August 2016

ENVIRONMENT CANTERBURY

Arthur's Pass Village Slope Stability Assessment

Submitted to:
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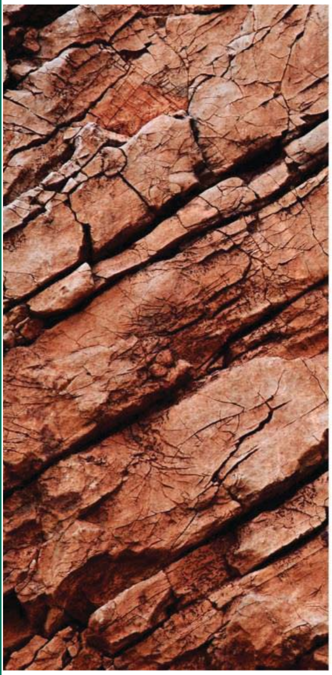

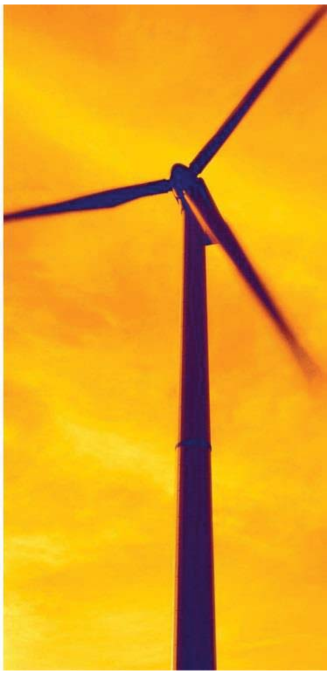

REPORT

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TABLE OF CONTENTS

TABLES

FIGURES

APPENDICES

1.0 INTRODUCTION

This report summarises the findings of a slope stability assessment undertaken by Golder Associates (NZ) Limited (Golder) of the Arthur's Pass area, and commissioned by Environment Canterbury.

Previous geological hazard studies, including Geotech Consulting 2006, have identified the vulnerability of Arthur's Pass to slope instability, in particular following large locally centred earthquakes. These studies highlight the importance of Civil Defence Emergency Management planning for slope instability hazards in the area.

Arthur's Pass Village buildings and infrastructure are located on the valley floor. Above the village are over-steepened slopes underlain by strong, fractured rock. In some areas metastable rock debris has accumulated at elevation and requires little in the way of triggering to generate significant debris flows, rockfall or a rock avalanche event. Triggers for these hazards are numerous, the most dramatic but least frequent is from earthquake shaking. Arthur's Pass is in an area with amongst the highest seismic hazard in the country and has experienced significant historical shaking, notably in 1929, 1994 and January 2015. Rainfall is a more frequent triggering mechanism, with local storm events often giving rise to debris flow and avulsion events. In addition, flooding can lead to isolation of the town due to severe erosion of the road or rail formations. These hazards have the potential to temporarily isolate the town as well as directly impact dwellings, vehicles and infrastructure.

In 2006, Geotech Consulting made the following recommendation in their Selwyn District Engineering Lifeline Project – Earthquake Hazard Assessment (Environment Canterbury report U06/7):

"One of the main conclusions from this study is the relative vulnerability of Arthur's Pass to secondary earthquake hazards such as mass movement and debris flow. To our knowledge there has not been any detailed engineering geological hazard assessment carried out for the town, and work of this type may help in guiding future development to avoid the most vulnerable areas."

The same report notes that the Midland railway and State Highway 73 links through Arthur's Pass to the West Coast may also be vulnerable to landslides and debris flows.

1.1 Study Objective

The areal extent of this study is defined as the Bealey Valley from Klondyke Corner to the northern limits of Arthur's Pass Village (see Figure 2). The objective of the current study is to guide any future land development in Arthur's Pass with respect to natural hazards. In addition, the study can be used to document the landslide and debris flow hazards, and to inform Civil Defence of the type of events and likely locations that could affect the area. Residential or commercial development outside of the present Village limits is not likely due to restricted space between the steep valley sides and the Bealey River; therefore, greater focus is placed on areas of existing development.

Flood hazard from storm flows in the Bealey River is not addressed in this report. Flooding as it relates to debris flow is discussed, i.e., where a debris flow blocks a waterway, resulting in consequent water outside of a river channel. Where hazard frequency is discussed, it is in qualitative terms based on documented and geological evidence.

1.2 Limitations

Your attention is drawn to the document, "Report Limitations", as attached. The statements presented in that document are intended to advise you of what your realistic expectations of this report should be, and to present you with recommendations on how to minimise the risks to which this report relates which are associated with this project. The document is not intended to exclude or otherwise limit the obligations necessarily imposed by law on Golder Associates (NZ) Limited, but rather to ensure that all parties who may rely on this report are aware of the responsibilities each assumes in so doing.

2.0 SITE SETTING

2.1 Physiography and Geology

Arthur's Pass Village is approximately 110 km northwest of Christchurch. It is located within the Bealey Valley on SH73, an important transport corridor between the Canterbury and West Coast regions. The highway reaches its highest point ('Arthur's Pass') at 924 m elevation, approximately 4 km north of Arthur's Pass Village. Arthur's Pass Village is at approximately 740 m elevation and the adjacent steep mountain ranges reach more than 1000 m above the village (see Figure 1). The floor of the Bealey Valley, on which Arthur's Pass Village is located, is approximately 250 m wide. A plan of the area is presented in Figure 2.

The dominant westerly weather pattern and steep relief gives the area a relatively high rainfall characterised by intense rainfall events. Arthur's Pass Village has a mean annual rainfall of about 4000 mm. However, a pronounced rain shadow affects the Bealey Valley, with mean annual rainfall of 6000 mm in the upper Bealey Valley reducing to about 2000 mm at Klondyke Corner. The estimated rainfall frequency for various recurrence intervals is presented in Table 1.

