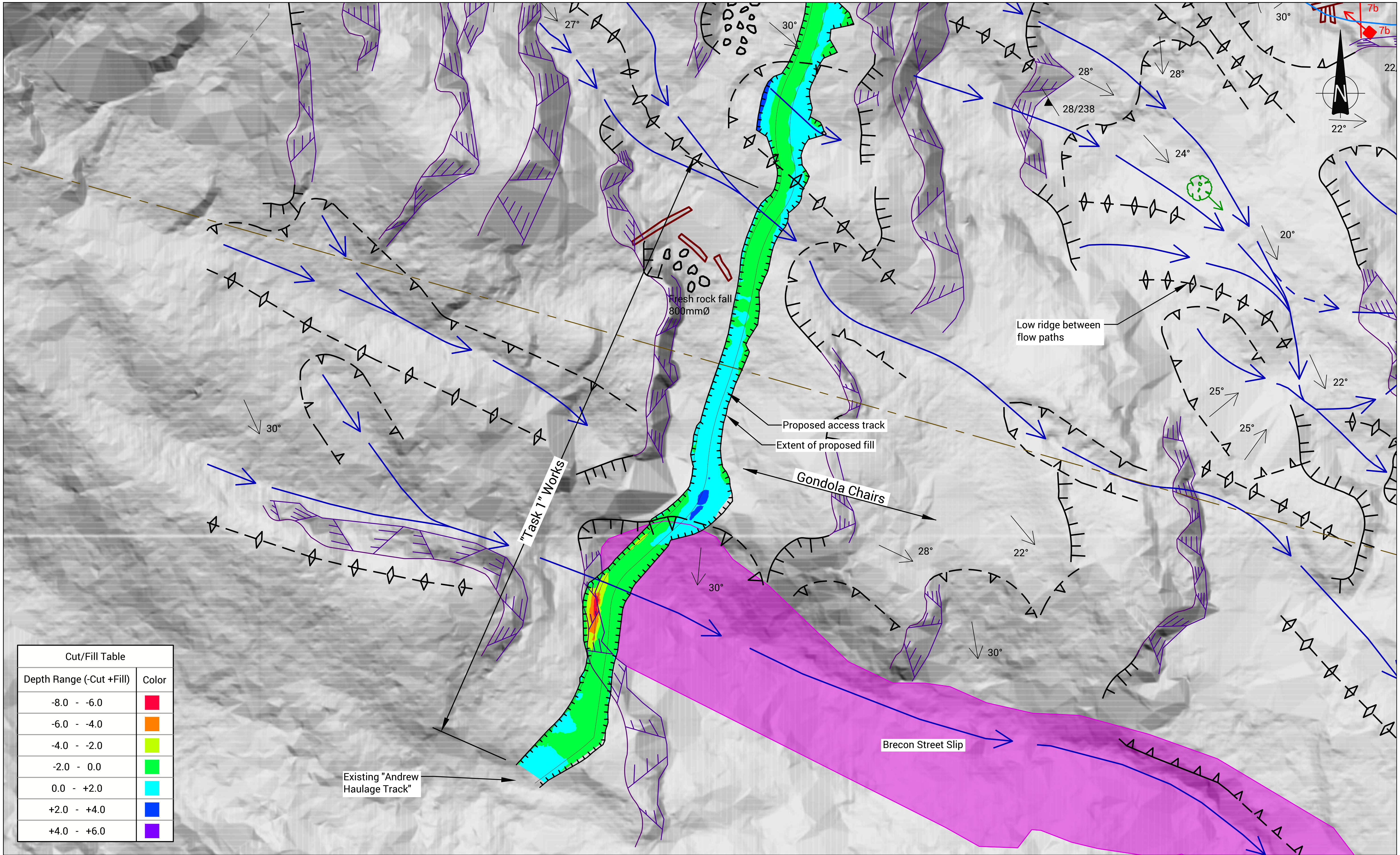
Skyline Debris Removal

Access Track

Geomorphology Plan B

FIG No: Appendix B, Figure 1b

REV. 2



Cut/Fill Table

Depth Range (-Cut +Fill)	Color
-8.0 - -6.0	Red
-6.0 - -4.0	Orange
-4.0 - -2.0	Yellow-green
-2.0 - 0.0	Green
0.0 - +2.0	Cyan
+2.0 - +4.0	Blue
+4.0 - +6.0	Purple

Notes:
1. These drawings have been prepared for the benefit of Skyline Enterprises Limited with respect to the particular brief given to us and it may not be relied upon in other contexts or for any other purpose without our prior review and agreement.
2. See Figure 2 for legend.

SCALE 1:750
0 7.5 15.0 22.5 30.0 37.5 (m)

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DRAWN	WCG	Apr.24
DRAFTING CHECKED		
APPROVED		
CADFILE: 160073.02_DR.dwg		
SCALES (AT A3 SIZE): 1:750		
PROJECT No: 160073.03		

Skyline Enterprises Ltd

Skyline Debris Removal

Access Track

Geomorphology Plan C

FIG No: Appendix B, Figure 1c

REV. 2

Legend:

30°	Slope direction and approximate angle/fall line		Water Flow Intermittent		Sharp break 40°+
30°	Concave slope direction and approximate angle/fall line		Hypothetical debris flow path from RAMMS software		Break of Slope - Crest
	Landslide Movement Direction (Inferred)		Glacial Till		Break of Slope - Toe
20b	Photograph location and number		Bouldery Colluvium		Break of slope
13/231	Foliation		Alluvial Fan		Ridgeline
20b	Channel Cross Section		Fill		Scarp
	Boulders	TS	Topsoil		Bluff
3.0mØ	Boulder on surface with diameter in metres	J J	Joint		Leaning Tree
	Organic Debris (trees, branches, etc)	T T	Tension Crack		Surveyed Break of Slope
	Surveyed Slip Access		Debris Bulb		Debris Material in Channel
	Proposed Fence				

GEOSOLVE
ENGINEERING CONSULTANTS

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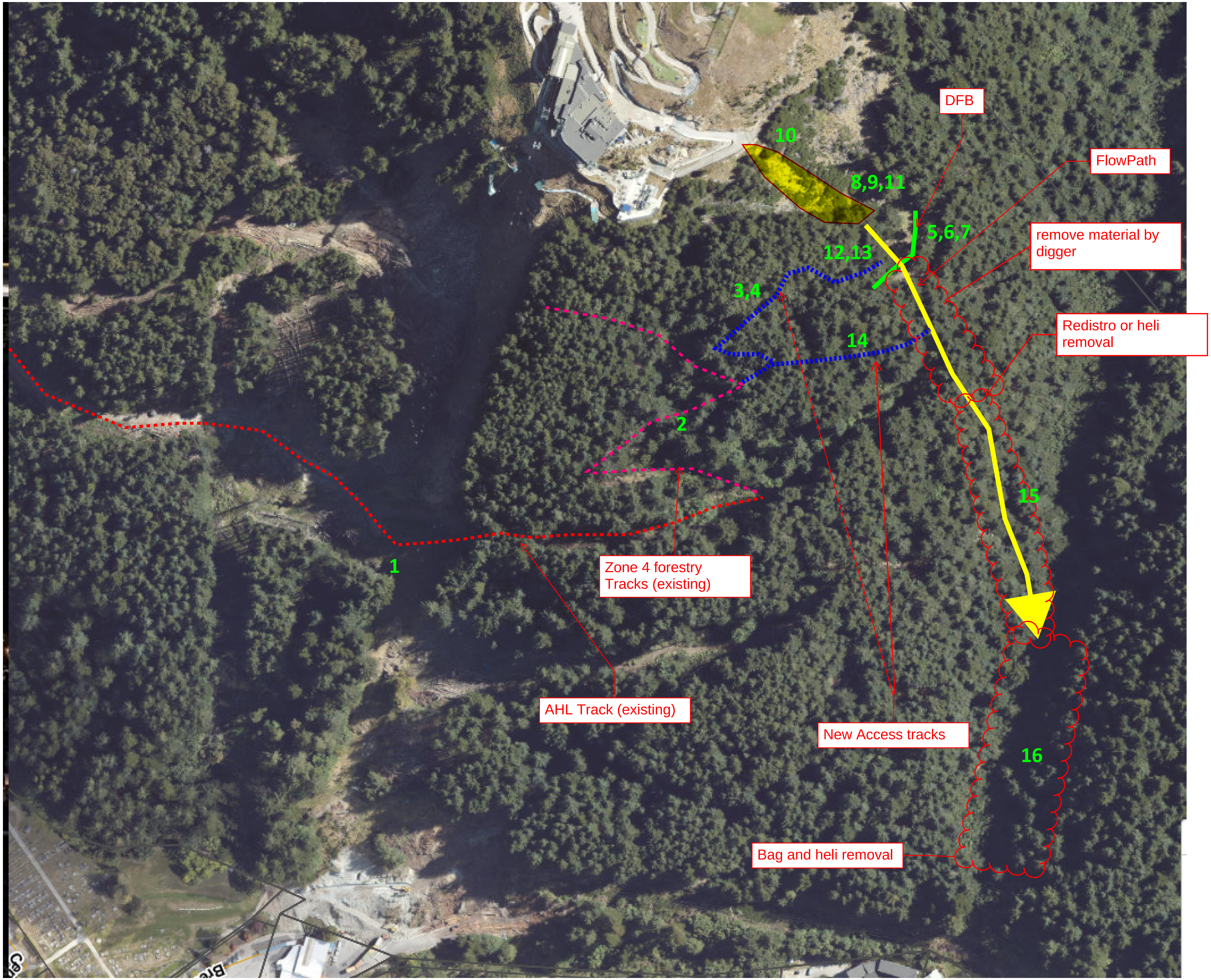
DRAWN	WCG	Feb.24
DRAFTING CHECKED		
APPROVED		
FILE :	160073.02_DR	
SCALE: (AT A4 SIZE)	AS SHOWN	
PROJECT No.	160073.03	

Skyline Enterprises Ltd
Skyline Debris Removal
Access Track
Geomorphology Legend

FIG No. Appendix B, Figure 2

Rev 0

Appendix C: Skyline Methodology



DFB
FlowPath
remove material by digger
Redistro or heli removal
Zone 4 forestry Tracks (existing)
AHL Track (existing)
New Access tracks
Bag and heli removal
10
8,9,11
5,6,7
12,13
3,4
14
2
1
15
16

REAVERS DEBRIS

Upper Debris Removal Methodology

Rev A – Draft

Commercial in Confidence

Contents

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DRAFT

Document Control

Date	Issue	Revision	Prepared	Approved for issue
240122	Draft for Comment	A	PEM	

Notes to Revision A:

This revision is issued for comment. It is based on the findings of the Reavers Debris Mitigation Options Report Rev 0, and on site review with experts (Geosolve, Patterson Pitts, Beaver Contractors, and Head Up Access) in late December 2023. This on site review provided confirmation of basic methodology, identified some constraints, and identified where time-cost priority was best applied for efficient work execution. Of particular note is the need for detailed Task Analyses to be provided for each step, which may only be done as more detailed design and procurement information becomes available.

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Introduction, Scope and Terms of Reference

Introduction

The Reavers slip consists of loose material of which approx.. 2,500m3 is deposited on slope just below Skyline, with a further 500 – 750m3 with the trees and channel leading down to the Culvert at Reavers Lane. Variability on information pertaining to the volumes is present due to limitations in surveying techniques, and volume of material removed from Reavers Lane post event not being available.

The upper part of the site is steep at an approx. average of 40 - 45 degrees, with the catchment as it leads down in to Reavers Creek characterised by numerous bluffs, rockfall deposits and thick mature Douglas fir tree cover. The lower part of the Creek is constrained by both steep grade, steep sides, and relatively poor access as development has occurred right up to where the creek exits the gully to its alluvial fan, where a formalised intake culvert has been installed. This culvert has no sedimentation filters, only a basic wide spaced grating to prevent larger debris entering the pipe.

Scope

A background level of risk from flood, debris flood, debris flow, rockfall, treefall and landslide exists in this catchment, however the introduction of the spoil material has both elevated the risk above the background level, and introduced a new risk. The risk presented by this material is to be eliminated, isolated or mitigated such that the residual risk presented by it is at a tolerable level for the community at risk from the material. Ongoing management (if any) is effectively considered as part of both the work scope and residual risk.

A debris fence has already been installed to address risk as presently exists in the lower catchment. This methodology covers removal of the risk from the upper debris flow, and once that is complete, reducing risk in the lower catchment.

Risk Levels

This Methodology will reduce the risk to no more than $1x10^{-5}$ in alignment with agreed acceptable level of residual risk.

Methodology Outline

The overall aim is to remove approximately 2500m3 of debris from the upper flow to remove the risk that it poses. This will be accomplished by making use of the existing forestry tracks, and repairing and extending these to reach the main debris field toe. A Debris Flow Barrier will be installed at this location, and thereafter the debris pushed down to the fence by winch assist spider excavator to a point where it is both feasible and safe for a traditional excavator to take over the task.

From this location material will be loaded to dumpers for forwarding to the Skyline access road, and from there to disposal offsite. Once this is completed further small track(s) may be pushed to intercept the lower debris flow where feasible to remove this material, and where tracks not feasible options to manually move debris out of flow path for redistribution to safe areas, or to bags for heli removal (subject to further geotechnical input). Fence and new tracks be removed at conclusion to restore to natural ground contours.

Programme

The schedule Programme is essentially considered in two parts: the first being the works to access and install the DFB, and then the second to remove the material that is present on the slopes. As water saturation has been identified as a key risk to overall debris stability, it is not considered either

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safe nor appropriate to attempt to move material during that time of year that significant weather can be expected. The overall aim therefore is to seek to have the barrier installed as soon as practicable (at which point the risk downslope form that material is fully addressed) and thereafter start removal of the material once fair weather may be expected: nominally 1 September.

Installation of the DFB by the end of June will require a commitment to design, approvals and procurement without delays, and may also require some efforts to fast-track or push some works into concurrency.

This detailed programming will continue to be developed as opportunities are found and exploited for the projects benefit.

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Contributing Parties and Roles.

Role	Who	Scope
Regional Authority	Otago Regional Council	RMA and RC with respect to waterway(s)
Local Body Authority	Queenstown Lakes District Council	RMA and RC with respect to land and district plan
Land Administrator	Queenstown Lakes District Council	Oversight and approval with respect to work in reserve, and ownership of structure within
CDEM	Queenstown Lakes District Council	Oversight of management of risk from debris
Work Manager	Skyline	Planning and Management of works programme
Project manager	TBC	Management and coordination of works programme on behalf of Skyline and QLDC
Geotechnical Engineer	GeoSolve	All Engineering associated with debris removal and Barrier
Hydrological Engineer	Geosolve	All engineering associated with water management risks during movement of debris
Surveyor	Paterson Pitts Group	All surveying, volumes and access track grade and profiles
Environmental Consultant	Enviroscope (TBC)	Development and monitoring of Environmental Management Plan
Planning Consultant	Southern Planning Group	All Planning work associated with the full scope of work
Debris Flow Barrier Contractor	Head Up Access	Specialist Contractor for full installation and removal of DFB*
Steep Slope Excavation Contractor	Specialised Excavation Services	Winch Assist Spider Excavator responsible for moving material downhill off steep slope
General Excavation Contractor	Beaver Contractors	Responsible for all tracking and removal of material once off steep slope
Helicopter Services	Heli Glenorchy (TBC)	Heli services for lifting of bagged debris, if required
Labouring Contractor	Mike Hurring Logging, Dirt Tech, (TBC)	Redistribution and/ or bagging of debris as/ if required
Independent HSE Auditor	Hillside Safety (TBC)	Third Party audit of safety management on site.

* DFB: Debris Flow Barrier

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Quality Control and Quality Management

This work is all of moderate to high risk. Careful planning and deliberate execution of work in adherence with that planning is critical to the safe and successful execution of the works. That does not mean that all tasks must be planned in minute detail without any scope for on site adjustment or deviation, only that each task must be considered, and the bounds of that deviation that might be reasonably anticipated considered and controlled.

All tasks shall be subject to an approved SSSP and JSA. This shall be reviewed by the relevant expert(s), Project Manager and Land Administrator prior to work occurring. For more complex tasks or those that have narrow margins for proper execution, Inspection and Testing plans shall be utilised to assure correct construction.

Professionals shall be engaged to oversee all works within their field of expertise. All deviations from approved planning documents shall require professional approval

Health and Safety Management

All contractors are required to submit for approval a Site Specific Safety Management Plan. These plans shall be reviewed and if appropriate approved by the Project Manager and the Land Administrator. The nature of this work is such that works being undertaken can, if improperly managed, present risk(s) to people and property significantly removed from the worksite. All planning must consider downslope risks, risks due to topography, and risks associated with coordination of activities with others on or in proximity to the reserve.

There will be significant periods where multiple workfaces are open, and coordination is required. Weekly site coordination and safety planning meetings shall be implemented on site, Chaired and minuted by the Project Manager

Skyline shall provide a level of oversight by providing their HSE manager to the project to assist with safe works planning and monitoring. Additionally third party audit will be conducted at least once during works to assure that all required control are in place and working as required to assure safe works execution.

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Stage 1- Enablement

This is described as that area from the Skyline Luge access track to the crest of the first bluff below. It includes all of the non- tree covered slope and some flatter terrain within tree cover above the bluff. Approx 2,500m3, 70m horizontal (from crest) and 70m vertical.

1) Reinstate Andrews Haulage(AHL) Road

This work required to facilitate removal of Reavers Debris, but conducted under Forestry Outline Plan – i.e. not part of RC application for Debris removal

Description

Restore access across the top of the Ben Lomond Slip to facilitate debris removal. Includes improvement to allow use for 4x4 dumpers.

Risks

- Risks exist in slip top stability and work within close proximity of steep faces. Edge protection and barriers will be required
- Loose material may roll into the gully. As Mike Hurring Contracting and Logging (MHCL) is likely to be working in the toe of this gully works will need to be coordinated to avoid having people working in the risk area. A catch pad or bund may be required. Work methodology for earthworks to make use of “edge back” and “up and out” work to limit material loss downslope.
- Water management will be key. Cut off and culverts to be installed where and how directed by Geosolve. Keeping the ground in this area dry has been identified as a key task in promoting ground stability.

Planning Inputs

It is likely that a level of geotechnical engineering input will be required to guide water management and any lose block rock risks. This will be particularly the case as/ if any level of specific engineering/ retaining is required to achieve road width.

Design life

Limited/ Temporary

Resources

Tracked excavators with bucket and rock breaker
Drill Rig TBC
Grout Plant TBC

Method

A small rock bench exists within the gully (may be a rock “floater” TBC). It is proposed to level the western track and ramp down to this level, and then both level the rock bench and cut back into the rock face approx. 1m to provide for an approx. 4m wide track. Loose material upslope of the track on the eastern side shall be removed to provide required track width, and loose material downslope on the eastern side shall likewise be removed to promote a stable batter (some geofabric may be required here). Water management shall be such that water is cut off from the tracks either side of the gully by culverts and then disposed to the downhill side, back to gully in position and manner as directed by Geosolve.

DRAFT

Should rock cutting/ levelling not be successful in creating the required safe track access, or site discovery indicates a lack of rock of sufficnet quality to permit track of safe width and strength, tthen opportunity exists to engineer some temporary retaining works (e.g. steel pipe and walers with reid bar tie backs) to provide for the required track width and stability. In this case use of drilling rig, grout plant and excavator for installation of this will be required. This work, if required, shall be designed and instructed by the Geotechnical Engineer.

Ongoing maintenance considerations/ schedules

As a temp track this work shall be inspected for competence no less than monthly, and after any significant weather event or seismic activity.

Programme

Estimated at 2 weeks if not retaining required. Estimated at 8 weeks if retaining is required.

Other Factors

Ongoing tree removal and remediation works to the Ben Lomond Slip in close proximity will require access coordination and safe work coordination.

DRAFT

2) Improve Grade of Existing Forestry Tracks

Description

Adjust grade of tracks between gondola line and first skid pad to the east to get as close as possible to 1:6 or better to facilitate safe and efficient use of wheeled dumpers. From here continue to improve grade and track condition through to where new access track will begin. Will potentially include removal or adjustment of some tree bunds, and installation of water control culverts and wind rows. Track surface proposed to be improved by making use of debris material once access is obtained to debris field.

Risks

- With this task essentially constituting earthworks on slope, risk exists of material rolling off downslope. This is however effectively addressed by the presence of a rockfall catchfence (#2) below the area (base of Bluff 10).

- Water management will be key. This will require cutoff drains and culverts to ensure that water remains within its natural catchment and is not directed to areas where it can cause erosion or instability. These controls to be directed by Gesolve

Planning Inputs

- It is likely that a level of geotechnical engineering input will be required to guide water management.
- Surveyors will identify line and grade of track adjustments, and confirm as built conditions.
- Capability of proposed dumpers to be confirmed to ensure grades built are suitable for the machines.

Design life

Limited/ Temporary

Resources

Tracked excavator(s) with bucket

Method

The existing Forestry track (AHL Track) rises from the gondola line to the east as a relatively steep grade. By making use of a small plateau it is possible to extent the length of the track slightly, as well as extending the length of the slope section of track at the top to provide for a better overall gradient. This may require either adjustment or removal of a tree bund at the bottom of forestry zone 4. Water management solutions will need to be adjusted to suit the change in grade. Once grade adjusted and suitable, surface of track will be improved making use of debris field material once access gained.

Ongoing maintenance considerations/ schedules

As a temp track this work shall be inspected for competence no less than monthly, and after any significant weather event or seismic activity. Once being used by dumpers regularly some level of operational maintenance can be expected (blade grading and topping with metal)

Programme

Estimated at 3 - 4 weeks.

DRAFT

Other Factors

Ongoing tree removal and remediation works to the Ben Lomond Slip in close proximity will require access coordination and safe work coordination.

DRAFT

3) Mark And Fell Trees for New Access Tracks

Description

Surveyor to mark new tracks alignments and grades. On direction of excavator operator mark trees required to be felled to facilitate track creation. Forester to directional fell required trees and shift to safe position with excavator. Note that this this work may progress somewhat concurrently with the cutting of the new track

Risks

- Loss of felled trees downslope. Mitigated by directional and cross slope felling. Felling plan to assess each tree individually and utilise butt stropping (as example) as and if required.

Planning Inputs

- Surveyors will identify line and grade of track adjustments, and confirm as built conditions.
- Marking and assessment of trees to be felled. These will require tree owner permissions.

Design life

Limited/ Temporary

Resources

Tracked excavator(s) with grapple or thumb bucket
Ground based forestry small quip

Method

Surveyors will on foot mark the alignment and set grades. Assisting the surveyor the excavator operator will identify and mark trees that will need to be felled to create the track alignment. Foresters will then fell these trees to place to previously identified safe locations (using excavator to forward if required).

Ongoing maintenance considerations/ schedules

Nil

Programme

Estimated at 1 week, concurrent with new track build

Other Factors

Ongoing tree removal and remediation works to the Ben Lomond Slip in close proximity will require access coordination

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4) Create New Access Tracks to Upper Debris Field

Description

Following alignment detailed in task 3, build tracks from existing Forestry tracks to the debris field/ proposed debris barrier location. Grade of tracks will be at or as close as possible to 1:6 or better to facilitate safe and efficient use of wheeled dumpers. Will include installation of water control culverts and wind rows. Track surface proposed to be improved by making use of debris material once access is obtained to debris field.

Risks

- With this task essentially constituting earthworks on slope, risk exists of material rolling off downslope. This is however effectively addressed by the entire area downslope being an exclusion zone right through to Reavers creek. That said, EMP will be required to consider and control any potential silt runoff. Signage shall be erected at Reavers lower DFB warning of upslope work and that the entire upslope are from that point being and exclusion zone.

- Water management will be key. This will require cutoff drains and culverts to ensure that water remains within its natural catchment and is not directed to areas where it can cause erosion or instability. These controls to be directed by Geosolve

Planning Inputs

- It is likely that a level of geotechnical engineering input will be required to guide water management.
- Surveyors will identify line and grade of track adjustments, and confirm as built conditions.
- Capability of proposed dumpers to be confirmed to ensure grades built are suitable for the machines.
- EMP to be developed to inform what controls will be required to limit construction emissions

Design life

Limited/ Temporary

Resources

Tracked excavator(s) with bucket.
Dumper
Bulldozer (TBC)

Method

Utilising 20T excavator cut (in preference to fill) track to previously identified alignment, installing cut off drains and culverts (including erosion controls as required) as directed by Geosolve, Envirosope, and Paterson Pitts. Once debris field reached obtain this material and use to improve track surface suitable for regular use by tracked dumpers. Minor on site adjustments to alignment and grade may be expected to accommodate opportunities presented during the excavation, and to respond to any potential ground issues. Where required make use of rock breakers to bench track into rock.

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Ongoing maintenance considerations/ schedules

As a temp track this work shall be inspected for competence no less than monthly, and after any significant weather event or seismic activity. Once being used by dumpers regularly some level of operational maintenance can be expected (blade grading and topping with metal)

Programme

Estimated at 2-3 weeks.

Other Factors

Ongoing tree removal and remediation works to the Ben Lomond Slip in close proximity will require access coordination and safe work coordination.

Tree felling (task 3) ongoing concurrently

DRAFT

Stage 2 – Risk Mitigation

5) Bench for Fence and Set Out Anchors

Description

Surveyor and Geotech to set out fence location, and anchor areas to be cleared off. Thereafter confirmed anchor locations set out.

Risks

- Drill rig, grouting rig, anchor bars and cement likely need to be flown into site to maintain programme expediency. Careful flight planning required with associating risk mitigations.
- Downslope bluff exists. Safety fence and exclusion zone to be established
- Environmental – dust and cement washout to be managed

Planning Inputs

- Geotech – fence design confirmed and approved. Anchor design approved. Anchor locations set.
- Surveyors will identify line of fence.
- Flight planning for delivery
- Environmental plan.

Design life

Limited/ Temporary – DFB only required for duration of debris removal task, est. 6months to 1 year TBC

Resources

Tracked excavator(s) with bucket or,
Hand tools TBC

Method

Ahead of full access track being cut, surveyor and Geotech Engineer to set out DFB location and anchor points. Excavator to track in as early as possible to clear off this alignment. If early tracking not possible, or only very limited clearance needed, then worker using shovels to clear the anchor locations instead.

Ongoing maintenance considerations/ schedules

Nil

Programme

Estimated at 2 days

Other Factors

None Noted

DRAFT

6) Drill and Install Anchors

Description

Move Drill rig, grout plant, anchors and cement to site. If required this shall be via heli lift form the Skyline Access Road.

Risks

- With this task essentially constituting earthworks on slope, risk exists of material rolling off downslope. This is however effectively addressed by the entire area downslope being an exclusion zone right through to Reavers creek. That said, EMP will be required to consider and control any potential silt runoff.

- Downslope bluff exists. Safety fence and exclusion zone to be established

Planning Inputs

- Geotech – fence design confirmed and approved. Anchor design approved. Anchor locations set.
- Surveyors will identify line of fence.

Design life

Limited/ Temporary

Resources

Drill Rig
Grouting Rig
Air Compressor
Helicopter
Water Tank
Hydraulic test rig

Method

As soon as possible after fence and anchor positions marked out, establish drill rig, grouting plant, and associated materials and gear on site. This will be by way of heli lifting. A lifting plan will be required, and lifts will be staged from the logyard off the Skyline access road. Use of helicopter lifting is required to allow drilling works to progress as early as possible, allowing significant programme benefits.

Once gear is on site, water tank for grouting and dust suppression shall be established, and a water line run uphill to water supply at Skyline Luge bottom station.

Establish as near as reasonable to work site the air compressor (towed to position by excavator) and make safe with fuel cache.

Progressively drill anchor holes and grout into place all anchors. Test as required by Engineers directions.

Ongoing maintenance considerations/ schedules

Incorporated in DFB maintenance and operation plan

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Programme

Estimated at 6 - 8 weeks

Other Factors

Tasks 2 – 4 likely to be ongoing concurrently. Coordination required

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7) Transport in DFB Parts, Install.

Description

Take Delivery of all DFB parts to Skyline Access Road. Transport from there to DFB site and Install.

Risks

- Heavy vehicle movements on tracks. Careful loading and movement of machinery required, incl. use of radios to ensure one way traffic on single width tracks.

- Heavy DFB parts – crush injury risk. All work done slowly and deliberately after detailed task planning. Heavy items broken down as much as possible. Use of Excavator and Trifors to move heavy items/ remove workers from lifting zones.

Planning Inputs

- Geotech – fence design confirmed and approved. Anchor design approved. Anchor locations set.

Design life

Limited/ Temporary

Resources

Excavator
Dumper

Method

From staging area DFB parts loaded to dumpers and/ or forwarded by excavators and forwarded to DFB location. There the DFB parts are removed from the dumpers by excavator. Excavator and specialist personnel assemble and install the fence according to the manufacturers and Geotechnical Engineers direction. On completion Engineer shall certify the installation.

Ongoing maintenance considerations/ schedules

Incorporated in DFB maintenance and operation plan

Programme

Estimated at 6 - 8 weeks

Other Factors

Possible that Zone 3,5 or 4 Tree removal work ongoing. Protocols will be required for safe use and transit of forestry tracks with the MHCL teams.

DRAFT

Stage 3 – Debris Removal

8) Fell Slip Trees and Remove.

Description

Mark up and remove trees within toe of debris bulb which will impede moving of material downslope and installation of access track up onto bulb later.

Risks

- Loss of felled trees downslope. Mitigated by directional and cross slope felling. Felling plan to assess each tree individually and utilise butt stropping (as example) as and if required.

Planning Inputs

- Excavator operator mark up and method advice (both traditional form toe and Spider excavator operator from top)

Design life

NA

Resources

Tracked excavator(s) with grapple or thumb bucket
Ground based forestry small quip

Method

The excavator operators will identify and mark trees that will need to be felled to create the track alignment and clearways for shifting debris. Foresters will then fell these trees to place to previously identified safe locations. Excavator operators shall shift these logs with their machines as required to outside of the debris flow. Presence of forestry operations on site may allow use of more specialised machinery to fell and remove (e.g. feller-buncher, forwarder etc).

Ongoing maintenance considerations/ schedules

Nil

Programme

Estimated at 1 week

Other Factors

Ongoing tree removal and remediation works to the Ben Lomond Slip in close proximity will require access coordination

DRAFT

9) Remove MacMat R Erosion Control Matting

Description

Remove previously installed MacMat and megaflow drains and set aside for reuse. Prepare slope for moving of material downslope to DFB.

Risks

- Work on steep and loose slopes. All work done on rope access by specialist technicians.
- Weather – work is conditional on suitable weather.

