Attachment A

SINGLE STAGE BUSINESS CASE

FOR

BENNETTS BLUFF CAR PARK AND VIEWING AREA

3 November 2017

CONTENTS

1 INTRODUCTION

Extract from Single Stage Business Case dated 4 July 2017:
This Single Stage Business Case seeks NZTA funding for safety improvements to the Bennetts Bluff Carpark and Viewing Platform adjacent to Lake Wakatipu.

This project was included within QLDC's minor improvements budget. Three construction options were priced as part of an open tender process. The submitted prices were all greater than the engineer's estimates and QLDC's budget range of $280,000 to $300,000.

Option 1

Engineer's estimate	*$452,307.45*	*Sealed bus park and two car parks at the southern end, fourteen sealed car parks at the northern end, pedestrian walkway to the viewing platform.*
Tenderer 1	*$480,949.48*	
Tenderer 2	*$548,547.25*	
Tenderer 3	*$620,507.37*	
Tenderer 4	*$652,711.28*	

Option 2

Engineer's estimate	*$361,845.65*	*Sealed bus park and two car parks at the southern end, four unsealed car parks at the northern end, partially formed pedestrian walkway to the viewing platform.*
Tenderer 1	*$418,070.51*	
Tenderer 2	*$482,668.90*	
Tenderer 3	*$495,969.03*	
Tenderer 4	*$562,121.82*	

Option 3

Engineer's estimate	*$291,085.40*	*Sealed bus park and two car parks at the southern end and viewing platform.*
Tenderer 1	*$350,366.50*	
Tenderer 2	*$419,533.85*	
Tenderer 3	*$426,226.78*	
Tenderer 4	*$460,621.59*	

As all options exceed the current minor improvements threshold, this business case is required to obtain NZTA funding as a standalone improvement.

As the project is already included in the RLTP under minor improvements, NZTA advise that a RLTP variation is not required. QLDC will inform the Regional Transport Committee if the change in funding for this project is approved.

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Completion of this project remains a priority due to the identified safety issues and concerns A Letter of Intent was issued to Fulton Hogan (Tenderer 1) for construction of Option 1. The contract value for the scope of works was $431,408.62 (exclusive of GST).

Construction was due to commence on site in September 2017, however work was placed on hold following further assessment of tension cracks located behind the crest of Bennetts Bluff. The detailed geotechnical assessment of tension cracks and the rock fall hazards along with recommended remedial options is detailed within Geosolve's *Bennetts Bluff Geotechnical Assessment* dated October 2017 (refer Appendix I).

Subsequent to the above, an agreement was reached between QLDC and Fulton Hogan to cancel the Contract. The Contract was not executed and it was agreed that Fulton Hogan were to be paid all costs reasonably incurred to date. These relate to Preliminary & General and material costs incurred during start up and site establishment, which have now been claimed and approved at $23,748.07 (exclusive of GST).

Geosolve's recommendations within the report relate to remedial options, control measures and/or monitoring for management of the risks. Geosolve advise that the options are limited, technically challenging and are likely a significant cost. As requested by QLDC, OPUS were engaged to undertake a Peer Review of the report. They have advised that the Gesolve assessment is relatively high level and recommend that further geotechnical investigation is required to fully understand the extent of the rock fall hazard, risk mitigation actions and associated costs.

In consideration of the above, an alternative location for the car park and viewing point has been investigated for QLDC's review.

Site Location

Image 1 shows a map with location of the existing Bennetts Bluff lookout. Image 2 provides an overview of location A (as tendered) and location B (proposed alternative) relative to the existing Bennetts Bluff Lookout.

Image 1 – Location Map

Image 2 - Existing and Proposed Viewing Locations

2 STRATEGIC CASE

2.1 Strategic fit and context

Road safety is a key priority in the Government Policy Statement on Land Transport 2015/16 – 2024/25. The project has a high strategic fit with the Government Policy Statement 2015 as well as being an improvement that was promised in the 16/17 Annual Plan. By completing this project it will remove the perceived risk of vehicles parking on a 35km bend where approaching traffic is suddenly greeted by a myriad of buses, campervans, and other vehicles parked close to the edge line as well as pedestrians.

This project gives effect to national, regional and local direction as outlined in the following documents:

- Government Policy Statement on Land Transport 2015/16 – 2024/25, which has road safety as a key priority.
- Safer Journeys 2020, the Ministry of Transport's Road Safety Strategy 2010-2020.
- Otago Southland Regional Land Transport Plans – Objective 1.1 Investment is made in effective road safety interventions, reflecting the importance of road safety to the region.
- QLDC is currently developing an Integrated Transport Strategy with one of the key principals being to Provide safe, reliable and pleasant access to visitor activities areas.

2.2 Problem description

There is an existing pull-off area at Bennetts Bluff which is used by tourists and locals as a viewpoint for Lake Wakatipu. It is located on a curve where the sight distance is insufficient for the speed environment. This combined with inadequate parking capacity is a safety issue.

	Glenorchy – Queenstown Road
Classification	Arterial - ONRC Primary Collector
ADT	872 (est.) 31/12/2005, 10% heavy
Posted speed limit	100 km/hr

Safety

A pre-construction Road Safety Audit was undertaken by MWH in May 2017. This highlighted a number of concerns as summarised below:

Serious - Major safety concern that must be addressed and requires changes to avoid serious safety consequences:

- Southern End Angle Parking – vehicles backing into live traffic lane - can be mitigated when constructing any option; and
- Pedestrian Safety – access to the viewing platform - can be mitigated when constructing any option.

Significant - Significant safety concern that should be addressed and requires changes to avoid serious safety consequences:

- Bus Parking Bay – restricted space available - can be mitigated when constructing any option;

- Larger Vehicle Parking – suitable parking required - can be mitigated when constructing any option;
- Viewing Platform location – safety of pedestrians getting to platform - can be mitigated when constructing any option; and
- Eastern Side Parking Shoulder – risk of rock fall on Eastern side of carriageway - can be mitigated when constructing in location B.

Moderate - Moderate safety concern that should be addressed to improve safety:

- Speed Limit and Cornering Speed Indication – inadequate signage - can be mitigated when constructing any option; and
- Former Viewing Area – signage to prevent pedestrians walking up carriageway - can be mitigated when constructing any option.

Minor - Minor safety concern that should be addressed where practical to improve safety:

- Signage - provide earlier warning of need to reduce speed - can be mitigated by constructing any option.

2.3 Benefits of investment

The main benefit of investing is increased safety for both road users, users of the viewing area, and pedestrians moving around the viewing area.

2.4 Stakeholder consultation

Several discussions have been held with the Glenorchy Community Association, resulting in a decision to undertake improvements to the Bennetts Bluff viewing area in the 16/17 Annual Plan.

3 POTENTIAL RESPONSES

3.1 Initial response

MWH were previously engaged to provide concept design options in location A. Following QLDC review, they were instructed to complete a detailed design for all three options. The documentation was issued for tender through GETS on 19 April 2017 and four tenders were received by the closing date of 19 May 2017. The pre-construction Road Safety Audit was undertaken by MWH alongside the tender.

MWH were recently engaged to provide construction cost estimates for the two options in location B, which they had previously prepared concept designs for in November 2015. It is recommended that QLDC re-assess the alternative location and associated designs for further development. Refer to Appendix II for the associated sketches, cost estimates and site photographs.

3.2 Options assessment

Table 1 outlines the various options assessed, including the three options tendered (viewing location A) and the alternative location (viewing location B) proposed for further consideration.

	No.	Description	Risks/Issues	Construction Cost (exclusive of GST)	Exclusions
VIEWING LOCATION A	1	Southern end and Northern end carparks, plus construction of a pedestrian walkway and viewing platform: Sealed bus park and two car parks at the southern end, fourteen sealed car parks at the northern end, pedestrian walkway to the viewing platform.	Significant rock fall hazard with limited risk mitigation actions (refer Geosolve Geotechnical Report dated October 2017)	$480,949.48 (Tendered, includes 10% contingency)	Professional & Internal Fees Further detailed geotechnical investigation report ($50k) and any recommended stabilisation, removal and/or risk mitigation costs.
	2	Southern end carpark, and viewing platform. Partial construction of Northern end carpark and pedestrian walkway: Sealed bus park and two car parks at the southern end, four unsealed car parks at the northern end, partially formed pedestrian walkway to the viewing platform.	Significant rock fall hazard with limited risk mitigation actions (refer Geosolve Geotechnical Report dated October 2017)	$418,070.51 (Tendered, includes 10% contingency)	Professional & Internal Fees Further detailed geotechnical investigation report ($50k) and any recommended stabilisation, removal and/or risk mitigation costs.
	3	Southern end carpark and viewing platform. Formation of earth bund at Northern end to make safe: Sealed bus park and two car parks at the southern end and viewing platform.	Rock fall hazard with limited risk mitigation actions (refer Geosolve Geotechnical Assessment dated October 2017)	$350,366.50 (Tendered, includes 10% contingency)	Professional & Internal Fees Further detailed geotechnical investigation report ($50k) and any recommended stabilisation, removal and/or risk mitigation costs.
VIEWING LOCATION B	4	Upgraded track to access a car park and the viewing area (all on DoC land): Unsealed access road and approximately eight car parks, 360 degrees panorama viewing area.	Land use agreement Resource Consent Traffic/road alterations required	$155,760.00 (Engineer's estimate, includes 10% contingency)	Professional & Internal Fees (including design and consent fees)
	5	Upgraded access road to a carpark with a new walking track up to the viewing area (all on DoC land): Maximum parking - Unsealed access road and bus/car parking (20+ parks), new 'short walk' track up to a 360 degrees panorama viewing area.	Land use agreement Resource Consent Traffic/road alterations required	$155,364.00 (Engineer's estimate, includes 10% contingency)	Professional & Internal Fees (including design and consent fees)

Table 1 – Options Assessment

4 PREFERRED OPTION

Option 5 is recommended for further development. This option includes:

- Unsealed access road;
- Approximately 1000m2 unsealed parking area;
- New 'short walk' track;
- Viewing area with 360 degrees panorama view (details to be confirmed); and
- Signage.

Option 5 is expected to achieve maximum benefit with regards to access and parking. The alternative car park and viewing location is not impacted by the rock fall hazard associated with Options 1-3. It is noted that surplus budget could be invested into additional facilities such as toilets, seating, bins etc. This option would result in significantly more parking capacity over other options and provide value for money due to the existing site conditions and formation.

In addition, further action may be required to mitigate risk associated with the rock fall hazard (ie additional signage, barriers and/or monitoring).

4.1 Benefit cost appraisal

MWH recommend that QLDC proceed with development and detailed design of Option 5. They have provided an estimate of construction costs to the value of $155,364.00 (exclusive of GST), which includes 10% contingency.

4.2 Effectiveness

NZTA's effectiveness rating framework assesses how well the project will deliver the desired results. QLDC's rating assessment is provided in *Table 2* below:

Component	Rating
Outcomes focused	High – expected to address all identified problems in the best possible way
Integrated	High – safety outcomes clearly signalled in national, regional and local planning documents
Correctly scoped	High – intervention is of an appropriate scale in relation to the issue
Affordable	High
Timely	High – benefits are obtainable immediately after construction and will continue
Confidence	High
Overall	High

Table 2 – QLDC Rating Assessment

5 IMPLEMENTATION

5.1 Financial considerations

Table 3 below provides a breakdown of the estimated costs to complete Option 5:

Project Estimate	
Costs expended to date: - Design - Construction (excludes internal costs)	$39,353.50 $23,748.07
Detailed Design, MSQA, Safety Audits & Tender Evaluation (15% of construction estimate)	$23,250.00 (estimate)
Internal Costs (5% of construction estimate)	$7,750.00 (estimate)
Option 5 Construction Costs (includes 10% contingency)	$155,364.00 (estimate)
Total	$ 249,465.57

Table 3 – Option 5 Estimated Costs

The costs expended to date have already been accounted for in the 16/17 budgets. The project implementation period could fall into the 2017/18 QLDC Annual Plan subject to approval to proceed.

5.2 Commercial considerations

The Contractor was procured through an open tender process. Four tenders were received (Fulton Hogan Ltd, Civil Construction, Southroads, Downer NZ Ltd) and evaluated in accordance with the tender evaluation methodology detailed within in the Request for Tender documentation. Fulton Hogan Ltd were the successful tenderer prior to cancellation of the Contract.

Considering the time involved and the costs incurred through the design and tender process, it is proposed that only Fulton Hogan Ltd are requested to provide a fixed price lump sum for the scope of works associated with construction of Option 5.

5.3 Recommendation

The project delivery will be overseen by QLDC with the following recommendations:

- QLDC confirm the scope change with NZTA;
- MWH are invited to provide a fixed fee for Engineering Professional Services associated with design and delivery of Option 5. This will include their assessment and recommendation for any risk mitigation actions associated with the geotechnical assessment as Appendix I;
- Fulton Hogan are invited to provide a fixed price lump sum for construction of Option 5 (following QLDC review and approval of the Detailed Design);
- Engage a suitably qualified practitioner to undertake a post-construction Road Safety Audit; and
- QLDC approve the above and related costs to be expended in the 2017/18 Annual Plan.

Risks include:

- DoC land use agreement;
- Regulatory Compliance;
- Traffic management and safe management of the public around the site;
- Heavy vehicle movements; and
- Changes to the parking layout and operation.

RECOMMENDED BY:	APPROVED BY:
Name:	Name:
Title:	Title:
Date:	Date

Appendix I
Geosolve Bennetts Bluff Geotechnical Assessment

Geotechnical Assessment

Bennetts Bluff

Glenorchy-Queenstown Road

Report prepared for:

Queenstown Lakes District Council

Report prepared by:

GeoSolve Ltd

Distribution:

Queenstown Lakes District Council

GeoSolve Limited (File)

October 2017

GeoSolve Ref: 160533.01

GEOTECHNICAL

WATER RESOURCES

PAVEMENTS

Table of Contents

1 Introduction

1.1 General

This report presents the results of a slope hazard assessment undertaken by GeoSolve Ltd for an area of Bennetts Bluff, Queenstown-Glenorchy Road.

Photograph 1.1 – Showing the tension crack behind Bennetts Bluff with Queenstown-Glenorchy Road and Lake Wakatipu shown in the background.

The assessment has been carried out for Queenstown Lakes District Council (QLDC) in accordance with GeoSolve Ltd proposal dated 30 June 2017, which outlines the scope of work and conditions of engagement.

1.2 Background and Aim of Report

A preliminary slope hazard assessment was completed on the Queenstown-Glenorchy Road in 2010 by Tonkin and Taylor[1].

This preliminary report identified large tension cracks, indicating significant ground movement, behind the crest of Bennetts Bluff and recommend that a detailed geotechnical assessment and ongoing survey monitoring be completed to determine the risk of future instability.

[1] *Tonkin and Taylor. (2010, November).* Preliminary Slope Hazard Assessment Queenstown to Glenorchy Highway. *Reference: 880224*

The aim of this report is to complete the following:

- Detail the results of survey monitoring work which has been intermittently completed on the Bennetts Bluff tension cracks since 2012;
- Complete a more detailed geotechnical assessment of the slope hazards associated with Bennetts Bluff and in particular the identified tension cracks;
- Complete a preliminary qualitative and quantitative risk assessment of the slope hazards in terms of loss of life and property loss so that the potential consequences associated with the identified hazards can be understood.
- Provide recommendations for future remedial work, control measures and monitoring depending upon the results of the above assessment.

This report considers the area of the tension crack only, located in the north eastern part of Bennetts bluff. A separate study and report is being completed for the assessment of the adjacent roadside cuts. The study area which is applicable to this report is shown on Figure 1a, Appendix A.

1.3 Site Description

The site is located approximately 19.7 km south of Glenorchy and 17.3 km west of Queenstown at approximately chainage 23.250 Glenorchy-Queenstown Road as shown on Figure 1.1 below.

Figure 1.1 – Site location plan

The section of Bennetts Bluff assessed by this report trends in a north-east to south west direction across the study area and is on the upslope side of the highway. Glenorchy-Queenstown Road intersects the bluff and crosses the southern end of the study area. At the south western end, adjacent to the highway, the bluffs transition into the rock cut excavated to accommodate the road. Details of the study area are shown on Figure 1a, Appendix A, which also shows the location of the tension cracks which run approximately parallel to the bluff face in this location.