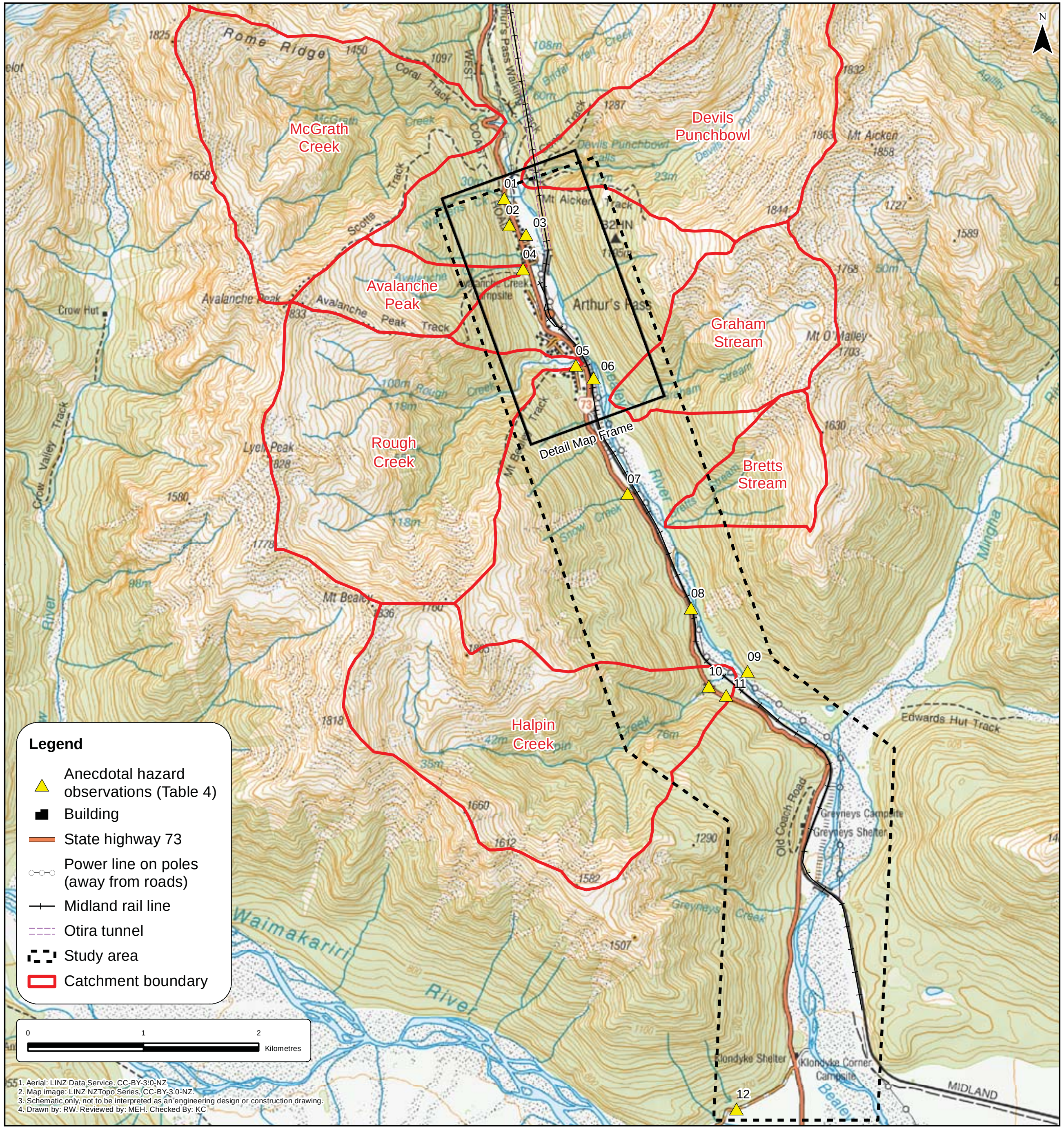
Table 1: Estimated rainfall frequency for Arthur's Pass Village (data from NIWA High Intensity Rainfall Design System (HIRDS) web-based database[1]).

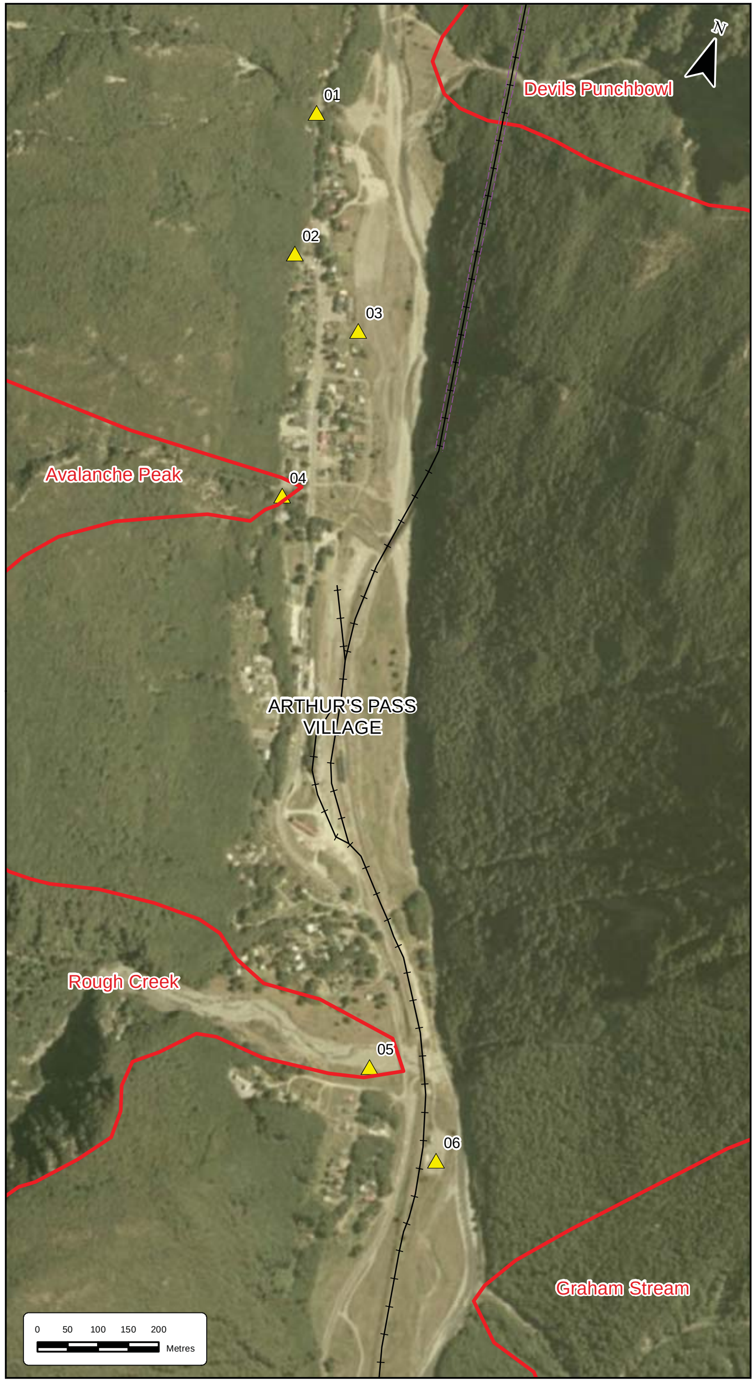
Annual Recurrence Interval (yrs)	1 hour duration rainfall (mm)	1 day duration rainfall (mm)
2	28	251
5	35	296
10	41	330
20	48	366
30	52	389
40	56	406
50	58	419
60	61	431
80	64	449

Torlesse 'greywacke' is the dominant rock type in the area. This rock type comprises indurated sandstone and minor mudstone and is a characterised by relatively high strength and complex, but well developed discontinuities. The Bealey Valley has been glaciated during the Pleistocene, though remnant glacial features have largely been eroded from the valley slopes. Holocene glacial advances in the Bealey Valley reached to McGrath's Creek, just north of Arthur's Pass Village. Buildings and infrastructure are located on or close to the valley floor, mostly on Holocene alluvial deposits or fans. The geomorphology of Arthur's Pass village is presented in Figure 3.

[1] Values approximate only

Figure 1: Arthur's Pass Village viewed from the south. Rough Creek catchment is in the foreground entering from the west (left of view).