Planning Inputs

- JSA for work to be prepared by specialist contractor

Design life

NA

Resources

Method

Rappel downslope and roll matting back up for removal. Methodology to be consider if removed upslope, or downslope. All steel cables and monitoring stakes to be removed. Megaflow drains will be removed as encountered by excavator operators later when working downslope

Ongoing maintenance considerations/ schedules

Nil

Programme

Estimated at 1 week

Other Factors

Coordination with skyline project site and public in close proximity

DRAFT

10) Establish Spider Digger and move material downslope

Description

Confirm anchoring for spider digger is suitable. Confirm that environmental controls are in place and serviceable. Once approved begin from top of debris blub shifting material downslope to be caught in DFB. It is expected that much material will mound up providing a wider working platform for the spider digger to work from relatively quickly.

Work constantly monitored by Geotech Engineers, with water cutoffs and controls installed as required/ directed (expected to be based on incoming weather forecasts)

Risks

- Digger instability
- Landslide/ bulk debris shift
- Debris saturation/ rapid movement
- Debris bypassing DFB
- Silt or other loss outside of worksite
- Weather – work is conditional on suitable weather

Planning Inputs

- Excavator operator detailed methodology
- Geotechnical planning (particularly as associated with slope stability during works/ risk mitigation)
- Environmental Management Planning

Design life

NA

Resources

Spider excavator(s) with bucket
Winch assist plant

Method

Environmental controls shall be installed as required by the EMP. Exclusion zones both up and downslope shall be established, and safe monitoring positions established to side of material to be shifted. Excavator anchors shall be tested as fit for purpose. Excavator shall then work over edge top down to push all lose debris (back to natural ground) downslope in a controlled fashion to be collected by the DFB. It is expected that this process to move al material down to such a point that the spider excavator is no longer required may take 4 – 8 weeks TBC. As material accumulates above DFB consideration may be made of extraction works may begin, and/ or if traditional excavator can access to assist movement of material. As directed by Geotechnical Engineers, install water cutoffs and drains to protect material being worked from water saturation or instability in response to weather forecasts. Note: this may dictate that this work can only be undertaken when drier weather for extended periods can reasonably be expected.

DRAFT

Ongoing maintenance considerations/ schedules

Nil

Programme

Estimated at 4 -8 weeks

Other Factors

DRAFT

11) Establish Tracked Digger and move material downslope

Description

Once enough material has been moved down slope and the batters confirmed as suitable, track machine up onto debris bulb and take over and/ or assist spider excavator to move all material down and over first bluff, leaving clean and stable slope behind.

Risks

- Digger instability
- Landslide/ bulk debris shift
- Debris saturation/ rapid movement
- Debris bypassing DFB
- Silt or other loss outside of worksite
- Weather – work is conditional on suitable weather

Planning Inputs

- Excavator operator detailed methodology
- Geotechnical planning (particularly as associated with slope stability during works/ risk mitigation)
- Environmental Management Planning

Design life

NA

Resources

Spider excavator(s) with bucket
Winch assist plant

Tracked excavator

Method

After Spider excavator has moved sufficient material downslope such that batter slope is 35-40 degrees, and sufficient material is in place for tracking, and Geotechnical Engineers have no objection, walk tracked excavator up and onto the debris bulb by pushing an access track diagonally up from the north east. Join the Spider excavator o its platform and in tandem work to continue pushing material downslope, at all times maintaining a wide bench width and surplus of material in front of the machine. Clear slope behind and only reduce bench height as Geotechs sign off surface left is at required standard of clean down.

Ongoing maintenance considerations/ schedules

Nil

Programme

Estimated at 2-4 weeks

DRAFT

Other Factors

DRAFT

12) Load out and dispose all material

Description

Load debris from position behind DFB to 4x4 dumpers and transport out to stockpile at Skyline access road. From this stockpile load to std 6 wheel truck and transport and dispose at approved site. (Site TBC)

Risks

- Digger instability
- Landslide/ bulk debris shift
- Debris saturation/ rapid movement
- Debris bypassing DFB
- Silt or other loss outside of worksite
- Heavy vehicle movement/ instability
- Weather – track may degrade in poor weather

Planning Inputs

- Excavator operator detailed methodology
- Geotechnical planning (particularly as associated with slope stability during works/ risk mitigation)
- Environmental Management Planning
- Dumper movement and stockpile management plans.

Design life

NA

Resources

- Tracked Excavators
- 4x4 Dumpers
- 6 Wheel Truck

Method

Environmental controls shall be installed as required by the EMP to both the DFB location, and to stockpile location. Establishing a loading skid pad, excavator(s) shall load 4x4 dumpers. These will transport material via the improved forestry tracks to the nominated stockpile location. Protocols will be required with respect to passing bays and ensuring no impediment of dumpers under load. From stockpile material will be loaded to standard 6 wheel trucks for transport and disposal at approved hardfill site.

This will be a relatively long duration task, and subject to review and approval may be able to start ahead of the downslope movement of material concluding – noting that upslope risks will be a major item to be managed if this opportunity is explored.

DRAFT

Ongoing maintenance considerations/ schedules

Nil

Programme

Estimated at 8 weeks

Other Factors

DRAFT

13) Restore Surfaces, remove DFB

Description

Review and tidy all surfaces upslope of the DFB under direction of Geotechnical Engineers. Apply grass seed or other treatment if and as directed by Geotechnical Engineers. Once signed off as safe and stable, progress to removal of DFB.

Disassemble and removed DFB from site, making use of tracks, excavators and dumpers. Place DFB into storage (location to be advised) for disposal with cost recovery, or reuse.

Remove access tracks and restore ground to natural contours.

Risks

- Digger instability
- Debris bypassing DFB
- Silt or other loss outside of worksite
- Heavy vehicle movement/ instability

Planning Inputs

- Excavator operator detailed methodology
- Geotechnical planning (particularly as associated with final slope acceptance criteria)
- Environmental Management Planning
- DFB disassembly plan

Design life

NA

Resources

- Tracked Excavators
- 4x4 Dumpers

Method

Environmental controls shall be installed as required by the EMP to the DFB location. Using hand and excavator methods, and working top down work ground to meet requirements of Geotechnical Engineers. Specialist contractor to disassemble DFB and remove all items to ground level. All material bundled and loaded by excavator to dumpers for transport out to Skyline roadway.

To both slope and DEFB location, apply surface treatment (seeding) and monitor as required.

Once machine access to DFB location known to no longer be required, remove roadway and culverts, and restore site topography to natural ground contours. Install silt control as required by EMP.

Ongoing maintenance considerations/ schedules

Nil

DRAFT

Programme

Estimated at 5 weeks

DRAFT

14) Track into lower debris flow, remove material

Description

To bench below DFB, track in from AHL road. Scrape and remove material and place to 4x4 dumper. Remove to stockpile and removal off site.

Risks

- Digger instability
- Silt or other loss outside of worksite
- Heavy vehicle movement/ instability

Planning Inputs

- Excavator operator detailed methodology
- Geotechnical planning (particularly as associated with final slope acceptance criteria)
- Environmental Management Planning

Design life

NA

Resources

- Tracked Excavators
- 4x4 Dumpers

Method

Environmental controls shall be installed as required by the EMP. Cut basic track to lower bench (only needs to be traversed a few times, so a lower standard of build/ roadbed is acceptable here). Remove debris material from flowpath to 4x4 dumper, and transport out to Skyline Access road stockpile for disposal to approved site. Once signed off by Geotechnical Engineer, reinstate tracks back to natural ground profiles and implement silt control.

Ongoing maintenance considerations/ schedules

Nil

Programme

Estimated at 2 weeks

DRAFT

15) Redistribute material out of flow path (or heli removal)

Description

Above creek, but below area worked in task 14. Access flow path on foot, and with hand tools and under direction of Geotechnical Engineer, shift material out of flow path to either approved safe distribution areas, or to bags for heli removal (TBC)

Risks

- Work on steep slopes/ around fall risks
- Silt or other loss outside of worksite
- Heli lifting task (TBC)

Planning Inputs

- Geotechnical planning (particularly as associated with final slope acceptance criteria and approved redistribution areas)
- Environmental Management Planning

Design life

NA

Resources

- Skilled Labour
- Heli (TBC)

Method

Works top down, manually move material out of flow path to approved redistribution areas where Geotechnical Engineers have confirmed remobilisation is not possible. Note that material depths through these areas are generally 150mm average in a tightly constrained surface channel.

Where suitable redistribution is not possible, manually place material to bags for heli removal

<u>If Heli removal is required, this will trigger a full separate methodology</u>

Ongoing maintenance considerations/ schedules

Nil

Programme

Estimated at 2-3 weeks

Other Factors

Heli longline may limit application of this technique. Initial discussions suggest no issues but this is subject to confirmation of tree heights in the area (250ft longline – 76m)

DRAFT

16) Remove material out of Reavers creek

Description

Within Creek, manually removal to heli bags debris material as directed by Geotechnical Engineers. Remove by Heli longline.

Risks

- Silt or other loss outside of worksite
- Heli lifting

Planning Inputs

- Geotechnical planning (particularly as associated with final acceptance criteria)
- Environmental Management Planning

Design life

NA

Resources

- Skilled Labour
- Heli

Method

Works top down, manually move material out of creekbed to heli bags. Care to be taken that only debris material removed and not natural streambed material. Work as directed by Geotechnical Engineer and Engineering Hydrologist

Bagged material to be removed by heli lift and then disposed of to approved hardfill site

Heli removal subject to a full separate methodology

Ongoing maintenance considerations/ schedules

Nil

Programme

Estimated at 2 weeks

Other Factors

Heli longline may limit application of this technique. Initial discussions suggest no issues but this is subject to confirmation of tree heights in the area (250ft longline – 76m)

DRAFT

Appendix D: Previous Reporting

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GeoSolve Ref: 150320
20 June 2016

Queenstown Lakes District Council
c/- Southern Planning Group
PO Box 1081
Queenstown

Attention: Sean Dent

Skyline Gondola Corridor, Queenstown
Tree Removal Natural Hazard Assessment

1.0 Introduction

The letter details the results of a hazard assessment completed by Geosolve Limited for the proposed tree removal along the Skyline Gondola corridor, Queenstown.

The aim of this work is to provide a hazard and risk assessment with respect to geological hazards at the site.

2.0 Proposed Works

It is proposed to remove a 'strip' of trees either side of the Gondola corridor. The approximate extend of tree removal is shown on the attached summary plan completed by Patterson Pitts Group (PPG).

A plan provided to Geosolve indicating the approximate extent of the area to be cleared by Helicopter is provided below (Figure 2.1). It is understood trees from this area will be re-positioned within the forest canopy in a suitable location a short distance to the north east. Elsewhere access to the tree corridor will be via existing tracks which will be extended as required.

Figure 2.1. Extent of Helicopter removal (south western area) and tree stockpile areas (shown to the north east).

3.0 Site Description

The site is located on the steep lower slopes of Ben Lomond/Bowen Peak immediately to the north west of Queenstown Centre. Overall the slope angles are approximately 35°, however the ground is locally steeper, particularly in upper areas of the corridor, and vertical bluffs varying from approximately 2m to 10m in height are present at regular intervals along the entire length. For the purposes of this report 4 major bluffs have been identified and the locations are indicated on the attached Figure 1 and Figure 2. Many other smaller bluffs and rock outcrops are also present throughout the study area.

Directly along the gondola corridor the vegetation comprises grass with the occasional bush or fern. On either side of the corridor dense forested ground is present, predominantly comprising mature pine trees although areas of younger and deciduous trees are also present.

The bluffs often extend through the corridor and into the forested areas on either side. The trees are frequently present immediately at the crest of the bluffs in these areas, and in several cases the root systems extend over the crest and/or are present in open cracks within the rock mass (See photograph 1).

For much of the study area the surface comprises a dense forest cover, with thin soils (<1.0m), often with boulders present around exposed roots, with no significant rock outcrops (see photograph 2).

There are no significant breaks or natural benches in the slope, and the gondola station building and an area of coach parking are present immediately at the toe.

4.0 Geology

Bedrock comprising Otago Schist is exposed in many locations along the length of the corridor. For much of the inspection area the bedrock has a thin cover of topsoil and colluvium with typical observed thickness of < 1.0m. At the base of some of the larger bluffs localised fans of rock fall debris are present. The rock fall material is typically moderately to highly weathered with a partial cover of colluvium and topsoil. In lower slope areas pockets of glacial soils were observed to be typically <1.0m in thickness.

The schist bedrock was typically quartz rich with a persistent planar foliation dipping at 15-25° towards the South West (oblique to the Hillside). Persistent sub-vertical defects, with orientations typically oblique to the bluff faces, are widespread with spacing's generally of 1 to 5m, however, locally areas with closely spaced defects were observed. The rock mass is generally un-weathered to slightly weathered, however pockets of moderate weathering were observed in areas with close defect spacing (see Photograph 3).

No active fault traces were observed in the field however, significant seismic risk exists in the region from potentially strong ground shaking associated with rupture of the Alpine Fault located along the west coast of the South Island. There is a high probability that an earthquake with an expected magnitude of over 7.5 will occur along the Alpine fault within the next 50 years.

5.0 Field Mapping and Classification of Risk Zones

An engineering geological site appraisal and field mapping were undertaken to assess the geological character of the study area with respect to rock fall.

5.1 Existing Rock Fall Conditions

Evidence from the field mapping indicates intermittent rock fall from the bluffs within the corridor, and in adjacent forested areas is occurring. In several locations boulders up to approximately 1.0m in diameter were observed on the slope (See Photographs 4 and 5). In some cases boulders were present above the topsoil, with little or no vegetation growth or weathering. These boulders were assessed to have fallen relatively recently. General fretting/spalling of small rock debris from the bluff faces was also observed in several areas.

In general the rock fall on this part of the hillside is assessed to be controlled by localised processes. These processes, such as the nature of the schist and the defects within it, slope geometry, weathering and vegetation, will vary from location to location. The rock fall is not considered to be driven by any underlying larger geological features, regional or wider scale instability issues, e.g. landslides or faulting. Individual rock falls are expected to occur relatively infrequently however will be ongoing. Rock fall is expected to be influenced by the following mechanisms:

Gradual weathering and weakening of the rock mass, particularly along defect surfaces, due to ground and surface water seepage;

Frost Jacking during periods of cold weather;

Root growth, opening up of defects due to this process was observed in several locations, and;

Ground shaking during seismic events.

Due to the nature of the schist and the distribution and spacing of the defects within the rock mass individual failed boulders are typically <1.0m in diameter with the majority being <0.5m. In some cases larger potentially unstable blocks of 1-2m^3 were identified.

At the crest of one of the major bluffs, and on the southern side of the corridor, a potentially large unstable block of schist (1 – 2m^3) was identified. Due to the exposed location of the block above a vertical drop preliminary assessment was feasible only, however, observations indicate a detached block has formed and some downslope movement may have occurred. The block may partially be supported by the presence of a mature tree located immediately on the downslope site (see Photograph 6, and Figure 2, attached).

Within forested areas most rock falls appear to be adequately controlled by the trees. Failed rocks are unable to gain momentum and travel only short distances before coming to halt, often within metres of the source area.

Outside of forested areas, (within the Gondola Corridor) there are few barriers and failed blocks, particularly if falling from the crest of larger bluffs, have the potential to travel significant distances and possibly to the toe of the slope.

5.2 Areas of Rock Fall

For the purposes of this assessment the ground conditions along the corridor have been divided into 3 area types (Type A, Type B and Type C) with respect to rock fall. The 3 types of rock fall area are described in Table 1 below, and the approximate extend of each area is indicated on Figures 1 and 2 attached.

Table 1 Descriptions of Rock Fall Areas.

Area Type	Description
A	Dense tree coverage, very few or no outcrops of bedrock, thin soils of ≤1.0m in thickness, small diameter boulders (0.3m) often present around exposed roots and at the ground surface (See Photograph 2)
B	Dense tree coverage, low bluffs (<3.0m in height) and areas of bare rock often with visibly detached blocks of up to 1.0m diameter present on the surface. Weakening of the rock mass at the crest of the bluffs due to the processes listed in Section 3.1. (See Photographs 3 and 6)
C	Isolated areas at the crests of the larger bluffs. These areas are subject to the processes listed in Section 3.1. Potential block sizes of 1.0m diameter are present, and isolated cases blocks of 1-2m^3 in volume are present. Due to the height of the bluffs, and potential larger size of a failed block, these areas are considered to have an elevated rock fall risk (see Photographs 1 and 5).

A detailed site assessment was completed by Geosolve in May –June 2014 and the report is attached (Geosolve Reference 140151) and should be read in conjunction with this report. This report outlined the general geological environment and associated hazards, specifically rock fall risk, associated with the tree removal.

Based on a review of the proposed tree clearance areas shown and the attached PPG plan the conclusions and recommendations in the Geosolve Report from June 2014 are considered appropriate.

6.0 Assessed Risk and Recommendations for Tree Removal

6.1 Rock Fall Risk

Given the lack of data with respect to rock fall risk, e.g. date, number and size of rocks etc., a quantitative assessment of the rock fall risk is not considered practical and a qualitative risk is provided only.

Evidence for historic rock fall, including recent movement, and areas of future instability, were identified during the site inspection. In general however rock fall debris was not widespread and was often covered in developing soils and vegetation. Rock fall is expected to be ongoing from the bluffs present within the gondola corridor, however site observations suggest failures occur relatively infrequently. Rock falls are considered more likely to occur during significant rainfall, periods of thaw and particularly during a significant seismic event.

A summary of the assessed rock fall risk is provided in Table 3 below. In this case the risk is of a boulder, or block, being displaced and travelling downslope, potentially impacting site personal (local rock fall affecting site personnel), or travelling a significant distance and impacting the toe of the slope (wider rock fall potentially impacting the lower slope).

Table 3 Rock Fall Risk Summary.

Area Type		Assessed Risk Level Prior to tree Removal	Assessed Risk Level Individual Tree Removal	Assessed Risk Level General Tree Removal
A	Local rock fall affecting the worksite/local area	Low	Low	Low
	Wider rock fall potentially impacting lower slope	Low	Low	Low
B	Local rock fall affecting the worksite/local area	Low to moderate	Low to moderate	moderate
	Wider rock fall potentially impacting lower slope	Low	Low	Low to moderate
C	Local rock fall affecting the worksite/local area	Low to moderate	Low to moderate	moderate
	Wider rock fall potentially impacting lower slope	Low to moderate	Low to moderate	Low to moderate

The above risk levels assume the stumps and roots will be left in place during tree removal. If stumps are removed then risks will be elevated in the short term and during the construction works. In a few locations at the crest of bluffs rock fall risk may be influenced in the medium to long term by dying roots.

In general the risk of rock fall from tree removal is not considered excessive and is similar to that of the existing background risk for most of the hillside. For Area Types B and C elevated risks are expected when working around the crest of bluffs and control measures are considered appropriate to manage the risk

6.2 Control Measures

The potential for dislodged or destabilised rocks to enter the un-forested corridor and potentially travel downslope is present at the site and measures to control this process are considered appropriate during tree removal. General recommendations are provided as Follows:

- In many areas the dense tree cover provides effective protection from rock fall. Working from the top of the corridor downwards will be more effective at maintaining a barrier of trees between the work site and the toe of the slope;
- Carefully placed timber boards/fencing placed a short distance downslope of the work site are expected to be an appropriate measure to deal with smaller rocks. The boards would catch the displaced rocks, or divert them back into the forested area.
- The crest of larger bluffs are more complex and it is recommended that prior to tree removal the area be inspected by both the contractor and geotechnical engineer/engineering geologist to clarify the individual trees, or extend of trees to be removed, and the likely impact on the rock. Stabilisation measures such as anchoring or removal of the rock may be appropriate in some cases.

The likely mechanisms for rock fall in areas A, B and C, and suitable control measures during tree removal are summarised in Table 3 below.

Table 3 Potential rock fall mechanisms during Tree Removal and Control Measures.

Area Type	Potential Rock Fall Mechanism During Tree Removal	Control Measures
A	Dislodging small boulders around the base of tree trunks	Hand removal of small boulders and placement in a safe forested area. If stumps are removed placement of timber boards downslope to catch/divert any displaced boulders. Trees present downslope likely to provide good protection in some cases if working from the top of the corridor downwards.
B	Dislodging small boulders around the base of tree trunks. Dislodgement of blocks present at the crest of low bluffs. Rock fall risk following tree removal associated with altered exposure to the elements, rotting of roots and stumps.	Hand removal of small boulders. If stumps are removed placement of timber boards downslope to catch/divert any displaced boulders. Trees present downslope likely to provide good protection in some cases if working from the top of the corridor downwards. Care should be taken working in all low bluff crest areas, controlled scaling of loose rocks before and/or after tree removal may be appropriate, timber boards placed downslope to catch divert smaller boulders. If larger blocks are identified as being at risk of instability, anchoring/meshing /removal of the rock may be appropriate and should be assessed on a case by case basis by the engineer and contractor. Areas to be inspected and assessed for longer term instability issues following tree removal.
C	Dislodging small boulders around the base of tree trunks. Dislodgement of blocks present at the crest of low bluffs. Rock fall risk following tree removal associated with altered exposure to the elements, rotting of roots and stumps.	Hand removal of small boulders and placement in a safe forested area. If stumps are removed placement of timber boards downslope to catch/divert any displaced boulders. Trees present downslope likely to provide good protection in some cases if working from the top of the corridor downwards. Care should be taken working in all crest areas, controlled scaling of loose rocks before and/or after tree removal may be appropriate, timber boards placed downslope. If larger blocks are identified as at risk of instability anchoring/meshing /removal of may be appropriate and should be assessed on a case by case basis. Areas to be inspected and assessed for longer term instability issues following tree removal.

7.0 Other Considerations

The forested slopes provide a relative effective control measure against most rock fall on the Gondola Hillside. Removal of trees, particularly blanket removal over a wide area, is likely to increase the potential for rock falls to reach the base of the slope and impact on property and people. Potentially unstable areas of rock were identified during the site inspection and it is recommended that if blanket removal of trees is undertaken, the general increase risk of rock fall reaching the base of the slope be considered.

The large potentially unstable block (see Photograph 6) should be assessed and, if appropriate, remedial works completed regardless of tree removal in this area.

8.0 Conclusions

- Overall the rock fall risk is assessed as low to moderate, however, tree removal along the gondola corridor is likely to influence rock fall behaviour and in some cases is expected to increase the rock fall risk;
- Rock fall is already occurring from the bluffs however evidence indicates the occurrence is relatively infrequent;
- The risk of rock falls reaching the base of the slope is elevated in the corridor as no trees are present in this area;
- The slope is steep with no natural breaks or benches and larger boulders falling down the un-forested corridor could travel a significant distance downslope and potentially impact the toe area;
- The size of potentially unstable blocks is variable with most being <0.5m in diameter. Larger boulders of 1.0m in diameter were however also identified, and, in rare cases, potentially unstable schist blocks of 1.0-2.0m3 were identified on the bluffs;
- Undertaking tree removal along the edges of the corridor is expected to result in an elevated risk of rock fall, both during the works and afterward. Control measures, as outlined in Section 5.2, are considered appropriate to control this risk, and;
- Further geotechnical input is recommended to ensure the risk of rock fall is managed correctly, particularly with respect to working close to bluff crests. An on-site meeting between the contractor and a geotechnical engineer / engineering geologist should occur to review specific trees, and the implications prior to commencement of site works.

9.0 Applicability

This report has been prepared for the benefit of Queenstown Lakes District Council with respect to the particular brief given to us and it may not be relied upon in other contexts or for any other purpose without our prior review and agreement.

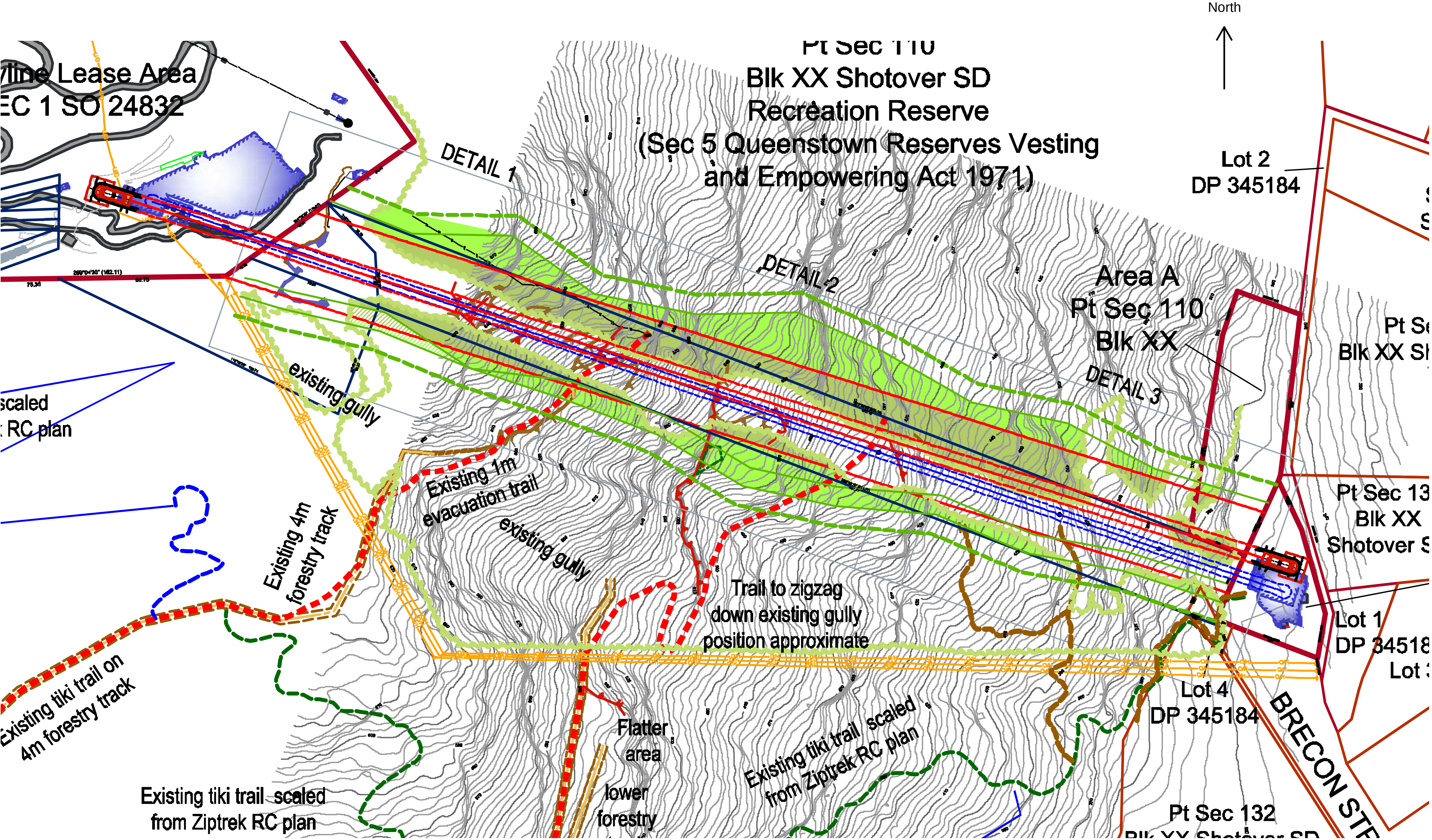
Yours faithfully,

Paul Faulkner

Senior Engineering Geologist

Attachments:

PPG Summary plan showing extent of tree removal
Photographs
Key for the Plan Symbols
Figure 1, Upper slope Site Plan
Figure 2, Lower Slope Site Plan



Excerpt from Paterson Pitts Group survey plans showing approximate tree clearance areas along the Gondola corridor (in Green). See full plans for details (provided seperately by others).

Photograph 1 Area of bluff with defects affected by root growth

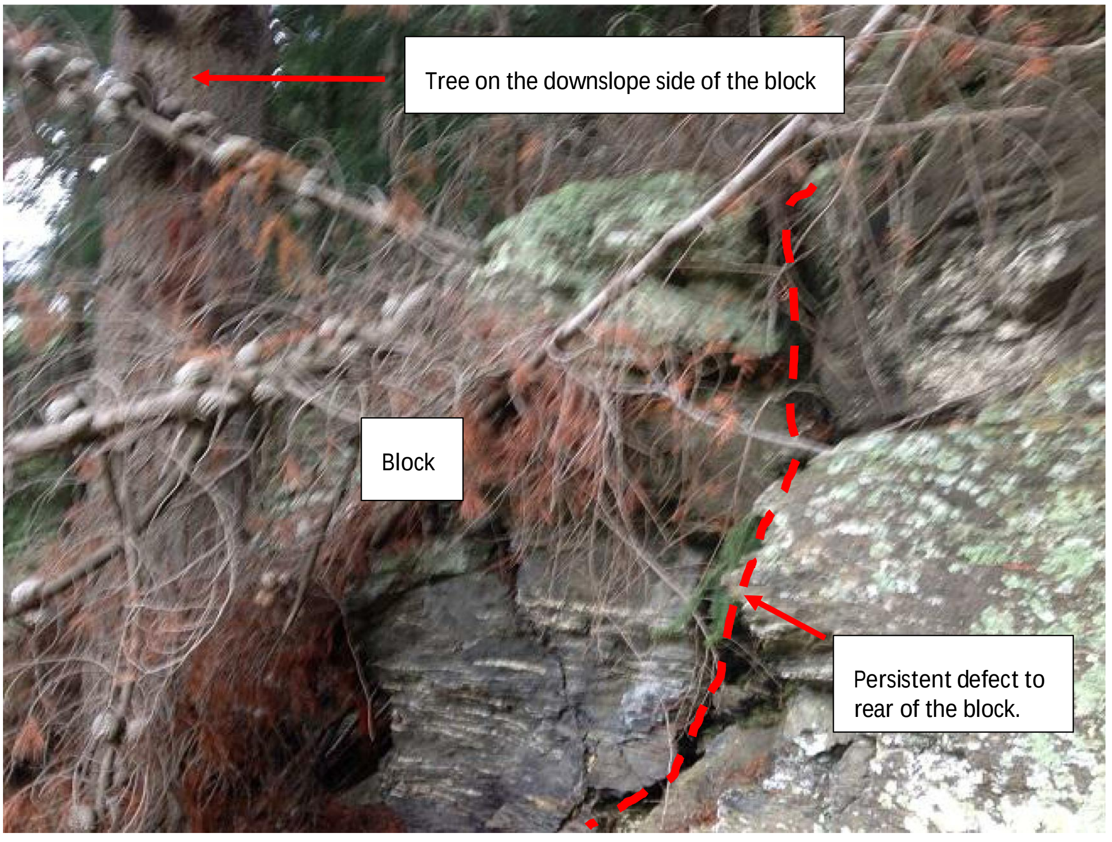
Photograph 2 Area showing dense forest with thin soils and surface boulders, Typical of Area Type A.

Photograph 3 Low bluff showing closely spaced defects, moderate weathering along defect surfaces, root growth penetration, and potential for small block fall from the crest.

Photograph 4 Recent failed block, approximately 1.0m in length, present in the trees immediately adjacent to the gondola corridor.

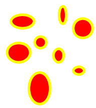
Photograph 5 Failed block beneath a major bluff. Prominent defects can be seen on the bluff face.