The land between the road and bluffs is lightly vegetated with shrubs and grass coverage in amongst rock fall debris. The vegetation cover becomes more complete with distance away from the bluffs and the associated rock fall debris. Where the slopes become very steep to sub-vertical there is negligible vegetation cover and the surface generally comprises exposed schist or schist rock fall debris.

Lake Wakatipu is situated 170 m to the west of and 45m lower than the Glenorchy-Queenstown Road.

1.4 Topography and Surface Drainage

The topography at the site has been estimated by photogrammetric aerial and topographic surveying, and is shown in Figure 1, Appendix A. Cross-sections through the bluff area, through the slope and to the road beneath are provided as Figures 2a and 2b.

In summary, the bluffs are generally 25 - 40 m in height and slope at angles of 70 - 90 degrees towards the north-west. There are sections of the bluffs which overhang, by as much as 3 - 5 m, as can be seen in Photograph 2.2. The base of the bluffs is approximately 40 - 60 m in elevation above the road.

Upslope from the bluffs the topography generally slopes towards the west at angles of between 20-45 degrees.

The land to the north of the bluff toe generally slopes at angles of between 30-40 degrees towards the west.

The site is naturally free draining and there are no water courses in the immediate vicinity of the study area.

1.5 Geological Setting

The Glenorchy to Queenstown highway is located within the Wakatipu basin, a feature formed by glacial advances. Published references indicate the last glacial event occurred in the region between 10,000 and 20,000 years ago. The glaciations have left glacial till, glacial outwash and lake sediments over ice scoured bedrock. Post glacial times have been dominated by the erosion of the bedrock and glacial sediments, with deposition of alluvial gravels by local watercourses and lacustrine sediments during periods of high lake levels.

IGNS, 1:250,000 Geological Map 18, Wakatipu identifies the bluffs themselves as schist bedrock. A historic schist landslide feature is shown immediately adjacent to and on the downslope (north western) side of the bluffs. This landslide is shown to extend downslope beneath the road.

Several known faults are present within the site recorded as inactive on the geological map (IGNS, 1:250,000 Geological Map 18, Wakatipu). The most notable fault is the Moonlight fault that crosses the Glenorchy – Queenstown Highway at Bobs Cove. No active fault traces are known to exist in the immediate vicinity of the site, however a significant seismic risk exists in the region from the rupture of the alpine Fault located along the west coast of the South Island. There is a reported high probability that an earthquake with a magnitude greater than 8.0 will occur on the Alpine Fault within the next 50 years.

2 Geotechnical Investigations

2.1 General

The following geotechnical investigations have been completed for the purpose of this report:

- A site appraisal by an engineering geologist and geomorphological mapping of key features;
- Review of high quality aerial photography taken of the study area by aerial drone;
- Review of survey monitoring data taken on the tension crack;

2.2 Geological Mapping

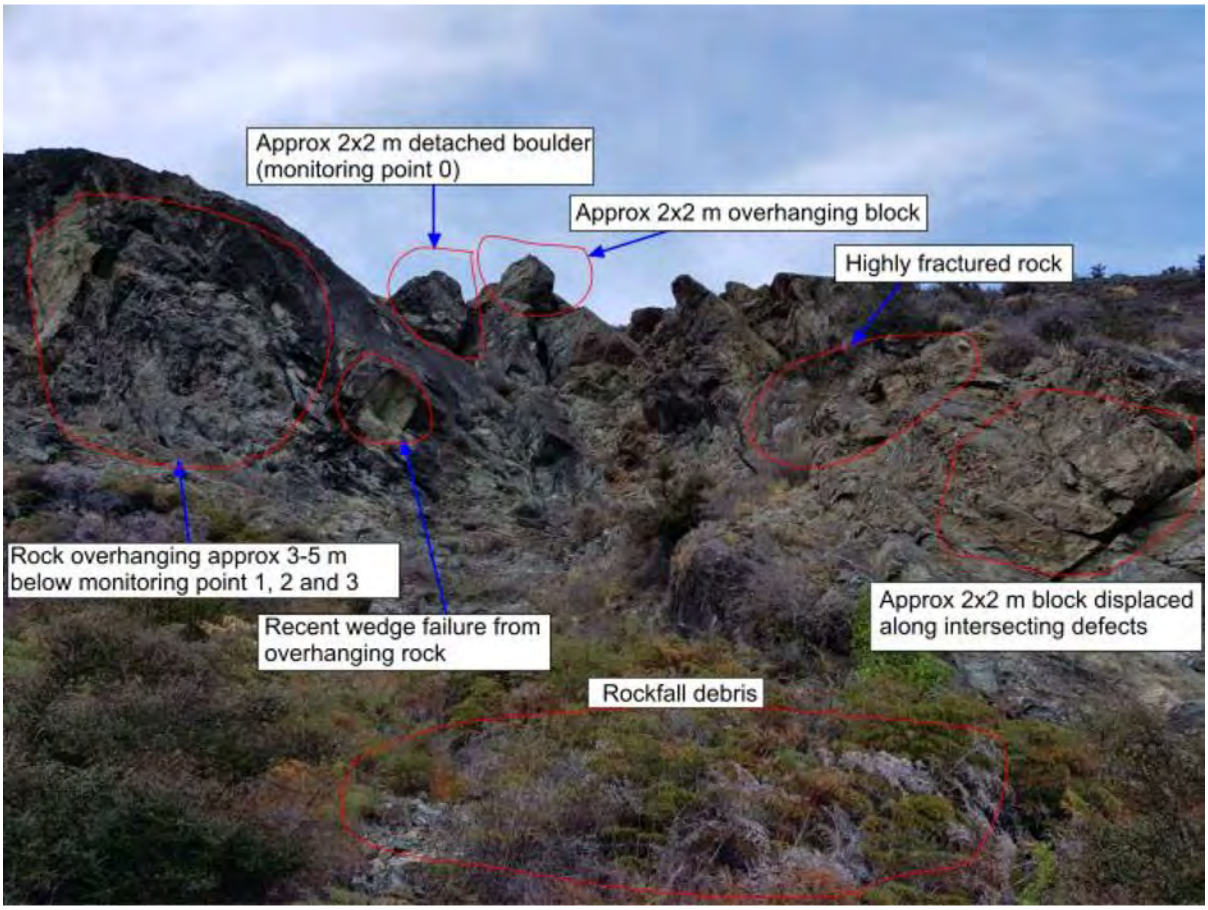
2.2.1 General

The following presents a summary of the geological mapping observations, review of the aerial photography and completion of the site geomorphology:

- Two tension cracks are present running parallel to and a short distance up slope of the bluff face. The main tension crack is situated approximately < 1.0 - 14 m behind the bluff, depending on location, and extends for a length of approximately 100 m. This tension crack is predominantly between 2 - 2.5 m wide. The depth of the crack has not been measured directly due to access issues however it is estimated to be several tens of meters. See Figure 1a, 2a and 2 b Appendix A;
- A line of secondary tension cracks is situated 20 - 30 m behind the bluff. These tension cracks are only visible for short lengths where there is limited vegetation cover. These cracks were observed extending further south than the main tension crack. The width of these cracks ranges between 0.1 - 1.0 m;
- The condition of the rock where the main tension crack exits the bluff face is highly fractured (as shown on Figure 1b, Appendix A) and there are several blocks of 1—8 m^3 considered to be potentially unstable;
- A ‘choke’ of large boulders is present within the the main tension crack where it exists the face at the south western end. There is a large boulder, approx. 8 m^3, which has detached from the other boulders and sits precariously on the edge of the bluff in this location. Survey monitoring point 0 was set up on this boulder, see Photograph 2.2 below;
- There is significant evidence of historic and recent rock fall. Widespread rock debris is present on the slopes between the road and the bluff and comprises boulder sizes ranging from 0.1 – 3.0 m in diameter (see photograph 2.1 below). In many cases smaller boulders have come to rest against the small scrubs or larger boulders, suggesting recent failure. The debris on the surface is loose and close to angle of repose at 35 - 40 degrees;

Photograph 2.1 – Showing the rock fall debris on the slopes above the road and below the main tension crack and monitoring locations.

- The rock face is overhanging in several locations. The most significant rock overhang location is assessed to be below monitoring points 1, 2 and 3 as shown on Figure 1b, Appendix A, and Photograph 2.2 below. Here the rock appears to be overhanging by 3 - 5 m;
- In general the bluff face shows signs of ongoing rock fall and fretting with non-uniform weathering and colouring at locations where blocks have dislodged;
- The slopes beneath the bluff are expected to be a historic landslide. The bluffs themselves form the back-scar (up-slope extent) of the landslide movement. The landslide extends downslope from the bluffs, beneath the Glenorchy –Queenstown Road and to the lake below. The toe of the landslide is not well defined and may be below lake level.



Photograph 2.2 – Showing the location of the overhanging rock with other features.

- The location and details of the identified tension cracks behind the crest of the bluff are shown on Figure 1a, Appendix A. Further inspection of the surrounding area identified a smaller tension crack extending further to the south of the main tension crack although these cracks have only displaced approximately 100 mm;
- Evidence of rock fall extending to the road and beyond is highly evident along the road length in this area as shown in photograph 2.3 below;

Photograph 2.3 – Showing many large boulders between 150-200 m away from the bluff adjacent to the road.

2.2.2 Summary

The following summary is provided:

- Significant movement of the bluff face has occurred.
- The failure mechanism is expected to be toppling, possibly with some component of downslope creep associated with the landslide;
- Total movements of approximately 2.5m+ for the main tension crack, and further movement of < 1.0m for the parallel upslope crack can be observed for a length of 100m+;
- The movement is in a north –westerly direction, downslope and towards the Glenorchy-Queenstown Road present a short distance below;
- The bluffs are interpreted to be the back-scar (up-slope extent) of a large historic schist landslide feature, and the tension cracks represent the up-slope regression of this instability;
- Accurately dating the movement is not possible however is expect to have initiated following the removal of ice support, approximately 12,000 years ago. The feature would then have been subject to ongoing stress and further movement in response to seismic and extreme weather events from then until the present day.
- The north eastern end of displaced bluff face is thin (<1.0m), fractured, and visually appears very susceptible to future movement;
- An area of boulders at the south western end of the main crack, and the general rock face in this area, also appear to be susceptible to instability in the short term.
- Low levels of ground creep of the landslide downslope of the bluffs may be occurring. Movement rates would typically be in the order of < 10 mm/yr on average for such features. This magnitude of movement rate would have gradual weakening effect on the bluff above.

2.3 Survey Monitoring

2.3.1 General

Intermittent survey monitoring of the main tension crack and large detached boulder at the south western end of the crack has been completed by Aurum Survey Consultants since 2012. Table 2.1 below shows the completed survey dates.

Table 2.1 – Survey monitoring dates of tension cracks and large detached boulder.

Completed Monitoring Dates
19-Jun-12
19-Jul-12
20-Aug-12
19-Sep-12
19-Nov-12
19-Jan-13
19-Mar-13
28-Jun-13
27-Jun-14
2-Mar-17

A total of 11 monitoring points and 3 control points were established, the locations are shown on Figure 1b, Appendix A.

The purpose of each of the monitoring points is as follows:

- Monitoring point 0 – Monitoring movement of the large detached boulder;
- Monitoring point 1-8 – Monitoring the ground movement at the main tension crack;
- Monitoring point 9-11 – Monitoring the ground movement at the second tension crack.

The control points were constructed by driving a steel tube with a sledge hammer down through the overburden to key into the underlying rock. The monitoring points comprise natural features identified on the rock face.

The surveys were completed by using a laser theodolite to survey the monitoring points over 3 different stations. These were then triangulated against the 3 control points to eliminate as much error as possible. The accuracy of the surveying is approximately 10 mm (i.e within +/- 5 mm) in both the vertical and horizontal directions. The accuracy of the calculated total displacement (i.e vector length) is 17 mm.

2.3.2 Monitoring Pin 0 (Large Detached Boulder)

Monitoring point 0 is on a large detailed boulder present at the south western end of the main tension crack. The results for monitoring point 0 are presented in Figures 2.1, 2.2, 2.3 and 2.4 below. The full tabulated results are presented in Appendix B.

In summary, there has been definitive movement of the boulder in a downhill direction with the monitoring point moving a total distance of 125 mm over the 5 year monitoring period.

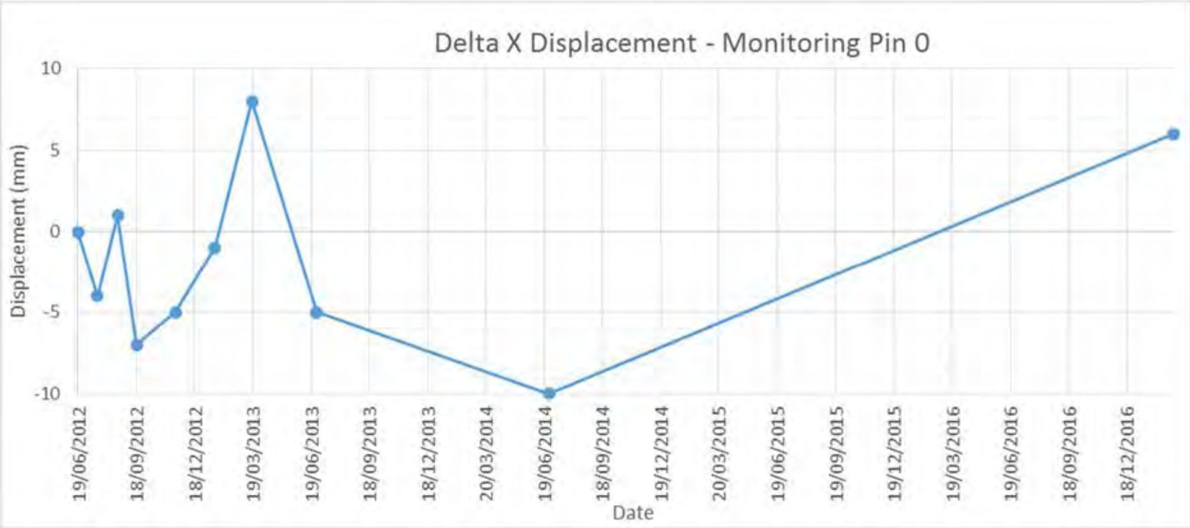


Figure 2.1 – Showing the displacement of monitoring point 0 on the x axis (i.e –left or +right on a horizontal plane when facing downhill)

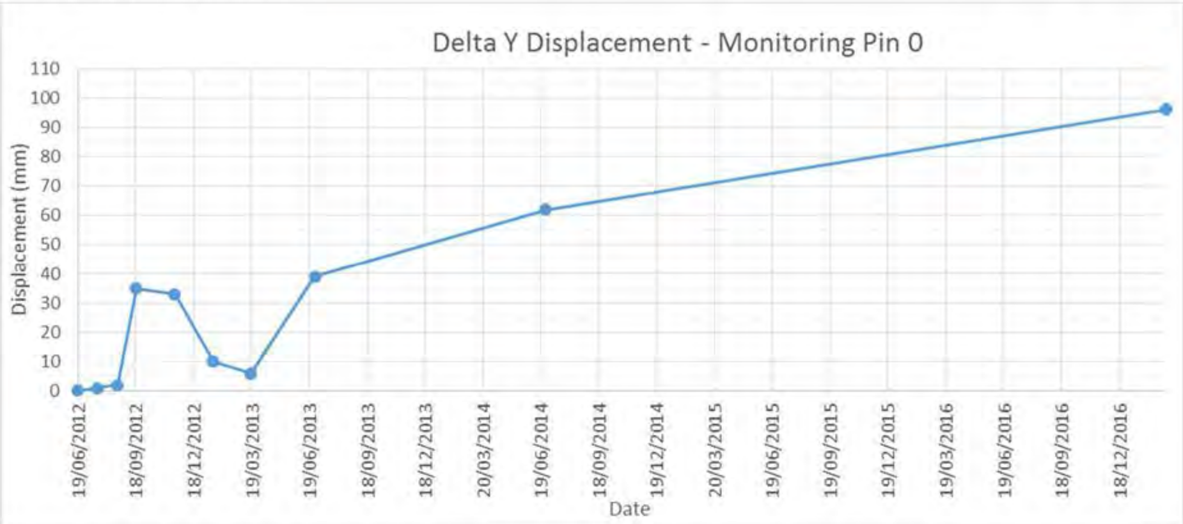


Figure 2.2 – Showing the displacement of monitoring point 0 on the y axis (i.e –backwards or +forwards on a horizontal plane when facing downhill)