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TITLE AUTHUR'S PASS LOCATION PLAN - HAZARD OBSERVATIONS DESCRIBED IN TABLE 3

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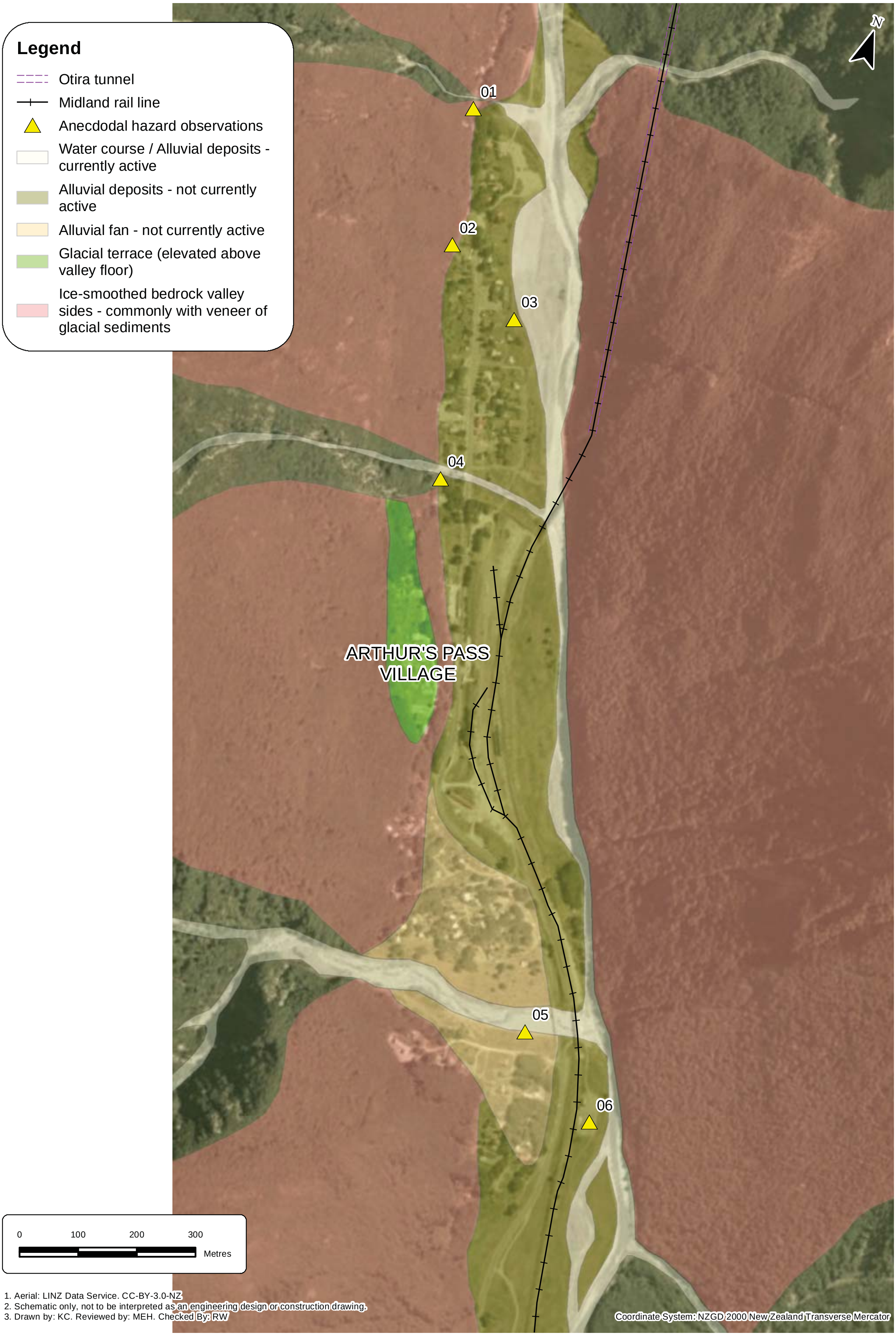

1. Aerial: LINZ Data Service. CC-BY-3.0-NZ
2. Schematic only, not to be interpreted as an engineering design or construction drawing.
3. Drawn by: KC. Reviewed by: MEH. Checked By: RW

Golder Associates

TITLE GEOMORPHOLOGICAL PLAN OF ARTHUR'S PASS VILLAGE

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2.2 Seismic Hazard

The Arthur's Pass area is characterised by high seismic hazard owing to the close proximity (25 km) of the Alpine Fault and many other recognised active faults (Stirling et al., 2007). The Alpine Fault has an average recurrence interval of approximately 300 years, with the most recent rupture being approximately 1717 AD (Yetton, 1998) and the estimated annual likelihood of surface rupture being about 1-2 %. . The Arthur's Pass area has also been affected by strong shaking from several historical earthquakes (Stirling et al., 2007).

The seismic hazard at Arthur's Pass Village has been characterised as peak ground acceleration (pga) and modified mercalli intensity (MMI) values for a range of return periods by Stirling et al. (2007), as summarised in Table 2.

Table 2: Estimates of seismic hazard at Arthur's Pass Village (after Stirling et al., 2007).

Return period (years)	Peak ground acceleration	Modified Mercalli intensity
50	0.25	7-8
150	0.40	8-9
475	0.57	9-10
1000	0.68	9-10

3.0 SLOPE STABILITY HAZARDS AFFECTING ARTHUR'S PASS AREA

The combination of steep slopes, high rainfall, high seismic hazard and strong, relatively brittle rock dictate the modes of slope instability that affect the Arthur's Pass area and their frequency. These are described in the following sections.

3.1.1 Rockfall

Rockfall describes a process where rock dominated material falls, bounces or rolls down steep slopes. Initiating failure mechanisms include bedding or joint controlled sliding or toppling failures within the greywacke rock mass. More rarely, the failure mass could comprise a gravel dominated alluvium or glacial moraine elevated above the valley floor. This process is common on the steep valley sides or cut slopes in the Southern Alps and has been widely recorded affecting the road and rail corridors. Typically rockfall is reported where the road or railway is located at the base of a steep slope. Because neither is close to the road at Arthur's Pass Village no rockfall is reported in these areas. There is no evidence for rockfall impacting Arthur's Pass Village.

Paterson (1994, 1995, 1996) and URS (2002) described the incidence of rockfall affecting various slopes in the Arthur's Pass area, outside the Village (no rockfall has directly impacted the village area). Small scale rockfalls that have little effect on traffic have occurred frequently along SH73 in the study area. Larger scale rockfall that block a lane or the entire highway are less common, but have occurred periodically. Of particular note are the numerous rockfalls that occurred along SH73 as a result of the M6.5 1994 Arthur's Pass earthquake (Paterson and Bourne-Webb, 1994) and the M5.5 1995 Arthur's Pass earthquake (Paterson and Berrill, 1995). However, progressive improvements to the road alignment and stability of the cut slopes have been completed over the last few decades aimed at reducing maintenance costs, and increasing route security and road user safety. A significant realignment of several kilometres of SH73 south of Arthur's Pass Village is currently underway, which will improve alignment and reduce the exposure of road users to slope hazards.

Figure 4: Rockfall onto SH73 at the Zig Zag (Otira side of Arthur's Pass) as a result of the 1929 Arthur's Pass earthquake.

3.1.2 Debris flow

Debris flow is a mechanism that transports slope debris as a viscous fluid and is often triggered by heavy rainfall. Debris flows are very erosive and can often cause severe down-cutting in the source area. They have the ability to transport large boulders and vegetation, including trees. Deposition of the material often occurs where the ground slope flattens, for example where a valley slope meets the valley floor. Debris flows have been recognised as a major depositional mechanism on alluvial fans, and as such is a potentially important hazard in alluvial fan areas . In the Arthur's Pass area, debris flows occur frequently and have resulted in closure and damage to SH73 and private properties (Paterson, 1996).

Any of the large catchments shown in Figure 2 (Rough Creek, McGrath Creek etc.) have the potential to generate significant debris flows due to their catchment size and corresponding debris flow potential, and due to their steep head slopes, which contain an ample supply of scree and shattered bedrock. The alluvial fan at the base of Rough Creek accumulated in geological history from multiple debris flow events (see Figure 3).