Photograph 6 Large potentially unstable block at the crest of a major bluff.

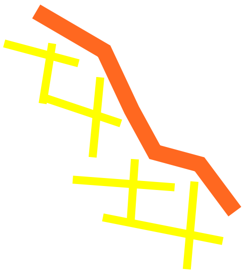


Photograph 7 Typical Area Type B, low bluffs and rock exposures with potentially unstable blocks present in the surface.

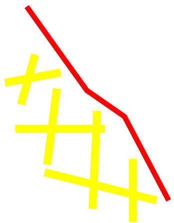
Key for Figures 1 and 2



Boulders

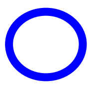


Major Bluff with Defects at the Crest

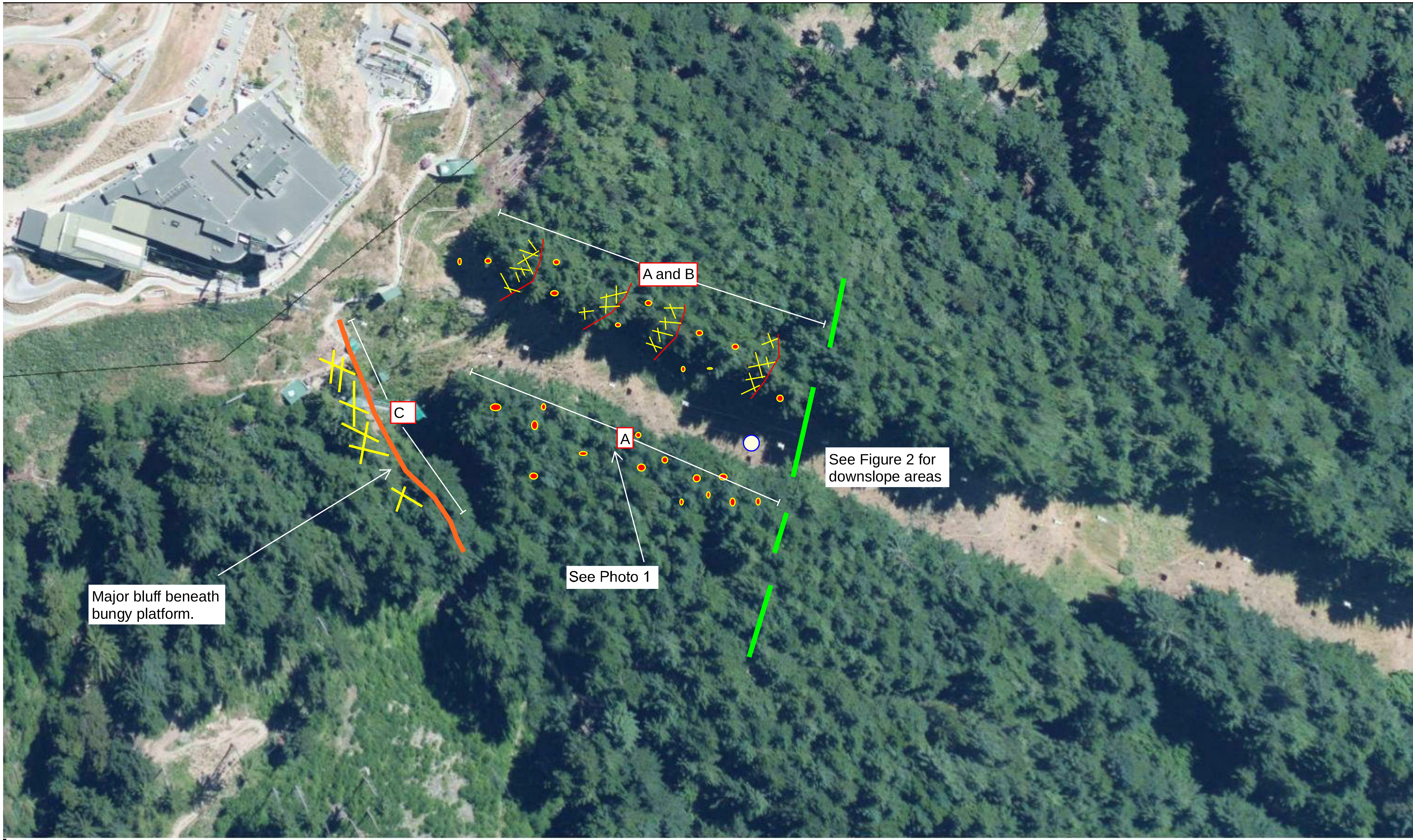


Minor Bluff with Defects at the Crest

A/B/C — Area Type



Gondola Stanchion (approximate location)



0 10 20 30 40 Metres

Scale 1:1000 @ A3

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APPROVED	
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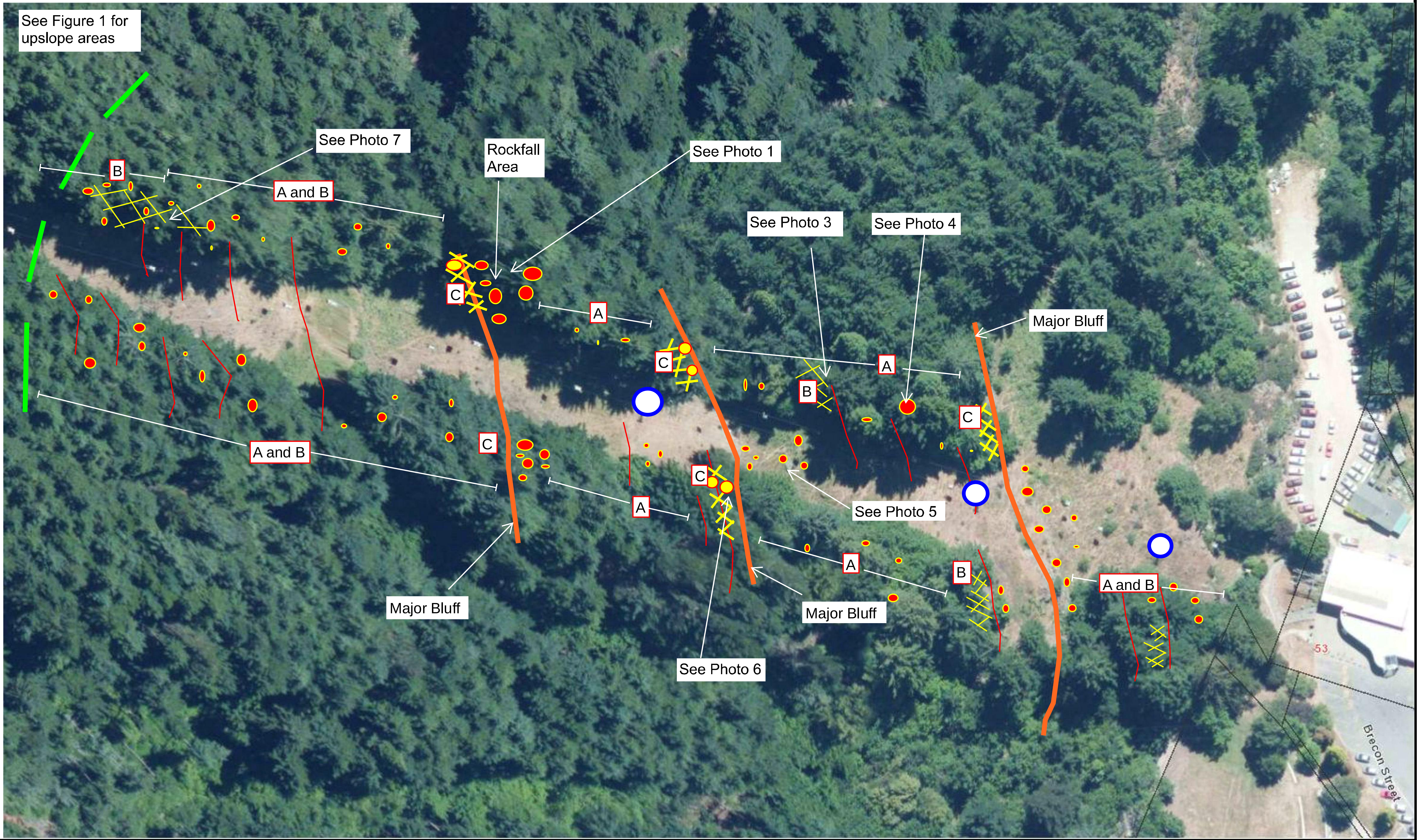
Tree Removal Rock Fall Assessment

Skyline Gondola Corridor

FIG No. Figure 1 **Site Plan 1 Upper Slope** REV. 0



Scale 1:1000 @ A3

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DRAFTING CHECKED	PGF
APPROVED	
FILE :	PDF
SCALE: (AT A3 SIZE) 1:1000	
PROJECT No. 140151	

Tree Removal Rock Fall Assessment
Skyline Gondola Corridor

FIG No. Figure 2 **Site Plan 2 Lower Slope** REV. 0

GeoSolve Ref: 160073.03
16 November 2023

Skyline Enterprises Limited
PO Box 17
Queenstown 9348

Attention: Steve Maclean and Paul Embleton Muir

Reavers Creek Fill Instability – Landslide Dam Potential

Dear Steve and Paul,

1 Introduction

In accordance with Queenstown Lakes District Council's request this letter summarises our assessment of the potential for instability of the fill at the top of the catchment to result in blockage of the Reavers Creek channel sufficient to form a 'landslide dam.'

A landslide dam results when a material enters and blocks an established flow path. The blockage behaves as a dam resulting in the detention of water on the upstream side. If rapid failure of the dam subsequently occurs a wave of water and debris can flow down the channel posing a hazard to downstream areas.

Reavers Creek is approximately 250 m (horizontal distance), and 220 m lower than the base of the upper catchment fill. The overall slope between the 2 locations is therefore approximately 40°, the slope is locally shallower and steeper. The slope is heavily forested and several sub vertical bluffs are present. Figure 1.1 below shows a general view of the area.

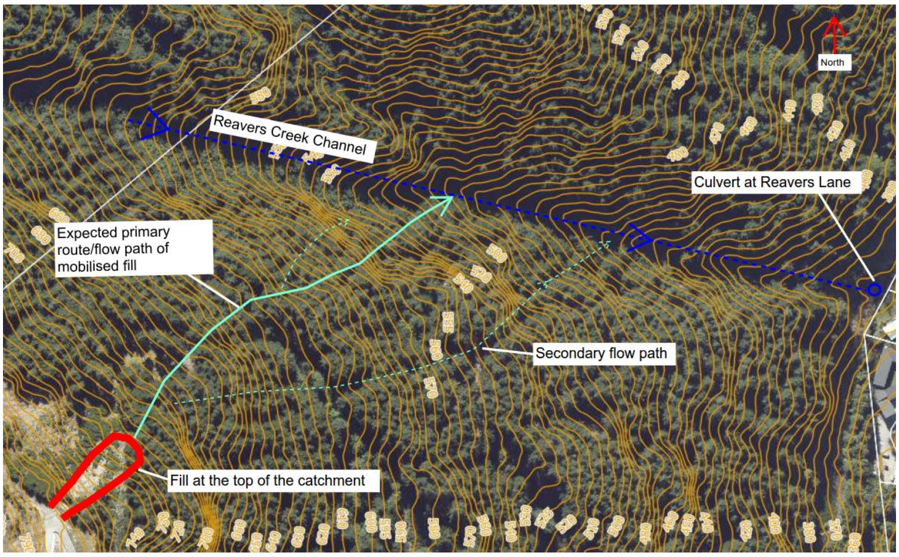

Figure 1.1 Site Area

For a landslide dam to form the fill at the top of the catchment will have to mobilise, enter the creek channel and remain contained in a localised area in sufficient depth and volume to form a dam.

To assess the potential for a landslide dam to form Geosolve have considered the following 2 scenarios:

- A rainfall trigger resulting in a debris flow, and
- A seismic trigger resulting in displacement.

Both scenarios are discussed further below.

2 Rainfall Trigger and Debris Flow

To assess this scenario Geosolve have assumed the fill will be sufficiently saturated for it to mobilise and 'flow' downslope to the Creek Channel. Rapid Mass Movement Simulation software (RAMMS) has been used to model the behaviour of the flow. Two volumes have been assessed:

- 3000 m^3, representing a very large event resulting in mobilisation of 'all' the remaining fill at the top, everything between the top fill and Reavers Channel, and some additional scoured material.
- 750 m^3, representing a small to medium sized event.

The RAMMS outputs showing the 'height' of the fill for above volumes are attached as Figures and 2. The results are summarised as follows:

3000 m^3

For the 3000 m^3 release volume, the fill is generally distributed across the hillside with significant volumes remaining close to the release area, on the slopes immediately below, in the Reavers Creek channel, at the culvert, and at the head of the fan.

With respect to landslide dam potential, the key area of accumulation is in the creek channel. The RAMMS output shows the fill to be well distributed along the length of the channel. Locally deeper and shallow spots are present however generally depths are consistently 1.0 to 2.5 m along the channel. The upstream extent of the fill does not show an abrupt change from 'no fill' to 'deep fill', instead the fill height gradually increases and no 'dam -like' feature forms. The flow of water in the creek is therefore not expect to be impounded upstream of the fill. The likelihood of a landslide dam forming as a result of a 3000 m^3 debris flow from the fill source at the top of the catchment is therefore considered low.

750 m^3

The RAMMS output for a 750 m^3 release volume shows a broadly similar distribution pattern as 3000 m^3, the fill heights are however reduced. No Landslide dam forms for this release volume.

For a rainfall induced debris flow the steep nature of the channel, and the saturated nature of the fill, result in the flow continuing down gradient once it enters the channel, as shown by the RAMMS modelling. The debris flow that occurred on the 21-22 of September 2023 also behaved in this manner and therefore provides a case study/calibration event for the modelled behaviour. Geosolve therefore conclude the likelihood of a landslide dam forming as a result of rainfall induced debris flow is low.

3 Seismic Trigger

Assessing a seismic trigger scenario is hindered by the lack of a clear analysis method. Factors of safety will be below 1 during a seismic event and therefore displacement of the fill is expected. As the fill is at or close to its 'angle of repose' standard displacement assessment methods e.g. Jibson, that rely on determining the seismic loading threshold value, do not provide a useful analysis method. The duration of the seismic event is also a key component.

Experience of modelling the performance of slopes around the Queenstown area indicates ground displacement under various seismic load scenarios can be significant. For large seismic events with prolonged ground shaking, e.g. an Alpine Fault rupture, we therefore expect significant displacement of the fill will occur. 'Significant' under this scenario is at least expected to comprise several metres of movement. It is highly likely that deformation of the fill will be extensive and material will mobilise downslope into the immediate forested area. Smaller seismic events are typically over in several seconds and are therefore unlikely to provide the continuous loading required to continuously reactivate mobilisation.

A short distance below the fill, the slope angle reduces to 20-30°. During the 21-22 rainfall event this reduction in slope angle was sufficient to capture approximately 250 m^3 of saturated and highly mobile debris flow fill. It is therefore considered highly unlikely that unsaturated fill material will run-out beyond this less steep area in any significant volume. The closely spaced trees will also hinder downslope movement.

If a seismic event occurred whilst the fill was saturated then displacement and run-out distances are likely to increase. The likelihood of a heavy rainfall event and a seismic event occurring simultaneously is however considered very low for the construction period, e.g. a 1 in 20-year rainfall event occurring at the same time as an Alpine Fault movement will be in the order of several thousand years. Geosolve note that recently installed drainage measures will have reduced the potential for fill saturation.

As an approximation of fill failure behaviour under seismic loading a RAMMS model utilising 'dry' parameters has been undertaken. The results, attached as Figure 3, show that very little fill reaches the creek channel. The shallower sloping areas below the fill, as described above, are shown to accumulate debris. No landslide dam is formed.

In summary Geosolve expect displacement of the fill will occur during a large seismic event and mobilisation beyond the current fill toe is feasible. Geosolve consider it highly likely the fill materials will 'stall' on the more shallower sloping areas above the creek. The likelihood of material reaching the creek during the relatively short period in which remedial measures are not in place, and in sufficient volumes to form a dam, is therefore considered to be low.

4 Applicability

This report has been prepared for the sole use of our client, Skyline Enterprises Ltd, with respect to the particular brief and on the terms and conditions agreed with our client. It may not be used or relied on (in whole or part) by anyone else, or for any other purpose or in any other contexts, without our prior review and written agreement.

Yours faithfully,

Paul Faulkner
Senior Engineering Geologist
GeoSolve Limited

Attachments:

Figure 1. Debris Flow RAMMS output 3,000m^3
Figure 2. Debris Flow RAMMS output 750 m^3
Figure 3. RAMMS output, dry parameters, 3,000 m^3

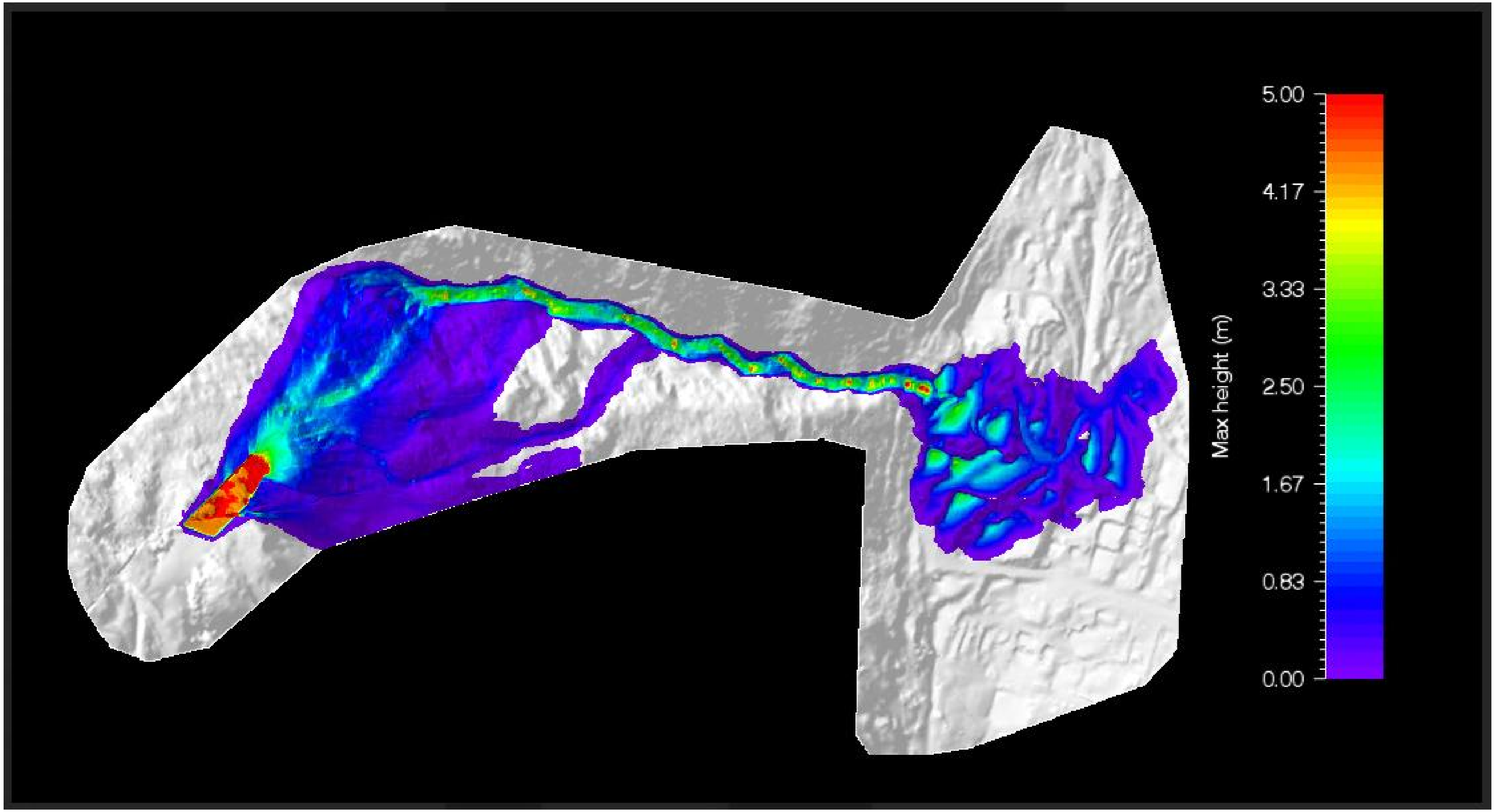

Figure 1. RAMMS output, 3000m^3 debris flow release volume.

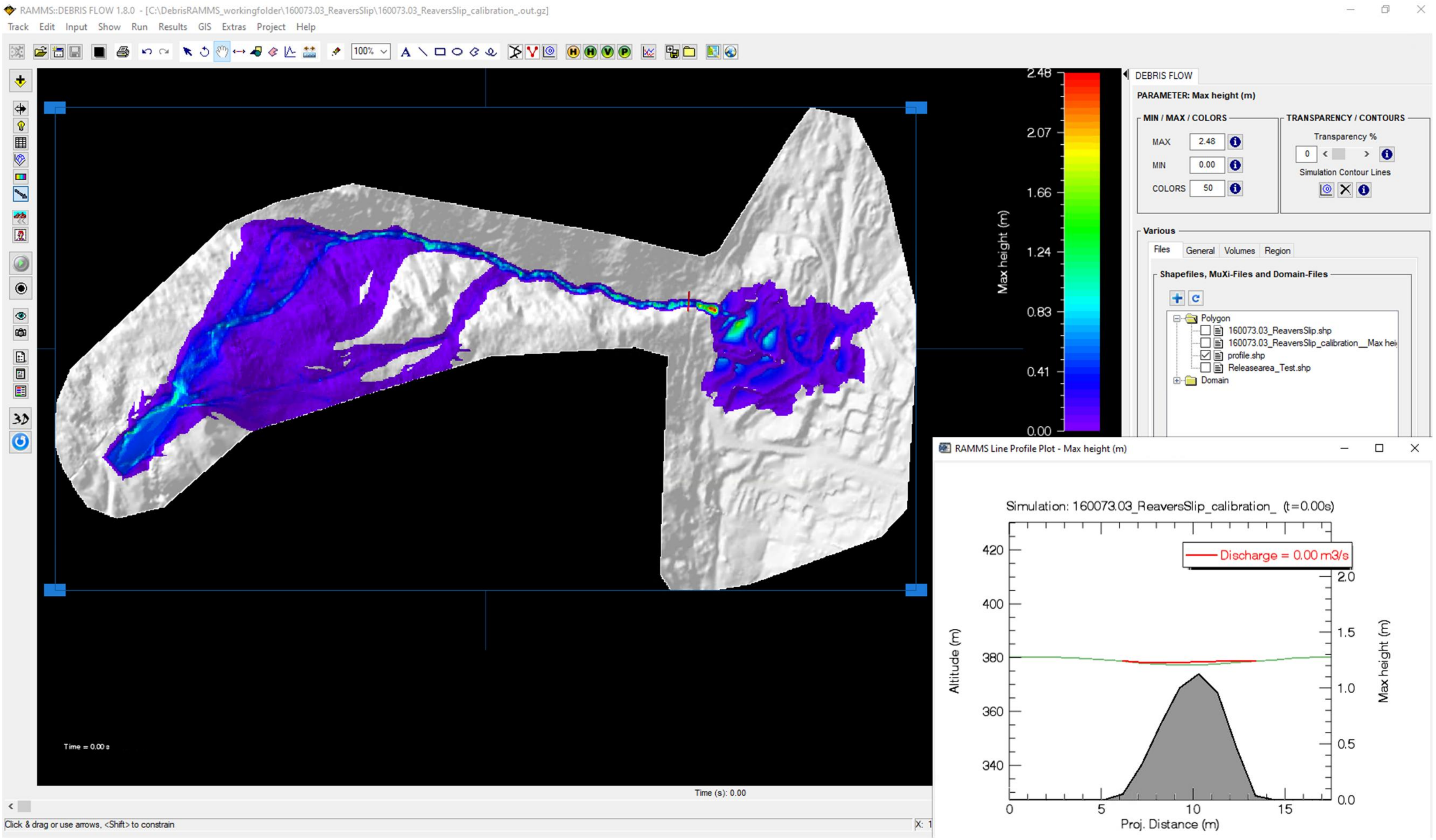

Figure 2. RAMMS output 750 m^3 debris flow release volume.

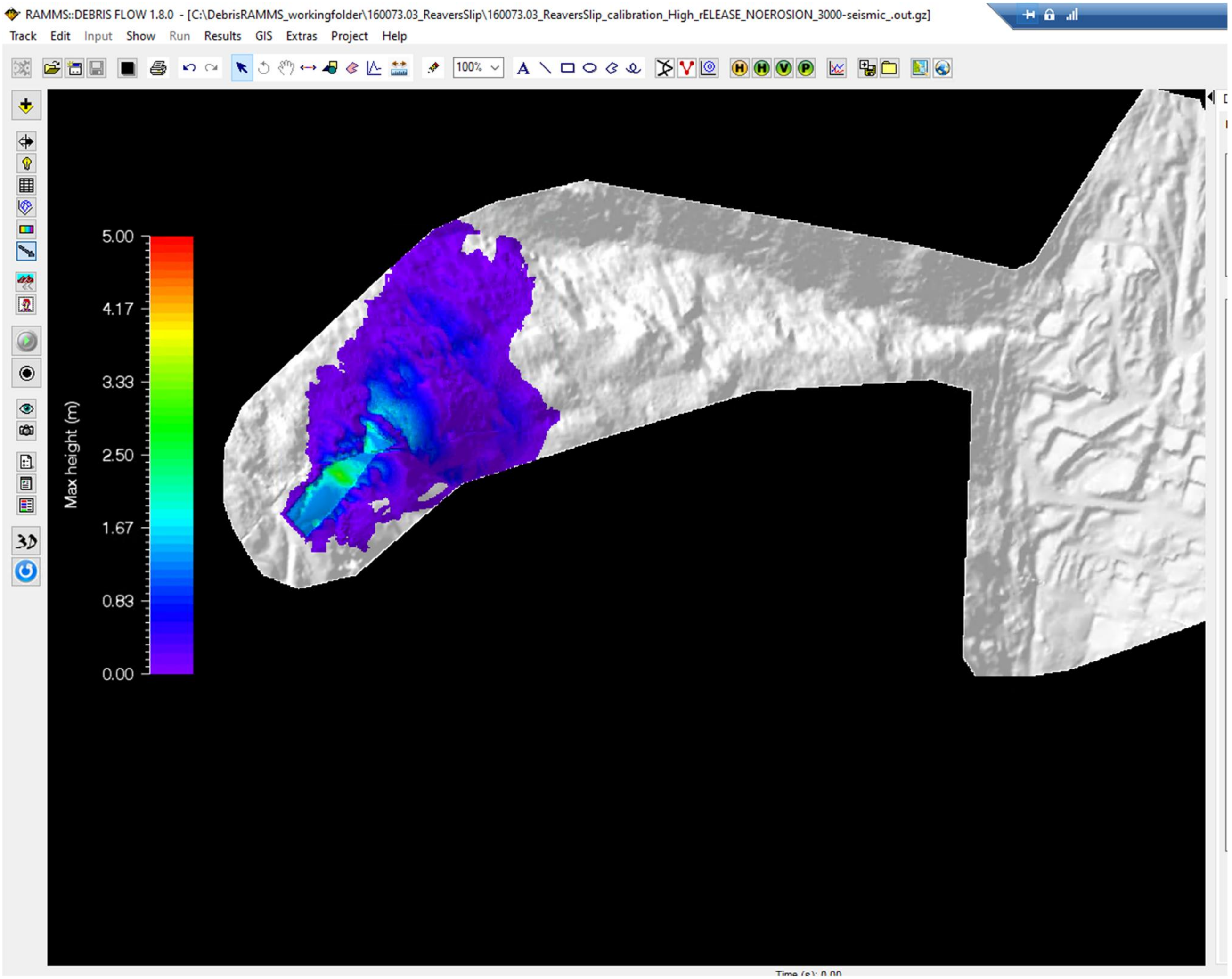

Figure 3. RAMMs output, dry parameters 3000m^3 release volume.

GeoSolve Ref: 160073.03
4 December 2023

Skyline Enterprises Limited
PO Box 17
Queenstown 9348

Attention: Steve Mclean and Paul Embleton Muir

Risk to Life Assessment Report for Remedial Options of Reavers Catchment, Queenstown

Dear Steve and Paul,

1 Introduction

In accordance with Queenstown Lakes District Council's request this letter summarises our assessment of the risk to life potential from instability of introduced fill into the Reavers Creek Catchment adjacent to the Skyline development. The residual risk to life resulting from the implementation of potential remedial options is also calculated.

This risk assessment is solely for the purpose of evaluating the potential decrease in Annual Individual Fatality Risk (AIFR) following implementation of various remedial options proposed by Skyline Enterprises Ltd (SEL) to address the fill. The remedial options and scope are further detailed in SEL Mitigation Options Report (of which Draft Revision B was in preparation at the time of writing of this report).

It is understood that a background level of risk from other natural hazards exists within the catchment, however GeoSolve have not assessed the risk posed by these hazards and they are excluded from the scope of the assessment reported herein.

2 Site Description

During a rainfall event on the 21-22 of September 2023 fill material present on the true right of the catchment, adjacent to the Skyline Development, became saturated triggering failure. Rapid movement of the fill down slope subsequently occurred, reaching Reavers Creek and the culvert at the top of Reavers Lane, several hundred metres downstream. The volume of material overwhelmed the culvert, resulting in overflow and inundation of the nearby residential area.

Following the event fill material remained on the slope and in the creek, distributed between the upper catchment and the culvert. Table 1 summarises the locations and estimated volumes of the remaining debris. Volumes have been determined by others, using LiDAR, site survey and on ground measurements. Figure 1 below shows a general view of the area.