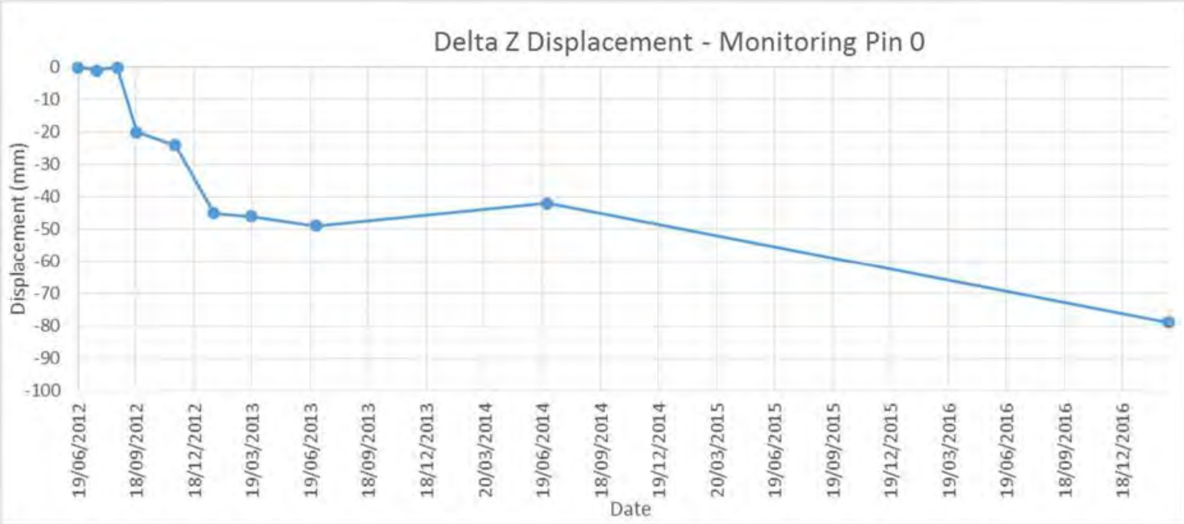


Figure 2.3 – Showing the displacement of monitoring point 0 on the z axis (i.e –down or +up on a vertical plane)

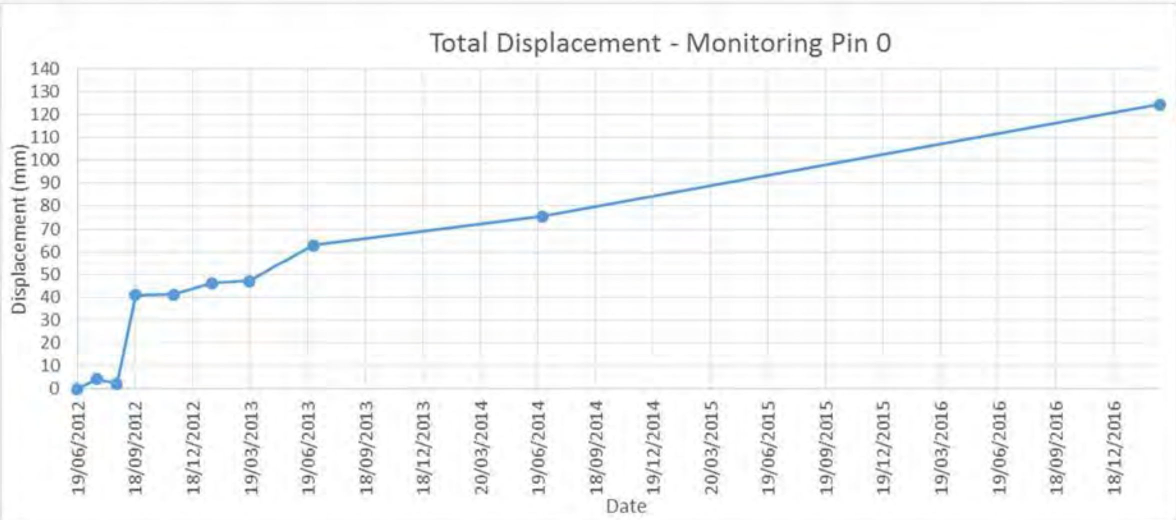


Figure 2.4 – Showing the total displacement (i.e vector length) of monitoring point 0

2.3.3 Monitoring Points 1-8 (Main Tension Crack)

The results of the monitoring for monitoring points 1-8 are presented in Figures 2.5, 2.6, 2.7 and 2.8 below. The full tabulated results are presented in Appendix B.

In summary, the spread of the results within the first year of monitoring are within the accuracy of the survey equipment and therefore not conclusive. The total spread increases at the next survey completed a year later and then again nearly 3 years later. The direction of the movement for the monitoring pins does not generally remain consistent between the monitoring dates. A clear trend of movement cannot be interpreted from the results in any of the three orthogonal directions. Overall displacements are low (<15 mm) and the increase of the total spread overtime is assessed to result to a decay of the survey points and natural processes such as freeze-thaw etc.

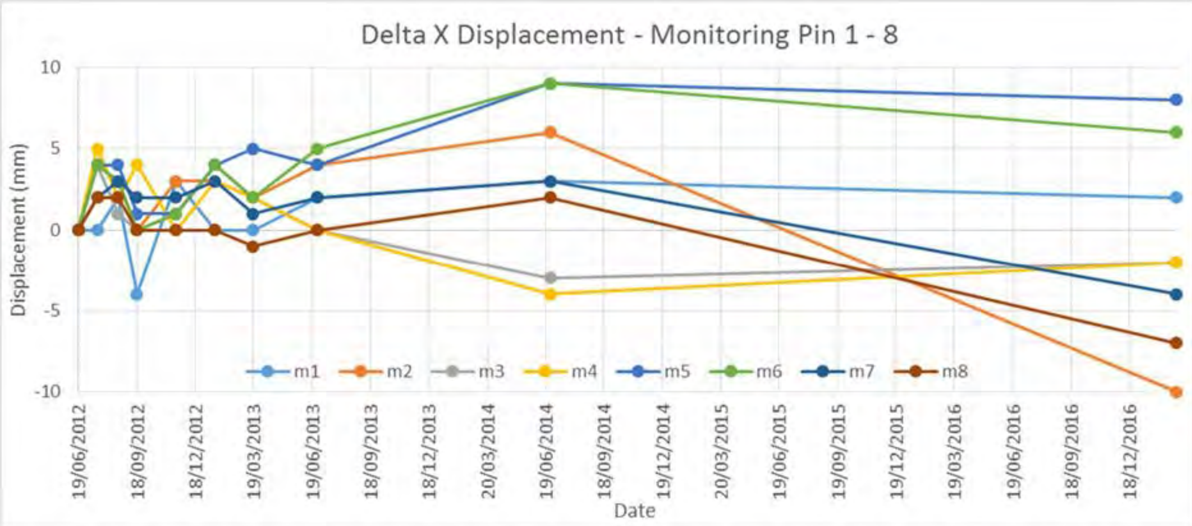


Figure 2.5 – Showing the displacement of monitoring points 1-8 on the x axis (i.e –left or +right on a horizontal plane when facing downhill).

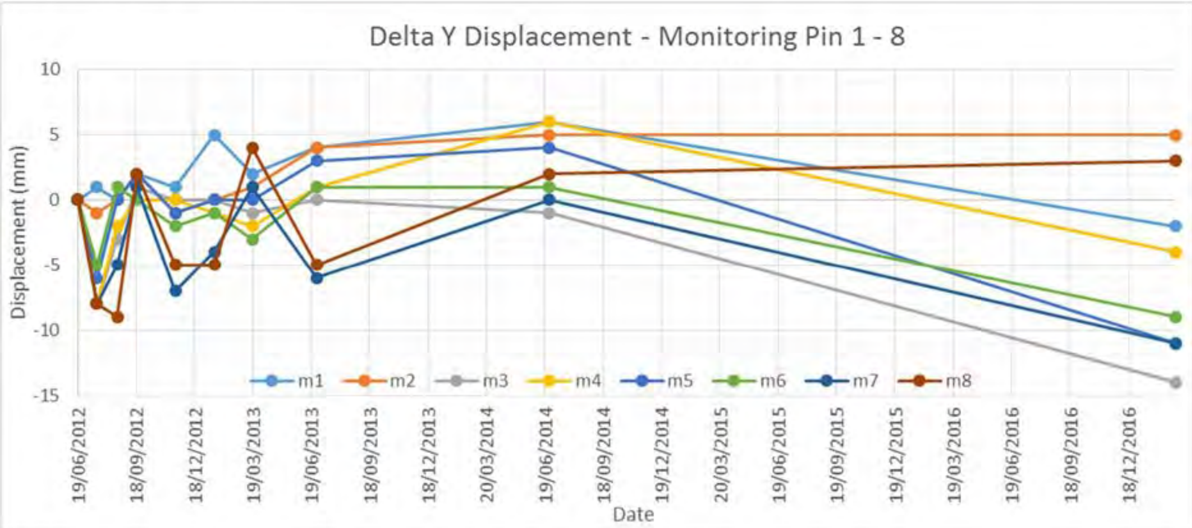


Figure 2.6 – Showing the displacement of monitoring points 1-8 on the y axis (i.e –backwards or +forwards on a horizontal plane when facing downhill).

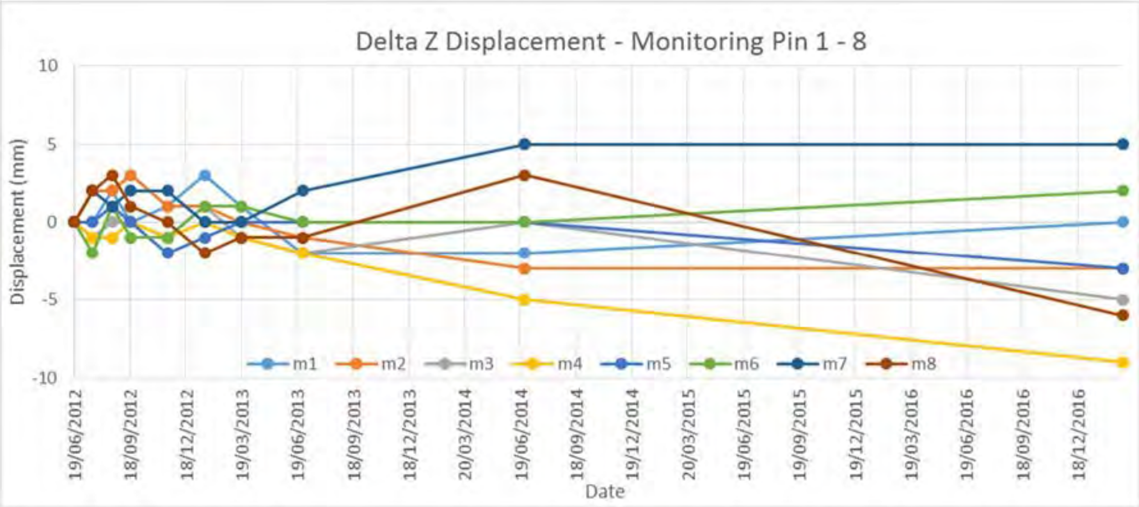


Figure 2.7 – Showing the displacement of monitoring point 1-8 on the z axis (i.e –down or +up on a vertical plane).

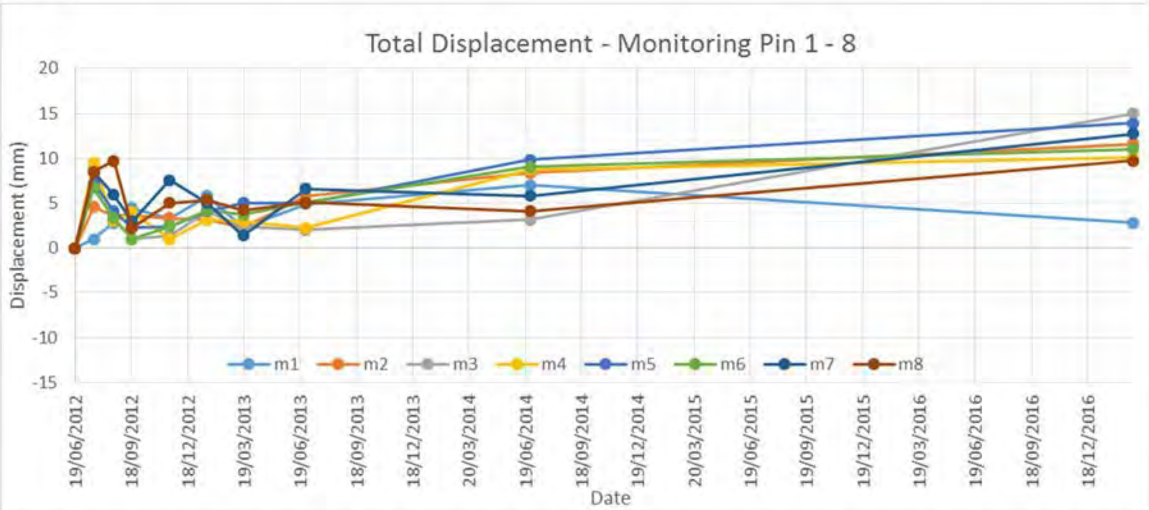


Figure 2.8– Showing the total displacement (i.e vector length) of monitoring points 1-8.

2.3.4 Monitoring Points 9-11 (Second Tension Crack)

The results of the monitoring for monitoring points 9-11 are presented in Figures 2.9, 2.10, 2.11 and 2.12 below. The full tabulated results are presented in Appendix B.

In summary, the monitoring results are within the accuracy of the survey equipment with the exception of monitoring point 11 on the y axis for which movement of 15 mm was recorded on the final survey. It is unclear what the cause of this movement is, however, it is inferred to be a result of local weathering/damage to the monitoring point given that no other points show similar movement.

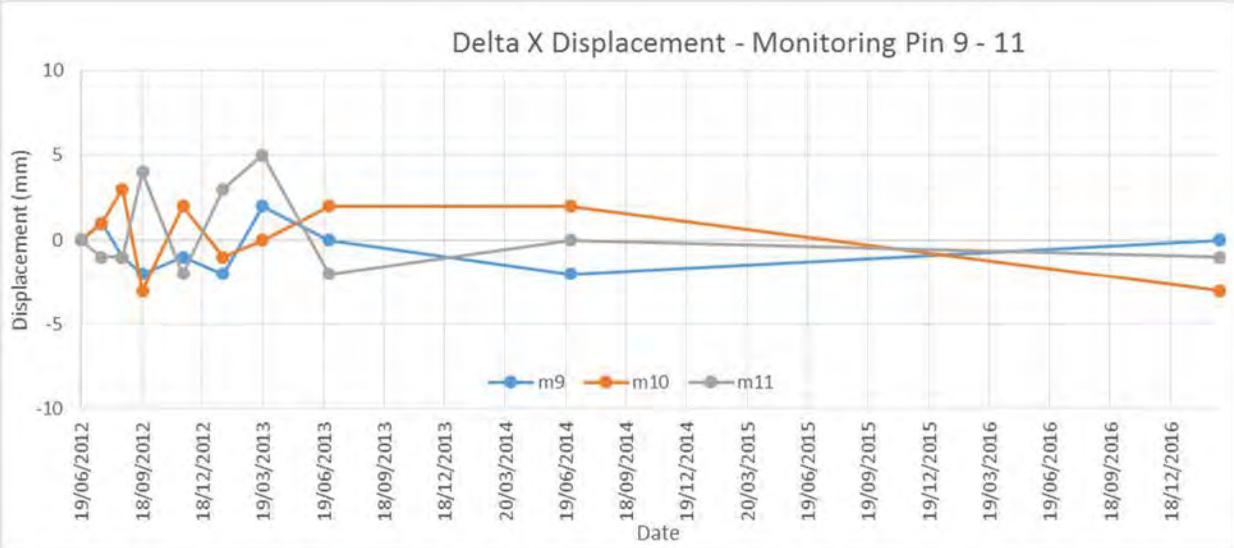


Figure 2.9 – Showing the displacement of monitoring points 9-11 on the x axis (i.e –left or +right on a horizontal plane when facing downhill).