Debris flow events have not been specifically recorded; however, their impact is noted where infrastructure is affected, such as the inundation of a bridge or erosion of the railway ballast (e.g., Rough Creek Bridge and Halpin Creek – see Table 4). Where debris flows have resulted in damage to infrastructure, the remediation work by the road or rail owner has partly mitigated the hazard. At Rough Creek, aggradation of debris has compromised the clearance between the road and rail bridges and the creek bed on numerous occasions. Redistribution of debris on the riverbed and training works has controlled the hazard. This has maintained the watercourse in its present path away from nearby houses on the flanks of the alluvial fan.

In addition, the longevity of the infrastructure means that the response described has captured large, low frequency events, with engineering measures eventually being improved to cope. For example, prior to the

1980s, Halpin Creek road and rail infrastructure was frequently damaged by debris flows (see Table 4, Item 12). No significant inundation has occurred following upgrade works in the 1980s.

3.1.3 Rock avalanche

Rock avalanche is a mechanism that is often transports large volumes of rock-dominated material at potentially very high velocity. It is the very high velocity, large scale and long run-out distance that differentiate rock avalanches from other landslides. As a result, rock avalanches can have major consequences if they impact on populated areas or important infrastructure. There are many examples of rock avalanches that have occurred in the Southern Alps, many of which have been associated with earthquakes. One of the most visible examples of a rock avalanche deposit is at the site of the viaduct on SH73 approximately 7 km north of Arthur's Pass (see Figure 6). This feature is typical of a large greywacke derived rock avalanche in the Southern Alps. It has a volume of 40 Mm^3 resulting from failure of glacially oversteepened mountain slopes following retreat of the glaciers after the last glaciation. The Otira rock avalanche deposit is thought to have formed in at least two pulses approximately 2000 and 4000 years before present (Paterson, 1996). It is often not possible to predict large scale catastrophic failures as seemingly inactive slopes have previously failed, e.g., Falling Mountain landslide near Arthur's Pass (see Figure 7). Given the lack of evidence of deep seated instability affecting the slopes at Arthur's Pass village, the frequency of such an event is estimated to be in the order of tens of thousands of years.

Figure 5: Aggradation/debris flow in Wardens Creek (1957).

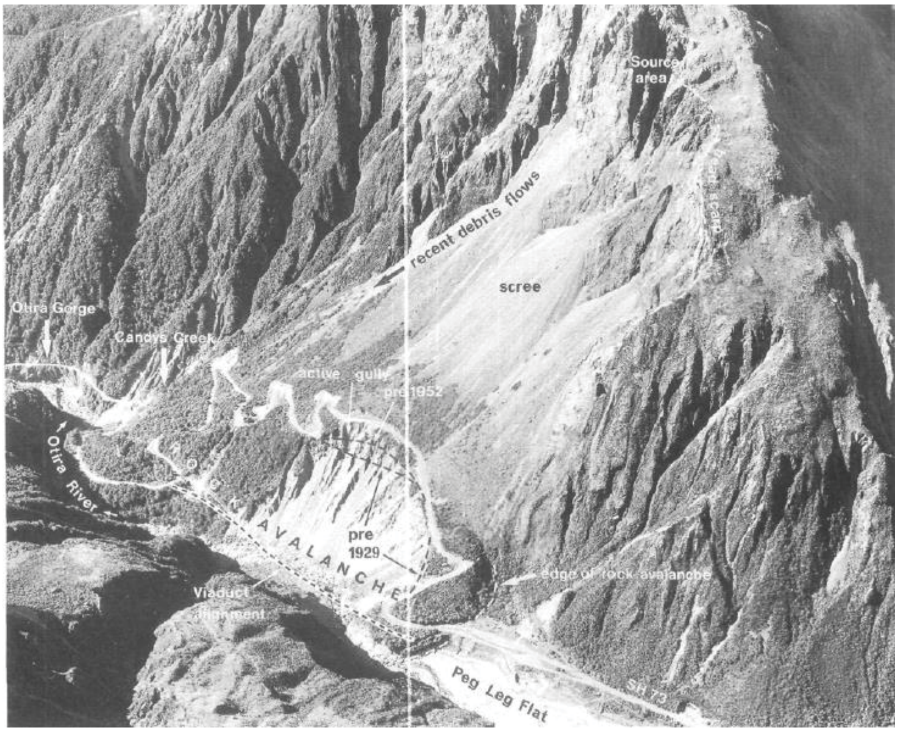

Figure 6: Otira rock avalanche deposit (after Paterson, 1996).

Figure 7: Falling Mountain landslide at Taruahuna Pass – it was triggered during the M7.1 Arthur's Pass earthquake of March 1929 (GNS Science, Ref CN06370/2).

3.1.4 Landslide dam breach

It is possible that a large landslide could block Bealey River or a tributary creating a landslide dam. Landslide dams are a relatively common feature in the Southern Alps. Subsequent overtopping of the dam is a potentially serious hazard as large river flows can result. However, even if a landslide dam occurred, it is likely that such a feature would be noticed within a short time of formation and that adequate time would be available to evaluate the risk associated with failure and evacuate populations at risk.

3.1.5 Alluvial processes

The steep catchments and high rainfall in the Southern Alps lead to particularly dynamic alluvial systems. Locally this can result in rapid deposition, channel avulsion and rapid erosion. These processes can have severe effects on infrastructure and populated areas. As described above, debris flows can often be an important depositional process associated with steep catchments and alluvial fans.

3.2 Triggering Mechanisms

Key triggering mechanisms for slope instability are rainfall and strong earthquake shaking. Both of these are characteristic of the Arthur’s Pass area, which combines steep terrain, high rainfall and severe ground shaking hazard. Heavy rainfall occurs frequently in Arthur’s Pass and represents a trigger of slope instability. Widespread earthquake induced rockfall is typically associated with ground shaking (pga) in excess of about 0.4 g (Massey et al., 2012), which equates to an average return period of 150 years (or annual exceedance probability of 0.7 %) for Arthur’s Pass (Table 2).

Heavy rainfall is the common trigger for relatively frequent, small scale slope instability, whereas strong earthquakes can trigger both small to large scale slope instability over a wide area but relatively infrequently. It is important to recognise that slope instability can also occur as a result of general slope degradation without triggering by either rainfall or earthquake shaking.

Deformation of the foundation of the rail or SH73 formation is a potential hazard that could prevent road or rail access the Arthur’s Pass Village. Such deformation could result from strong earthquake shaking or river erosion as described in Section 3.1.5.

4.0 AVAILABLE INFORMATION

4.1 Previous Relevant Studies

Significant research and data collection on slope instability has already been undertaken in the Arthur’s Pass area. Studies have included research papers, university theses, regional geological hazard studies and specific risk assessments for highway and rail authorities. The main information sources we have referred to in this study are summarised in Table 3. A full reference list is presented in Section 9.0.

Table 3: Key reference documents for the current study.

Author and reference	Relevant information
Brian Paterson (Paterson and Bourne-Webb, 1994; Paterson and Berrill, 1995; Paterson, 1996)	Brian Paterson completed many engineering geological investigations of slope instability affecting SH73 during the period 1975 to 1998.
URS New Zealand Ltd (2002, 2003)	URS was contracted by Transit New Zealand (now New Zealand Transport Agency) to complete a quantitative risk assessment of slope instability affecting SH73 between Springfield and Arthur's Pass.
Emily Smith (2004)	Emily Smith completed a study of the potential effects of slope stability hazards on infrastructure between Arthur's Pass and Greymouth as an MSc (Engineering Geology) thesis from University of Canterbury.
Geotech Consulting Ltd (2007)	A geological hazard study of Selwyn District was commissioned by Environment Canterbury, with a focus on the effects of earthquakes on the key lifelines in the district.
Kate Dundas (2008)	Kate Dundas undertook a study of geological hazards affecting Arthur's Pass as an MSc (Engineering Geology) thesis from University of Canterbury.
Barrell, et al. (2011)	Detailed description of glacial geomorphology of the central South Island, including the Arthur's Pass area.
Robinson and Davies (2013)	Description of the potential effects of an Alpine Fault earthquake including slope instability.