Table 1: Summary of remaining debris locations and volumes

Debris Location Description	Estimated Volume (m^3)
Zone A. Upper Site- The original source area at the top of the catchment	~2,500
Zone B. Reavers Channel and Trees- On the slopes between the top source area and Reavers Creek Culvert.	750
Total Remaining	~3250

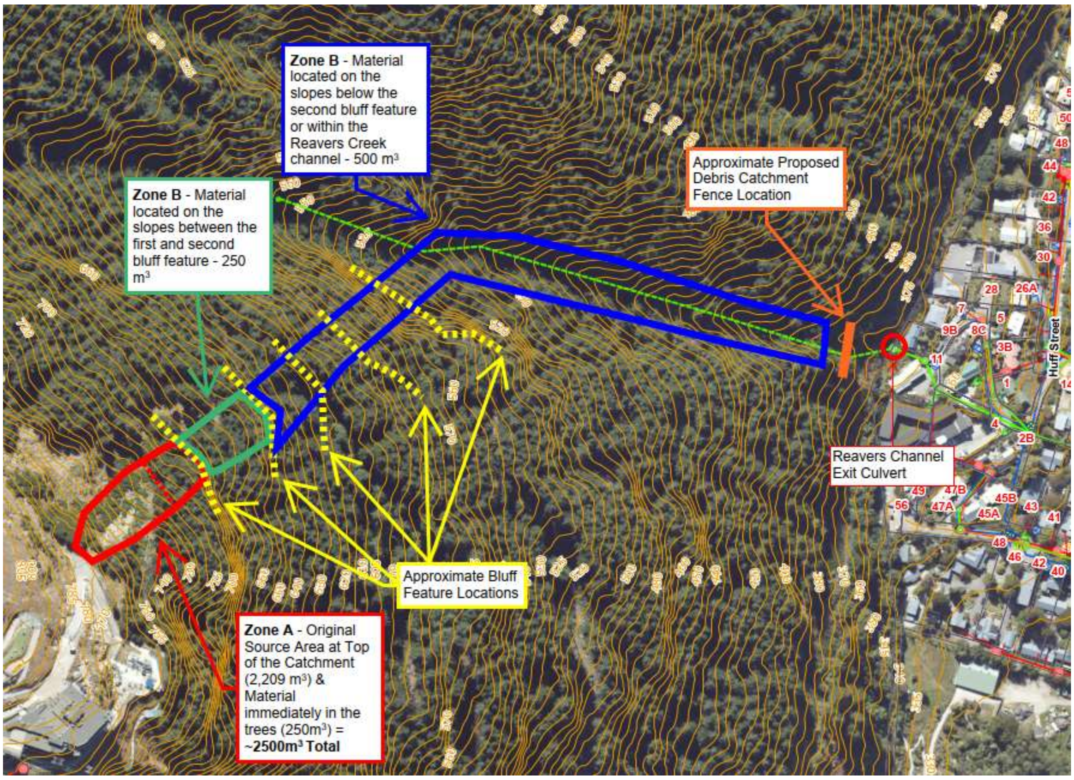

Figure 1: Site Area

The remaining fill, and proposed remedial works, will be considered as the 2 separate areas, Zone A and Zone B, as presented in Table 1.

3 Remedial Options

Remedial works for the upper site (Zone A) generally comprise the following options:

- Do nothing (not assessed).
- Removal of the material- by various methods.
- Redistribution on Slope (not assessed and considered unlikely to be a suitable solution).
- Stabilise in Place- by soil nail support.
- Installation of a debris flow fence at the bottom of the upper slope, with an approximate capacity of 2500 m^3.

Remedial works for the Reavers Channel and Trees (Zone B) generally comprise:

- Installation of a debris flow fence at the bottom of the Reavers Creek Catchment with an approximate capacity of 750 m^3.
- Removal of this material from the debris flow fence after sediment mobilising events.

A combination of multiple options is a potential solution. For more detail on the potential remedial options, refer to the Skyline Development's Mitigation Options Report.

To quantify the risk reduction resulting from the implementation of a remedial option the risk value for the current 'un-remediated' fill state needs to be determined. This existing situation risk level (AIFR) is provided as a background reference for the proposed remedial risk reduction measures to inform decision making only. The value only considers the introduced fill and does not include risks associated with other hazards. It is therefore provided for comparative purposes only and should not be used as a conclusive value for the catchment as a whole.

4 Risk Assessment- Method and Assumptions

This section presents the method and assumptions of the quantitative risk assessment, including estimating the AIFR resulting from the instability of fill within Zone A and Zone B.

The risk is primarily posed to people in residential dwellings adjacent to Reavers Creek culvert.

The risk assessment undertaken has involved:

- Calculation of the probability of debris flow affecting residential dwellings, and the associated risk to the person who will spend most time exposed to the hazard, i.e., the "person most at risk".
- Placing the risk in context in comparisons to relevant guidelines, such as those provided by AGS.

The risk of landslide dam failure has been qualitatively assessed to not be the governing risk to life mechanism, as discussed in previous GeoSolve reporting entitled "Reavers Creek Fill Instability- Landslide Dam Potential", 16 November 2023. The governing risk to life will be conventional storm event debris flow.

The risk assessment has not involved evaluation of the greater Reavers catchment and consideration of hazards that may pose a risk to life beyond that caused by the instability of the fill in Zone A & B.

The method for the risk assessment of slope instability used for this report generally follows the approach used for assessing the annual probability of loss of life (death) of an individual from AGS 2007[1].

The following details have been assumed for the risk assessment:

[1] Australian Geomechanics Society, Volume 42, No. 1 March 2007.

- The volume of the fill material mobilisation will be dependent on the severity of the rainfall event, which is tied to a corresponding ARI (Annual Recurrence Interval) rainfall event, as shown in Table 2.
- Dependent on the remedial option(s) chosen, resulting in retention or removal of material, the volume of material that can be mobilised will be reduced by the amount shown in the options table provided below.

Table 2: Summary of volume of material that can mobilise for various ARI rainfall events.

ARI (Years)	Pre-treatment Estimated Sediment Volume for Mobilisation (m^3) from Zone A	Pre-treatment Estimated Sediment Volume for Mobilisation (m^3) from Zone B	Estimated Volume of fill with the potential to mobilise and reach Reavers Lane following installation of 750m^3 debris barrier at bottom of catchment (m^3)	Estimated Volume of fill with the potential to mobilise and reach Reavers Lane following installation of 2500m^3 debris barrier at top of catchment (m^3) or removal or stabilisation in of 2500m^3 debris material at top of catchment (m^3)
10	750	375	375	375 (from Zone B)
20	924	750	924	750 (from Zone B)
50	1217	750	1217	750 (from Zone B)
100	1500	750	1500	750 (from Zone B)
500	2500	750	2500	750 (from Zone B)

- RAMMS has been used to calculate the probability of spatial impact. A sensitivity analysis was undertaken for the upper and lower catchment release locations, using hydrograph and block release, to determine the most conservative input values. Conservatively, a block release mechanism from the lower catchment release area has been used to represent the worst-case scenario for flow velocity and depth. This scenario represents remobilisation of a high volume of material which has accumulated in the lower catchment.
- RAMMS has been used to provide a rough estimate of flow depth and velocity to inform inputs for vulnerability values.
- The RAMMS debris flow results are conservative, but represent the worst-case scenario (of a single, large surge debris flow) capable of impacting the most vulnerable dwellings at the head of the Reavers fan. The flow depth at this location has been used to inform the critical vulnerability values. Downslope from this area it is considered that flow will behave more similarly to that observed in the September 2023 event, and the RAMMS results have not been used for vulnerability calibration for dwellings further downslope.
- Vulnerability values have then been derived assuming the dwellings are Timber Framed structures in general accordance with the recommendations of GNS report "Vulnerability of Dwellings to Landslides"[2] and calculated using their prescribed criteria, as shown in Figure 2 below.
- The infrastructure at the base of the Reavers Creek is residential and the person most at risk' i.e., the person who spends the most time in the dwelling may be senior, very young,

[2] Massey CI, Thomas K-L, King AB, Singeisen C, Horspool NA, Taig T. 2018. SLIDE (Wellington): vulnerability of dwellings to landslides (Project No. 16/SP740). Lower Hutt (NZ): GNS Science. 76 p. (GNS Science report; 2018/27)

disabled, or vulnerable, and may spend a very high proportion of their life within their home. An 80% occupation time has been assumed for a residential dwelling.

- The length of the western edge of the proposed building footprint facing the hazard is approximately 11 m (11 Reavers Lane).
- The spatial input for the $P_{(T:S)}$ of the calculation is the probability a person is present in space when the hazard event is occurring. This is calculated by dividing the length of the building by the width of the building user/s, assuming each person occupies a 1 metre space.

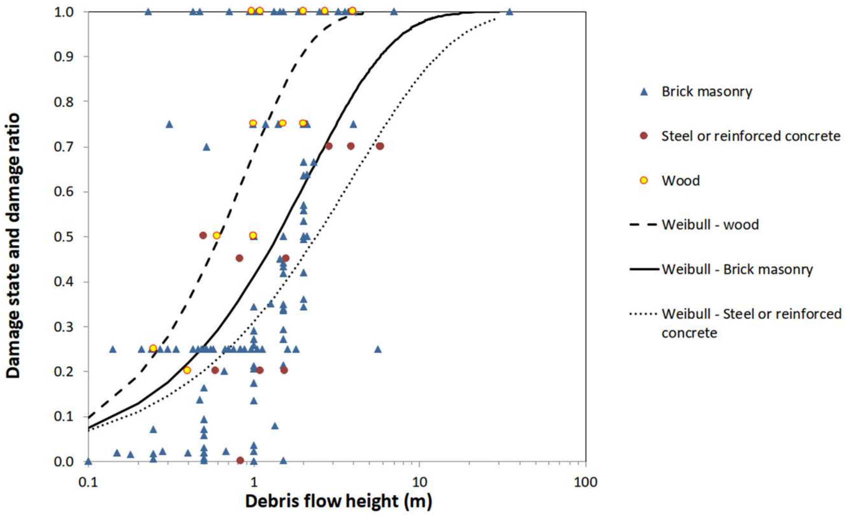

Figure 2: The Vulnerability of Buildings to Debris Flows

5 Risk Assessment- Results

Based on the assumptions outlined above, the AIFR results have been calculated for the various remedial options and are presented in Table 3:

Table 3: Summary of AIFR results for the various proposed remedial options.

Area of Catchment	Remedial Option	Comments	Estimating the Annual Individual Fatality Risk (AIFR),
Zone A & B	No Remediation - Background Risk Assessment for Reavers Debris Bulb	Prior to remedial works, excluding natural hazards in the Reavers Catchment.	**1.25×10^{-2}**
Zone A	Stabilise fill material in Place (2500m3)- by soil nail support.	Design Life 100 years. Material Present in Zone B.	**2.75×10^{-3}**
Zone A	Removal of upper fill material (2500m3)	Material still present in Zone B.	**2.75×10^{-3}**
Zone A	Install Fence at top of catchment to take 2500m3	Material still present in Zone B. Design Life 25 years.	**2.75×10^{-3}**
Zone B	Install Fence at bottom of catchment to take 750m3	Material still present in Zone A. Design Life 25 years.	**5.96×10^{-3}**

Zone A & B	Install Fence at the bottom (750m3) and remove/stabilise the upper fill material.	Fence Design Life 25 years..	**$*1.45 \times 10^{-6}$**
Zone A & B	Install Fence at top of catchment to take 2500m3. Install Fence at bottom of catchment to take 750m3.	Fence Design Life 25 years.	**$*1.45 \times 10^{-6}$**
* No spatial impact was determined following remedial measures in Zone A & B; therefore, this value is conservative and required to enable an AIFR assessment to be completed. Therefore, the risk is negligible.			

6 Risk Guidelines and Risk Comparisons

'Tolerable' and 'Acceptable' risk from a natural hazard is a complex subject with significant research and debate published. GeoSolve consider that prescribing tolerable/acceptable risk values for the site is a decision to be made by the relevant stakeholders and the regulating body. Acceptable and Tolerable risks are described as follows:

- Tolerable Risks are risks within a range that society can live with so as to secure certain benefits. It is a range of risk regarded as non-negligible and needing to be kept under review and reduced further if practicable.
- Acceptable Risks are risks which everyone affected is prepared to accept. Action to further reduce such risk is usually not required unless reasonably practicable measures are available at low cost in terms of money, time and effort.

Guidance on acceptability criteria is presented in the Australian Geomechanics Society (AGS) 2007 document on Landside Risk Management. This document is a guideline only, and does not necessarily need to be adopted. The AGS recommendations in relation to Tolerable risk for loss of life are summarised in Table 4 below.

Table 4: AGS suggested tolerable loss of life for individual risk.

Situation	Suggested Tolerable Loss of Life Risk for the person most at risk
Existing Slope (1) / Existing Development (2)	10^{-4} / annum
New Constructed Slope (3) / New Development (4) / Existing Landslide (5)	10^{-5} / annum

7 Summary and Conclusion

In order to mitigate the debris flow risk posed to the residential area near the Reavers Lane culvert multiple remedial options have been considered, such as stabilisation and/or removal of the introduced fill in the Reavers Creek catchment.

A risk assessment has been completed to determine the anticipated reduction in AIFR risk that would result from implementation of the potential remedial options, including combinations of those options in order to address sediment located in both the upper and lower catchment, described as Zone A and Zone B in this report.

Calculated risk values for undertaking remedial works in both Zone A and Zone B of the catchment are significantly lower than the tolerable risk guidelines provided in AGS 2007, noting that the design life of engineered structures is limited in risk reduction in perpetuity.

It is considered that once the introduced sediment has been captured and/or removed from the catchment the risk will be reduced to the approximate pre-existing level. Until that time, it is considered that engineering structures are an appropriate means of mitigating the risk.

8 Applicability

This report has been prepared for the sole use of our client, Skyline Enterprises Ltd, with respect to the particular brief and on the terms and conditions agreed with our client. It may not be used or relied on (in whole or part) by anyone else, or for any other purpose or in any other contexts, without our prior review and written agreement.

Yours faithfully,

Simon Reeves
Senior Engineering Geologist
GeoSolve Limited

Reviewed for GeoSolve by:

Paul Faulkner, Senior Engineering Geologist
Neil Williman, Senior Water Resources Engineer

Attachments: Risk Calculations [7pp]
Ramms Debris Flow Modelling [7pp]

GEOSOLVE			Remedial Option- Background Risk Assessment For Reavers Debris Bulb				27/11/2023 SR Rev-0 160073.03
				Probabilities			
Calculation	Return Period		Person Most at Risk	Probability of spatial impact	Temporal Spatial Probability	Vulnerability	Total AIFR Or Societal Risk
	Proportional notation (1 in x years)	Scientific notation					
1	10	1.00E-01	Reavers Lane Dwelling	1.0	7.27E-02	0.90	6.55E-03
2	20	5.00E-02	Reavers Lane Dwelling	1.0	7.27E-02	1.0	3.64E-03
3	50	2.00E-02	Reavers Lane Dwelling	1.0	7.27E-02	1.0	1.45E-03
4	100	1.00E-02	Reavers Lane Dwelling	1.0	7.27E-02	1.0	7.27E-04
5	500	2.00E-03	Reavers Lane Dwelling	1.0	7.27E-02	1.0	1.45E-04
						Total	**1.25E-02**

GEOSOLVE

	Remedial Option- Stabilse of Upper 2500m3 with 750m3 remaining (Zone B)						27/11/2023 SR Rev-0 160073.03
				Probabilities			
Calculation	**Return Period**		**Person Most at Risk**	**Probability of spatial impact**	**Temporal Spatial Probability**	**Vulnerability**	**Total AIFR Or Societal Risk**
	Proportional notation (1 in x years)	**Scientific notation**					
1	10	1.00E-01	Reavers Lane Dwelling	1.0	7.27E-02	0.05	3.64E-04
2	20	5.00E-02	Reavers Lane Dwelling	1.0	7.27E-02	0.4	1.45E-03
3	50	2.00E-02	Reavers Lane Dwelling	1.0	7.27E-02	0.40	5.82E-04
4	100	1.00E-02	Reavers Lane Dwelling	1.0	7.27E-02	0.4	2.91E-04
5	500	2.00E-03	Reavers Lane Dwelling	1.0	7.27E-02	0.4	5.82E-05
						Total	**2.75E-03**

Calculation	Return Period		Person Most at Risk	Probabilities			
				Probability of spatial impact	Temporal Spatial Probability	Vulnerability	Total AIFR Or Societal Risk
	Proportional notation (1 in x years)	Scientific notation					
1	10	1.00E-01	Reavers Lane Dwelling	1.0	7.27E-02	0.05	3.64E-04
2	20	5.00E-02	Reavers Lane Dwelling	1.0	7.27E-02	0.4	1.45E-03
3	50	2.00E-02	Reavers Lane Dwelling	1.0	7.27E-02	0.40	5.82E-04
4	100	1.00E-02	Reavers Lane Dwelling	1.0	7.27E-02	0.4	2.91E-04
5	500	2.00E-03	Reavers Lane Dwelling	1.0	7.27E-02	0.4	5.82E-05
						Total	**2.75E-03**

GEOSOLVE

Remedial Option- Removal of Upper 2500m3 with 750m3 remaining (Zone B)

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GEOSOLVE	Remedial Option- Install Fence at top of catchment to take 2500m3- Design Life 25 years						27/11/2023 SR Rev-0 160073.03
				Probabilities			
Calculation	Return Period		Person Most at Risk	Probability of spatial impact	Temporal Spatial Probability	Vulnerability	Total AIFR Or Societal Risk
	Proportional notation (1 in x years)	Scientific notation					
1	10	1.00E-01	Reavers Lane Dwelling	1.0	7.27E-02	0.05	3.64E-04
2	20	5.00E-02	Reavers Lane Dwelling	1.0	7.27E-02	0.4	1.45E-03
3	50	2.00E-02	Reavers Lane Dwelling	1.0	7.27E-02	0.40	5.82E-04
4	100	1.00E-02	Reavers Lane Dwelling	1.0	7.27E-02	0.4	2.91E-04
5	500	2.00E-03	Reavers Lane Dwelling	1.0	7.27E-02	0.4	5.82E-05
						Total	**2.75E-03**

GEOSOLVE

Remedial Option-Install Fence at bottom to take 750m3- Design Life 25 years

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Rev-0
160073.03

				Probabilities			
Calculation	**Return Period**		**Person Most at Risk**	**Probability of spatial impact**	**Temporal Spatial Probability**	**Vulnerability**	**Total AIFR Or Societal Risk**
	Proportional notation (1 in x years)	**Scientific notation**					
1	10	1.00E-01	Reavers Lane Dwelling	1.0	7.27E-02	0.05	3.64E-04
2	20	5.00E-02	Reavers Lane Dwelling	1.0	7.27E-02	0.90	3.27E-03
3	50	2.00E-02	Reavers Lane Dwelling	1.0	7.27E-02	1.0	1.45E-03
4	100	1.00E-02	Reavers Lane Dwelling	1.0	7.27E-02	1.0	7.27E-04
5	500	2.00E-03	Reavers Lane Dwelling	1.0	7.27E-02	1.0	1.45E-04
						Total	**5.96E-03**

GEOSOLVE	Remedial Option- Retention or remove of debris at the top of the catchement (2500m3) and Install Fence at the bottom (750m3)							27/11/2023 SR Rev-0 160073.03
				Probabilities				
Calculation	**Return**		**Person Most at Risk**	**Probability of spatial impact**	**Temporal Spatial Probability**	**Vulnerability**	**Total AIFR Or Societal Risk**	
	Proportional notation (1 in x years)	**Scientific notation**						
1	10	1.00E-01	Reavers Lane Dwelling	0.0	7.27E-02	0.00	0.00E+00	
2	20	5.00E-02	Reavers Lane Dwelling	0.0	7.27E-02	0.0	0.00E+00	
3	50	2.00E-02	Reavers Lane Dwelling	0.0	7.27E-02	0.00	0.00E+00	
4	100	1.00E-02	Reavers Lane Dwelling	0.0	7.27E-02	0.0	0.00E+00	
5	500	2.00E-03	Reavers Lane Dwelling	0.1	7.27E-02	0.1	1.45E-06	
						Total	**1.45E-06**	

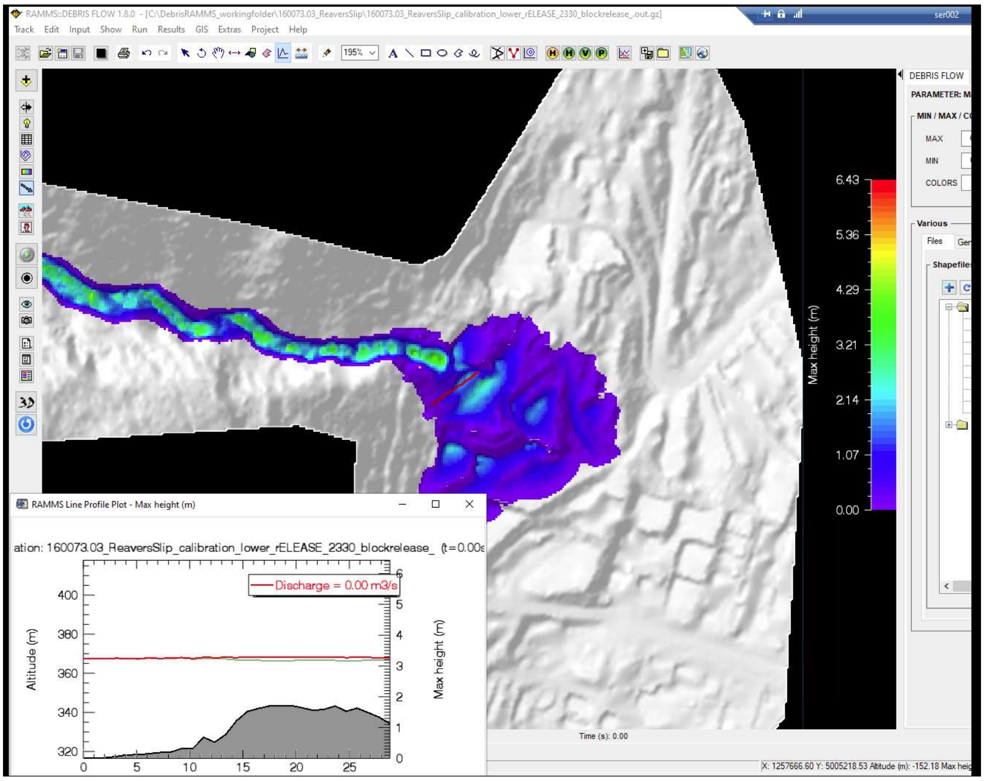
* No spatial impact was determined following remedial measures in Zone A & B, therefore this value is conservative and required to enable an AIFR assessment to be completed.

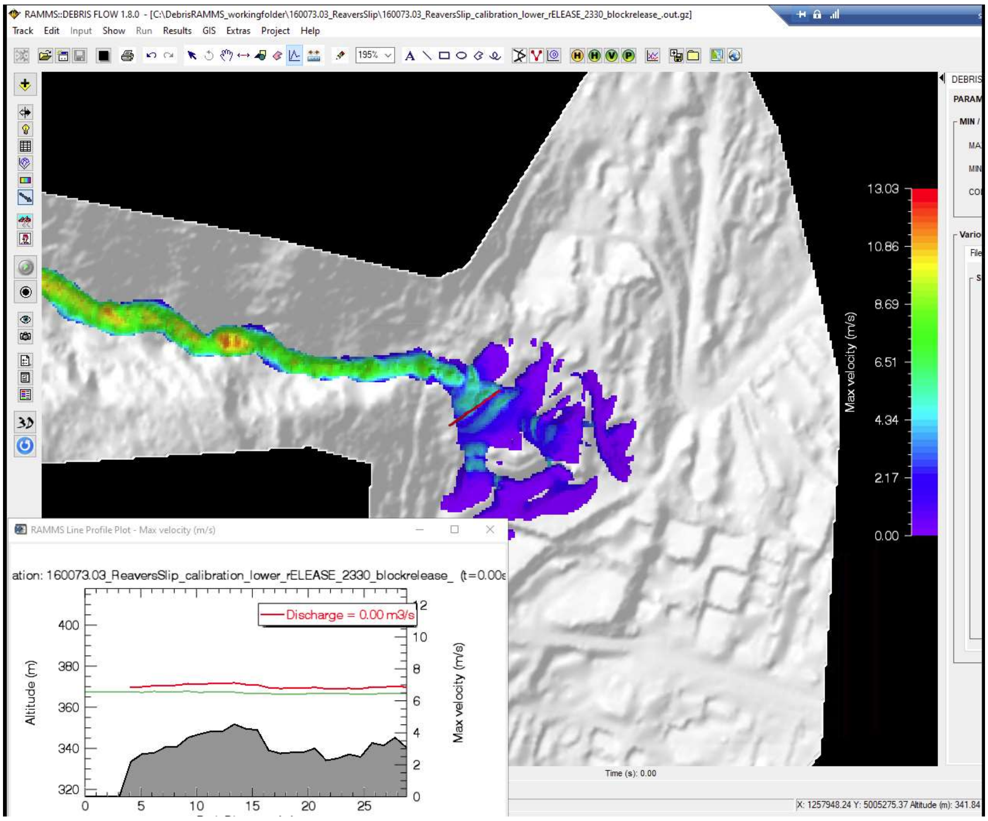
GEOSOLVE	Remedial Option- Install Fence at the top (2500m3) and Install Fence at the bottom (750m3)						27/11/2023 SR Rev-0 160073.03
				Probabilities			
Calculation	**Return**		**Person Most at Risk**	**Probability of spatial impact**	**Temporal Spatial Probability**	**Vulnerability**	**Total AIFR Or Societal Risk**
	Proportional notation (1 in x years)	**Scientific notation**					
1	10	1.00E-01	Reavers Lane Dwelling	0.0	7.27E-02	0.00	0.00E+00
2	20	5.00E-02	Reavers Lane Dwelling	0.0	7.27E-02	0.0	0.00E+00
3	50	2.00E-02	Reavers Lane Dwelling	0.0	7.27E-02	0.00	0.00E+00
4	100	1.00E-02	Reavers Lane Dwelling	0.0	7.27E-02	0.0	0.00E+00
5	500	2.00E-03	Reavers Lane Dwelling	0.1	7.27E-02	0.1	1.45E-06
						Total	**1.45E-06**

* No spatial impact was determined following remedial measures in Zone A & B, therefore this value is conservative and required to enable an AIFR assessment to be completed.

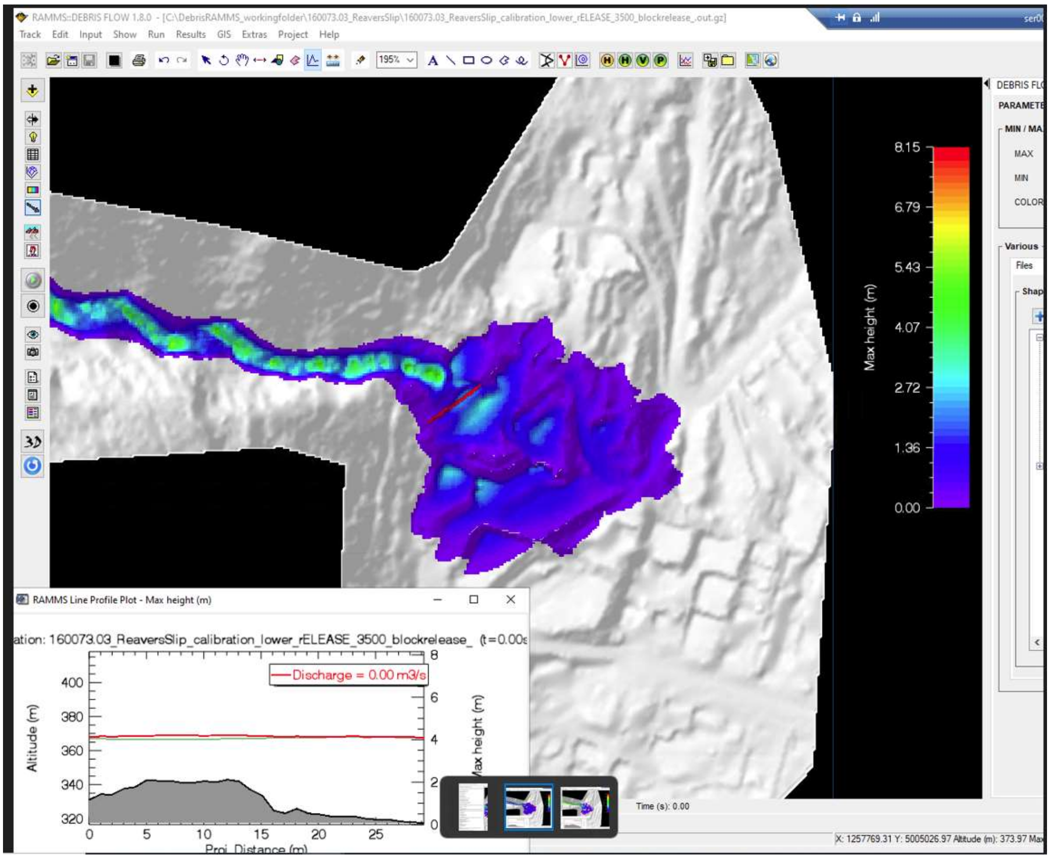
1. Background Risk Assessment for Reavers Fill Material In Zone A & Zone B:

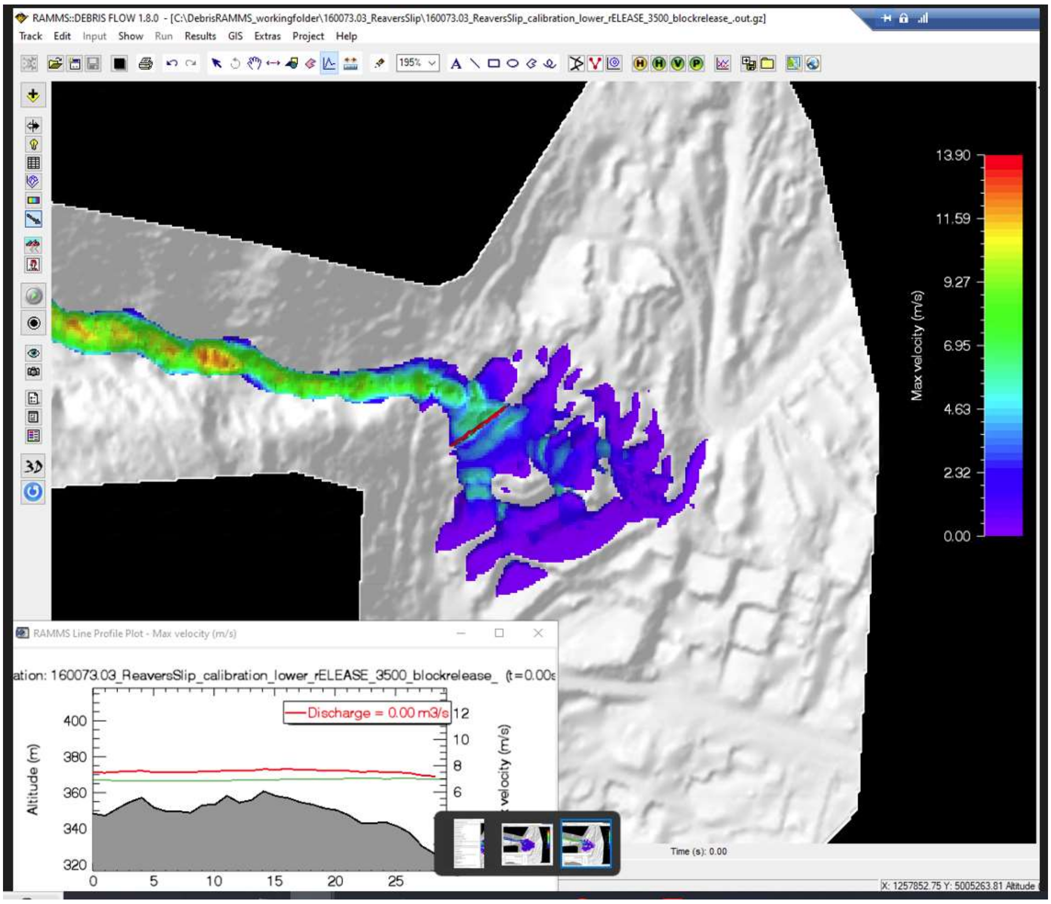
Return Period 10 Years- lower release-1125m3 sediment- Vulnerability 0.9