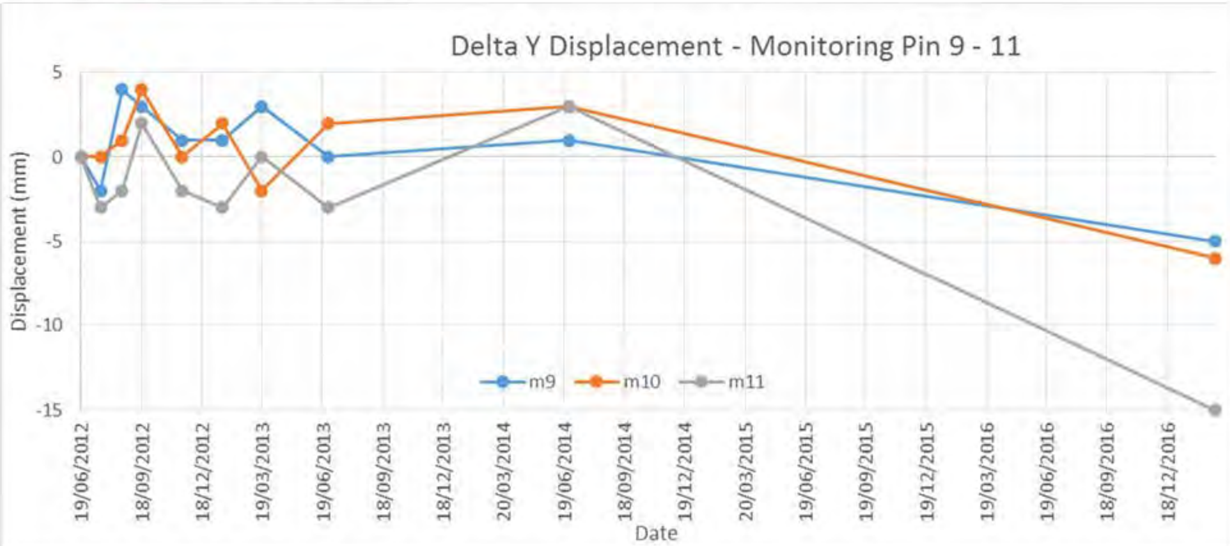


Figure 2.10 – Showing the displacement of monitoring points 9-11 on the y axis (i.e –backwards or +forwards on a horizontal plane when facing downhill).

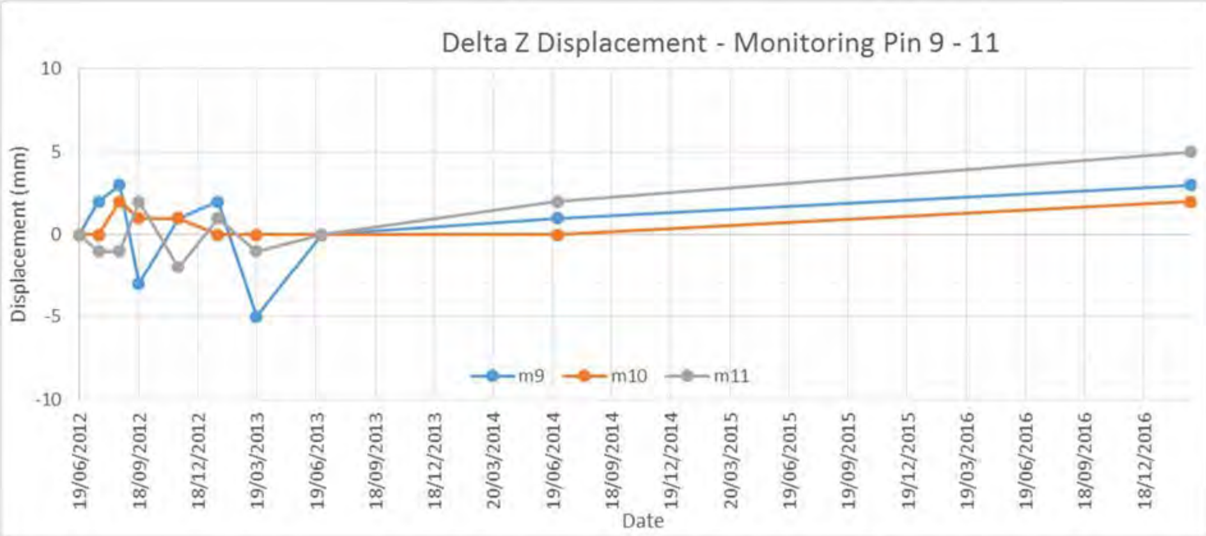


Figure 2.11 – Showing the displacement of monitoring point 9-11 on the z axis (i.e –down or +up on a vertical plane).

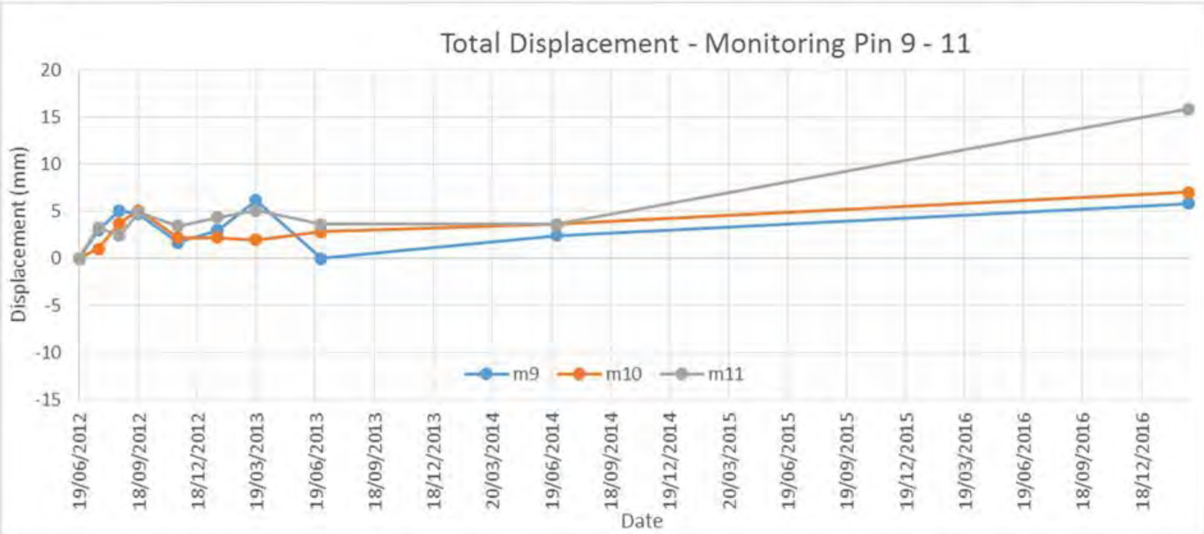


Figure 2.12– Showing the total displacement (i.e vector length) of monitoring points 9-11.

2.3.5 Summary

The following conclusions are provided from the monitoring results:

- No significant movement, or trend of movement, has been identified for the main tension crack;
- The isolated boulder, present where the main tension crack exits the face at the south western end (Monitoring Point 0) exhibits clear movement both away from the face and in a downslope direction.

Since monitoring began there have been several small seismic events in the Southland and Otago regions however none have resulted in significant ground shaking in the Wakatipu area. The movement rates presented above are therefore assessed to be largely representative of the movement rates expected during typical (non-seismic) conditions.

3 Terminology and Hazard/Risk Assessment Structure

3.1 General

Information from the site mapping and surveying indicates a more formal risk assessment of the identified areas of instability is warranted, and is provided below. New Zealand does not have its own formal system for assessing landslide/rock fall risk. However, the methodologies outlined by the Australian Geotechnics Society (AGS 2007[2]) is now generally followed in New Zealand when a quantitative or qualitative assessment is required. The methodology of AGS 2007 has been adopted for this study.

3.2 Terminology

The technical jargon associated with landslide risk terminology can be confusing to unexperienced stakeholders (e.g landowner, regulators, insurers etc) and with no formal New Zealand framework there can variance of interpretations of terms. For the purpose of this report we have adopted the following definitions of the terms:

Hazard – A condition with the potential for causing an undesirable consequence (e.g the landslide or rock fall). Generally comprising the landslide characteristics e.g. location, volume/area, classification and velocity and any resultant detached material, and the probability or likelihood of their occurrence within a given period of time.

Risk – A measure of the probability and severity of an adverse effect to health, property or the environment. Risk is often estimated by the product of probability x consequences. However, a more general interpretation of risk involves a comparison of the probability and consequences in a non-product form.

In general, the hazard relates to the likelihood of the landslide/rock fall occurring and its characteristics, whereas risk relates to the outcomes of such an event should it occur and the expected loss typically in terms of life, property and environment.

Additionally, probabilities in this report are generally presented in scientific notion (e.g. $1x10^{-6}$) which is sometimes best understood in other notions. Table 3.1 below provides the equivalent numerical values in a range of notions typically adopted for the reader's information purposes only.

[2] Australian Geomechanics Society. 2007. Landslide Risk Management. Australian Geomechanics, Vol. 42, No. 1 March 2007.

Table 3.1 - Equivalent numerical values in a range of notions

Scientific Notion	Proportional Notation	Decimal Notation	Percentage Notation
10^{-1}	1 in 10	0.1	10%
10^{-2}	1 in 100	0.01	1%
10^{-3}	1 in 1,000	0.001	0.1%
10^{-4}	1 in 10,000	0.0001	0.01%
10^{-5}	1 in 100,000	0.00001	0.001%
10^{-6}	1 in 1,000,000	0.000001	0.0001%
10^{-7}	1 in 10,000,000	0.0000001	0.00001%

4 Hazard Assessment

4.1 General

The investigations and monitoring as detailed above have identified the following hazards:

- Rock fall – General/minor fretting of the rock bluff which is within close proximity to the road;
- Rock fall – Several larger blocks generally between 1- 8 m^3, located within the highly fractured zone where the main tension crack exits the bluff face at its south western end. These blocks are either fractured, have detached, are overhanging, and/or have adversely oriented defects.
- Toppling failure – Large volume structural failure of the bluff face from the main tension crack outwards in a north westerly direction.

Minor fretting of the rock bluff is not going to be assessed as this level of small scale failure is not considered a significant risk. Larger rock fall and large volume toppling failure are assessed below.

4.2 Rock Fall

4.2.1 Probability of failure and volume

The debris slope beneath the bluff contains several large boulders, and numerous smaller boulders, indicating historic instability, and recent rock fall activity.

The large boulder which is being monitored at monitoring point 0 is moving in a downslope direction (by 125 mm over the last approx. 5 years), and without remedial work to secure this block it is expected that this block may dislodge within the next 5-10 years if the movement trend continues.

There are several blocks observed that would almost definitely dislodge under a large seismic event e.g. rupture of the Alpine Fault or a smaller more local earthquake e.g. within the Fiordland region.

We estimate that at least one rock fall will occur within the next 5 years (i.e. an annual probability of 2 x 10^{-1}). Additionally, one or more blocks would be expected to detach during an Alpine Fault rupture, which currently has an annual probability of failure of 1% (i.e 1 x 10^{-2}) per annum, note this probability increases with every year that passes without rupture.

For the purpose of the preliminary assessment of existing conditions we have assumed a 2 x 10^{-1} probability of a large boulder release.

Generally block size is in the order of 1-8 m^2. The observed blocks considered to have the highest probability of failing are in the 4-8 m^3 range.

4.2.2 Run out and spatial impact area

A 3D statistical rock fall analysis has been undertaken to confirm the likely rock fall run-out and impact area beneath the inferred block release zone using rock fall analysis software RAMMS (Rockfall).

A total of 85 rock fall scenarios were analysed comprising 8 different blocks ranging between 0.5 to 8.0 m^3. These blocks were released at a number of randomly generated orientations. The trajectories of the rock falls is shown on Figure 4.1 below.

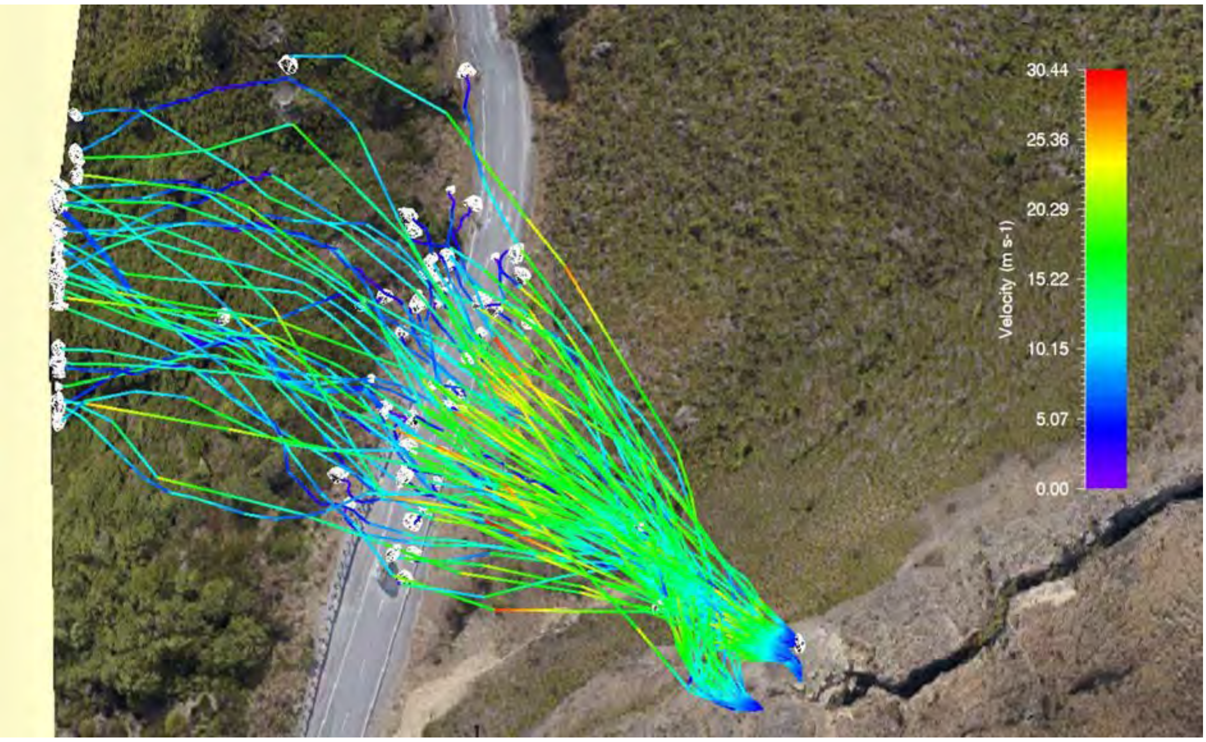


Figure 4.1 – Showing the predicted trajectories of the subject rock falls.

The results of the analysis show that approximately 13% of the blocks did not reach the road, remaining on the slope above. The probability of the rocks impacting the 70 m length of road is assessed to be 87%.

4.3 Toppling Failure

4.3.1 Probability of failure

Assessing the probability of failure of the main bluff is problematic. Some factors which remain unknown and cannot be determined with accuracy include:

- The depth of the tension cracks;
- The location and orientations of rock defects beneath the surface;
- Performance during the last alpine fault event;
- Time and trigger of the last significant movement, and overall movement history;
- The possible impact of slow creep movement of the downslope landslide.

The tension crack survey monitoring results suggest the bluff face is relatively stable during typically daily conditions, with no ongoing movement detected over the monitoring period.

It is uncertain what period of time the main tension crack has been at its current width and if any progression of movement occurs with alpine fault events, i.e. approximately every 300 years or so, or at shorter intervals.

A failure could range from the release of individual blocks, a narrow length of the tension crack, or a broad failure comprising the full length of the tension crack.

Creep movement of the downslope landslide could gradually reduce the stability of the bluffs until a ‘tipping point’ is reached, resulting in failure during typical daily (non-seismic) conditions.

The most at risk area is considered to be the north-eastern end of the main tension crack which comprises an approximately < 1.0 to 3 m wide rock column 10-20 m in height.

Based on our site observations, we believe that there is a high probability of at least partial failure of the rock mass. Without having a better understanding of the rock mass and landslide history for the purposes of this assessment we have assumed the full length of the main tension crack will fail during the next Alpine Fault event (i.e 1×10^{-2}) resulting in a large rock avalanche or progressive failure and rock falls during the earthquake with a duration of 2-3 minutes.

In terms of volume, as a first estimate, the failure could result in rapid mobilisation of 1,000 – 10,000 m^3 (2,700 to 27,000 tonnes) of rock.