In addition to the key references noted in Table 3, the current study has included a review of aerial images and terrain models, a site visit and collation of anecdotal accounts from various sources, which are summarised in Section 4.2.

4.2 Observations from Current Study

This study has included documentation of observations and records collected by Mr John Charles, a resident of Arthur's Pass for over 50 years, and a field visit, including helicopter reconnaissance completed by Golder and Environment Canterbury staff. This section of the report summarises the findings of these tasks.

4.2.1 Anecdotal evidence

Mr John Charles has lived continually in Arthur's Pass since 1959. During most of that time Mr Charles has worked for the Department of Conservation and has been a member of Search and Rescue. He has collected comprehensive records of significant events that have affected the area, including slope instability occurrences (summarised in Table 4).

4.2.2 Aerial photograph interpretation and site visit

A site visit to Arthur's Pass was undertaken by Matt Howard on 3 May 2015 to observe the site and interview Mr Charles. An additional site visit by Tim McMorran of Golder and Marion Gadsby of Environment Canterbury was carried out on 22 February 2016 to observe the site in light of the objectives of this study. Key locations within the village were visited to evaluate the potential effects of slope stability or alluvial hazards affecting the existing or future infrastructure. A helicopter survey was completed to view the upper slopes of the adjacent mountain ranges to observe potential source areas for large scale slope failures. Photographs of the observations are presented in Appendix B.

Key observations from the site visit and discussions with Mr Charles include:

- The steep, glacially carved sides of the Bealey Valley are well vegetated and have not been subject widespread slope instability in the recent geological past. Tension cracks and scarps, that would be indicative precursors to large scale slope failure, were not observed in the ridge crests and slopes above (west of) Arthur's Pass village.

- Slopes of the Bealey Valley opposite (i.e., east of) Arthur's Pass are well vegetated and do not show indications of significant instability.
- Deeply incised tributary catchments are subject to ongoing slope instability, for example Rough Creek catchment, Avalanche Peak catchment, Devils Punchbowl catchment (see Figure 1 for location of these). This leads to considerable sediment load in each stream and the Bealey River. Currently, the major tributary catchments do not appear to be choked with sediment. However, sediment load is expected to vary episodically in response to large failures in each catchment.
- The head of the catchments where slope failures most often occur are typically 1-2 km from Arthur's Pass village. Due to the runout distances, slope failures within the tributaries do not directly inundate dwellings in the village, as debris is distributed as it travels downstream. The consequences of catchment slope failure would be much greater if this were not the case.
- Larger tributary catchments, such as Rough Creek, have well-developed alluvial fans where they enter the Bealey Valley. Some residential development and infrastructure have been built on these fans and are potentially vulnerable to flooding, avulsion or debris flow hazards, although this is partially mitigated by ongoing alluvial redistribution earthworks (see Section 3.1.2).
- Sediment and debris load in the streams can restrict water flow beneath bridges over time, but this can mostly be avoided by regular observation and earthmoving (which is presently done by NZTA and Kiwirail).
- Tributary creeks that pass through or close to Arthur's Pass and potentially present a flood or debris flow hazard have maintained channels, flood protection embankments and culverts or bridges that have been sized based on damage or observations from previous channel performance. As examples, Halpin's Creek SH73 bridge has been realigned and rebuilt after damage as a result of stream aggradation and significant river training works were undertaken after flood damage to a building at the Chalet Restaurant (Table 4: Item #3).
- While most of the valley slopes are covered in mature beech forest, some areas above Arthur's Pass appear to be covered with lower vegetation species. On the slopes above the village, particularly on the northwestern side of the valley, these do not appear to be the result of forest damage by slope instability and are believed to reflect variations in substrate rather than age of vegetation. Historical aerial photographs indicate localised, small-scale slope failures are not unusual throughout the Arthur's Pass area. The vegetation appears to re-establish in these areas with a decade or two. Small scale failures have occurred occasionally but the consequences have been minor (temporary inundation). Most of west side of the village is exposed to this hazard. The life risk associated with these small scale failures is likely to be acceptably low as the housing structure has historically offered sufficient protection. The burial and subsequent deaths of four campers (see Item 12 in Table 4) may not have happened had the victims been in a building.

There is a lack of large areas suitable for future development in Arthur's Pass due to the confined shape of the valley floor. Thus future redevelopment within the existing village footprint is more likely than expansion outside it. Consideration of the hazards observed at Arthur's Pass will need to be made in granting resource consent for any future development.

Table 4: Anecdotal observations of natural hazards in Arthur's Pass to Klondyke corner from Mr John Charles (2-3 May 2015). Locations are shown in Figure 1, referenced photographs presented in Appendix B.

Item #	Location	Hazard and consequences	Date	Details
01	Wardens Creek	Flooding of 3 houses but no significant damage	c. 1982	Present culvert crossing SH73 copes with present demand
02	Avalanche Peak face (un-named creek, not Avalanche Creek) Refer Figure 13, Figure 14.	Flooding – up to window sill on one house. Standing water in wide area west of SH1.	1969	During a storm, the unnamed stream south of Wardens Creek experienced significantly greater flow than previously experienced. Flowed 200 m south between buildings and Avalanche Peak mountain side, entering a culvert and crossing SH73 next to the Post Office. Minimal damage: water rose for less than 1 hour up to the window sill of the house previously occupied by J Charles. Standing water was present in the low area between the stream and the tearooms (total distance approximately 400 m). J Charles notes that since that time, additional development has occurred in the flooded area. Some of these have a lower floor elevation than the roadside dwellings. Drain not particularly well maintained and has lower capacity than in the previous decades. It is possible that flooding could result in a similar event
03	Upper Bealey River (north end of Arthur's Pass) Refer Figure 15, Figure 16, Figure 17	Flooding – house washed off foundations; erosion of gravel undermined garage foundations at Chalet Restaurant.	1961	During a storm, the Bealey River changed course to the true right (west) of the valley. Flows down the Devils Punchbowl Creek were particularly high, which may have encouraged the course change. One house was washed from its foundations, floated downstream and disintegrated upon impact with the Bealey River rail bridge near the tunnel entrance. Garage/workshop at back of Chalet Restaurant was undermined by flood flow. Following this event the Selwyn District Council apportioned funds to the Bealey Flood Fund. This was used to re-contour the river bed and build groynes to force the river onto the true left side of the valley floor.
04	Avalanche Creek refer Figure 18	Flooding	-	Avalanche Creek copes well with storm events and J Charles does not know of any significant flooding that has occurred. Channel and culvert under SH73 well maintained and apparently suitably sized. The grassed, downstream, low lying areas are occasionally inundated, but this does not cause damage. In the early days of the village's development, water from Avalanche Creek flowed uncontrolled to the Bealey River.
05	Rough Creek refer Figure 19, Figure 20	Aggradation – Following a storm, Rough Creek was mostly filled with sediment and rock.	1970s	No damage, but capacity of creek and height to bottom of bridge reduced. Earthmoving equipment used to push material to either side of Rough Creek. Rail bridge has shallow piles, so earthworks cannot over-excavate in that area, or piles will be undermined. Removal of debris maintains river flow away from houses.
06	Power Station (east and	Flooding – none recorded; present protection sufficient.		River protection works (probably by the owner) provide adequate protection from scouring. Well maintained.