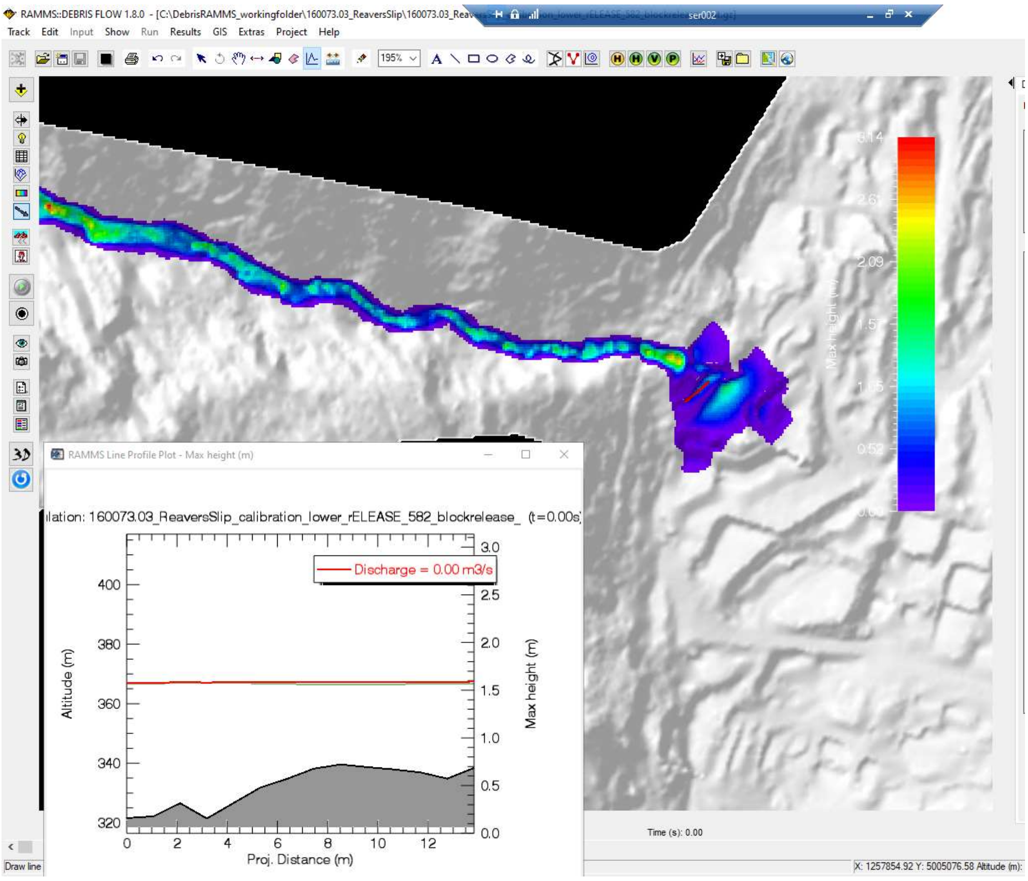
Return Period 20 Years- lower release- 1674m3 sediment- Vulnerability= 1

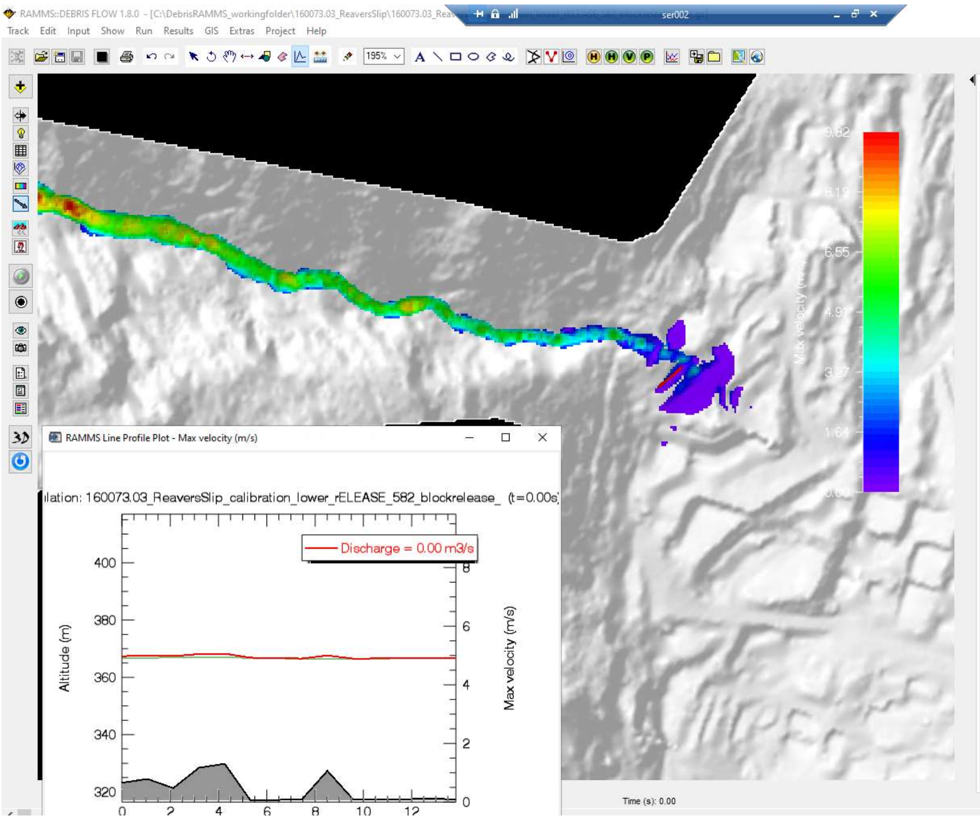




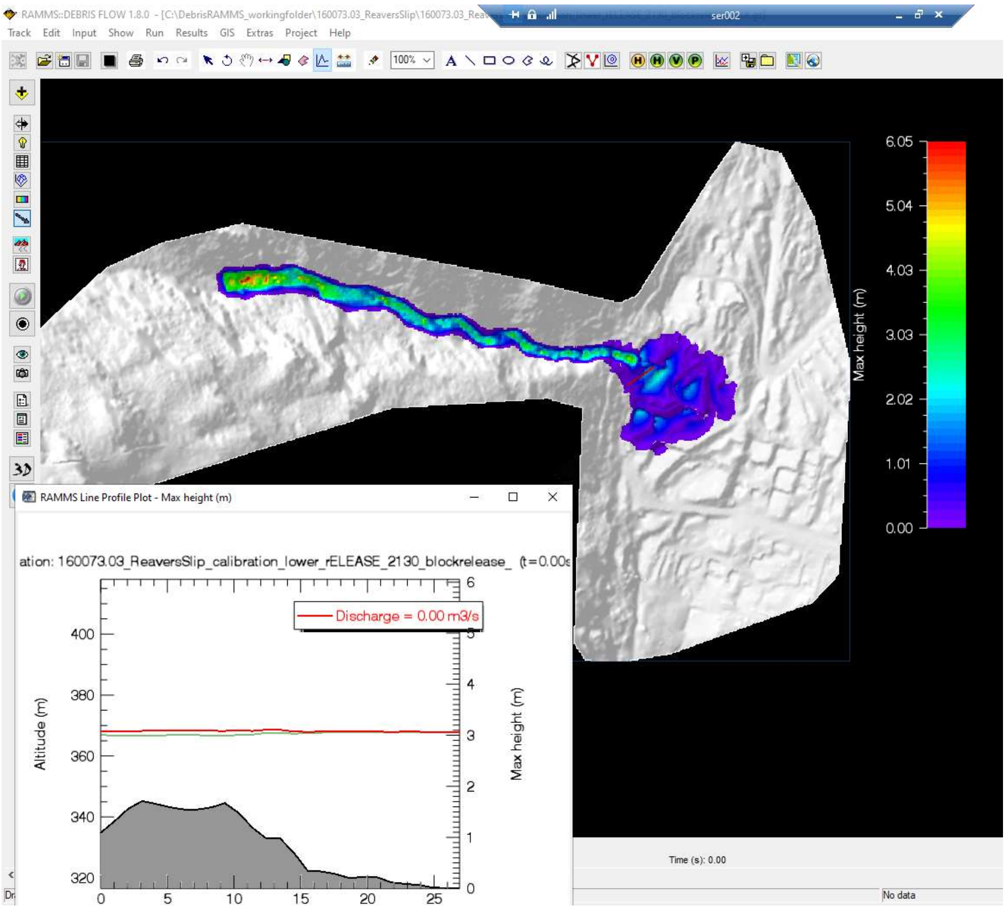
2. **Install Fence at bottom to take 750m3- Design Life 25 years**

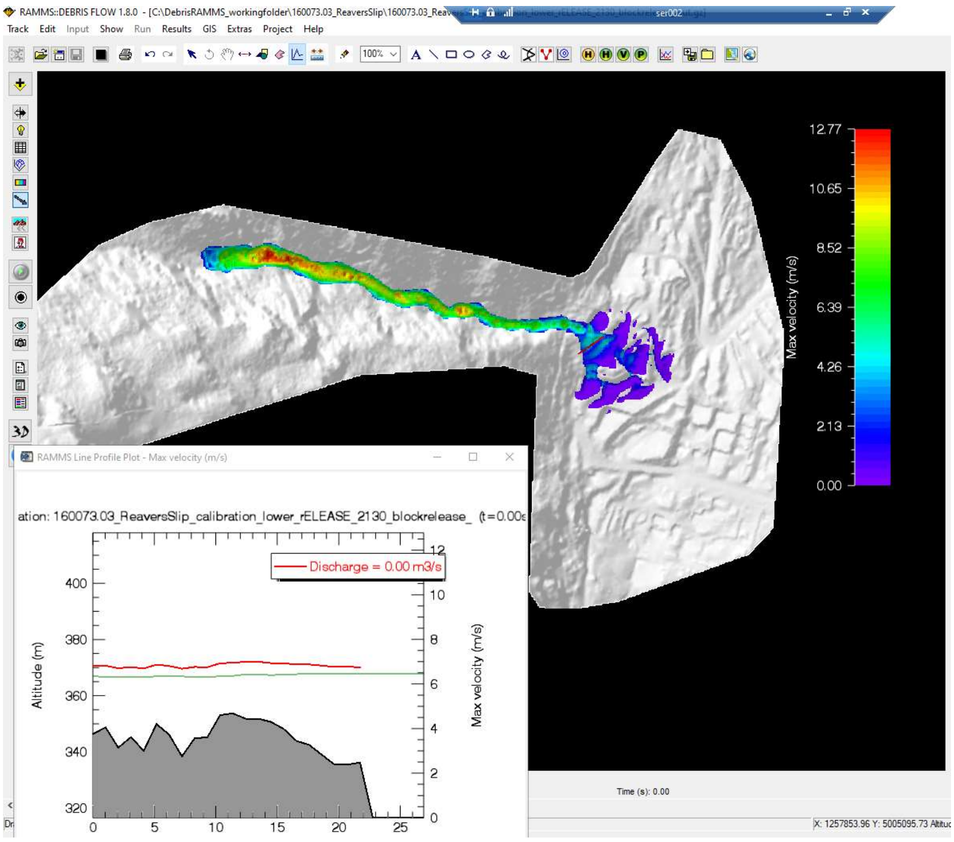
Return Period 10 Years- lower release- 375m3 sediment- Vulnerability 0.05



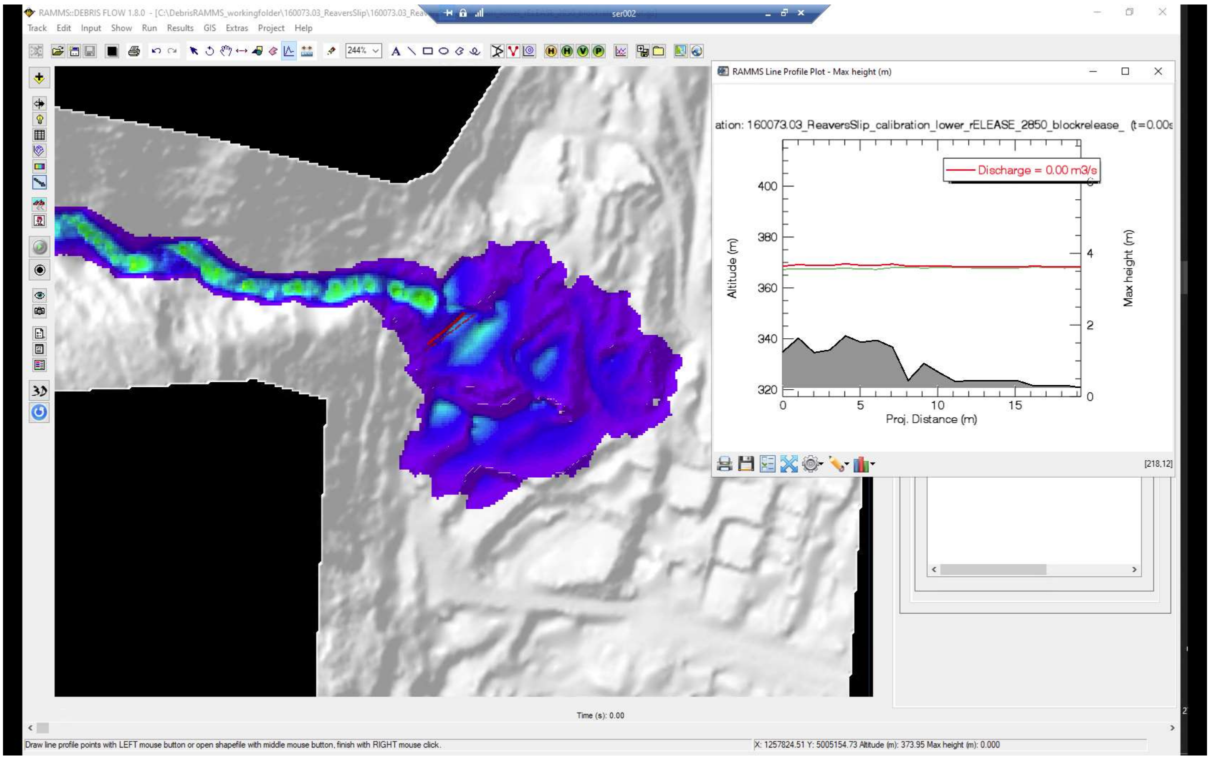


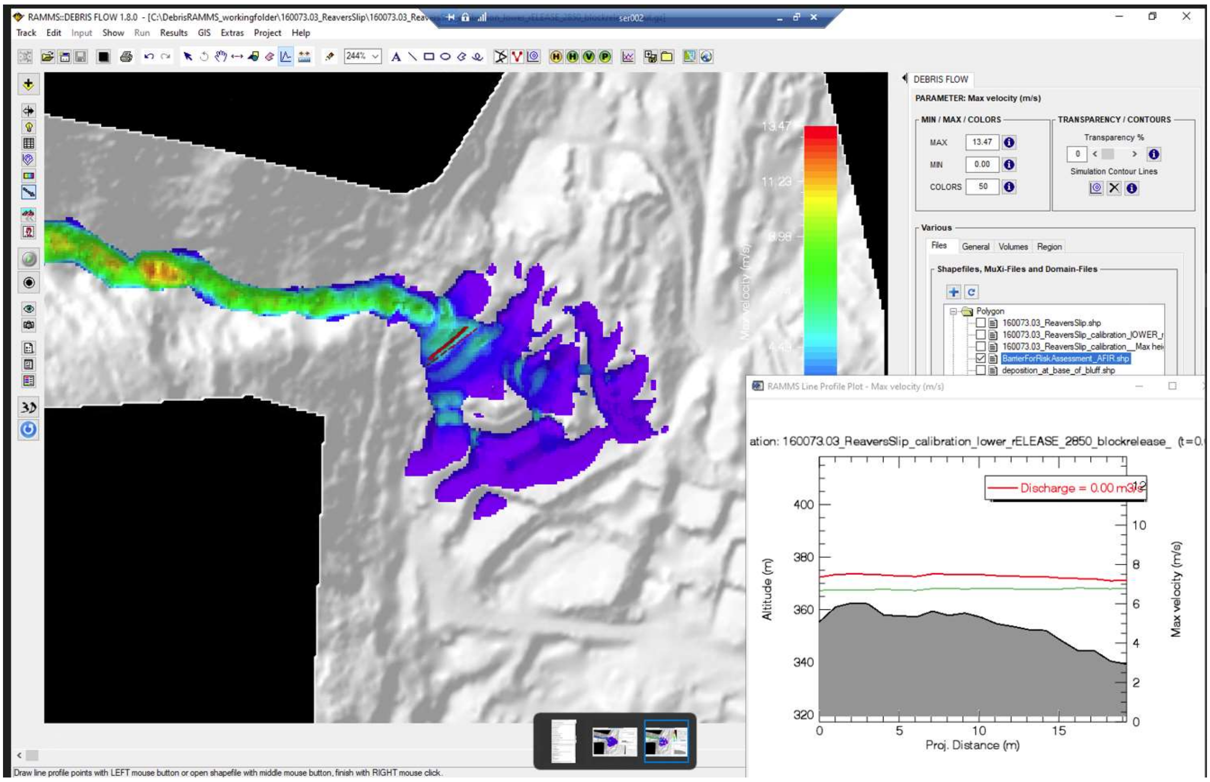
Return Period 20 Years- lower release- 924m3 sediment- Vulnerability 0.9





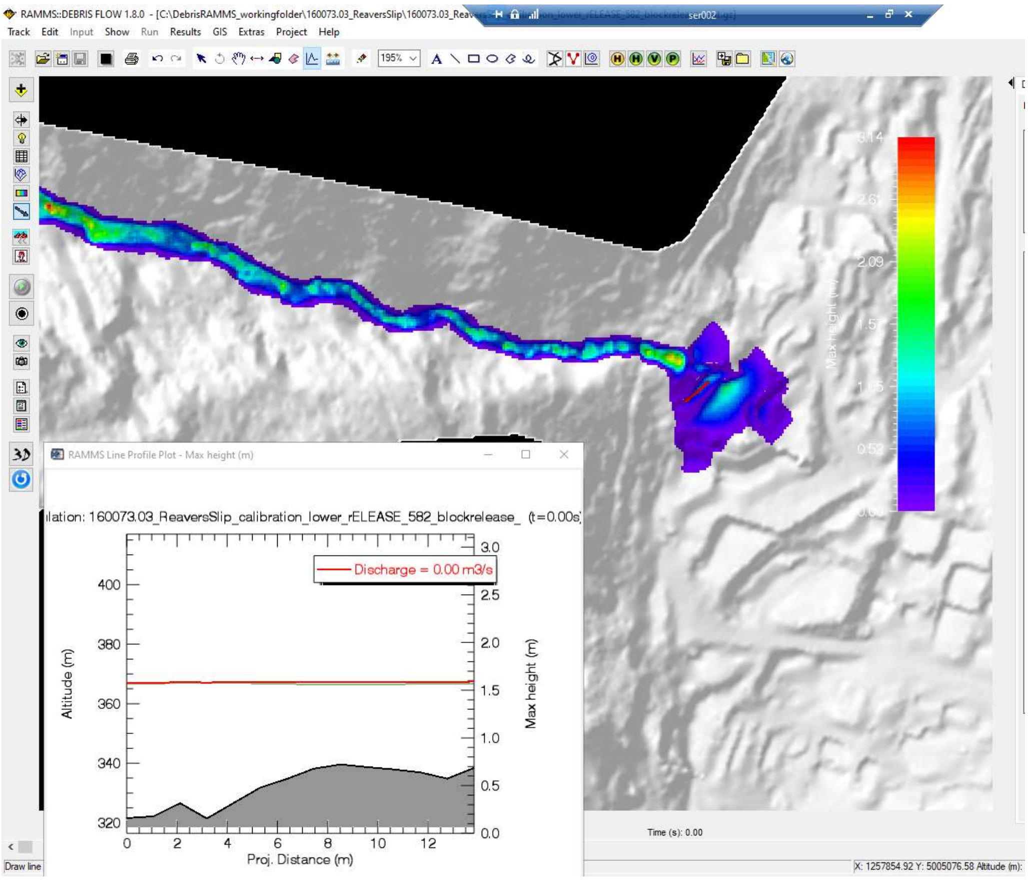
Return Period 50 Years- lower release- 1217m3 sediment- Vulnerability 1

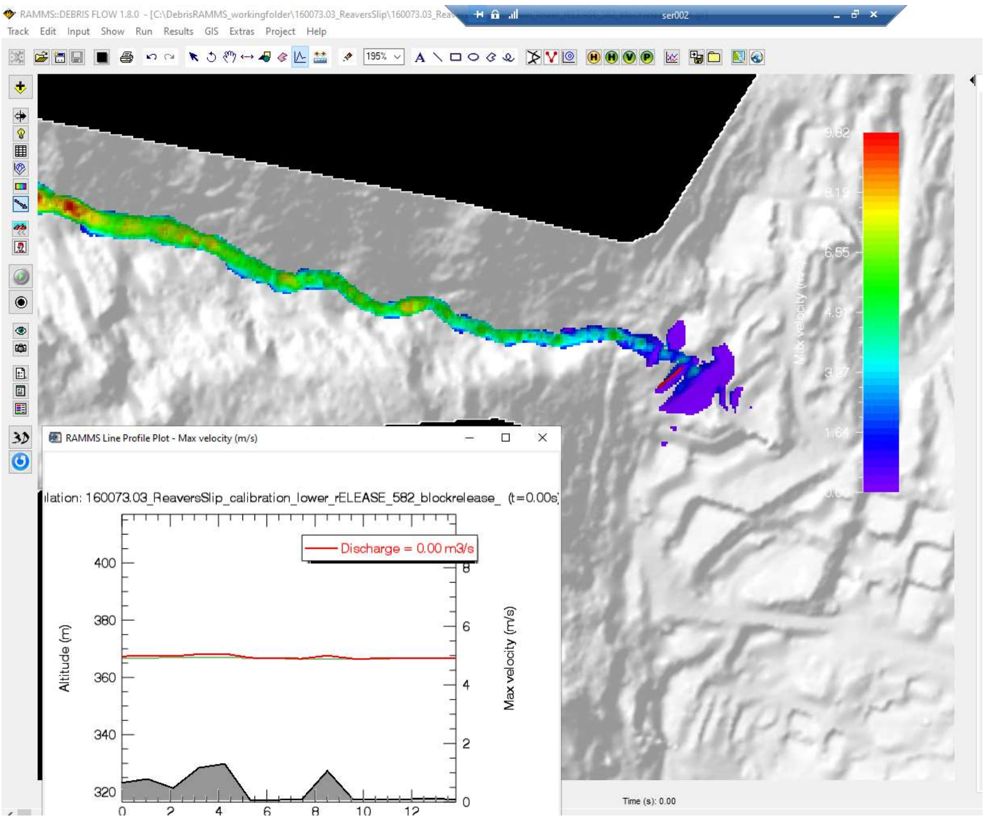




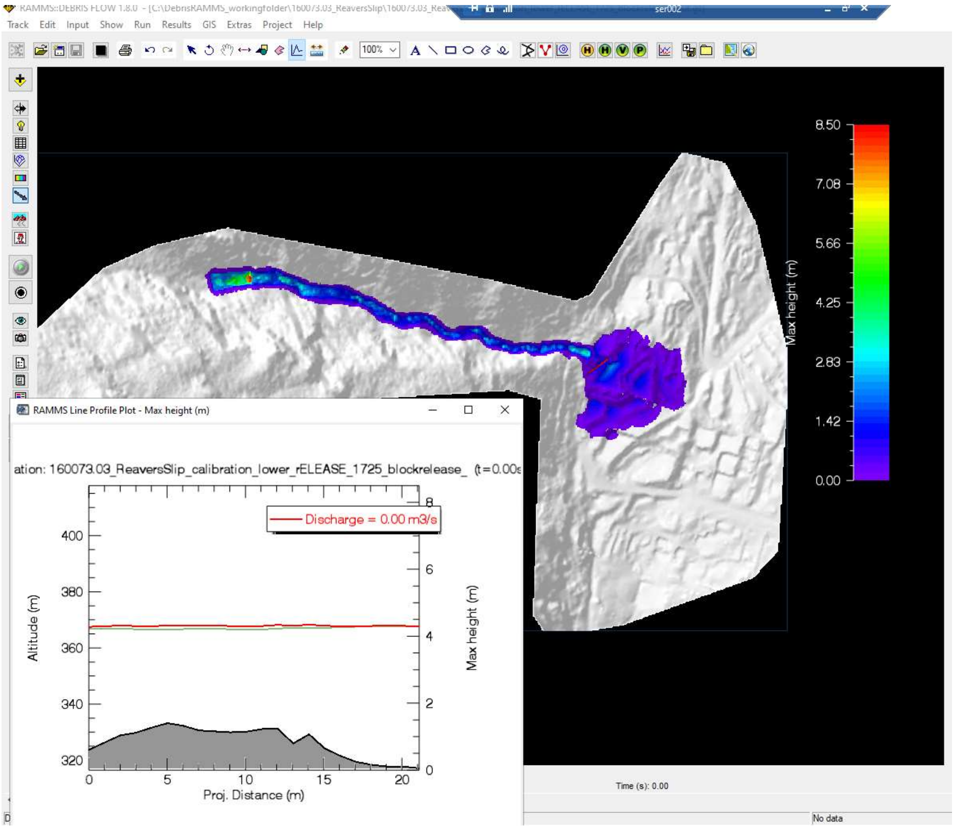
3. **Removal or retention of upper 2500m3 in Zone A, with 750m3 remaining in Zone B**

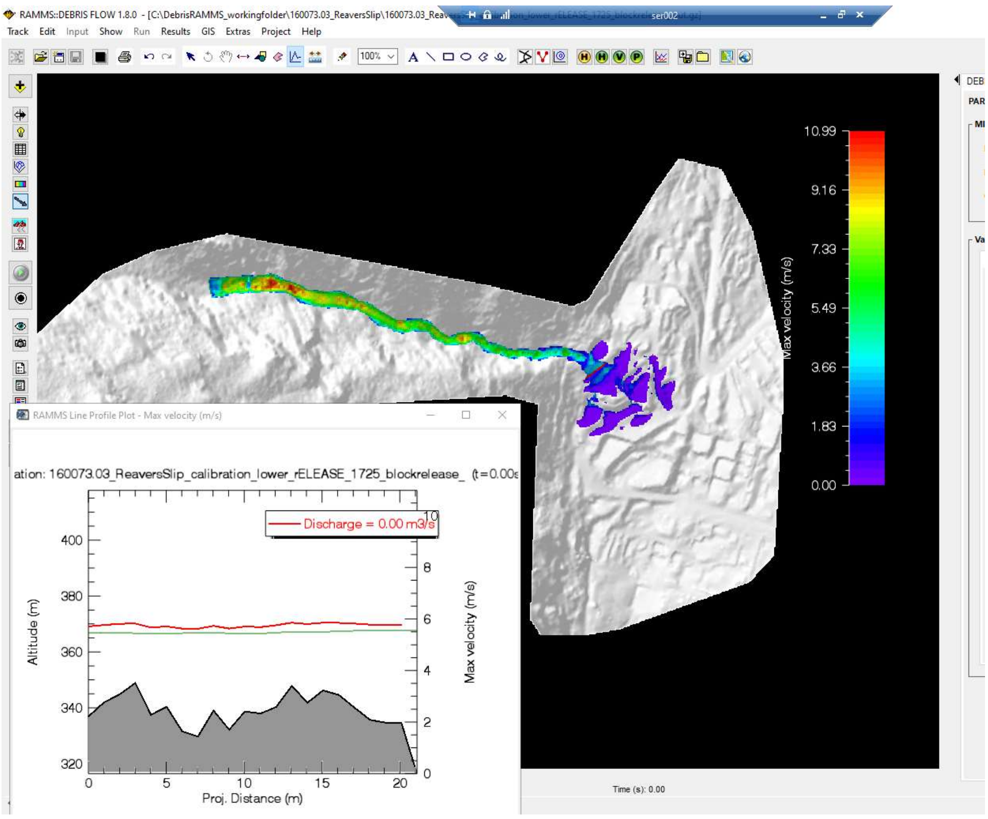
Return Period 10 Years- lower release- 375m3 sediment- Vulnerability 0.05





Return Period 20 to 250 Years- lower release- 750m3 - Vulnerability 0.4





Stormwater Discharge – Detailed Hazard Assessment

Skyline Upgrade

Queenstown

Report prepared for:

Skyline Enterprises Limited

Report prepared by:

GeoSolve Ltd

Distribution:

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GeoSolve Limited (File)

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ACENZ MEMBER

Table of Contents

Appendix A – GeoSolve Drawings

1 Introduction

1.1 General

This report presents the results of a detailed hazard assessment undertaken by GeoSolve Ltd, and with the assistance of Fluent Solutions Ltd, to assess natural hazard risks associated with increasing the discharge from two existing storm water outlets as part of the Skyline building upgrade.

The hazard assessment has been completed for Skyline Enterprises in accordance with terms and conditions outlined in GeoSolve Ltd proposal dated 2 February 2017.

1.2 Background and Scope of Work

The Otago Regional Council (ORC) has expressed concerns through its submissions on the resource consent application of the Queenstown Skyline upgrade that negative effects on natural hazards could result from additional storm water discharge. The increased roof area of the new building will generate an increased runoff volume and higher peak discharge from the existing storm water outlet locations. The ORC is concerned these increases could result in debris flows or activation of slope instability and any consequent risk to downstream receptors.

Subsequently, ORC commissioned a report from GNS Science to confirm if the risk was valid. The report identified that there may be potential for debris flows to occur at the site and that a higher level of assessment than had already been undertaken was considered necessary to address the concerns outlined above for resource consent.

Therefore the purpose of this report is to:

- Present the results of detailed geological mapping along the stormwater flow paths;
- Complete slope stability assessments to determine the likelihood of debris flow or slope instability occurring as a direct result of the increased storm water discharge;
- Complete a quantitative and qualitative risk assessment of the effects of increased discharge;
- Provide opinion on the storm water discharge proposal, based on site observations and the outcome of the above assessments, and assess if the development proposal will have any adverse effects on natural hazards (i.e. landslide, debris flow and flooding);
- If appropriate, recommend solutions, control measures or mitigation works to safely discharge storm water to the slopes.