4.3.2 Run out and spatial impact area

A total of 280 rock fall scenarios were analysed comprising 8 different blocks ranging between 0.5 to 10 m^3. This assumes the rock will readily break up on the slopes above the road. These blocks were released at a number of randomly generated orientations at points along the bluff for the length of the main tension crack. The final resting location of the blocks and the results of the analysis are presented in Figure 4.2 below.

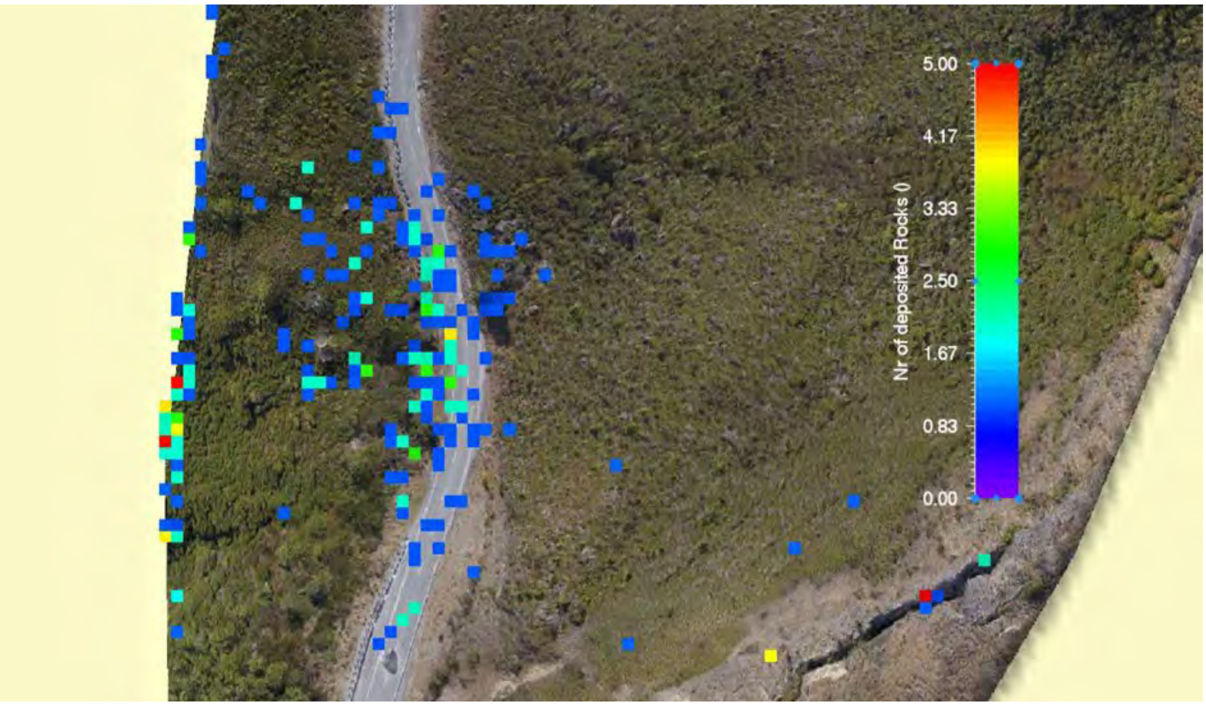


Figure 4.2 – Showing the final resting locations of the modelled rock fall blocks.

The results indicate an approximately 85% probability of reaching the road at the southern end of the main tension crack reducing to approximately 50% at the northern end.

For the purpose of this assessment we have assumed a 65% probability of 100 m length of road being effected.

5 Risk Assessment

5.1 General

The risk assessment comprises the evaluation of the risk to "life". Due to the rural setting and lack of structures beneath the area the risk to property has been excluded.

Because of 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.

This risk assessment may be considered preliminary as the mechanism of the landslide, and statistical assessment of the existing rock fall on the slopes below the bluffs, has been inferred.

The hazards used in the risk assessment are detailed in Section 4, and include individual rock fall from the south eastern end of the tension crack, and a large scale toppling failure of the bluff face.

5.2 Loss of Life

5.2.1 General

Loss of life, is the annual probability of the "person most at risk" being killed either by landslide or rock fall. 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:

$$R_{(LoL)} = P_{(H)} \times P_{(S:H)} \times P_{(T:S)} \times V_{(D:T)}$$

Where:

$R_{(LoL)}$ is the risk (annual probability of loss of life (death) of an individual.

$P_{(H)}$ is the annual probability of the landslide.

$P_{(S:H)}$ 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.

$P_{(T:S)}$ 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.

$V_{(D:T)}$ is the vulnerability of the individual (probability of loss of life of the individual given the impact).

Additionally, if the possible loss of large numbers of lives from a landslide incident is high, society will generally expect that the probability that the incident might actually occur should be low. This accounts for society's particular intolerance to incidents that cause many simultaneous casualties. This can be referred to as societal risk and is assessed in terms of F-N plots where F is frequency/probability of the event annually and N is the number of people killed.

5.2.2 Risk from Rock fall

A total of three different scenarios has been assessed based on the rock fall hazard scenarios described in Section 4.

The probabilities provided are for the current conditions. The associated probabilities will be reduced by several orders of magnitude if the proposed remedial works are completed.

The assumptions and results of these assessments are presented below.

<u>Person most at risk</u>

- A person living in Glenorchy who travels to Queenstown and back (or vice versa) once a day every day of the year is assumed to be the most at risk person;
- The boulder size is 8 m^3;
- The length of the car is 5 m and travels at a velocity of 70 km/hr through the rock fall zone;
- The area of road impacted by the rock fall is 3 m wide;
- The annual probability of the rock fall occurring, and of the rock fall reaching the road is as per Section 4;
- The probability of the driver of the car being killed by the boulder impact is 0.6;

The probability of the person most at risk to lose their life annually to the subject rock fall risk based on the assumptions outlined above is <u>9.9×10^{-7}</u>.

<u>Societal Risk - Risk of someone (an individual) being killed</u>

- The AADT of the road is 1500 vehicles per day;
- The boulder size is 8 m^3;
- The length of the average vehicle is 5 m and travels at a velocity of 70 km/hr through the rock fall zone;
- The area of road impacted by the rock fall is 3 m wide;
- There is on average 2 people in the vehicle;
- The annual probability of the rock fall occurring, and of the rock fall reaching the road is as per Section 4;
- The probability of a passenger in the vehicle being killed by the boulder impact is 0.6;

The annual risk of someone being killed is <u>1.49×10^{-3}</u>. This risk is not static and will increase as the number of vehicles per day increases over time.

Societal Risk - Risk of tourist bus being hit – Multiple people killed

- A bus service operates to Glenorchy 5/7 days a week with 40 passengers;
- The length of the bus is 13.8 m and travels at a velocity of 70 km/hr through the rock fall zone;
- The boulder size is 8 m^3;
- The area of road impacted by the rock fall is 3 m wide;
- The annual probability of the rock fall occurring, and of the rock fall reaching the road is as per Section 4
- The probability of someone being killed on the bus by the boulder impact is 0.1.

There is a 2.48×10^{-6} annual risk of 4 people being killed. The number of people killed is shown as an example only.

5.2.3 Risk from Large Scale Toppling Failure of the Bluff

A total of three different scenarios have been assessed based the toppling failure hazard as described in Section 4.

The probabilities provided are for the existing conditions.

The assumptions and results of these assessments are presented below.

Person most at Risk

- A person living in Glenorchy who travels to Queenstown and back (or vice versa) once a day every day of the year is assumed to be the most at risk person;
- The length of the car is 5 m and travels at a velocity of 70 km/hr through the rock fall zone;
- The area of road impacted by the rock fall is 100 m long;
- The annual probability of the rock fall occurring, and of the rock fall reaching the road is as per Section 4;
- The probability of the driver of the car being killed by boulder impact is 1;

The results of the risk assessment for the most at risk person based on the assumptions as outlined above is 8.2×10^{-7}.

Societal Risk - Risk of someone (an individual) being killed

- The AADT of the road is 1500 vehicles per day;
- The length of the average vehicle is 5 m and travels at a velocity of 70 km/hr through the rock fall zone;
- The area of road impacted by the rock fall is 100 m long;
- There is on average 2 people in the vehicle
- The annual probability of the rock fall occurring, and of the rock fall reaching the road is as per Section 4;
- The probability of the occupants of the vehicle being killed by the rock fall impact is 1;

The annual risk of at least one person being killed is 1.22×10^{-3}.

This risk will increase gradually as the number of vehicles per day increases over time, and as the annual probability of an alpine fault earthquake increases every year.

Societal Risk - Risk of tourist bus being hit, multiple people killed.

- A bus service operates to Glenorchy 5/7 days a week with 40 passengers;
- The length of the bus is 13.8 m and travels at a velocity of 70 km/hr through the rock fall zone;
- The area of road effected by the rock fall is 100 m long;
- The annual probability of the rock fall occurring, and of the rock fall reaching the road is as per Section 4
- The probability of someone on the bus being killed by the impact is 0.8.

There is a 6.3×10^{-7} annual risk of 32 people being killed. The number of people killed is shown as an example only.

5.2.4 Summary of Loss of Life Risk Assessment

The results of the loss of life risk assessment are summarised in Table 5.1

Table 5.1 – Summary of loss of life risk assessment results.

Instability	Person most at risk	Societal Risk (individual)	Societal Risk (multiple)
Rock Fall	9.9×10^{-7}	1.49×10^{-3}	2.48×10^{-6}
Large Bluff Failure	8.2×10^{-7}	1.22×10^{-3}	6.3×10^{-7}

5.3 Property Risk

No buildings or other structures are present beneath the bluffs and so a property risk estimate (property loss risk) is not considered appropriate. The road is however present, and some damage to the surface would be expected in the event of a large rock fall. In addition, any blockage will have a knock on effect to commercial use of the road, particularly for Glenorchy.

5.4 Tolerable/Acceptable Risk Guidelines

5.4.1 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.

It should be noted the suggested values below are for “tolerable” risk. “Acceptable” risks are usually considered to be one order of magnitude lower than the “tolerable” risks.

5.4.2 Loss of Life

5.4.2.1 Individual Person Most at Risk

Examples of acceptable and tolerable risk from a number of organisations are provided in Table 5.4 below.

Table 5.4 - 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 5.5 below.

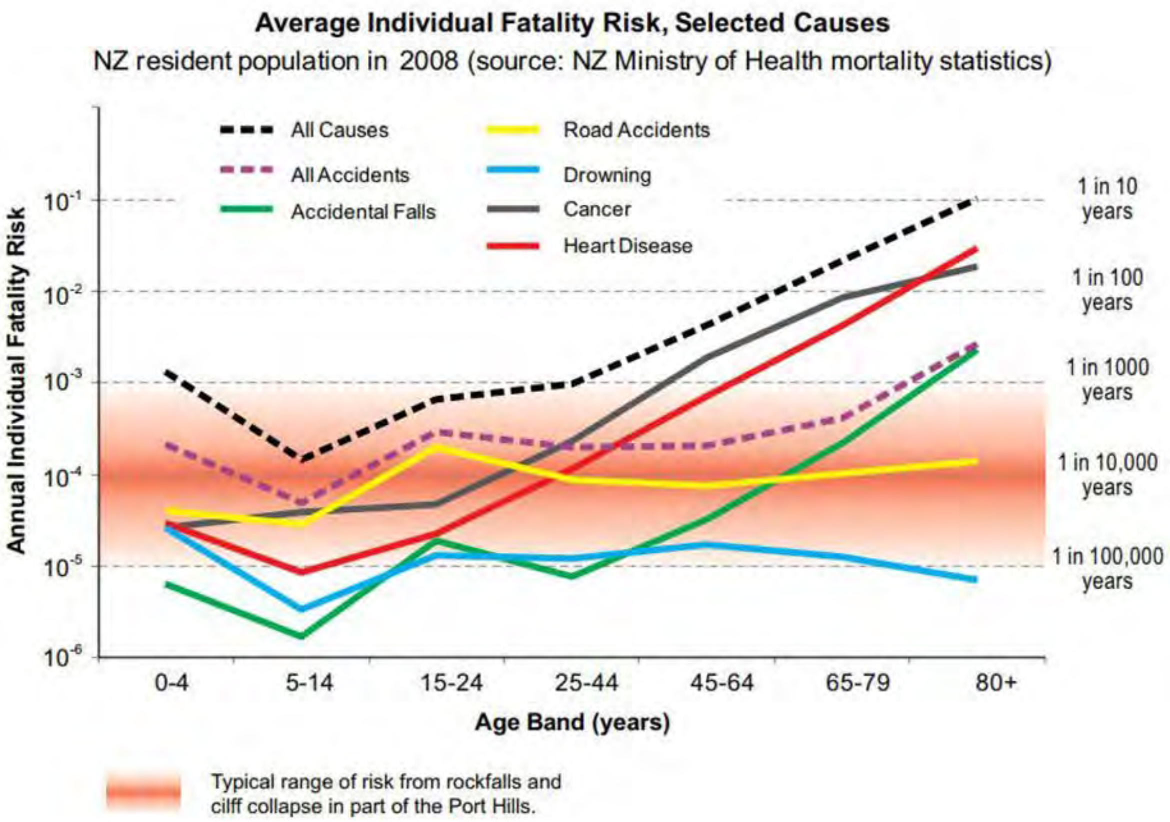
Table 5.5– AGS suggested tolerable loss of life individual risk.

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

In this case, the loss of life risk for the person most at risk as calculated in the previous sections is below all the published loss of life risk criteria above at a range of 8 x10^{-7} to 9.9 x 10^{-7}.

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 5.1 below shows the risk of fatality from a number of sources.

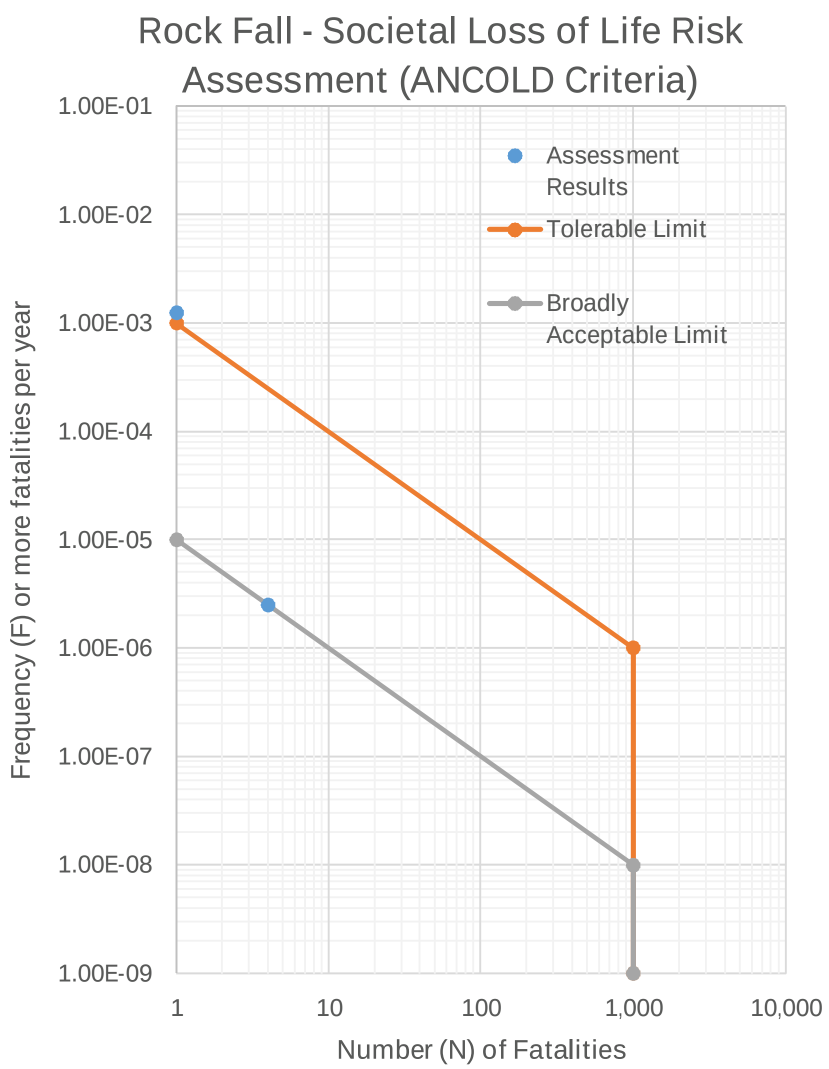
Figure 5.1 – Showing the average individual fatality risk from multiple causes (source: GNS)



5.4.2.2 Societal Risk

The risk tolerable limits for societal risk are much less well documented as they are typically more complex and sensitive in nature then individual risk. AGS 2007 recommends that the Australian National Committee on Large Dams (ANCOLD)[3] criteria be adopted for assessing tolerable societal risk.