Item #	Location	Hazard and consequences	Date	Details
	downstream of Rough Creek)			
07	Snow Creek refer Figure 21, Figure 22	Flooding – storm caused flooding of SH73	3 Dec 1979	-
08	North of Halpin Creek refer Figure 23, Figure 24	Debris Flow – erosion of railway ballast and debris on road	Dec 2013	Area was previously not known to cause problems during storm flows
09	Mt O'Malley	Rockfall – flyrock at SH73	1994	Rockfall was the result of 1994 Arthur's Pass earthquake.
10	Halpin Creek refer Figure 25, Figure 26	Debris Flow – previous flooding	3 Dec 1979	Prior to the existing bridge being built in the 1980s, regular debris flows and floods blocked the road and caused rail damage. Due to large catchment it carries a large volume. Substantial rock armouring has taken place on the upstream side of Halpins Creek. Major bridge upgrade in 1980s has largely eliminated road flooding
11	River scour near Halpin Creek Figure 27	Erosion – scour of railway embankment	3 Dec 1979	Scour west of Halpin Creek due to Bealey River changing course
12	Klondyke Corner refer Figure 28, Figure 29	Debris Flow – buried four campers	3 Dec 1979	J Charles notes that the rainfall was approximately 250 mm in the hours prior to the debris flow. Wet weather had saturated the ground in the days prior. The same event washed out Halpins Creek bridge, hampering recovery efforts. Lots of trees were blown down in the Poulter and Andrews valleys. Water-soaked ground from prior rain combined with heavy rain to trigger event

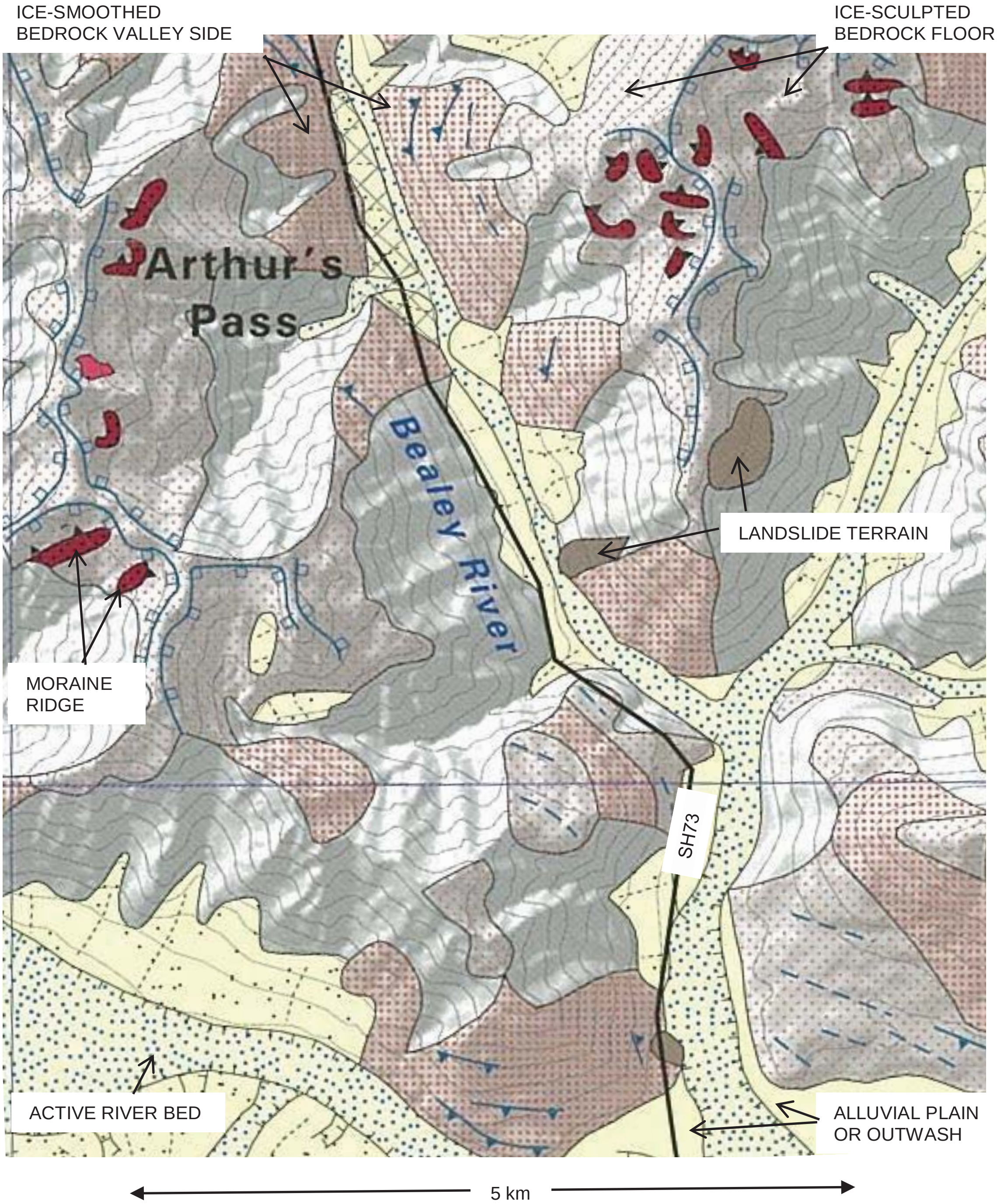

Figure 8: Glacial geomorphology of Arthur's Pass area (from Barrell et al., 2011). Diagonal hatch is Arthur's Pass Village, unhatched is general bedrock terrain.

5.0 SLOPE STABILITY ASSESSMENT

Potential slope instability hazards that could affect the Arthur’s Pass Village or the critical access routes for the village are described in Section 3.0. Some of these hazards occur as frequently as once per year, while some are relatively rare occurrences (i.e., less than once every several thousands of years). Evaluation of the likelihood that these hazards affect the public or critical infrastructure is a key element in understanding the risk posed by the various hazards. Risk quantification is outside the scope of this study; however, this section presents a qualitative assessment of risk with an objective of identifying locations where the risk associated with the identified hazards could be unacceptably high and may warrant further study.

Rockfall risk

Rockfalls, from road cuttings in particular, have been a relatively frequent occurrence in the Arthur’s Pass area, occurring adjacent to SH73 more than once per year. These rockfalls have ranged from cobble-size rock fragments falling onto the road pavement and requiring intermittent clean-up, to large-scale failures, including blocks up to 1 m in maximum dimension, partially or completely blocking the highway. In a single historical case, a rockfall occurred from slopes on the east side of the Bealey Valley, with the high velocity flyrock having crossed the valley floor and potentially impacted on the road and rail corridors (see location 9 in Table 4). Potential consequences of rockfall include direct impact on inhabited buildings or areas where the public congregate, interruption of road or rail access to Arthur’s Pass Village, and direct impact of rockfall or debris flow material on vehicles.

Artificial cut slopes can have a higher likelihood of generating rockfall than natural slopes that have been exposed to rainfall, earthquakes and erosion for thousands of years and have reached a natural equilibrium. The most likely rockfall source is road cuttings along SH73. Based on this assessment, the risk to the public and infrastructure when using SH73 is therefore relatively high from rockfall. Currently significant realignment of SH73 is taking place between Mingha Bluff and Arthur’s Pass township, which is expected to be completed by 2017. The extent of risk reduction afforded by these works has not been evaluated as part of this study. In Arthur’s Pass Village, rockfall is not considered a significant risk relative to other hazards due to the lack of nearby cut rock slopes.