The role of GeoSolve has been to provide assessment on the geotechnical aspects of the storm water discharge proposal including confirmation of geology and land stability. Fluent Solutions role has been to provide input, modelling and assessment of the flooding hazards and hydrological aspects of the proposal.

The Fluent report is discussed where appropriate in this report, and is provided in Appendix C

2 Site Description

2.1 General

The existing top Skyline complex is situated on the upper slopes of Bobs Peak, Queenstown at an elevation of approximately 780 m above sea level and 470 m above central Queenstown, see Figure 2.1 below.

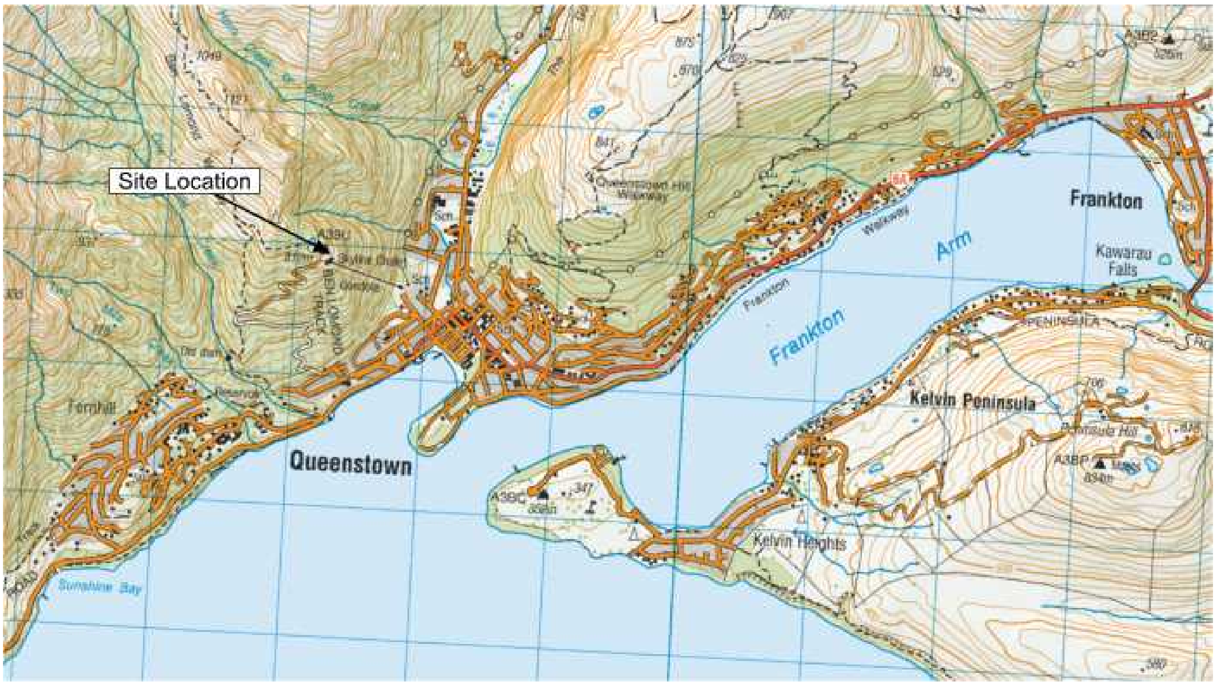


Figure 2.1 – Site location

The land surrounding the top terminal building has been modified to accommodate the existing buildings, level viewing platforms, footpaths and amenities. Localised retaining, excavation and fill earthworks have been completed. Exposure of the underlying geology, in particular schist, glacial till and colluvium/slope debris, is present in several locations across the site and slopes beneath.

The slopes below the complex onto which the storm water is discharged are generally covered in wilding and mature pine and patches of native forest with grass and scrub covering the remaining areas. In general the hillside slopes between approximately 15-40 degrees. A series of sub-vertical schist bluffs intermittently step down the hillside, in particular on the eastern slopes, to the base of Bobs Peak, see Figure 1b Appendix A, and cross-sections provided as Figures 2a, 2b and 2c, Appendix A.

2.2 Existing Storm water Layout

The existing storm water network for the luge track and other pavement areas is shown on as-built plans completed by Patterson Pitts Ltd (PPL) and is provided in Appendix B. The design philosophy for these areas has been to capture the storm water over short distances and utilise regular discharge to prevent concentration of storm water flow into any single location. The aim was to leave the natural catchment and flow rates relatively unchanged by the development.

The discharge locations and storm water network for storm water collected by the roof area of the existing building is not well documented. PPL have advised the majority of the storm water collected from the roof area currently discharges from a 200 mm pipe on the south of the Skyline building (DL1). Other smaller areas of the roof discharge to the ground, and where this water flows overland it is collected by the luge track system and discharged to the east of the lower luge chairlift terminal through a 100 mm pipe (DL2).

The design of the storm water network for the top Skyline building upgrade and associated additional roof area is yet to be finalised, as the finished site levels and roofing design have not been confirmed. The preferred choice for storm water discharge are the existing DL1 and DL2 locations, which are shown on Figure 1b, Appendix A. Based on the assessment completed in this report, alternative locations may be discussed or recommended as appropriate.

2.3 Discharge Location 1

The location of DL1 is shown on Figure 1b, Appendix A, and detailed mapping of the flow path and adjacent areas are shown on the Figures 1d, 1e, 1f, 1g, 1h Appendix A.

The existing 200 mm storm water pipe at DL1 currently extends from the skyline development and into the northern edge of a forested area of mature wilding pines, where it discharges directly onto schist bedrock. This forested area, and the flow path, extends downslope approximately 90 m to a clearing within the Ziptrek operations area. Downslope from this location the defined flow path ceases to exist and dispersal of overland flow currently occurs.

Modelled hypothetical flow paths (Lidar and RAMMs) indicate 2 possible routes, one to the south and one the south east. These flow paths are shown on Figure 1b, Appendix A. Long sections of the flow paths are provided in Figure 2a and 2b, Appendix A. Channel section notes are provided in Appendix D.

2.4 Discharge Location 2

The location of DL2 is shown on Figure 1b, Appendix A and detailed mapping of the flow path and adjacent areas are shown on the Figures 1i, 1j and 1k, Appendix A.

The existing 100 mm diameter storm water pipe at DL2 discharges to the east of the lower luge chairlift building. The discharged storm water flows down a steep 20-30 m high sub-vertical schist bluff and is directed to a well-defined shallow schist gully which extends downslope towards the east. From here the slope falls through steeply sloping forested benches, schist bluffs and outcrops which extend to the base of the hill.

The modelled hypothetical flow path (Lidar, RAMMs) is shown on Figure 1b, Appendix A. This primary flow path exits the slope toe at the northern end of the Skyline Car Park. A long section of the flow path is provided in Figure 2c, Appendix A. Channel section notes are provided in Appendix D.

2.5 Observed Run-off

An inspection of the site was completed during a period of heavy rainfall on the 13 June 2017, at 10 a.m. Statistical analysis for this event indicates rainfall was falling at an average of 8 mm/hr during the period. The average return interval (ARI) for this rainfall is assessed to be approximately 7 months, and this scale of event is therefore expected to occur once to twice per year. The following observations from this inspection are provided below:

DL1

- The outflow was observed to fall directly onto rock;
- The upper part (40-50 m) of the channel flows down a steep rock face, some dispersal of the flow was observed, however, it was largely confined to a width of approximately 3 m;

- Minor surface flow was observed in the channel for a distance of approximately 40 m below the upper rock section, with a very light seepage from the end of the recognised channel (channel Section 8a, location as shown on Figure 1h, Appendix A);
- Minor transportation of fines was observed across the footpath (between channel Sections 2a and 3a, locations as shown on Figure 1h, Appendix A);
- Partial diversion of the flow was observed in one location due to path construction and a fallen tree, with an estimated at 20% of the flow diverting over the true left side of the channel. This flow continued downslope over landscaped pathways and dispersed a short distance (approx. 30 m) downslope, see Figure 1h, Appendix A;
- No flow was observed immediately downslope of channel Section 8a, where the recognisable flow channel ends, and;
- No overland flows were identified in the lower flow path areas (channel Sections 9a to 17a).

DL2

- Overland flow was observed exiting the steep bluff and the narrow gully with some transportation of organics particles, pine needles and vegetation;
- At the base of the bluff the flow headed down slope following the identified mapped channel;
- The flow produced very little scour, however, was sufficient to flatten grass and transport fine particles for approximately 30 m. Down slope from here the flow dissipated quickly and was no longer visible by channel Sections 3b and 4b, on Figure 1i, Appendix A.

3 Geology and Geomorphology

3.1 General

Detailed mapping of the slopes below DL1 and DL2 has been completed with specific attention paid to the flow paths. Surface exposures of geological materials were logged and geomorphological features were recorded. Geomorphological maps are provided in Appendix A and flow path channel data is provided in Appendix D. The flow path routes were determined by modelling a hypothetical debris flow (Lidar and RAMMs) generated from the slopes immediately below DL1 and DL2, visual inspection and review of Fluent Solutions flooding flow paths.

The data from the site mapping, together with other relevant data, is summarised in the following Sections.

3.2 Geological Setting and Slope Development

The slopes beneath the Skyline complex have been subject to several known periods of glaciation extending back 600,000+ years. Published information indicates the most recent glaciation was approximately 18,000 to 24,000 years ago and glacial retreat since then has left the slopes free of ice. Glacial till deposits are present above and below the current upper Skyline building indicating extensive historical ice coverage of the area. Sub glacial fracturing of the rock mass and modification of the bluff faces by ice movement (plucking) is expected to have been extensive.

Following ice retreat a period of active bluff instability and down washing of loose surface debris is expected to have occurred as the slopes adjusted to the removal of ice support. Site mapping indicates widespread historical instability has occurred, particularly below DL1.

Failures (rock fall, down washing of debris) are expected to have been relatively frequent immediately after ice retreat, reducing over time as the more unstable areas are removed or modified. This process will have been facilitated by high rainfall and seismic events. Large rock fall debris fans are present beneath DL1, these features fall steeply to the toe, with no significant run-out, and are therefore inferred to be older than sediments deposited in the cemetery area. A narrow band of hummocky ground and partially buried boulders is present along the cemetery – slope toe boundary.

Debris fans were identified at the slope toe in two locations, the cemetery, and the northern end of the existing Skyline car park. The cemetery fan overlies the rock fall debris fan and the sediments beneath, and is inferred to be younger than both these features. This fan is not connected to the identified DL1 or DL2 flow paths and is expected to be formed by debris flows or similar processes. The car park fan is directly present beneath the DL2 flow path and is steeper and rockier possibly indicating more colluvial and rock fall processes.

Sediments, deposited during the post glacial period are present at the slope toe and are associated with glacial outwash and high lake level environments. Historically, Lake Wakatipu was approximately at RL360 m, 50 m above current levels. This corresponds roughly with the base of the steep slopes, the cemetery and the lower gondola lift building.

Historic schist landslide instability is present on the slopes a short distance below DL1. Evidence from the site mapping indicates translational failure of large schist blocks has occurred. Most of the landslide has a veneer of colluvium and glacial till soils, with intermittent schist outcrops of relatively competent schist.

The slopes currently have a veneer of rock material in most areas. Ongoing weathering, dense vegetation growth, topsoil development and intermittent rock fall continues to modify the slopes. Extensive colluvium deposits have developed and are overlain by a thin layer of topsoil in many areas. Topsoil development, even in identified run off channels, suggests more stable slope conditions in recent years. Some surface rock fall was present beyond the slope toe, however, was not extensive. Note, a large surface boulder 3 m in width was present in the cemetery grounds. The age of the rock fall is difficult to date accurately and could be relatively recent in geological terms. The source of the rock fall is expected to be the bluffs directly above, which are not on the modelled flow path.

No active fault traces were observed in the field or have been reported in this vicinity. However, significant seismic risk exists in the Wakatipu area from strong ground shaking associated with the Alpine Fault, located along the West Coast of the South Island. There is a high probability that an earthquake of Magnitude 8.0 will occur along the Alpine Fault within the next 50 years. Such an earthquake would result in strong and prolonged shaking in the Queenstown region. With an average return period for the Alpine Fault in the order of 290 years the slopes are expected to have been subject to many earthquakes from this fault alone since ice retreat.

3.3 Stratigraphy

The stratigraphy below the discharge locations generally comprises schist bedrock at relatively shallow depths with a veneer of soil materials which varies in thickness and origin depending on location. Geological exposures are marked on the attached mapping sheets and the extent of the mapped landslide below DL1 is shown on Figures 1d and 1e Appendix A.

The stratigraphy below each discharge location is summarised as follows:

DL1

The upper 40 m of the flow path and the outlet area comprises in-situ **schist rock**. Schist bedrock is also present as a prominent bluff approximately 150 m to the south west of the DL1 outlet, and on the projected flow path. High (up to 40 m) schist bluffs are present in south western and southern areas of the slope in central and lower areas. Foliation orientations are consistently dipping to the south west.

Topsoil/organic deposits, well developed in some locations (50 - 300mm thickness) cover large areas of the hillside and is present in channel areas. Topsoil is poorly developed where coarse boulder deposits are present.

Slope colluvium is widespread across the slopes and is present at the base of most bluffs and areas between schist exposures. This material is described as a 'cobbles and boulders with varying fractions of silt sand and gravel, well graded, angular and loose-medium dense.' In some areas the colluvium and rock fall deposits amalgamate into general **slope debris**

Glacial till is present in many areas. This material comprises a sandy gravelly silt with gravels, cobbles and boulders typically rounded to sub-rounded, firm to stiff.

Rock fall debris is present in many locations, particularly downslope of the high bluffs in central and lower slope areas south east of DL1. Here the debris covers most of the slope surface. Thickness is very variable, however, is estimated to be up to several metres. This material is typically angular and coarse with diameters frequently >0.5 m and up to 4.0 m.

Schist landslide materials are present below DL1, in the Ziptrek area, and to the south west. The landslide does not extend to the south east. A review of historic mapping data and further mapping from this assessment indicates:

- The main body of the landslide is thought to comprise a series of segmented schist block failures. The failures are believed to have occurred along intersecting foliation shears and joint sets.

- A common set of scarps appears to be present on aerial photographs trending in a northeast to southwest direction, dipping towards the southeast, which cut perpendicular to the southwest dip direction of the schist foliation. These intersecting defect trends are likely to be the origins of the oblique translational wedge failures.
- The schist rock has not undergone en masse displacement; instead the movement has occurred as multiple retrogressive blocks. This is evidenced by the multiple internal scarps visible on aerial photographs and the variable nature of the rotated and displaced schist blocks.
- Ongoing creep is thought to be occurring in some locations, and following the initial landslide movement, is most probably the cause of the disaggregated nature of the schist in places.

DL2

In-situ **schist rock** is present at shallow depths and is exposed at the surface in many locations below DL2. The foliation dips to the south west, oblique/slightly back into the slope. The outflow from DL2 discharges directly onto a schist bluff.

Topsoil/organic deposits are well developed in some locations (50 -300mm thickness) and cover significant areas of the hillside, on both sloping areas between bluffs and in the modelled flow path areas. Topsoil deposits are thin and sparse in very coarse boulder areas.

Slope colluvium is widespread across the slopes and is present at the base of most bluffs and areas between schist exposures. This material is described as a 'cobbles and boulders with varying fractions of silt sand and gravel, well graded, angular and loose-medium dense.' In some areas the colluvium and rock fall deposits amalgamate into general **slope debris** and form local fans of material beneath the bluffs.

Materials present beneath the topsoil and within the mapped channels are shown on the field sheets provided in Appendix D, and typically comprise coarse and angular interlocked gravels, cobbles and boulders.

3.4 Groundwater

The regional groundwater table is inferred to lie at depths of several tens of metres across the site. Perched groundwater is expected to develop on the contact between the schist rock and overlying soils during periods of heavy rain.

3.5 Mapping

3.5.1 General

Detailed geomorphological mapping has been completed for the slopes below DL1 and DL2.

Fine tuning of the mapped areas, particularly channel dimensions and characteristics, was facilitated by generating a hypothetical debris flow (Lidar and RAMMs) from both discharge locations, and looking in detail at the resultant flow path. The flow paths are shown on Figure 1b, Appendix A.

Geomorphological plans are provided in Appendix A and channel sections notes and photographs are provided in Appendix D.

3.5.2 DL1

DL1 key observations:

- DL1 discharges directly onto in-situ rock (see Photograph 29a) and flows largely over a steep exposure of rock for the upper 40-50 m;
- Below the upper 40 – 50 m, the flow path follows a reasonably well defined channel (see Channel sections 1a to 8a and corresponding photographs for details). The channel, falls at 28-40° and passes over coarse boulder slope and landslide debris;
- Immediately downslope of channel Section 8a and approximately 90 m from the DL1 outlet, the defined channel disappears. From this point overland flow will disperse over the hummocky ground in this area (see Photographs 9a and 10a and 11 a). Hypothetical debris flow modelling indicates overland flow may head either to the south east, towards a large persistent channel that falls most of the way to the slope toe, or, to the south, into a hummocky area with no defined channels;
- The southern route heads into a hummocky (historic landslide) area with no defined channels, low schist outcrops, bouldery glacial till covered slopes and dense native and pine vegetation cover. The flow is guided by local undulations, and old access and logging paths. The lack of defined channels in this area and the site characteristics indicate significant potential for dispersal and bifurcation in this area;
- If the flow heads to the south east it will initially pass through an area with no defined channel, expected to result in dispersal of the flow. Beneath this area, a bluff, which forms the southern side of a prominent channel, is present and the flow could pass over its crest, or close to it. At the base of the bluff a wide (≤25m) well defined channel is present which extends most of the way to the slope toe (see channel sections 9a to 17a and corresponding photographs). The channel is typically formed in very coarse boulder debris (diameters of 1 m + are common) on the northern side, and rock fall debris or schist bedrock on the southern side. The channel bed also comprises large angular boulders. This channel has not been formed by overland flow.
- The south east channel is not consistently present and disappears for a length of approximately 50 m just below transect 16a, and then re-appears again a short distance above the toe. Dispersal/bifurcation of overland flow would be expected here. A high potential for reduction in flow velocity is considered to be present in this area which comprise large angular boulders several metres in diameter, which form a very rough surface, and mature trees (See photograph 20a);
- The outflow of the modelled flow path is at the southern end of Queenstown cemetery. There is no evidence of cone shaped fan deposition or other outflow in this area (See Photograph 23a). There is no evidence of active or historic channelling of debris to the base of the slope in this location. Some local undulations are present a short distance beyond the toe. These features are assessed to be large underlying boulders associated with the rock debris fan now partially overlain by sediments and landscaped.

3.5.3 DL2

DL2 key observations:

- The flow channel is initially well defined in the outflow area, where it passes over schist rock and within a steep confined channel for the upper 50 - 60 m.

- The flow channel leaves the steep bluff upper section in a well-defined location (See channel section and photograph 1b) and enters the mixed bluff/steeply sloping soil covered slopes beneath.
- The modelled flow route can generally be followed down the slope from this location, although it is poorly defined in some areas.
- Site observations indicate the most likely flow route will be down to the northern end of the Skyline car park. The route traverses poorly defined gullies and benches between a mix of bluffs and sloping colluvium surfaces.
- No evidence for active overland flow or entrainment of material was identified in central or lower areas of the slope.
- No significant active instability of the bluffs was present, with one potential wedge failure identified low down on the slope. Limited evidence of loose blocks (500-800mm in diameter) was observed on the rock face in some locations, however this was not widespread. Debris from historical falls is present at the toe of the bluffs in some areas.
- No instability of the surface soils, e.g. rotational slips, was observed.
- Topsoil was well established in many areas, including in potential flow channels, indicating relatively stable overland flow conditions.

3.6 Identified Existing Hazard Summary

Tables 3.1 and 3.2 summarise the identified instability and hazards on the slopes beneath DL1 and DL2.

Table 3.1. Summary of Identified Instability Features and Hazards below DL1 Modelled Flow Path Routes only.

Hazard	Location and position relative to DL1	Activity	Recent Activity	Trigger	Affected Area/Hazard Zone	Volume	Rate of Movement
Landslide (Schist bedrock, translational)	Covers a large area south and south east of DL1.	Historic movement, intermittent creep expected.	Low levels of creep possible	Ice retreat, defect interaction.	Contained on the slope, lower extents are 400 m+ above the slope toe.	Large mass of hillside	0-10 mm/year
Scour/erosion in DL1 Channel	Upper DL1 channel. Top 40-90 m.	Recent/ongoing	Recent/ongoing	General Rainfall into the catchment/pipe outflow	Contained on the slope, in the upper channel area only, 500 m above the slope toe	Minor, 0.5 to 2 m^3	Rapid
Rock Falls from Gully wall (Channel Section 10a)	150 m south east (Channel Section 10a)	Expected to have been active for a long period	Failures in 10-50 year timeframe inferred.	Highly fractured rock mass and defect interaction, root action, weathering, and seismic activity.	Contained on the slope. Debris runout extends <30 m from the source bluff face and stays 400 m (approx) above the slope toe. Away from public access paths in remote location.	2-8 m^3	Rapid
General Rock Fall	Various from low bluffs and exposures	Historical failures and low level fretting of rocks ongoing	Low level fretting of low volume rocks ongoing	Weathering and seismic activity	Contained on the slope, typically < 10 m from failure.	<1 m3	Rapid
Large rock failure/debris fan, block slide	From the bluffs in lower parts of the slope (below transect 9a) and in particular on the south side of the main south eastern modelled flow path.	Historic movement shortly following ice retreat.	No indications of any recent failures, or significant volumes of potential failure material on the slope.	Ice retreat, defect interaction, seismic activity	Mostly contained on and forms a large area of the slope, however extends to the toe and borders the cemetery.	Significant, 250,000 to 350,000 m estimated.	Rapid

The debris fan present at the northern end of the cemetery is not influenced by outflow from DL1 and DL2 and so is not included in the above table.

Many of the high bluffs are not on the flow paths and so are not included in the above table.

Table 3.2. Summary of Identified Instability Features and Hazards below DL2, Modelled Flow Path Route.

Hazard	Location and position relative to DL2	Activity	Recent Activity	Trigger	Affected Area/Hazard Zone	Volume	Rate of Movement
Scour/erosion in DL2 Channel	Upper DL2 channel, top 100 m only.	Recent/ongoing	Recent/ongoing	General rainfall into the catchment/pipe outflow	Contained in the upper channel area only, 400 m above the slope toe	Minor, 0.5 to 2 m^3	Rapid
General Rock Fall	Various from low bluffs and exposures	Historical failures and low level fretting ongoing.	Low level fretting of rocks ongoing.	Weathering and seismic activity	Observations indicate failures are contained on the slope for typical conditions.	Typically <1 m^3, larger falls may occur under seismic loading.	Rapid
Slope debris fans/colluvium fans	Localised fans of colluvium on some benches between the bluffs.	Historical, possible ongoing slow aggradation in some areas.	No recent indications of activity.	General debris creep, scour, rock fall over long periods in response to seismic event.	Locally beneath bluffs.	Possibly moderate volumes historically, aggradation by infrequent small events.	Variable, slow - rapid

4 Stormwater Modelling

Fluent Solutions Ltd (Fluent) have prepared a 2D storm water flow model, based on LiDAR information of the DL1 and DL2 sub-catchments to assess the increase in outflow as a result of the proposed extended roof area. In particular the following has been assessed by Fluent:

- The increase in outflow volumes from the existing DL1 and DL2 pipes, and;
- The relative change in storm water flow volumes at the base of the slope.

Fluent assumed the roof area from the new gondola terminal (the western roof area) would be discharged at DL1, and the eastern extended roof area would be discharged at DL2. A summary of the flows expected at each location are presented in Table 4.1 below.

Table 4.1 – Peak Roof Runoff flows to be discharged to DL1 and DL2 (see Fluent Solutions report, Appendix C for full details).

Storm Duration	DL1 Sub-Catchment		DL2 Sub-catchment	
	Pre-development DL1 Peak Flow (l/s)	Post-development DL1 Peak Flow (l/s)	Pre-development DL2 Peak Flow (l/s)	Post development DL2 Peak Flow (l/s)
10 year, 4 hr	4.3	10.8 (increase 6.5l/s)	7.7	19.1 (increase 11.4l/s)
100 year, 2 hr	7.7	19.2	14.1	35.4

The peak runoff flow from the DL1 and DL2 sub-catchments are set out in Table 4.2 below.

Table 4.2 – Summary of peak Flow Results for Discharge Location Sub-Catchments (see Fluent Solutions report, Appendix C for full details).

Storm ARI (yr) and Duration (hr)	DL1 Sub-catchment		DL2 Sub – catchment	
	Pre-Development Peak Flow (l/s)	Post development DL1 Peak Flow (l/s) (Difference over pre-development Flow - %)	Pre-Development Peak Flow (l/s)	Post development DL1 Peak Flow (l/s) (Difference over pre-development Flow - %)
10 year, 2 hr	51	-	56	-
10 year, 4 hr	**95**	**98** **(3l/s = +3.2%)**	**104**	**105** **(1l/s = +1%)**
10 year, 6hr	91	-	100	-
100 year 1hr	325	-	398	-
100 year, 2hr	**388**	**398** **(1l/s = +2.6%)**	**454**	**456** **(2l/s = +0.4%)**
100 year, 4hr	286	-	329	-

The results provided in Table 4.2 indicate very small (≤+3.2%) increases in flow volumes are expected in the sub catchments below DL1 and DL2 for the critical rainfall events.

Fluent Solutions provided the following conclusion from their assessment:

"The model results confirm that the effects of the increased building area on the urban area of Queenstown would be relatively minor. Virtually none of the steep land area in the DL1 and DL2 sub-catchments is suitable for urban development and therefore the damping effect of the topography on stormwater flows would not decline over time. If the extensive tree cover in the sub-catchments below the Skyline buildings were removed then the overall rate of runoff and erosion is likely to increase but the effect of the proposed additional building area as a proportion of the total flow would be expected to decrease.

If the QLDC stormwater infrastructure is under capacity, then detention storage at the Skyline site could be used to offset the increase in direct runoff from the proposed building areas."

The full details of Fluent's assessment can be found in their report attached in Appendix C.

5 Debris Flow Assessment

5.1 General

Debris-flow initiation was evaluated and assessed by the following methods:

1. Visual assessment;
2. Detailed slope stability analyses in Slide v7.0 for a representative slope comprising schist-derived debris;
3. Assessment of both slope debris and topsoil initiation via empirical relationships;

These are further described in the following sections.

5.2 Visual Assessment

5.2.1 General

There are no indications of recent debris flow activity. Most soil materials on the slope are assessed to be glacial, rockfall, colluvial, or organic (topsoil) in origin. These materials are not confined to channels, cover most slope areas away from the bluffs and are present as a veneer of soil typical of a post glacial hillside in this area of the Wakatipu.

Some scour, mobilisation of vegetation/organics and finer materials, typically fine gravel sized and lower has been observed in upper sections of the DL1 and DL2 Flow paths. There were no indications of any overland flow specifically related to the discharge locations in most channel areas below the immediate upper outflow channel.

Vegetation and topsoil are established in most possible flow path channel areas, indicating very low overland flow velocities. This suggests for current outflow volumes, general dispersal and velocity reduction is occurring a short distance below the discharge locations, and conditions are stable enough for topsoil and vegetation to develop.

The debris fan at the northern end of the cemetery is expected to be a relatively old feature. No scouring, established topsoil and vegetation in the gully upslope indicates a relatively long period of stability. Note this fan feature is not connected to the DL1 or the DL2 drainage paths and is therefore not expected to be affected by increased discharge.

The fan at the northern end of the existing skyline car park is steep and course grained, possible colluvium and rock fall in origin. No mapped upslope mechanism is currently delivering significant volumes of debris to this area so the feature is inferred to be historic in origin.

5.2.2 Comment on GNS Debris Flow Observation DL1

GNS Science identified debris flow deposits a short distance below the top of the slope and close to the outflow from DL1. The evidence provided identified soil materials caught on the upslope side of trees in this location. Our assessment indicates the presence of this material does not result from debris flow activity. The reasons for this conclusion are outlined below and the main observations are shown on Photographs 26a, 27a and 28a.

- The affected area is very close to the crest of the slope with only a small area of available catchment above. There is no large slope, or channel, to generate and direct high volumes of concentrated surface water, or debris, in this direction.
- A low bluff is present above in one location, and in-situ schist bedrock surrounds much of the area, with no discernible flow path or incised channel;

- Much of the debris is in locations which cannot be influenced by flow from DL1, see Figure 1g, Appendix A. The flow from DL1 passes over a steep rock face approximately 10-15 m to the east of the upper areas of tree caught debris, with no opportunity to avulse. An alternative source for this debris, separate from the DL1 channel, is therefore required.

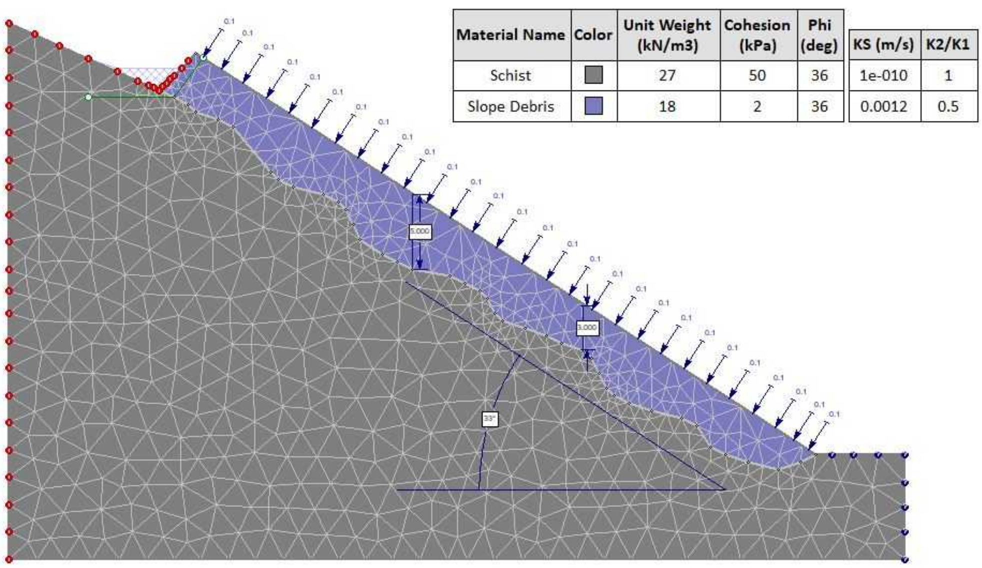
A large fill slope constructed during the luge development (late 1990's) is present directly upslope from the tree caught debris. The most likely source of this debris is therefore expected to be fill which rolled downslope during construction. In addition, fill materials were observed in this area during site inspection work, see Photograph 29a, Appendix D, and staff involved with the fill placement confirmed that material did roll downslope from the site area during construction.