The results of the societal loss of life risk for both hazards (rock fall and large toppling failure) has been plotted against the ANCOLD criteria and are presented on Figure 5.2 and 5.3 below.



[3] Australian National Committee on Large Dams (ANCOLD). 2003, *Guidelines on Risk Assessment*.

Figure 5.2 – Societal loss of life assessment results for 1 person and 4 people plotted against the ANCOLD criteria for the rock fall hazard

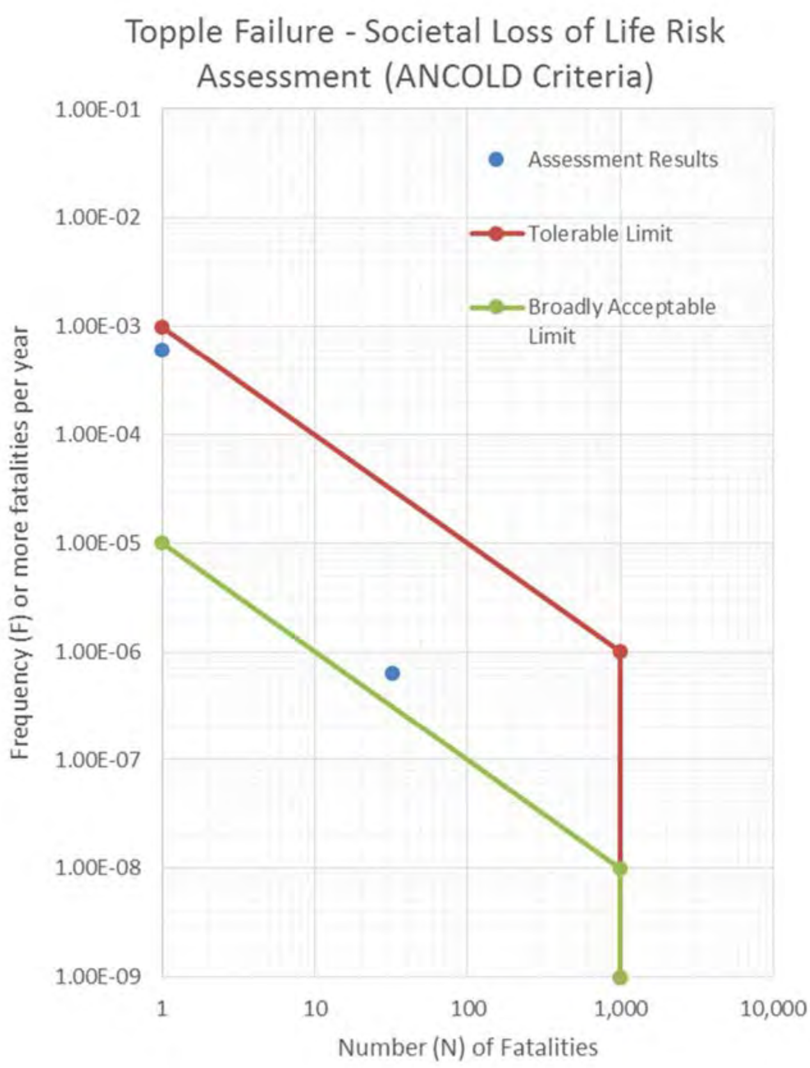


Figure 5.3 – Societal loss of life assessment results for 1 person and 32 people plotted against the ANCOLD criteria for the toppling failure hazard.

Figures 5.2 and 5.3 indicate for the individual person the societal loss of life is shown to be very close to the tolerable limit, being just over this limit for rock fall, and just under it for large scale bluff failure. For multiple people the societal loss of life is shown to be very close to the broadly acceptable limit.

To put this into some context, a range of F-N curves based on statistical observations (not the acceptable or tolerable thresholds) for man-made and natural risks has been assessed by Proske 2004 and is shown on Figure 5.4 below.

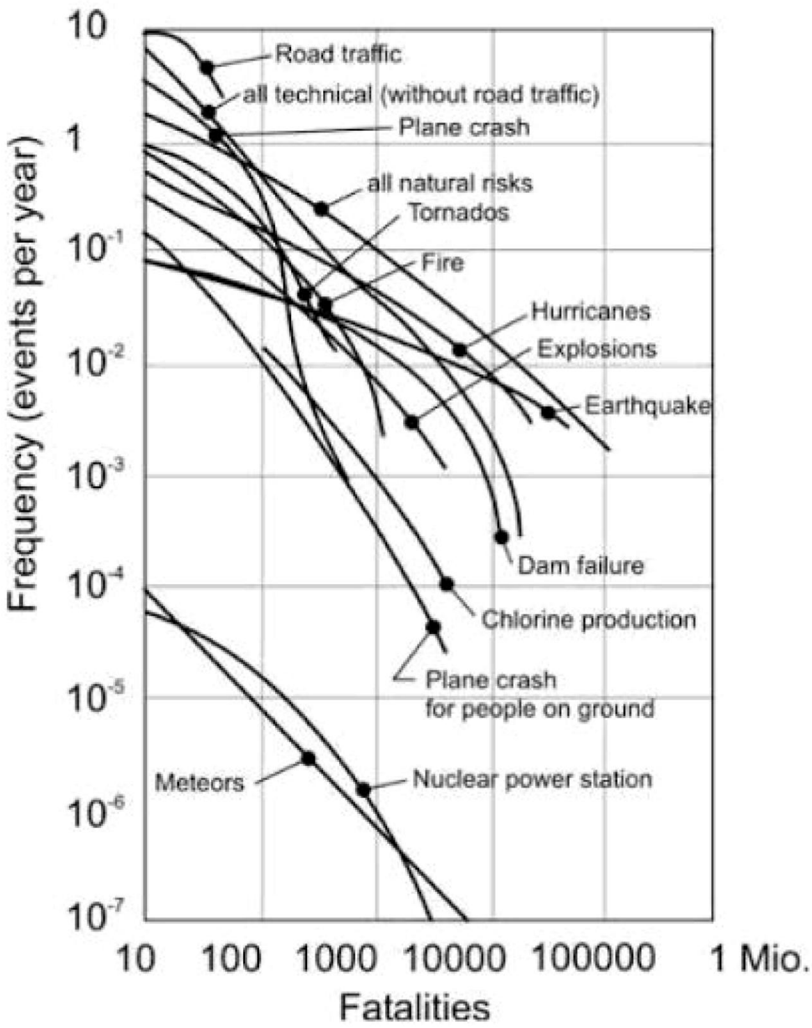


Figure 5.4 - F-N curves of statistical observations (not the acceptable or tolerable thresholds) for a range of man-made and natural risks.

6 Discussion and Recommendations

General Rock Fall

We recommend that the identified loose boulders and blocks be scaled and that any loose blocks removed or secured by rock bolts and/or mesh where required, notably at the south western end of the tension crack. This will improve the risk of loss of life to levels that are typically acceptable. As a minimum the boulder on which monitoring point 0 is located should be stabilised.

The area directly beneath this area of the bluff should be designated a “no stopping zone” with signs and/or barriers erected to this affect.

Large Scale Toppling/Rock Fall Failure

The remedial options available to reduce the risks associated with large scale failure of the bluffs and of a large rock fall are limited. In general, if the risks for this failure are considered unacceptable, then the following actions should be considered:

- Avoid the risk: move the road and infrastructure away from the hazard;
- Reduce the frequency of an event: undertake stabilisation or removal works at the rock fall source;
- Reduce the consequences of an event: install defensive measures downward of the rock fall source to protect the road, people and infrastructure;
- Manage the risk: install monitoring, warning systems, signage;
- Accept the risk: take no action;
- Postpone the decision: where there are significant uncertainties, undertake additional studies to reduce the uncertainties.

<u>Avoiding the risk</u> would comprise moving the road to an alternative route. This is unlikely to be practical due to the topography up and downslope.

<u>Reduce the frequency of an event</u> would be achieved by stabilisation or removal of the bluff face/tension crack area. This would be a significant technically challenging project with very high costs.

- Stabilisation of the tension crack is likely to involve the progressive installation of anchors and backfilling of the crack with concrete from the bottom up. Anchors would need to be of a considerable length and strength and high volumes of concrete would be needed. Several safety issues would need to be overcome and may preclude this option i.e. it is not currently thought that anchors could be drilled through the north-eastern extents of the bluff due to safety concerns and the risk of drilling inducing failure in this area.
- Removal of the bluff face could be completed and would require explosives. There would be inherent risk in inducing a failure that is larger than expected and impact on the downslope area would be likely. Rock fall could damage and block the road, protection measures and a significant clearance program would be required. Staged/progressive or partial removal may be feasible.

Reduce the consequences of an event by protecting the road and road users would involve the installation of measures downslope, e.g. an earth embankment constructed along the upslope side of the road where rock fall is expected. Detailed analysis and design would be required to size the embankment but it may need to be 4-8 m wide at the base and in the order of 4-6 m high. Since the road is cut into the slope the design bounce height and associated height of the embankment might be significant. There is currently no space beside the road to construct this option.

A catch fence is generally suitable for individual rock fall and it is not currently thought that a catch fence could be designed to tolerate multiple simultaneous large volume impacts associated with failure of the bluff face.

Managing the risk is recommended as a minimum protection measure. If a few hours or days' notice of a failure can be achieved then the risk to road users can be controlled.

Several options are available to monitor the crack e.g. the installation of several remote precision extensometers which automatically transmit data at regular intervals would be appropriate. Additionally, the system could have alarms/trigger levels if movement of a certain value e.g. 10 mm, occurs over a pre-determined time period. This alarm should be sent via email or text alert to designated council or road maintenance employees. Subsequently, we would expect GeoSolve to be contacted immediately to review the data and instruct appropriate measures.

If the tension crack begins to widen at an increased rate then prevention of failure or further movement would is unlikely to be achievable in the short term, however, with monitoring equipment in place the risk of loss of life would be greatly reduced as the road could be closed or vehicle movements controlled. Additionally, a management plan could be prepared and contractors mobilised. It should be noted that the magnitude of movement required to induce a large failure may be impossible to predict and if rapid movement occurs, such as during a large earthquake, then a manageable response would be difficult to achieve. Automatic barrier systems linked to movement levels may be feasible to control vehicle movements during a rapid failure.

Postponing the decision may be undertaken to enable a more detailed investigation and assessment to be completed. Given the nature of the site and the variables involved then obtaining meaningful data is likely to be problematic, as discussed in Section 4.3.1.

7 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.

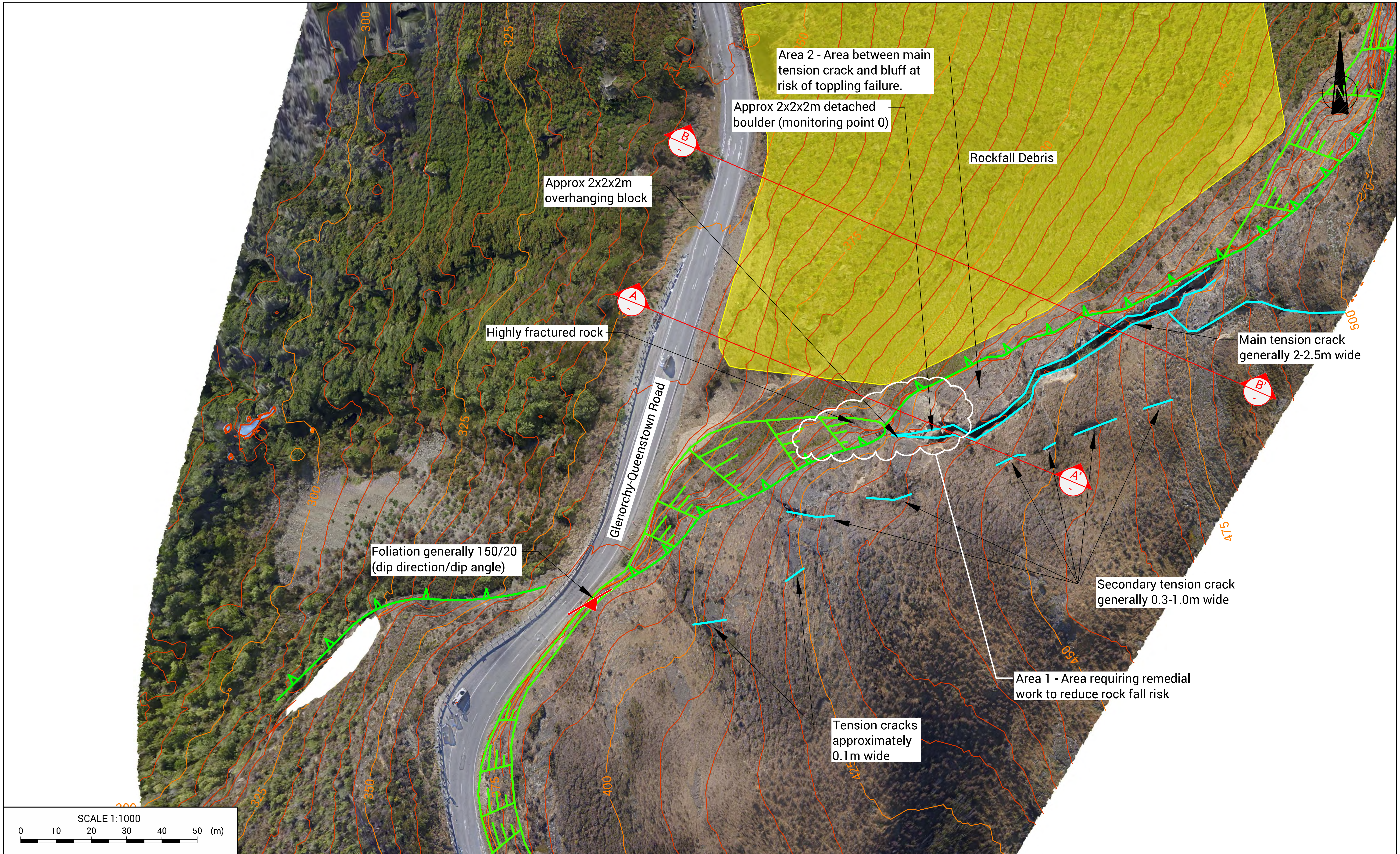
Report prepared by: Reviewed for GeoSolve Ltd by:

....

Blair Matheson
Geotechnical Engineer

Paul Faulkner
Senior Engineering Geologist

Appendix A: Site Plan & Cross-Sections



Key:

Tension Cracks

Scarp

Bluff

Bluff/Scarp

Note: Minor contours at 5m intervals, Major contours at 25m intervals.