Debris flow risk

Debris flows are a relatively common phenomenon in the Arthur’s Pass area and occur several times a year, although damaging events occur are less frequent. They usually follow high rainfall events, particularly where the ground has been saturated by previous precipitation. Generally, significant, damaging debris flows have occurred in existing stream channels and particularly within large catchments (e.g., Rough Creek catchment). Sufficiently large debris flows have the potential to overwhelm the channel capacity, especially on the lower reaches of alluvial fans.

Due to the potentially high velocity and flow rate, debris flows can be very damaging, rapidly depositing large volumes of sediment. Debris flows can carry large boulders and debris such as trees, which can readily block culverts or bridges. Small debris flows onto the highway can usually be quickly removed with earthmoving equipment. However, debris flows impacting on vulnerable property or infrastructure, including buildings, vehicles and rail corridors can lead to severe damage and fatalities. Larger stream channels typically have flood protection works and building exclusions around the existing channels offers protection from small debris flows.

Mitigation of the debris flow hazard by road or rail stakeholders is often the result of debris flow impacting infrastructure, e.g., at Rough Creek Bridge, where accumulated debris is regularly redistributed to maintain flow capacity. Inundation of Rough Creek causing flooding of adjacent dwellings is unlikely while this activity continues.

Debris flows could also occur from slopes between the larger streams, particularly from the small stream channels that run down the mountain slopes to the west of Arthur’s Pass village (for example, Figure 18). The current NZTA realignment works on SH73 (www.nzta.govt.nz) will probably reduce the vulnerability of the highway to debris flow because the road will be further from steep slopes. However, the highway and the adjacent rail corridor will still be vulnerable to large debris flows, possibly resulting in interruption of road and rail access from Canterbury.

Smaller debris flows can be difficult to predict as they may be a non-repeating event, which is triggered by particularly unfavourable conditions. The flow of debris may exhaust the supply of material available, meaning that subsequent similar events are less likely in the future. A debris flow near Klondyke Corner led to four fatalities when a camp site on an alluvial fan was inundated by a debris flow at night during particularly heavy rain on already saturated ground. The remnants of the debris flow are difficult to distinguish 30 years later and the event does not appear to have been repeated in the area. Sporadic, smaller scale debris fans have the potential to form from the slopes on either side of Arthur's Pass Village. It is difficult to predict the hazard zone for small of debris flows because their source supply of debris and catchment size cannot easily be assessed as they are small and covered by vegetation. In some cases all available debris will be mobilised and no further flows are possible.

Given the frequency of heavy rainstorms (see Table 1), historical flooding and debris flows in the Arthur's Pass area, the risk of damage to property or fatalities due to debris flows is probably relatively high compared to other slope instabililty hazards. However, in the last approximately 80 years there have been few cases of significant damage, so the risk is judged to be acceptably low at present. Following a large earthquake, the likelihood of debris flows will increase for several decades following an event due to earthquake induced slope failures within the catchments, increasing the potential source of debris flow material. This potential change in risk profile should be considered in any Civil Defence planning for the area.

Rock avalanche risk

While many rock avalanches have been recognised in the Southern Alps, they are relatively sparsely distributed. No rock avalanches have been recognised within the project area, either historically or in the recent geological past.

The potential consequences of a rock avalanche on the project area would be severe, potentially including long term interruption of road and rail access from Canterbury or inundation of many dwellings and other buildings and associated fatalities.

Despite these potential consequences, the likelihood of a rock avalanche occurring (estimated to less than once every several thousands of years) is low. Given the unpredictable nature of this hazard, it is considered that no part of Arthur's Pass Village can be excluded from rock avalanche.

Risk associated with alluvial processes

Given the relatively frequent heavy rainfall events that affect Arthur's Pass (more than once per year), the water courses tend to experience 'flash' flooding, i.e., rapid increases and decreases in flow. Flood flows in water courses have led to erosion of stream banks, damage to flood protection works, down-cutting of stream beds and standing water. Flood protection works have generally increased levels of protection over time. Significant flood control works in most cases offers protection to road and rail infrastructure, with incidental protection to residential dwellings. Continued maintenance of flood protection works is essential to maintain the present level of risk control.

An important consideration in planning for future flood protection is that significant additional sediment load will likely be introduced into watercourses following strong earthquake shaking. As a result, aggradation of stream bed levels could reduce flow capacity of flood protection works for decades following the earthquake, or lead to stream avulsion. As such, flood protection works will need to be re-evaluated following a major earthquake.

6.0 IMPLICATIONS FOR PLANNING AND CIVIL DEFENCE

All natural hazards discussed in Section 3.0 have the potential to impact Arthur’s Pass Village dwellings and the road and rail between the village and Klondyke corner. The areal extent of damage from each hazard is difficult to define due to the large uncertainty of magnitude of any event. This is particularly the case with sporadic debris flows and earthquake-related events. For this reason a ‘hazard map’ that shows delineated hazard areas is not presented in this study.

Despite the hazards that are present, the relative lack of historical damage to dwellings and infrastructure at Arthur’s Pass indicates that the hazards can be adequately mitigated. Existing maintenance of culverts, river channels and flood protection for infrastructure are an important flood and stream avulsion mitigation measure for the buildings in Arthur’s Pass village. However, drainage channels within the village that were once regularly cleared seem not to be maintained and some drains have been built over by residents wanting to extend the useable area (pers. comm. J Charles, 2015; see Figure 13, Appendix B).

The possibility of future development outside that already occupied by buildings is unlikely as most of the accessible, relatively flat buildable land is already developed. There are some areas that could conceivably be developed (e.g., ‘Maori Flat’, located at the southern end of the village, south of Rough Creek). However, we understand that any land not owned by residents/bach-holders, or the rail or road authorities is officially part of Arthurs Pass National Park. If this is the case, permission would have to be granted by the government before a Resource Consent could be applied for. This is likely to make development outside presently titled sections impractical.

For even a qualitative assessment of risk, it is important to consider the small number of residents per dwelling in the village. It is estimated that there are about thirty permanent residents currently in the village, which could conceivably support up to ten times that number in the approximately seventy dwellings (pers. comm. J Charles, 2016). Population numbers increase during the summer period due to seasonal workers and tourist stays, but the village only ever has a small proportion of buildings permanently occupied.

The hazards described in this report also have important implications for civil defence. Effective response in the event of a large slope failure or earthquake will possibly be hindered by reduced road service. Availability of suitable helicopters will likely be an important consideration in planning for such events. Given the relatively small population at Arthur’s Pass, it is likely that helicopter evacuation of affected people could be readily achieved. This would not necessarily be the case if large numbers of visitors were present, such as during holiday periods or when a passenger train is present.

7.0 CONCLUSIONS

1) Arthur’s Pass area is susceptible to slope instability processes such as rockfall, debris flow and rock avalanche as a result of the steep slopes, high seismic hazard and high rainfall. Existing maintenance of culverts, river channels and flood protection for infrastructure are an important flood and stream avulsion mitigation measure for the buildings in Arthur’s Pass village.

2) The risk associated with rockfall mainly affects road users and the potential short term disruption of road and rail traffic between Arthur’s Pass and Canterbury. Rockfall is a fairly frequent occurrence along SH73 and thus the risk to road users is relatively high.

3) On-going improvements to road cuttings along SH73 have reduced, but will not eliminate the rockfall risk to road users.