5.3 Slope Debris Stability Analysis

5.3.1 General

Slope stability analyses were performed in Slide v7.0, a limit equilibrium slope stability software package which also incorporates finite element groundwater seepage analysis, on a geological cross section generally representative of the slope debris slope characteristics observed on site, as shown in Figure 5.1 below.

The slope was modelled under both dry and rainfall conditions using the finite element groundwater module in Slide v7.0. Saturation of the slope and consequent reduction in the slope factor of safety as function of time was simulated as a constant-head boundary condition immediately upstream of the slope. The analysis assumed a constant water depth of 2.5 m directly above the slope and that this remains static for the full analysis period. This assumption is considered conservative and highly unlikely as in reality water entering the slope will quickly flow downhill without the opportunity to form a constant head, or will be lost through the debris during saturation. Water levels would in fact rise and fall to match the flood hydrograph so the time for full saturation would be prolonged. Rainfall infiltration of 100 mm/day normal to the slope was also included for the full length of the slope. This is also conservative as it is likely the majority of this would runoff rather than infiltrate the slope due to a cover of topsoil, colluvium and glacial till.



Material Name	Color	Unit Weight (kN/m3)	Cohesion (kPa)	Phi (deg)	KS (m/s)	K2/K1
Schist		27	50	36	1e-010	1
Slope Debris		18	2	36	0.0012	0.5

Figure 5.1 - Showing the slope stability model adopted in the assessment

Geotechnical parameters for the analysis were determined based on visual observation, local experience and resistance envelopes from either laboratory testing or back-analysis of existing slopes in Kawarau, Cromwell and Roxburgh gorges undertaken as part of the Clutha Valley Development Stability Analysis for the Clyde Dam in c.1980.

Based on visual observation, the permeability of the slope debris should be relatively high as it contains significant pore spaces (porosity) between the boulder matrix that should readily transmit incoming floodwater and thus prevent groundwater pressure build up. However, the random nature and variable fines content could reduce the overall permeability in places. Accordingly, both upper and lower bound permeability has been analysed. The upper bound was calculated as the theoretical maximum permeability, above which the catchment is unable to supply a sufficient volume of water to saturate the slope within the storm duration, i.e. the floodwater would be drained faster than it enters the slope and an adverse phreatic surface is unable to develop.

Table 5.1 below shows the geotechnical parameters adopted for the assessment.

Table 5.1 - Geotechnical parameters applied in the analysis

Unit	Bulk Density γ (kN/m^3)	Effective Cohesion c' (kPa)	Effective Friction ϕ' (deg)	K_h (m/s)
Schist-derived slope debris	18	2	36	1.2×10^{-3} (upper bound) 1×10^{-5} (lower bound)
Intact Schist*	27	50	36	1×10^{-10}
*Note these values are conservative and likely to be higher in the field				

Typical slope characteristics were measured on site from geomorphic mapping and are summarised in Table 5.2 below.

Table 5.2 - Typical slope characteristics

	Material description	Landcover	Slope angle (range)	Length	Thickness (range)	Contact surface
Slope Debris	Coarse angular slope debris	Thin topsoil, mature trees	32-34° (25-40°)	10–100 m	4-5 m (1-10 m)	Uneven due to glacial scoring

5.3.2 Results

The results of the assessment are provided in Figure 5.2 below.

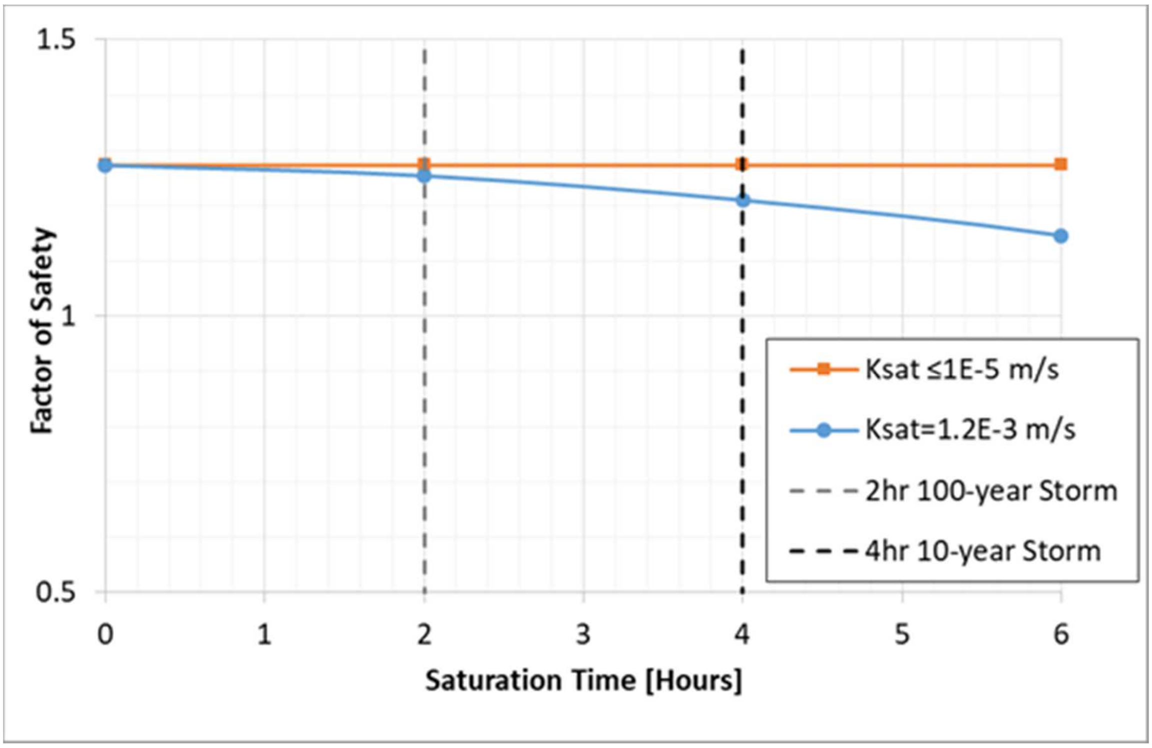


Figure 5.2 - Effect of saturation time on the analysed factor of safety for slope debris

Figure 5.2 illustrates the reduction in factor of safety over time assuming the constant supply of water into the slope from upstream by a 2.5 m deep constant wall of water. The red and orange lines represent upper and lower bound permeability estimates of the slope debris. The 'true' factors of safety will lie within the envelope presented.

The analysis demonstrates that:

- The factor of safety is not greatly influenced by the introduced water providing the permeability is small (≤ 1E-5 m/s or less). This is because the groundwater flow into the slope body is very small and slow moving, so only the very uppermost portions of the slip become saturated and only after some time. A permeability of ≤ 1E-5 m/s or less would be expected if parts of the slope debris included soils such as sand and silts in the matrix.
- A reduction in the factor of safety is observed for the upper bound permeability indicating that some partial saturation of the slope will occur for longer duration storms of high intensities. The reduction in factor of safety is <10% for the critical storm durations.

It is important to note the time axis on Figure 5.2 corresponds to the range of critical storm durations and that storms of longer duration are going to be of lower intensity and therefore will not have sufficient excess volume to build up behind the slip body.

5.4 Debris Flow Initiation - Empirical Methods

5.4.1 General

A study by the U.S. Geological Survey into a large number of debris flows initiated following heavy rainfall in Colorado in 2013 concluded that low forest density was the most universal predictor of debris-flow initiation regardless of aspect (UGSG, 2014). This suggests that the subject site has a low risk of debris-flow initiation based on its high vegetation density alone.

Several researchers have identified the critical parameters influencing debris flow initiation based on statistical analyses and experiments (Takahashi, 1991; Rice et al., 1998; Tognacca et al., 2000;

Gregoretti, 2000; Gregoretti and Fontana, 2008). Key parameters controlling debris initiation include the slope angle, surface water discharge, and particle composition (Takahashi, 1978; Wang et al., 1989; Cui, 1992; Martin and Moody, 2001).

The methodology proposed by Cui et al. (2014) was used to determine the critical threshold for both slope-debris and topsoil debris flow initiation at locations identified by field mapping as containing loose materials that may be susceptible to movement. Inputs to the methodology include the ground slope, debris density and grain diameter. A total of 28 transects along the two main channels downstream of DP1 and DP2 were analysed with the inputs required assessed from field observations. The results of this assessment is presented in the following sections.

5.4.2 Slope Debris Initiation

Figure 5.3 presents the calculated threshold for debris flow initiation in the slope debris (i.e soils between the topsoil and rock) compared to the maximum post-development flowrate for DL1 or DL2 as calculated from Fluents storm water model.

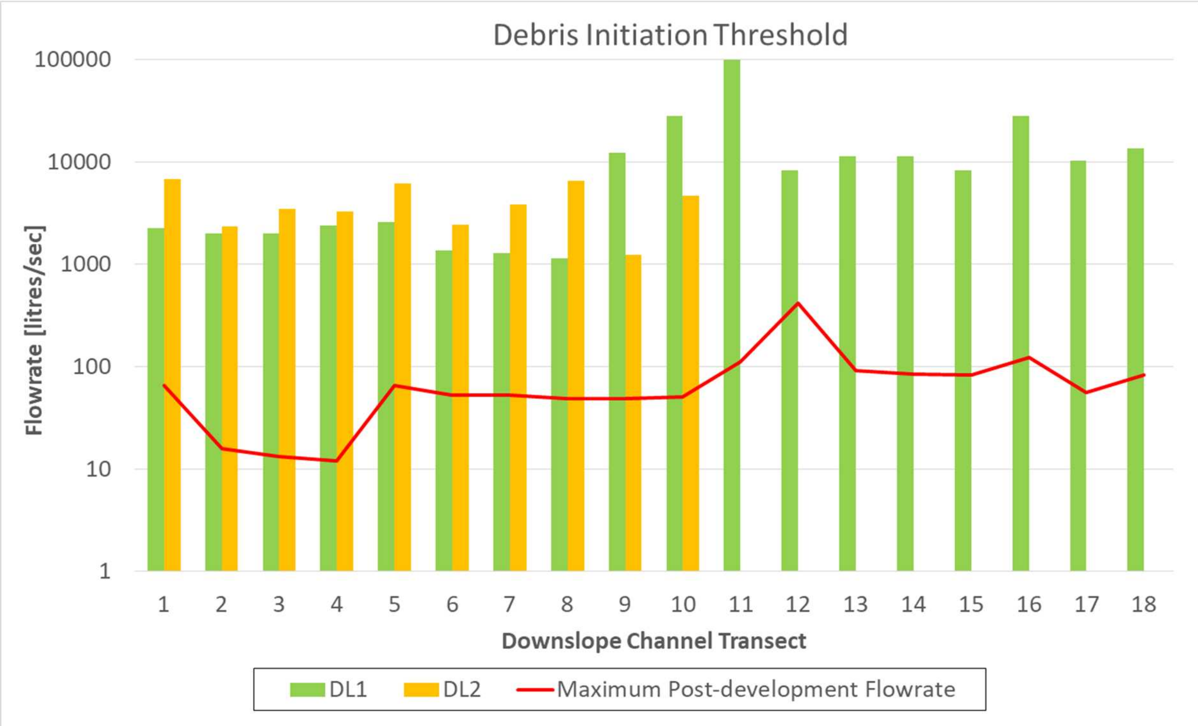


Figure 5.3 - Critical threshold for debris flow initiation downstream of DL1 and DL2. Red line represents the maximum pre- or post-development peak flowrate for the 10-year or 100-year storm at each location

Results from the empirical analysis indicate that the initiation threshold for the slope debris far exceeds the maximum post-development flowrates by two or three orders of magnitude. This agrees well with the stability modelling in the preceding sections, and with site observations.

5.4.3 Topsoil initiation

The threshold for initiating topsoil movement will be less than that of the underlying slope debris, largely due to the much smaller mean grain diameter and lower soil density.

It is important to note that the consequence of topsoil being initiated is much less than if slope debris or larger particles form a debris flow. Initiated topsoil during a large storm will generally manifest as surface erosion/sediment-laden water that could inundate, but is not expected to cause significant damage to the downstream environment.

The assumed geotechnical parameters applied in our analysis are presented in Table 5.3.

Figure 5.4 and 5.5 present the critical thresholds for initiating topsoil movement at DL1 and DL2 respectively, along with the pre- and post-development peak flowrate, at each of the transects.

Table 5.3 - Assumed geotechnical parameters for topsoil debris flow initiation analysis.

Mean Particle Diameter (m)	Width of The Channel Bed (m)	Slope Gradient (degree)	Soil Density (kg/m³)
0.002	Varying for each section	Varying for each section	1700

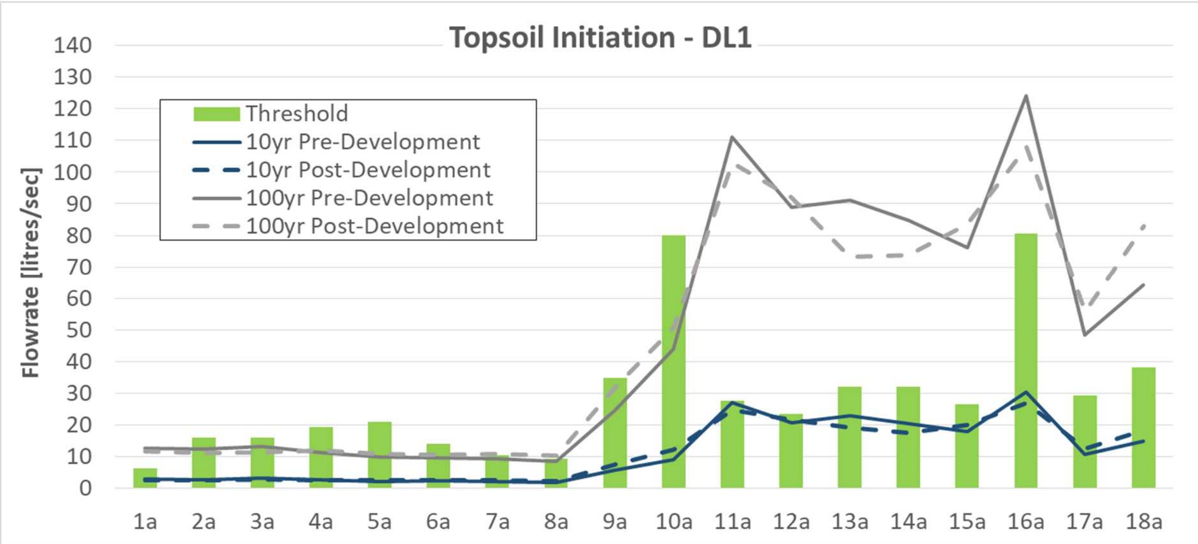


Figure 5.4 - Critical threshold for topsoil debris flow initiation downstream of DP1

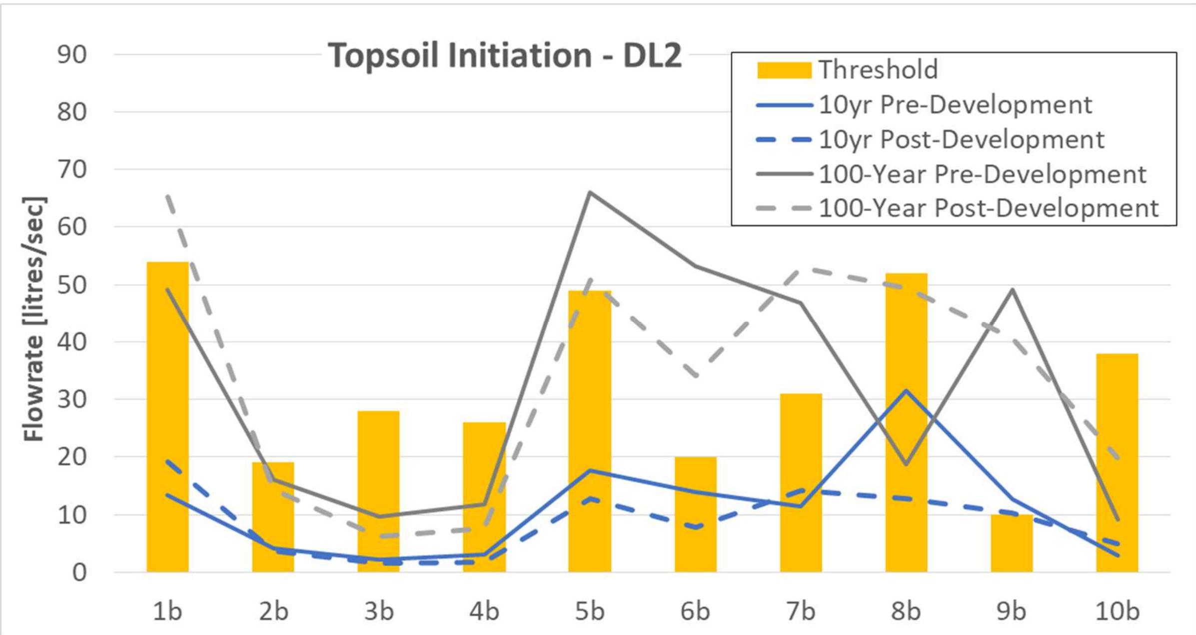


Figure 5.5 - Critical threshold for topsoil debris flow initiation downstream of DL2

Results from the analysis indicate that no topsoil is mobilised pre- or post-development during a 10-year storm, with the possible exception of 9B downslope of DL2 which is initiated for the pre-development flow but not the post-development. Transect 11a and 12a downslope of DL1 are right on the threshold.

Some topsoil is seen to be mobilised for the 100-year storm for both the pre- and post-development conditions. All locations where topsoil is initiated post-development are assessed to be at the same, or very similar, risk of initiation for the pre development conditions, with the exception of 8b downslope of DL2 only.

5.5 Summary

- A visual assessment of existing conditions was completed. There are no indications of recent debris flow activity. Some scour, mobilisation of vegetation/organics and finer materials, typically fine gravel sized and lower has been observed in upper sections of the DL1 and DL2 Flow paths. There were no indications of any overland flow specifically related to the discharge locations in most channel areas below the immediate upper outflow channel.
- A geological cross section generally representative of the slope debris slope characteristics observed on site was analysed in Slide v7.0 with varying inflows of groundwater which represent the changes in floodwater entering the slopes. The analysis indicates that the design storms are of insufficient duration to initiate slope movement of the slope debris.
- The empirical methodology proposed by Cui et. al. (2014) was used to determine the critical threshold for coarse slope debris and topsoil movement initiation at locations along the flows paths identified as containing materials that may be susceptible to movement. The results indicate that the threshold for debris flow movement for the coarse slope debris is far in excess of the post-development peak runoff (by one or two orders of magnitude) and no debris flows are therefore anticipated.
- Some topsoil is expected to be mobilised in some sections during heavy rainfall. This is expected to manifest as scour/erosion and sediment laden water. Analysis indicates the overall increased risk of topsoil mobilisation due to the development is negligible and comparable to the existing conditions. See Figures 5.4 and 5.5.

6 Landslide Stability Assessment

6.1 General

Simplified sliding block analyses were performed on sections of fractured schist blocks. Parameters such as slope angle, block thickness and block length were varied to assess the sensitivity of these on computed factors of safety. In total 54 separate scenarios were analysed using the parameters presented in Table 6.1 below.

Table 6.1 – Presenting the parameters adopted for the sliding block stability assessment.

Block Depth (m)	Slope angle (degrees)	Block Length (m)
10, 25, 50	25, 28, 30	5, 10, 20, 30, 40, 50

It was assumed in the analysis that a failure surface of residual gouge material 1.0 m thick lies at the base of the blocks. Effects of increased groundwater into the gouge via open defects was included as a reduction in vertical effective stress at the base of the gouge. This assumes that the schist is unable to become saturated and that there is an insufficient volume of water and time for hydrostatic conditions to develop behind the sliding block. This is conservative as most of the slopes have a veneer of heavily vegetated colluvium and glacial till which will restrict ingress of water into the landslide mass.

6.2 Geotechnical Parameters

Geotechnical parameters for the analysis were determined based on visual observation, local experience and resistance envelopes from either laboratory testing or back-analysis of existing slopes in Kawarau, Cromwell and Roxburgh gorges undertaken as part of the Clutha Valley Development Stability Analysis for the Clyde Dam in c.1980.

Table 6.2 - Geotechnical parameters applied in the analysis

Unit	Bulk Density γ (kN/m^3)	Effective Cohesion c´ (kPa)	Effective Friction ϕ´ (deg)
Gouge material	18	0	23
Intact Schist*	27	50	36
*Note these values are conservative and likely to be higher in the field			

Typical slope characteristics were measured on site from geomorphic mapping and are summarised in Table 6.3 below.

Table 6.3 - Typical slope characteristics

	Material description	Landcover	Slope angle (range)	Length	Thickness (range)	Contact surface
Slope Debris	Coarse angular slope debris	Thin topsoil, mature trees	32-34° (25-40°)	10–100 m	4-5 m (1-10 m)	Uneven due to glacial scoring
Landslide	Schist blocks	Topsoil	25-30°	5-50 m long blocks	25 m (10 – 50 m)	Failure surface ~1 m thick

6.3 Results

The results of the assessment are summarised in Figure 6.1 below which shows the reduction in factor of safety due to groundwater ingress.

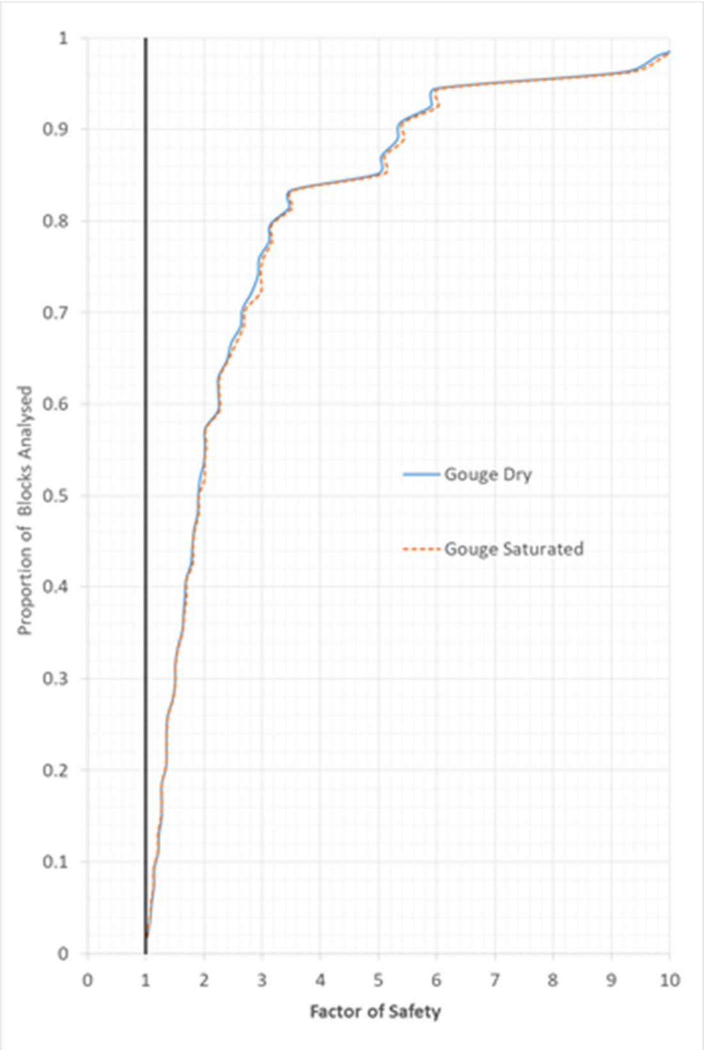


Figure 6.1 - Cumulative distribution function of calculated factor of safety for schist block sliding block analysis

The analysis demonstrates the majority of the schist blocks are reasonably stable in their present condition which agrees well with site observations. The slopes have reached some level of equilibrium in recent geological history, no recent large active failures are present, most instability features being 100's to 1000's of years old.

Factors of safety only marginally above unity (FOS=1) were calculated for relatively shallow (<10 m deep) blocks on steep angles (30°+). These are reasonably rare, probably contributing <5% of the landslides observed across the slope. The consequences of blocks falling below unity would be some minor slope creep when saturated or perhaps minor displacements under seismic loads. It would be unlikely that large schist blocks become mobilised and progress into a rapid-moving landslide. The effects of saturation on the gouge material are seen to be relatively small, generally ~1%.

7 Rock Fall

7.1 General

An inspection of the prominent bluffs directly on the modelled flow channel paths has been undertaken. Bluffs not directly on the flow path have not been assessed.

The following general comments are provided:

- The Rock bluffs have a mantle of vegetation and tree roots, slope debris and/or glacial till. These materials will restrict ingress of surface flow into the rock mass, particularly where low permeability glacial tills are present. Should an overland flow overtop a bluff it is considered more likely to overflow the crest and down the face rather than seep into the rock mass.
- The rock mass has closely spaced defects in some areas however spacing of the persistent defects is typically very wide (>2m). Ingress of water into open defects is feasible, however there is very limited opportunity at the crest of the bluffs, or in direct line of the identified flow paths, for this to occur, and most defects have very narrow or tight apertures.
- Loose rock is present on the bluff faces in some locations and, should flow extend over the face of a bluff, some dislodging of loose rock is considered possible however will be individual rocks in small volumes.
- Site observations indicate that should overland flows reach a bluff it is very unlikely they will be concentrated and flows will be dispersed and low in volume.

7.1.1 DL1 South Eastern Flow Path

The top of the DL1 flow path is over steeply sloping (40-80°) schist rock for the upper 40-50 m. Being directly below the outlet, the flow channel is well established and frequently active. The flow is well contained and does not have the opportunity to dissipate/avulse. This area comprises competent schist bedrock with no significant open defects or structural block forming occurring. The risk of increased rock fall risk in this area from an increase in outflow is therefore considered very low.

The flow path could potentially pass directly over 1 significant bluff. This location is on the southern side of the gully wall (channel sections 9a and 10a, and corresponding photographs), approximately 150 m from the outlet. The following observations are provided with respect to this bluff:

- Intermittent failures are occurring from the bluff and are estimated to be 2-8m^3 in volume, and to occur over a 10-50 year timeframe;
- The run-out distances are relatively short being ≤30 m;
- The failures are significantly removed from any public access foot or bike paths and developed areas at the toe;
- The rock has a closer defect spacing than most bluffs and has possibly been subject to increased fracturing relating to the landslide, located a short distance above, and glacial plucking (Glacial ice would have passed directly over this area). Defect surfaces are more weathered than elsewhere;
- The foliation is favourably orientated, dipping oblique to and slightly back into the slope.
- Triggers for failure appear to be a combination of factors including, general weathering of a weakened rock mass, a high degree of fracturing, steeply orientated intersecting defects, augmented by tree growth and root action.

A qualitative assessment indicates that should flow overtop this bluff, a marginal increase in the likelihood of a rock fall occurring should be expected. The actual risk to property or loss of life is very low due to the isolated location of the bluff face high up on the slope and the observed short run-out distances for historical failures.

There are no other significant bluffs directly in the flow path line for the DL1 south eastern flow path.

7.1.2 DL1 Southern Flow path

The upper part of the southern flow path is as outlined above for the south eastern flow path, and the risk of rock fall resulting from the increased flow is considered very low for the reasons discussed.

No significant bluffs are present in downslope areas for the southern flow path. Several low outcrops/exposures of schist are present which tend to be <5.0 m in height, with no significant active rock fall. Due to the undulating nature of the ground overland flows will be dispersed and unlikely to concentrate at the crest of any particular outcrop. The likelihood of an increase of rock fall from flow heading to the south from DL1 is therefore considered low.

7.1.3 DL2

Directly beneath the outflow for DL2 the upper 60 m is largely confined to a well-defined and steep rock channel for most of its length. This part of the channel will be well tested with regular and concentrated flows. Beneath this area the flow path is less well defined, however, the natural fall line passes between the bluffs rather than directly over the crests. Any flow over bluffs would be dispersed, brief and restricted by a mantle of soils from entering the rock mass.

An inspection of the prominent bluffs along the flow paths has been completed and the following general points are provided:

- The schist foliation is favourably orientated being oblique to and slightly back into the bluffs and there is no risk of deeper instability relating to the foliation.
- Secondary defects where present on most bluff areas with tight or very narrow apertures being typical, restricting water ingress.
- Some loose blocks 500-800 mm in diameter were identified on the bluff faces, or at the slope crest, however they were not commonplace.
- Historical high angle wedge failures have occurred in 1 location and the potential for a future failure was considered to be present. The rock was 1.8 m in diameter and relatively well interlocked on the rock face, dislodgement by overland flow is therefore considered unlikely.

From the visual inspection the risk of triggering rock fall from mobilised topsoil along the flow path is considered to be low.

8 Risk Assessment

8.1 General

The methods outlined in Australian Geomechanics Society (AGS) March 2007 publication 'A National Landslide Risk Management framework for Australia' have been used to complete a risk assessment of the identified hazards and the impact of the proposed stormwater discharge.

The risk assessment comprises the evaluation of both the risk to "property" and "life". The risk to property has been determined semi-qualitatively and the risk of loss of life has been determined quantitatively.

Given the lack of recorded history of the hazards (e.g. date, number, size of rock events, observed surface run-off, instability etc.), track data information and the historical nature of some of the events, it is necessary to make some assumptions for input to quantitative assessments.

See Tables 3.1 and 3.2 in Section 3 for identified hazards.

8.2 Property Loss Risk

Risk is defined as a product of likelihood and consequence, and a useful means of representing risk is through a qualitative risk matrix. Undertaking a qualitative assessment is considered valuable in cases where there is insufficient data for meaningful quantitative assessments to be completed.

For risk to property, AGS 2007 provides a recommended risk matrix for the purpose of estimation of property loss risk and this is presented below in Table 8.1. Example implications of the various risk categories are provided in Table 8.2. The design life of any structures for the purpose of the assessment is assumed to be 50 years.

A qualitative property loss risk assessment of the identified instability hazards on the DL1 flow paths has been completed and is presented in Tables 8.3 and 8.4 below.

A qualitative property loss risk assessment of the identified instability hazards on the DL1 flow paths has been completed and is presented in Table 8.5 below.

Table 8.1 Qualitative Risk Analysis Matrix (reproduced from AGS 2007).

LIKELIHOOD		CONSEQUENCES TO PROPERTY (with indicative Approximate Cost to Damage)				
	Indicative Value of Approximate Annual Probability	Catastrophic 200%	Major 60%	Medium 20%	Minor 5%	Insignificant 0.5%
A – Almost Certain	10^{-1}	VH	VH	VH	H	M or L
B – Likely	10^{-2}	VH	VH	H	M	L
C – Possible	10^{-3}	VH	H	M	M	VL
D – Unlikely	10^{-4}	H	M	L	L	VL
E – Rare	10^{-5}	M	L	L	VL	VL
F – Barely Credible	10^{-6}	L	VL	VL	VL	VL

Table 8.2 Risk Level Implications (reproduced from AGS 2007).