GEOSOLVE

Level 1, 70 MacAndrew Road, South Dunedin
www.geosolve.co.nz

DRAWN	WCG	Sep.17
DRAFTING CHECKED		
APPROVED		
CADFILE: 160533.01_SP.dwg		
SCALES (AT A3 SIZE): 1:1000		
PROJECT No: 160533.01		

Queenstown Lakes District Council

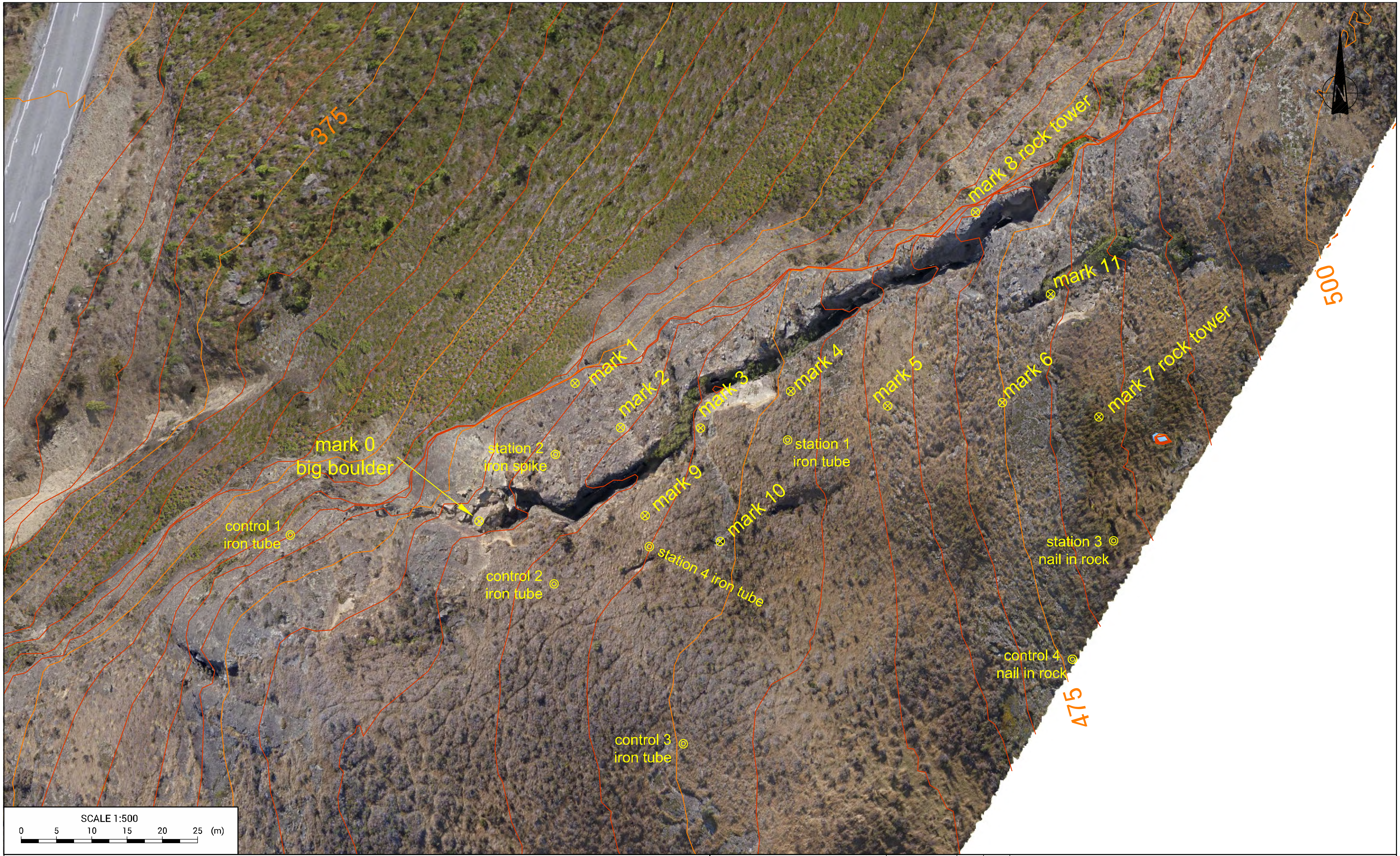
Bennetts Bluff, Queenstown-Glenorchy Road

Geotechnical Assessment

Site Plan

FIG No: Figure 1a

REV. 0



Note: Minor contours at 5m intervals, Major contours at 25m intervals.

GEOSOLVE

Level 1, 70 MacAndrew Road, South Dunedin
www.geosolve.co.nz

DRAWN	WCG	Sep.17
DRAFTING CHECKED		
APPROVED		
CADFILE: 160533.01_SP.dwg		
SCALES (AT A3 SIZE): 1:1000		
PROJECT No: 160533.01		

Queenstown Lakes District Council

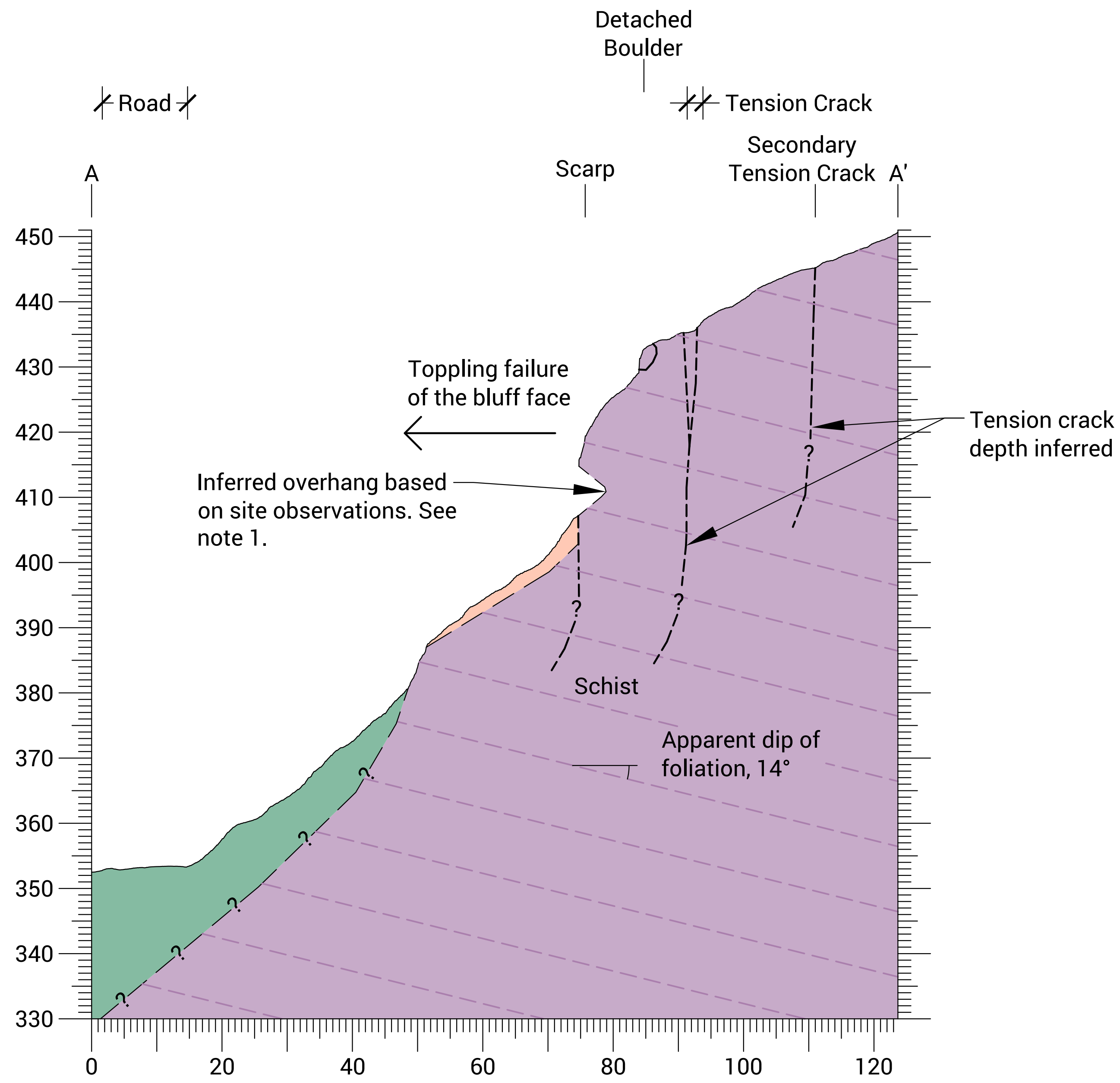
Bennetts Bluff, Queenstown-Glenorchy Road

Geotechnical Assessment

Monitoring Points Plan

FIG No: Figure 1b

REV. 0



SCALE 1:1000

0 10 20 30 40 50 (m)

Key:

- Rockfall debris
- Landslide debris
- Schist

Note: Aerial Survey data does not show overhang.

GEOSOLVE

Level 1, 70 MacAndrew Road, South Dunedin
www.geosolve.co.nz

DRAWN	WCG	Sep.17
DRAFTING CHECKED		
APPROVED		
CADFILE: 160533.01_CS.dwg		
SCALES (AT A3 SIZE): 1:1000		
PROJECT No: 160533.01		

Queenstown Lakes District Council

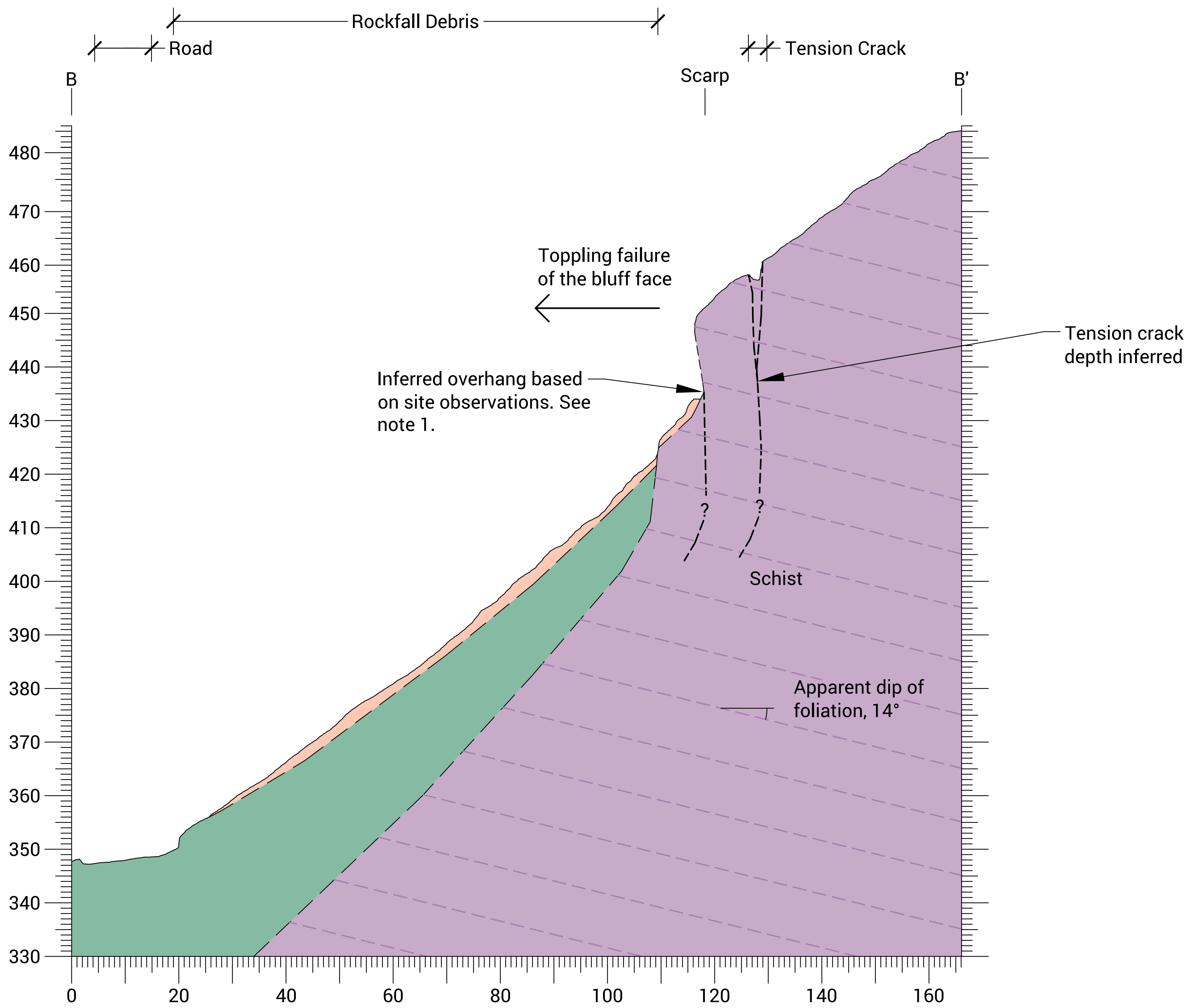
Bennetts Bluff, Queenstown-Glenorchy Road

Geotechnical Assessment

Cross Section A

FIG No: Figure 2a

REV. 0



SCALE 1:1000
0 10 20 30 40 50 (m)

Key:
- Rockfall debris
- Landslide debris
- Schist

Note: Aerial Survey data does not show overhang.

GEOSOLVE

Level 1, 70 MacAndrew Road, South Dunedin
www.geosolve.co.nz

DRAWN	WCG	Sep.17
DRAFTING CHECKED		
APPROVED		
CADFILE: 160533.01_CS.dwg		
SCALES (AT A3 SIZE): 1:1000		
PROJECT No: 160533.01		

Queenstown Lakes District Council

Bennetts Bluff, Queenstown-Glenorchy Road

Geotechnical Assessment

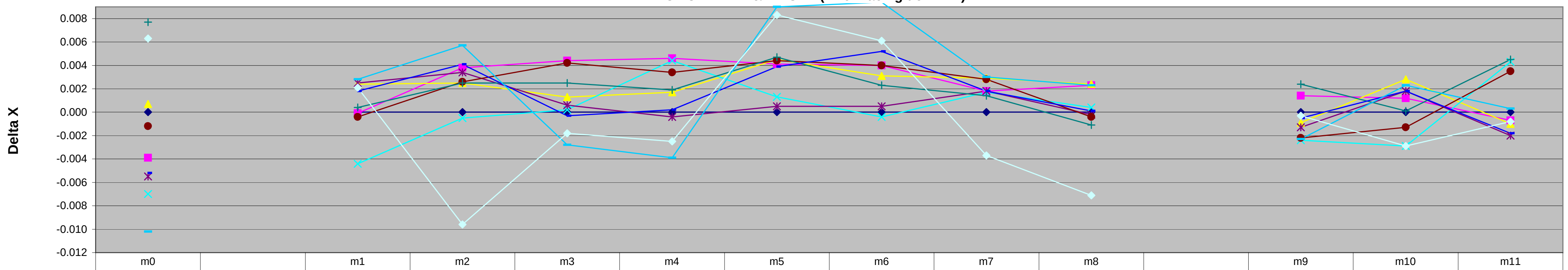
Cross Section B

FIG No: Figure 2b

REV. 0

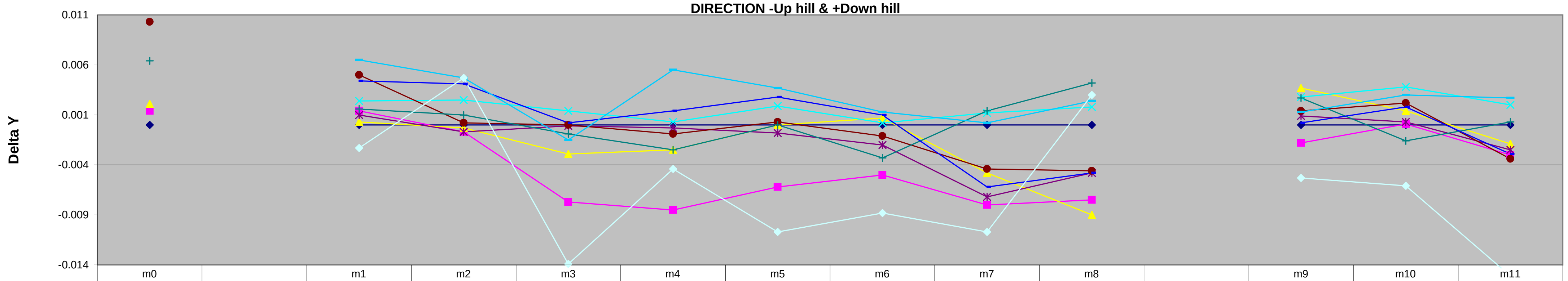
Appendix B: Survey Data

BENNETTS CLIFF MONITORING
DIRECTION -LEFT & +RIGHT (when facing downhill)



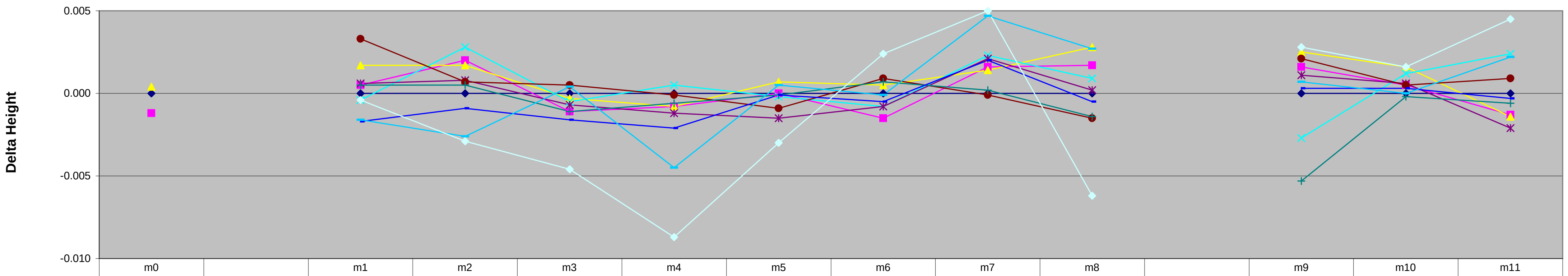
	m0		m1	m2	m3	m4	m5	m6	m7	m8		m9	m10	m11
19Jun2012	0.000		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000		0.000	0.000	0.000
19Jul2012	-0.004		0.000	0.004	0.004	0.005	0.004	0.004	0.002	0.002		0.001	0.001	-0.001
20Aug2012	0.001		0.002	0.003	0.001	0.002	0.004	0.003	0.003	0.002		-0.001	0.003	-0.001
19Sep2012	-0.007		-0.004	0.000	0.000	0.004	0.001	0.000	0.002	0.000		-0.002	-0.003	0.004
19Nov2012	-0.005		0.003	0.003	0.001	0.000	0.001	0.001	0.002	0.000		-0.001	0.002	-0.002
19Jan2013	-0.001		0.000	0.003	0.004	0.003	0.004	0.004	0.003	0.000		-0.002	-0.001	0.003
19Mar2013	0.008		0.000	0.002	0.002	0.002	0.005	0.002	0.001	-0.001		0.002	0.000	0.005
28Jun2013	-0.005		0.002	0.004	0.000	0.000	0.004	0.005	0.002	0.000		0.000	0.002	-0.002
27Jun2014	-0.010		0.003	0.006	-0.003	-0.004	0.009	0.009	0.003	0.002		-0.002	0.002	0.000
02Mar2017	0.006		0.002	-0.010	-0.002	-0.002	0.008	0.006	-0.004	-0.007		0.000	-0.003	-0.001

BENNETTS CLIFF MONITORING
DIRECTION -Up hill & +Down hill



	m0		m1	m2	m3	m4	m5	m6	m7	m8		m9	m10	m11
19Jun2012	0.000		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000		0.000	0.000	0.000
19Jul2012	0.001		0.001	-0.001	-0.008	-0.008	-0.006	-0.005	-0.008	-0.008		-0.002	0.000	-0.003
20Aug2012	0.002		0.000	0.000	-0.003	-0.002	0.000	0.001	-0.005	-0.009		0.004	0.001	-0.002
19Sep2012	0.035		0.002	0.002	0.001	0.000	0.002	0.000	0.001	0.002		0.003	0.004	0.002
19Nov2012	0.033		0.001	-0.001	0.000	0.000	-0.001	-0.002	-0.007	-0.005		0.001	0.000	-0.002
19Jan2013	0.010		0.005	0.000	0.000	-0.001	0.000	-0.001	-0.004	-0.005		0.001	0.002	-0.003
19Mar2013	0.006		0.002	0.001	-0.001	-0.002	0.000	-0.003	0.001	0.004		0.003	-0.002	0.000
28Jun2013	0.039		0.004	0.004	0.000	0.001	0.003	0.001	-0.006	-0.005		0.000	0.002	-0.003
27Jun2014	0.062		0.006	0.005	-0.001	0.006	0.004	0.001	0.000	0.002		0.001	0.003	0.003
02Mar2017	0.096		-0.002	0.005	-0.014	-0.004	-0.011	-0.009	-0.011	0.003		-0.005	-0.006	-0.015

BENNETTS CLIFF MONITORING IN HEIGHT DIRECTION



	m0		m1	m2	m3	m4	m5	m6	m7	m8		m9	m10	m11
19Jun2012	0.000		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000		0.000	0.000	0.000
19Jul2012	-0.001		0.000	0.002	-0.001	-0.001	0.000	-0.002	0.002	0.002		0.002	0.000	-0.001
20Aug2012	0.000		0.002	0.002	0.000	-0.001	0.001	0.001	0.001	0.003		0.003	0.002	-0.001
19Sep2012	-0.020		0.000	0.003	0.000	0.000	0.000	-0.001	0.002	0.001		-0.003	0.001	0.002
19Nov2012	-0.024		0.001	0.001	-0.001	-0.001	-0.002	-0.001	0.002	0.000		0.001	0.001	-0.002
19Jan2013	-0.045		0.003	0.001	0.001	0.000	-0.001	0.001	0.000	-0.002		0.002	0.000	0.001
19Mar2013	-0.046		0.001	0.000	-0.001	-0.001	0.000	0.001	0.000	-0.001		-0.005	0.000	-0.001
28Jun2013	-0.049		-0.002	-0.001	-0.002	-0.002	0.000	0.000	0.002	-0.001		0.000	0.000	0.000
27Jun2014	-0.042		-0.002	-0.003	0.000	-0.005	0.000	0.000	0.005	0.003		0.001	0.000	0.002
02Mar2017	-0.079		0.000	-0.003	-0.005	-0.009	-0.003	0.002	0.005	-0.006		0.003	0.002	0.005

Appendix II
Proposed Alternative Location B

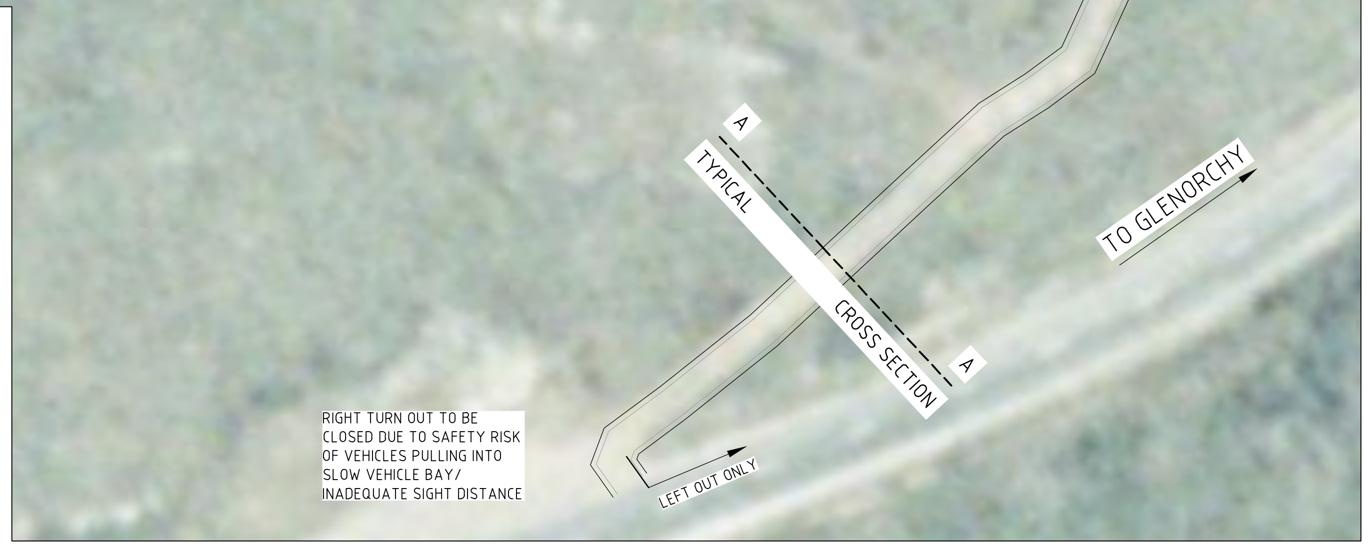
Option 4 Concept Sketch & Estimate

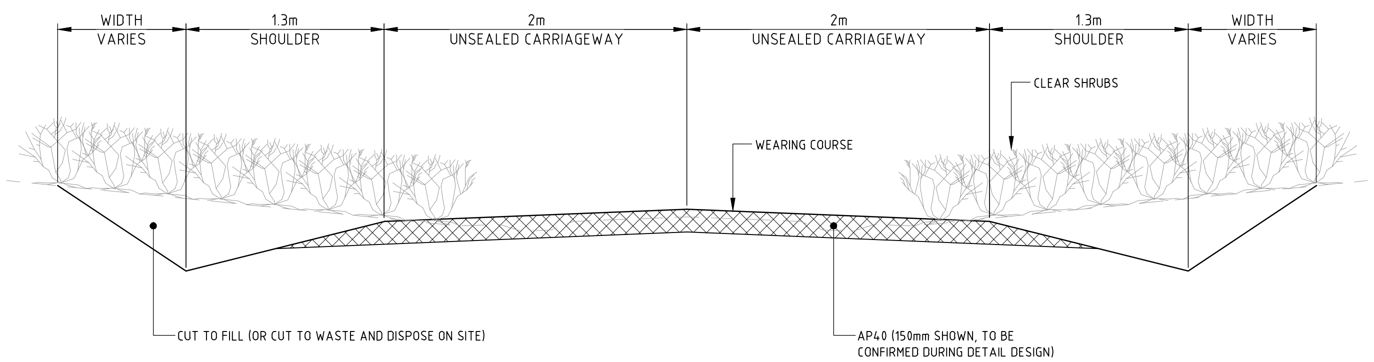
Option 5 Concept Sketch, Estimate (recommended)

Option 5 Site Photographs

DO NOT SCALE - IF IN DOUBT, ASK

ORIGINAL SIZE A1



TYPICAL CROSS SECTION A-A

1 : 25 (A1)

NOT FOR CONSTRUCTION

REV	REVISIONS	DRN	CHK	APP	DATE

SURVEYED		
DESIGNED	Ben Greenwood	04/11/2015
DRAWN	Ben Greenwood	04/11/2015
CAD REVIEW	Grant Kluyts	04/11/2015
DESIGN CHECK	Grant Kluyts	04/11/2015
DESIGN REVIEW	Mike Flatters	04/11/2015
APPROVED	Mike Flatters	04/11/2015
PROF REGISTRATION:		

MWH.

Client: QUEENSTOWN LAKES DISTRICT COUNCIL

BENNETT'S BLUFF CARPARK
CONCEPT SKETCH

NEW CARPARK
PLAN AND TYPICAL CROSS SECTION

Status Stamp: **WORKING PLOT**

Date Stamp: **04/11/2015**

Scales: 1:500 (A1) 1:1000 (A3)

Drawing No.: 80508514-0362-C002

Rev.: A

MWH now part of Stantec

Project No:	80508724 0441
Date:	27-Oct-17

Scoping Estimate for:

Bennetts Bluff

Alternative Viewing Location Option 1 (vehicle access)

Prepared by	Checked by
BG	IB

Item	Description	Unit	Quantity	Rate	Amount
1	**Preliminary & General**				
1.1	Allowance for Establishment, Contract Management, TMP, QA, Set-out, Insurances and other Contractor Overheads	%	20	$118,000.00	$23,600.00
2	**Site Clearance and Bulk Earthworks**				
2.1	Remove Vegetation, Shrubs, Small Trees and Stumps to Waste	m²	1800	$5.00	$9,000.00
2.2	Cut to Waste Including Forming Swale Drain	m³	500	$30.00	$15,000.00
2.3	Undercut to Waste and Import Granular Fill (Allowance for Areas with Low CBR)	m³	50	$100.00	$5,000.00
3	**Drainage**				
3.1	Allowance to Install Three Culverts (Nominally 100m Apart) Under New Access Road Formation	m	18	$250.00	$4,500.00
3.2	Precast Concrete Headwall	ea	6	$1,000.00	$6,000.00
3.3	Subsoil Drainage (Assume it is Required Only on 1 Side of Road)	m	350	$35.00	$12,250.00
4	**Pavement and Surfacing**				
4.1	AP 65 Subbase to 150mm Depth (Access Road and Car Park)	m³	350	$100.00	$35,000.00
4.2	AP 20 Base with Running Course to 50mm Depth (Access Road and Car Park)	m³	90	$200.00	$18,000.00
4.3	AP 65 Subbase to 150mm Depth (Accessway)	m³	15	$250.00	$3,750.00
4.4	M/4 AP 40 Basecourse to 150mm Depth (Accessway)	m³	10	$250.00	$2,500.00
4.5	Two Coat Grade 3/5 Chipseal (Accessway)	m²	50	$20.00	$1,000.00
5	**Pavement Markings and Signage**				
5.1	Remove Existing Slow Vehicle Bay Pavement Markings	LS	1	$3,000.00	$3,000.00
5.2	New Right Turn Bay	LS	1	$2,000.00	$2,000.00
5.3	Signage	LS	1	$1,000.00	$1,000.00
	SUB TOTAL (excluding Contingency)				**$141,600.00**
6	**CONTINGENCY SUM (Provisional Sum)**	%	25	$141,600.00	$28,320.00
TOTAL					**$169,920.00**

THIS DRAWING IS NOT INTENDED FOR TENDER OR CONSTRUCTION. IT IS A CONCEPT DRAWING FOR DISCUSSION PURPOSES ONLY.

DO NOT SCALE - IF IN DOUBT, ASK

ORIGINAL SIZE A1

NOT FOR CONSTRUCTION

REV	REVISIONS	DRN	CHK	APP	DATE

SURVEYED		
DESIGNED	Ben Greenwood	10/08/2017
DRAWN	Ben Greenwood	10/08/2017
CAD REVIEW		
DESIGN CHECK	Iain Banks	10/08/2017
DESIGN REVIEW	Iain Banks	10/08/2017
APPROVED	Iain Banks	10/08/2017
PROF REGISTRATION:		

MWH

Client: QUEENSTOWN LAKES DISTRICT COUNCIL

BENNETT'S BLUFF CARPARK
CONCEPT SKETCH

NEW CARPARK - ALTERNATIVE OPTION
PLAN AND TYPICAL CROSS SECTION

Status Stamp: WORKING PLOT
Date Stamp: 10/08/2017
Scales: 1:500 (A1) 1:1000 (A3)
Drawing No.: 80508514-0362-C004
Rev.: A

MWH now part of Stantec

Project No:	80508724 0441
Date:	27-Oct-17

Scoping Estimate for:
Bennetts Bluff
Alternative Viewing Location Option 2 (walking track)

Prepared by	Checked by
BG	IB

Item	Description	Unit	Quantity	Rate	Amount
1	**Preliminary & General**				
1.1	Allowance for Establishment, Contract Management, TMP, QA, Set-out, Insurances and other Contractor Overheads	%	20	$117,700.00	$23,540.00
2	**Site Clearance and Bulk Earthworks**				
2.1	Remove Vegetation, Shrubs, Small Trees and Stumps to Waste	m²	2000	$5.00	$10,000.00
2.2	Cut to Waste Including Forming Swale Drain	m³	300	$30.00	$9,000.00
2.3	Undercut to Waste and Import Granular Fill (Allowance for Areas with Low CBR)	m³	30	$100.00	$3,000.00
3	**Drainage**				
3.1	Allowance to Install Two Culverts (Nominally 100m Apart) Under New Access Road Formation	m	12	$250.00	$3,000.00
3.2	Precast Concrete Headwall	ea	4	$1,000.00	$4,000.00
3.3	Subsoil Drainage (Assume it is Required Only on 1 Side of Road/ Track)	m	270	$35.00	$9,450.00
4	**Pavement and Surfacing**				
4.1	AP 65 Subbase to 150mm Depth (Access Road and Car Park)	m³	300	$100.00	$30,000.00
4.2	AP 20 Base with Running Course to 50mm Depth (Acess Road and Car Park)	m³	90	$200.00	$18,000.00
4.3	AP 65 Subbase to 150mm Depth (Accessway)	m³	15	$250.00	$3,750.00
4.4	M/4 AP 40 Basecourse to 150mm Depth (Accessway)	m³	10	$250.00	$2,500.00
4.5	Two Coat Grade 3/5 Chipseal (Accessway)	m²	50	$20.00	$1,000.00
4.6	AP20 Basecourse (Walking Track)	m³	40	$450.00	$18,000.00
5	**Pavement Markings and Signage**				
5.1	Remove Existing Slow Vehicle Bay Pavement Markings	LS	1	$3,000.00	$3,000.00
5.2	New Right Turn Bay	LS	1	$2,000.00	$2,000.00
5.3	Signage	LS	1	$1,000.00	$1,000.00
	SUB TOTAL (excluding Contingency)				**$141,240.00**
6	**CONTINGENCY SUM (Provisional Sum)**	%	25	$141,240.00	$28,248.00
TOTAL					**$169,488.00**

Option 5 **Car Park and Viewing Area**

Panorama Viewing Area

View Towards Glenorchy

Proposed Parking Area