Risk Level	Example Implications
VH – Very High Risk	Unacceptable without treatment. Extensive detailed investigation and research, planning and implementation of treatment options essential to reduce risk to Low; may be too expensive and not practical. Work likely to cost than value of the property.
H – High Risk	Unacceptable without treatment. Detailed investigation, planning and implementation of treatment options required to reduce risk to Low. Work would cost a substantial sum in relation to the value of the property.
M – Moderate Risk	May be tolerated in certain circumstances (subject to regulators' approval) but requires investigation, planning and implementation of treatment options to reduce the risk to Low. Treatment options to reduce to Low risk should be implemented as soon as practical.
L – Low Risk	Usually acceptable to regulators. Where treatment has been required to reduce the risk to this level, ongoing maintenance is required.
VL – Very Low Risk	Acceptable. Manage by normal slope maintenance procedures.

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Table 8.3 DL1 South Eastern Flow Path Qualitative Risk Assessment to Property for Existing Conditions and Following Proposed Increase in Discharge.

Hazard	Existing Conditions, or Following increase in Discharge	Likelihood during lifetime of the structure. (Indicative Value of Approximate Annual Probability).	Consequences to Property	Qualitative Risk Category
Debris Flow (mobilisation of coarse cobble and boulder rich soils (slope debris) by overland flow)	Existing Conditions	**RARE (10^{-5})** As assessed in Section 5.0 excessively large storm water flows, larger than the holding capability of much of the channels, are required to trigger movement of the underlying slope debris. This in conjunction with the lack of evidence of any debris flow activity of this material along the flow path suggests a very long return period.	**MAJOR TO MEDIUM** Flow path exits the slope toe in Queenstown Cemetery. The nearest structures, are the campground cabins 60 m distant.	**Low**
	Following increase in discharge	**RARE (10^{-5})** As assessed in Section 5.0 excessively large storm water flows, larger than the holding capability of much of the channels, are required to trigger movement of the underlying slope debris. This in conjunction with the lack of evidence of any debris flow activity of this material along the flow path suggests a very long return period.	**MAJOR TO MEDIUM** Flow path exits the slope toe in Queenstown Cemetery. Nearest structures, campground cabins 60 m distant.	**Low**
Debris Flow (Mobilisation of surficial layer of organic topsoil by overland flow)	Existing Conditions	**LIKELY (10^{-2})** Analysis in Section 5.0 indicates topsoil mobilisation in lower channel in 1/100 year event. Also evidence of erosion close to pipe discharge location.	**INSIGNIFICANT** Initiated topsoil will generally manifest as surface erosion/sediment-laden water. Flow path exits at cemetery.	**Low**
	Following Increase in discharge	**LIKELY (10^{-2})** Analysis in Section 5.0 indicates topsoil mobilisation in lower channel in 1/100 year event. Erosion close to discharge pipe.	**INSIGNIFICANT** Initiated topsoil will generally manifest as surface erosion/sediment-laden water. Flow path exits at cemetery.	**Low**
Rock Fall from Gully Wall (Channel Section 9a and 10a)	Existing Conditions	**LIKLEY (10^{-1} to 10^{-2})** Relatively fresh rock fall debris beneath the bluff, several relatively recent events/falls observable estimate to be 50 year ARI.	**INSIGNIFICANT** Short run out distances (<30 m) and the bluff location 400 m from the slope toe. Instability significantly removed from downslope property and any public footpath areas in a remote location.	**Low**
	Following increase in discharge	**LIKLEY (10^{-1} to 10^{-2})** Broadly similar likelihood as the existing.	**INSIGNIFICANT** Short run out distances (<30 m) and the bluff location 400 m from the slope toe. Instability significantly removed from downslope property and any public footpath areas in a remote location.	**Low**
Large Rock Fall Event/Debris Fan	Existing Conditions	**RARE (10^{-5})** Large rock falls forming debris fan features are assessed to have been formed pre deposition of sediments at the slope toe/or similar age, during high lake levels. No indications of similar volumes of unstable rock remaining upslope.	**MAJOR** Possible rock roll into the cemetery or campground area.	**Low**
	Following increase in discharge	**RARE (10^{-5})** No indications of similar volumes of unstable rock remaining upslope, so no credible impact on likelihood of large scale stability from relatively small volumes of flow.	**MAJOR** Possible rock roll into the cemetery or campground area.	**Low**
Schist Landslide Increase	Existing Conditions	**POSSIBLE (10^{-3})** Creep movement only	**INSIGNIFICANT** Contained to slope, movement, if it occurs, would typically be <10mm/yr	**Very Low**
	Following increase in discharge	**POSSIBLE (10^{-3})** Creep movement only as per the existing conditions. No significant impact on the landslide expected from increased flow, see Section 6.0.	**INSIGNFICANT** Contained to slope, movement, if it occurs, would typically be <10mm/yr. No increase in creep rate from flow volume increase.	**Very Low**
General Slope Instability of the soil/boulder slope debris	Existing Conditions	**UNLIKELY (10^{-4})** Instability of locally steepened soil slopes is expected to occur intermittently.	**MINOR** Displacement would be local and confined to the slope area	**Low**
	Following increase in discharge	**UNLIKELY (10^{-4})** Instability of locally steepened soil slopes is expected to occur intermittently.	**MINOR** Displacement would be local and confined to the slope area	**Low**

Table 8.4 DL1 Southern Flow Path Qualitative Risk Assessment to Property for Existing Conditions and Following Proposed Increase in Discharge.

Hazard	Existing Conditions, or Following increase in Discharge	Likelihood during lifetime of the structure. (Indicative Value of Approximate Annual Probability).	Consequences to Property	Qualitative Risk Category
Debris Flow (mobilisation of coarse cobble and boulder rich soils (slope debris) by overland flow)	Existing Conditions	**RARE (10^{-5})** As assessed in Section 5.0 excessively large storm water flows, larger than the holding capability of much of the channels, are required to trigger movement of the underlying slope debris. This in conjunction with the lack of evidence of any debris flow activity of this material along the flow path suggests a very long return period. The southern flow path generally has shallower fall angles than other areas.	**MAJOR TO MEDIUM** The flow path could transect some of the paths and access roads before dispersing over the lower slopes where there is no distinct flow path. Debris would need to be cleared and paths/roads reinstated.	**Low**
	Following increase in discharge	**RARE (10^{-5})** As assessed in Section 5.0 excessively large storm water flows, larger than the holding capability of much of the channels, are required to trigger movement of the underlying slope debris. This in conjunction with the lack of evidence of any debris flow activity of this material along the flow path suggests a very long return period. The southern flow path generally has shallower fall angles than other areas.	**MAJOR TO MEDIUM** The flow path could transect some paths and access before dispersing over the lower slopes where there is no distinct flow path. Debris would need to be cleared and paths/roads reinstated.	**Low**
Debris Flow (Mobilisation of surficial layer of organic topsoil by overland flow)	Existing Conditions	**LIKELY (10^{-2})** Analysis in Section 5.0 indicates topsoil mobilisation can occur in some locations. There are no recognisable channels below this area and so extensive entrainment of topsoil is therefore expected to be very unlikely as flows will bifurcate, disperse and be restricted by vegetation.	**INSIGNIFICANT** Initiated topsoil will generally manifest as surface erosion/sediment-laden water, but is not expected to impact any properties. Some minor clean-up of roads and paths could be required.	**Low**
	Following Increase in discharge	**LIKELY (10^{-2})** Analysis in Section 5.0 indicates topsoil mobilisation can occur in some locations. There are no recognisable channels below this area and so extensive entrainment of topsoil is therefore expected to be very unlikely as flows will bifurcate, disperse and be restricted by vegetation.	**INSIGNIFICANT** Initiated topsoil will generally manifest as surface erosion/sediment-laden water, but is not expected to impact any properties. Some minor clean-up of roads and paths could be required.	**Low**
Rock Fall from the low bluffs along the flow path	Existing Conditions	**LIKELY TO POSSIBLE (10^{-2} to 10^{-3})** Low bluffs/exposures, no active rock falls, some minor fretting only. Current condition and likelihood of failure not influenced by the existing outflow.	**INSIGNIFICANT** Low bluffs, short run-out distances, dense vegetation, failed material unlikely to reach the slope toe.	**Low**
	Following increase in discharge	**LIKELY TO POSSIBLE (10^{-2} to 10^{-3})** Likelihood is considered as per the existing conditions.	**INSIGNIFICANT** As per the existing conditions.	**Low**
Schist Landslide Increase	Existing Conditions	**POSSIBLE (10^{-3})** Creep movement only, not related to current outflow.	**INSIGNIFICANT** Contained to the slope and removed from the toe, movement, if it occurs, would typically be creep only measures in mm/yr.	**Very Low**
	Following increase in discharge	**POSSIBLE (10^{-3})** Creep movement only as per the existing conditions. No significant impact on the landslide expected from increased flow, see Section 6.0	**INSIGNFICANT** As per the existing conditions.	**Very Low**
General Slope Instability of the soil/boulder slope debris	Existing Conditions	**UNLIKLEY (10^{-4})** Instability of locally steepened soil slopes is expected to occur intermittently.	**MINOR** Displacements would be local and confined to the slope area	**Low**
	Following increase in discharge	**UNLIKELY (10^{-4})** Instability of locally steepened soil slopes is expected to occur intermittently.	**MINOR** Displacements would be local and confined to the slope area	**Low**

Table 8.5. DL2 Flow Path Qualitative Risk Assessment to Property for Existing Conditions and Following Proposed Increase in Discharge.

Hazard	Existing Conditions, or Following increase in Discharge	Likelihood during lifetime of the structure. (Indicative Value of Approximate Annual Probability).	Consequences to Property	Qualitative Risk Category
Debris Flow (mobilisation of coarse cobble and boulder rich soils by overland flow)	Existing Conditions	**RARE (10^{-5})** As assessed in Section 5.0 excessively large storm water flows, lager than the holding capability of much of the channels, are required to trigger movement of the underlying slope debris. This in conjunction with the lack of evidence of any debris flow activity of this material along the flow path suggests a very long return period.	**MAJOR TO MEDIUM** The identified flow path exits the slope toe at the northern end of the skyline car park. A car park structure is likely to be present in the near future.	**Low**
	Following increase in discharge	**RARE (10^{-5})** As assessed in Section 5.0 excessively large storm water flows, lager than the holding capability of much of the channels, are required to trigger movement of the underlying slope debris. This in conjunction with the lack of evidence of any debris flow activity of this material along the flow path suggests a very long return period.	**MAJOR TO MEDIUM** The identified flow path exits the slope toe at the northern end of the skyline car park. A car park structure is likely to be present in the near future.	**Low**
Debris Flow (Mobilisation of surficial layer of organic topsoil by overland flow)	Existing Conditions	**LIKELY (10^{-2})** Analysis in Section 5.0 indicates topsoil mobilisation in lower channel in 1/100 year event. Also evidence of erosion close to pipe discharge location.	**INSIGNIFICANT** Initiated topsoil will generally manifest as surface erosion/sediment-laden water. Flow path exits at existing carpark. Overland flow paths direct water to pond in Kiwibirdlife Park. Some clean up on silt may be required.	**Low**
	Following Increase in discharge	**LIKELY (10^{-2})** Analysis in Section 5.0 indicates topsoil mobilisation in lower channel in 1/100 year event. Erosion close to discharge pipe.	**INSIGNIFICANT** Initiated topsoil will generally manifest as surface erosion/sediment-laden water. Flow path will exit behind proposed carpark building. Overland flow paths are being designed to direct water to pond in Kiwibirdlife Park. Some clean up on silt may be required.	**Low**
Rock Fall from the low bluffs along the flow path	Existing Conditions	**LIKELY (10^{-2})** No major recent or active rock fall areas identified. Some loose debris present on the face adjacent to the flow channel, but not extensive. Possible isolated failure of rocks expected due to typical processes in a mountains environment, however these are not considered to be overland flow related.	**INSIGNIFICANT** Isolated small diameter boulders infrequently falling/sliding from the face in upper areas. Observed failures expected to have short run-out distances with downslope movement restricted by trees.	**Low**
	Following increase in discharge	**LIKLEY (10^{-2})** Likelihood expected to be as per existing conditions following increase.	**INSIGNIFICANT** Isolated small diameter boulders infrequently falling/sliding from the face in upper areas. Observed failures expected to have short run-out distances with downslope movement restricted by trees.	**Low**
General Slope Instability of the soil/boulder slope debris	Existing Conditions	**UNLIKLEY (10^{-4})** Instability of locally steepened soil slopes is expected to occur intermittently.	**MINOR** Displacement expected to be local and confined to the slope area	**Low**
	Following increase in discharge	**UNLIKLEY (10^{-4})** Instability of locally steepened soil slopes is expected to occur intermittently.	**MINOR** Displacement expected to be local and confined to the slope area	**Low**

8.3 Loss of Life Risk

8.3.1 General

Loss of life, is the annual probability of the "person most at risk" being killed either by landslide, rock fall or debris flow. It is a function of several factors including the probability of an event occurring, the probability of a person being impacted and their vulnerability to impact.

For loss of life, the individual risk can be calculated from:

$$\mathbf{R}_{(LoL)} = \mathbf{P}_{(H)} \times \mathbf{P}_{(S:H)} \times \mathbf{P}_{(T:S)} \times \mathbf{V}_{(D:T)}$$

Where:

$\mathbf{R}_{(LoL)}$ is the risk (annual probability of loss of life (death) of an individual.

$\mathbf{P}_{(H)}$ is the annual probability of the landslide.

$\mathbf{P}_{(S:H)}$ is the probability of spatial impact of the landslide impacting a building (location) taking into account the travel distance and travel direction given the event.

$\mathbf{P}_{(T:S)}$ is the temporal spatial probability (e.g. of the building or location being occupied by the individual) given the spatial impact and allowing for the possibility of evacuation given there is warning of the landslide occurrence.

$\mathbf{V}_{(D:T)}$ is the vulnerability of the individual (probability of loss of life of the individual given the impact).

8.3.2 DL1

The analysis presented in this report indicates the likelihood in instability is not expected to change significantly for pre to post development for the identified hazards.

The potential for rapid failure that could endanger a person's life was identified for 2 hazards only, mobilised topsoil manifesting itself as erosion, and rock fall from the gully wall adjacent to channel cross-section 10a. Other hazards were either assessed as not credible, had large return periods, or exhibited creep movement rates (Landslide) which by their nature would not result in loss of life.

Based on this, the loss of life assessment is restricted to mobilised topsoil (debris flow) and Rock fall from the gully wall only.

It is considered the risk of loss of life associated with rock fall from the gully wall can be determined as very low (> than 10^{-6}/annum) with no impact on nearby traffic/people movement. For the following reasons:

- The location is significantly removed from any recognised access routes for walking/biking;
- The location is in upper central areas of the slope, significantly above the slope toe and developed areas;
- The location is physically challenging to reach and is not a natural route/access point across the hill so unlikely to be frequented.
- Observed rock fall run-out from the bluff is < 30m;
- Persons standing within 30 m of the bluff (traffic) would be extremely rare, possibly less than a 5 minute interval per annum.

The risk to loss of life due to the mobilisation of a topsoil debris flow has been assessed quantitatively and is presented in Table 8.6 below.

Table 8.6 – The annual probability of loss of life for most at risk individual below DL1 due to topsoil debris flow (post and pre development).

Parameter	Description	Probability	Assumptions/Comments
P(H)	Probability of topsoil debris flow occurring annually	1.00E-02	Assuming topsoil mobilises in a 1/100 year rainfall event.
P(T:S)	Probability that the length of track effected by topsoil debris flow is occupied by the most at risk individual	4.17E-04	• The hypothetical most at risk individual walks the track twice daily, is 1 m in length, and walks at 2 km/hr. • The width of the channel/length of the track which the debris flow crosses is 10 m. Note: Conservative as In reality the person would see the flooding across the track and avoid it or wouldn't be walking if it was raining.
V(D:T)	Probability of loss of life of the individual	1.00E-02	The topsoil debris flow will be observed as flooding and sediment-laden water crossing the track. Probability conservatively assumed to be 1/100.
R(LoL)	Annual probability of loss of life (death) of most at risk individual	4.17E-08	

The probability of the hypothetical most at risk person below DL1 as defined in Table 8.6 above losing their life as a result of a topsoil debris flow is estimated to be 4.17E-08.

8.3.3 DL2

The mobilised topsoil (debris flow) hazard was identified as the only hazard for DL2 that could endanger a person's life. Other hazards were either assessed as not credible, had very large return periods, or exhibited creep movement rates (Landslide) which by their nature would not result in loss of life.

The risk to loss of life due to the mobilisation of a topsoil debris flow has been assessed quantitatively for the post development scenario and is presented in Table 8.7 below

Table 8.7 – The annual probability of loss of life for most at risk individual below DL2 due to topsoil debris flow (post development).

Parameter	Description	Probability	Assumptions/Comments
P(H)	Probability of topsoil debris flow occurring annually	1.00E-02	Assuming topsoil mobilises in a 1/100 year rainfall event.
P(S:H)	Probability of topsoil debris flow exiting at the carpark building location	1.00E+00	The carpark building is located immediately downslope of the flow path.

P(T:S)	Probability of the most at risk individual being in the carpark building close to the debris flow exit location	9.13E-03	The hypothetical most at risk individual works two shifts a day 5 days a week and parks their car in the carpark closest to the debris flow exit location every day. They spend 5 minutes in or around the car when they arrive/leave the carpark.
V(D:T)	Probability of debris flow entering the building and the most at risk individual losing their life	1.00E-03	The topsoil debris flow will manifest itself as erosion, sediment-laden water and flooding. The flow will follow the overland flow paths around the building. Probability conservatively assumed to be 1/1000
R(LoL)	Annual probability of loss of life (death) of most at risk individual	9.13E-08	

The probability of the hypothetical most at risk person below DL2 as defined in Table 8.7 above losing their life as a result of a topsoil debris flow is estimated to be 9.13E-08.

8.4 Tolerable/Acceptable Risk Guidelines

8.4.1 General

Tolerable and or acceptable risk to natural and manmade hazards is a complex subject, with much research and debate published. We cannot prescribe a level of tolerable risk for the site. That decision must be made by the relevant stakeholders and the regulating body, taking all factors, including public perception and commercial risk into account. Each location or case is different for the stakeholders involved, with significant factors in tolerating risk including the perceived level of voluntary versus involuntary risk and the potential nature of the fatality.

It is important to distinguish between “acceptable risks” and “tolerable risks”.

Tolerable Risks are risks within a range that society can live with so as to secure certain benefits. It is a range of risk regarded as non-negligible and needing to be kept under review and reduced further if practicable.

Acceptable Risks are risks which everyone affected is prepared to accept. Action to further reduce such risk is usually not required unless reasonably practicable measures are available at low cost in terms of money, time and effort.

8.4.2 Loss of Life

Examples of acceptable and tolerable risk from a number of organisations is provided in Table 8.9 below.

Table 8.9 - Example individual loss of life tolerable and acceptable risk from various organisations.

Organisation	Industry	Description	Risk/annum	Reference
Health and Safety Executive, United Kingdom	Land use planning around industries	Broadly acceptable risk. Tolerable limit	10^{-6}/annum, public and workers 10^{-4}/annum public[1] 10^{-3}/annum workers	HSE (2001)
Netherlands Ministry of Housing	Land use planning for industries	Tolerable limit [2]	10^{-5}/annum, existing installation 10^{-6}/annum, proposed installation	Netherlands Ministry of housing (1989), Ale (2001), Vrijling *et al.* (1998)
Department of Urban Affairs and Planning, NSW, Australia	Land use planning for hazardous industries	"acceptable" (tolerable) limits [2]	$5x10^{-7}$/annum hospitals, schools, childcare facilities, old age housing 10^{-6}/annum residential, hotels, motels $5x10^{-6}$/annum commercial developments 10^{-5}/annum sporting complexes	
Australian National Committee on Large Dams	Dams	Tolerable limit	10^{-4}/annum existing dam, public most at risk subject to ALARP 10^{-5}/annum new dam or major augmentation, public most at risk, subject to ALARP.	ANCOLD (2003)
Australian Geomechanics Society guidelines for landslide risk management	Landslides (from engineered and natural slopes)	Suggested tolerable limit	10^{-4}/annum public most at risk, existing slope 10^{-5}/annum, public most at risk, new slope	AGS (2000)
Hong Kong Special Administrative Region Government	Landslides from natural slopes	Tolerable limit	10^{-4}/annum public most at risk, existing slope. 10^{-5}/annum public most at risk, new slope	Ho et al. (2000), ERM (1998), Reeves *et al.* (1999)
Iceland ministry for the environment hazard zoning	Avalanches and landslides	"acceptable" (tolerable) limit	$3x10^{-5}$/annum residential, schools, day care centres, hospitals, community centres. 10^{-4}/annum commercial buildings $5x10^{-5}$ recreational homes[3]	Iceland Ministry for the environment (2000), Arnalds *et al.* (2002)
Roads and Traffic Authority, NSW Australia	Highway landslide risk	Implied tolerable risk	10^{-3}/annum[4]	Stewart *et al.* (2002), RTA (2001)

AGS recommendations in relation to tolerable risk for loss of life are summarized in Table 8.10 below.

Table 8.10 – AGS suggested tolerable loss of life individual risk.

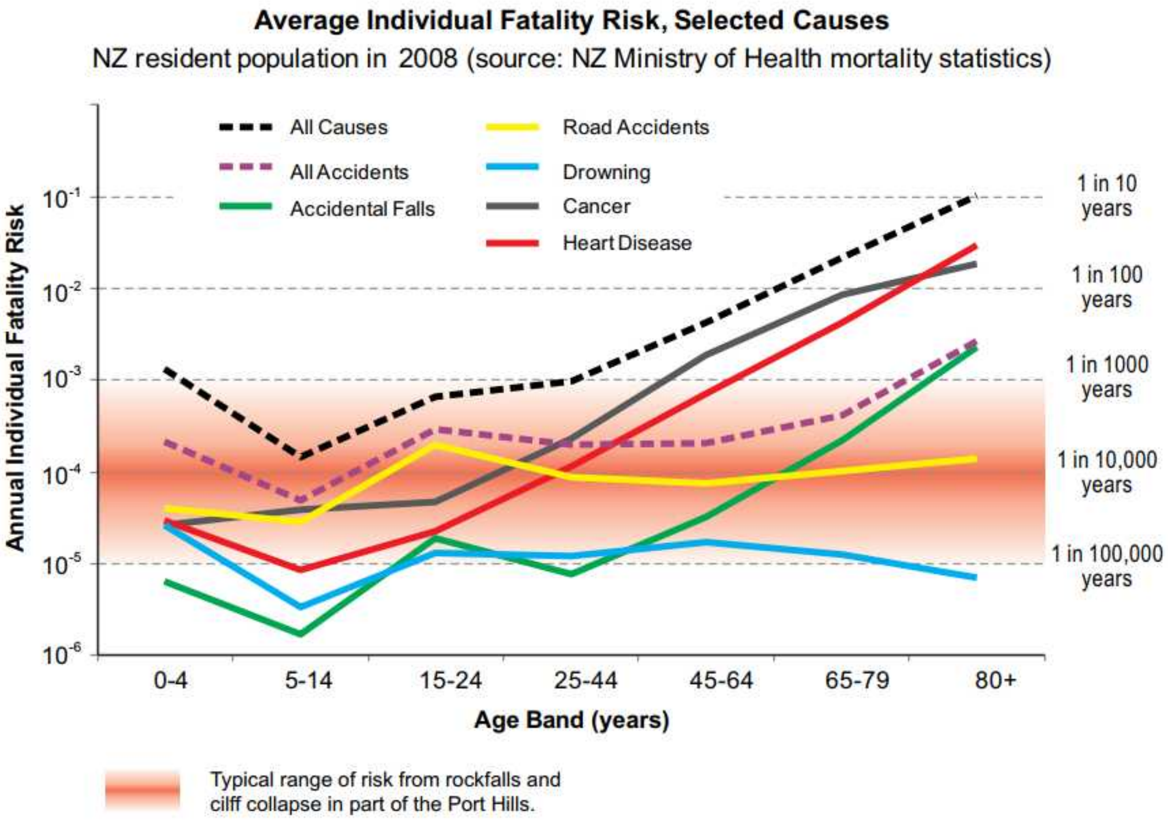
Situation	Suggested Tolerable Loss of Life Risk for the person most at risk
Existing Slope (1) / Existing Development (2)	10^{-4} / annum
New Constructed Slope (3) / New Development (4) / Existing Landslide (5)	10^{-5} / annum

"Acceptable" risks are usually considered to be one order of magnitude lower than the "tolerable" risks.

In the case of the Skyline development the loss of life risk is well below all the published loss of life risk criteria above.

In order to put the risk of individual fatality into perspective it is helpful to put it into terms that most people are familiar with. Figure 8.1 below shows the risk of fatality from a number of sources.

Figure 8.1 – Showing the average individual fatality risk from multiple causes (source: GNS)



8.4.3 Property

The acceptable or tolerable values for risk to property from a natural hazard is rarely quoted in literature, and there are several indicators such as Benefit-to-Cost Ratio, Net Present Value and Incremental Benefit-to-Cost Ratios which can be assessed to help provide understanding of property loss risk.

AGS has developed assessment of property damage in terms of a qualitative risk assessment. AGS recommendations in relation to tolerable qualitative risk for property damage are summarized in Table 8.11 below.

Table 8.11 – AGS suggested tolerable qualitative risk for property damage.

Importance Level of Structure (1)	Suggested Upper Limit of Acceptable Qualitative Risk Property (2)	
	Existing Slope (3) / Existing Development (4)	New Constructed Slope (5) / New Development (6) / Existing Landslide (7)
1	Moderate	Moderate
2	Low	Low
3	Low	Low
4	Very Low	Very Low

If the recommended criteria of AGS is adopted, then the property damage risk below DL1 and DL2 for both pre and post development would meet this criteria. Though again it should be noted it is up to the governing authority and other parties to confirm an acceptable level of risk.

9 Recommendations

9.1 General

The recommendations and opinions contained in this report are based upon ground investigation data obtained at discrete locations and historical information held on the GeoSolve database.

The nature and continuity of subsoil conditions away from the investigation locations is inferred and cannot be guaranteed.

9.2 Risk Reduction Recommendations

The results of the assessment suggest the stormwater discharge from the development will only result in minor effects downslope, and the risk in terms of loss of life and property are low and are of a level that is typically acceptable (though this should be confirmed by the governing authority).

Options to mitigate the risks from natural hazards should always be investigated regardless of the outcomes of risk assessment. In this case there are several options that could be implemented at a relatively low cost that would have an impact on reducing the risks at the site.

Increased scouring can be expected in the upper channel areas and so additional measures are considered appropriate to prevent scour and erosion in these areas.

The following recommendations are provided:

1. The storm water pipe above DL1 should be re-located to avoid local instability identified in the fill slope above. The pipe should be constructed 90 degree to the fill slope toe and sleeved with a larger diameter pipe through the fill to allow potential ongoing creep of the surrounding fill soils to occur around the pipe.
2. Scour protection/armouring in the upper 40-50 m of the soil slope (below the upper rock sections) for both DL1 and DL2 is recommended. The armouring should transition the higher velocity flows from the rock to the soil slopes beneath, and promote dispersal in the upper 50 m or so of the channel. Location of armouring should be instructed by a geotechnical engineer.
3. Inspections during/following heavy rainfall could be completed to confirm the effectiveness of the armouring and modifications completed as required.
4. Mapping indicates a 3rd discharge point could be safely located approximately 30 m east of DL1. No footpaths/public areas are present in this area and the upper catchment comprises in-situ rock. There are no defined channels and dispersal of the flow is expected to occur relatively quickly. This flow path would join the modelled DL1 south eastern flow path 150 m down slope where assessment indicates the increased risk of instability is negligible.

Further options, e.g. detention tanks, could be implemented, however based on the analysis these are not consider mandatory.

10 Conclusion

A hazard assessment has been undertaken on the stormwater discharge flow paths that originate from the Skyline complex located on Bobs Peak.

The purpose of the study is to provide an understanding of the effects of a proposed increase in stormwater discharge on natural hazards. In particular, on potential for the increased discharge to result in ground instability, e.g. debris flow, slope instability and rock fall.

Detailed field mapping of the stormwater flow paths has been undertaken to determine slope and soil characteristics and enable the assessment to be completed.

Section 5 outlines the likelihood of debris flows being initiated along the flow paths, and the conclusions are summarised as follows:

- There are no indications of recent debris flow activity. The debris fans at the northern end of the cemetery and carpark are considered to be historic features. Some scour, mobilisation of vegetation/organics and finer materials, typically fine gravel sized and lower has been observed in upper sections of the DL1 and DL2 flow paths;
- A geological cross section generally representative of the slope debris slope characteristics observed on site was analysed in Slide v7.0 with varying inflows of groundwater which represent the changes in floodwater entering the slopes. The analysis indicates that the design storms are of insufficient duration to initiate movement of the slope debris;
- Topsoil mobilisation, manifesting as erosion and sediment-laden flooding water is predicted in different locations along the stormwater flow paths depending upon slope angle, grain size, interlocking etc, for rainfall events with ARI's of 10 to 100 years.
- All locations where topsoil mobilisation is predicted post-development are assessed to be at the same, or very similar, risk of initiation for the pre development conditions (except for immediately downslope of the discharge pipe where additional erosion is predicted);
- The flow initiation threshold for the coarse 'slope debris' below the topsoil far exceeds the maximum post-development 10 or 100 year API flowrates by two or three orders of magnitude.

An assessment of landslide stability below DL1 has been completed and is provided in Section 6. The assessment indicates a low chance of the stormwater discharge having an impact on the existing landslip. An assessment of rock fall is provided in Section 7, which indicates the stormwater discharge will have negligible impact on existing rock fall risk.

A quantitative risk assessment has been completed on the risk of loss to property and a quantitative risk assessment on loss of life. The risks in terms of loss of life and property are determined to be low and are of a level that is typically acceptable (though this should be confirmed by the governing authority), further details are provided in Section 8.

Options to mitigate the risks from natural hazards should always be investigated regardless of the outcomes of risk assessment. In this case there are several options that could be implemented at a relatively low cost that would have an impact on reducing the risks at the site. These recommendations for design and construction are provided in Section 9.2.

11 Applicability

This report has been prepared for the benefit of Skyline Enterprises with respect to the particular brief given to us and it may not be relied upon in other contexts or for any other purpose without our prior review and agreement.

It is important that we be contacted if there is any variation in subsoil conditions from those described in this report.

Report prepared by:	Reviewed for GeoSolve Ltd by:
....	....
Blair Matheson Geotechnical Engineer	Paul Faulkner Senior Engineering Geologist

Authorised and technical review for GeoSolve by:

....

Colin MacDiarmid
Senior Geotechnical Engineer

829 Frankton Road, PO Box 1780, Queenstown 9348, ph 03 451 0172

Appendix A: GeoSolve Drawings