4) Rock avalanche deposits are common in the Southern Alps and have been identified in the vicinity of Arthur’s Pass. Given the large size and high velocity of rock avalanches, the potential consequences on Arthur’s Pass village or the transportation route could be severe. However, the relative frequency of rock avalanche deposits in the landscape is low and the likelihood that a rock avalanche will impact Arthur’s Pass village is low.

5) Debris flows are a relatively common phenomenon in the Arthur's Pass area owing to the steep slopes and high rainfall. The project area has been directly affected by debris flows on several occasions during the last few decades. Due to the high velocity and potentially large affected area, the consequences of a large debris flow affecting dwellings and infrastructure are substantial. As a result the debris flow risk to Arthur's Pass is relatively high, although in some locations is mitigated by redistribution of debris (e.g., Rough Creek).

6) Protection measures constructed within the project area have been maintained and progressively improved to mitigate flooding arising from debris flows aggradation. Ongoing maintenance is critical to maintaining the effectiveness of these measures because large flood events will damage the flood protection and require repair. This currently seems to be managed adequately by infrastructure stakeholders (NZTA, KiwiRail). If this maintenance is reduced, a corresponding increase in hazard could be expected.

7) A large regional earthquake, such as on the Alpine Fault, is likely to increase the frequency and scale of slope related failures and associated flooding. Debris that has been generated by the earthquake will enter and be transported down the river/stream channels and accumulate on the flatter sections of the streams and Bealey River within and adjacent to the valley floor. Slope failures and increased sediment supply within the catchments will potentially increase the likelihood of debris flows, stream channel aggradation and increased flood hazard. Effective response in the event of a large slope failure or earthquake will possibly be hindered by reduced road and rail service, although the exact location and magnitude of the hazard is difficult to define.

8) Damage to the forest vegetation as a result of fire, wind throw or pests could expose additional slope to more severe erosion processes than they currently experience. This could significantly increase the risk associated with debris flow and other slope instability hazards.

9) The exposure of Arthur's Pass residents to natural hazards is low relative to the number of buildings. The permanent population of approximately 30 is much less than could be accommodated in the habitable buildings. Visitors and temporary residents periodically increase the hazard exposure.

8.0 RECOMMENDATIONS

1) Existing flood training and debris redistribution earthworks should continue. The hazard from debris flows is mitigated considerably while this is in place.

2) Culverts and drainage courses that service Arthur's Pass should be regularly inspected and maintained as necessary. Where informal development has occurred (e.g., building over an open drain), their effect on drainage capacity should be assessed and removed, if necessary.

3) This study should be repeated in the event of the hazard profile substantially changing from the present situation. Damage to slopes following a large earthquake can lead to increased slope failures, potentially increasing the hazard. The same may be necessary if the present maintenance works cease. For example, if the railway was abandoned, removal of debris under railway bridges may not occur. A significant increase in aggradation in the Bealey River may also require re-evaluation of the hazard.

4) Consideration should be given to the benefit of retaining earthmoving equipment in Arthur's Pass Village. This would undoubtedly be useful following a large, local earthquake.

5) It could be useful to simulate the size and potential for disruption during an earthquake or large flood-related debris flow from some of the large catchments. Blocking and subsequent overflow breach of large debris flows in the larger catchments to the west of the village (McGrath Creek, Avalanche Creek, Rough Creek) could cause localised flooding.

6) Recording of hazard event details in a GIS format would be useful to highlight areas not already identified. This is especially important as existing long-term residents will not always be available for questioning. It is suggested that the focus area be that which directly affects Arthur's Pass Village as other infrastructure providers maintain their own event database.

7) Users of any future natural hazard prediction model for Arthur's Pass Village should be aware of the uncertainties of assumptions made. The aggregation of numerous complex hazard types mean the overall model confidence is low. Careful consideration should be given to initiating such studies.

8) Details of permanent residents and weekly estimated visitors throughout the year should be made available to Civil Defence. If this information does not already exist, a survey of accommodation and restaurants should give a reasonable estimate. Road and rail use information would also be useful.

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APPENDIX A

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APPENDIX B

Photographs

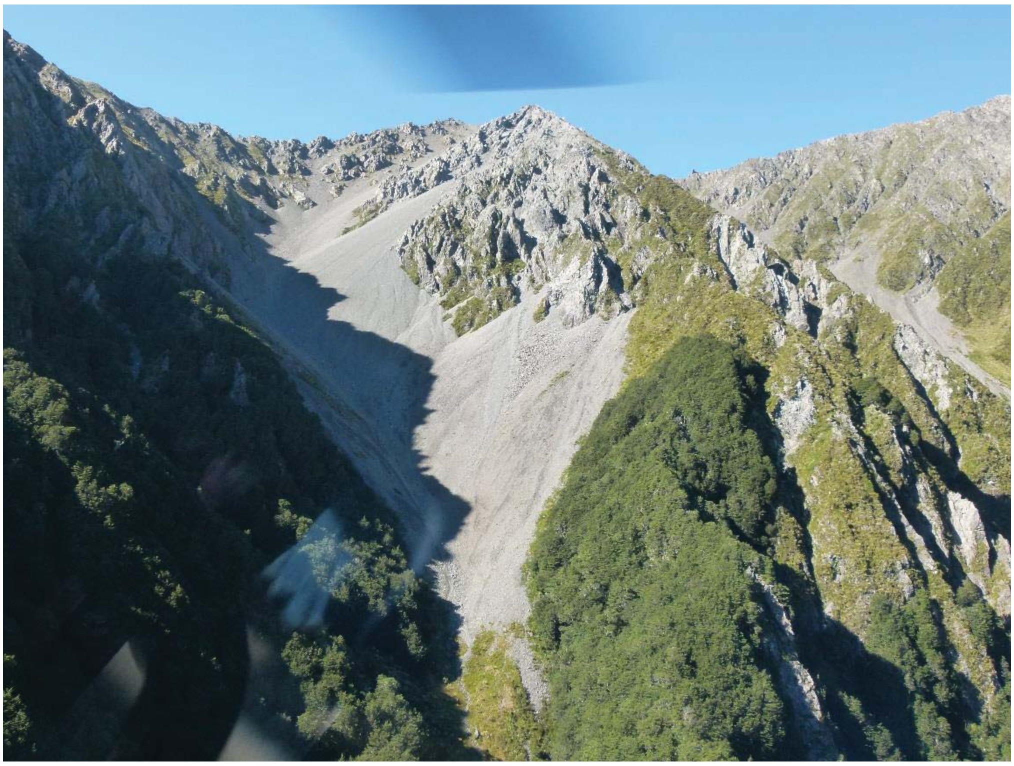

Figure 9: Rough Creek catchment showing steep eroding rock slopes and scree development.

Figure 10: Minor slope failures in small catchments above Arthur's Pass village.

Figure 11: Bealey River valley viewed from north showing Arthur's Pass in centre of view.

Figure 12: Slopes above north end of Arthur's Pass showing variation in vegetation.

Figure 13: Culverts of un-named stream crossing SH73 in Arthur's Pass village showing gravel lag and vegetation in channel.

Figure 14: Channel of small un-named stream in Arthur's Pass village.

Figure 15: Bealey River flood plain in the area of flood damage near Chalet Restaurant.

Figure 16: Channel contouring in the flood plain of the Bealey River.

Figure 17: Contoured flood channel for the Bealey River.

Figure 18: Flood channel for Avalanche Creek.

Figure 19: Rough Creek bridge SH73 with rail bridge in background.

Figure 20: Channel of Rough Creek showing flood protection banks.

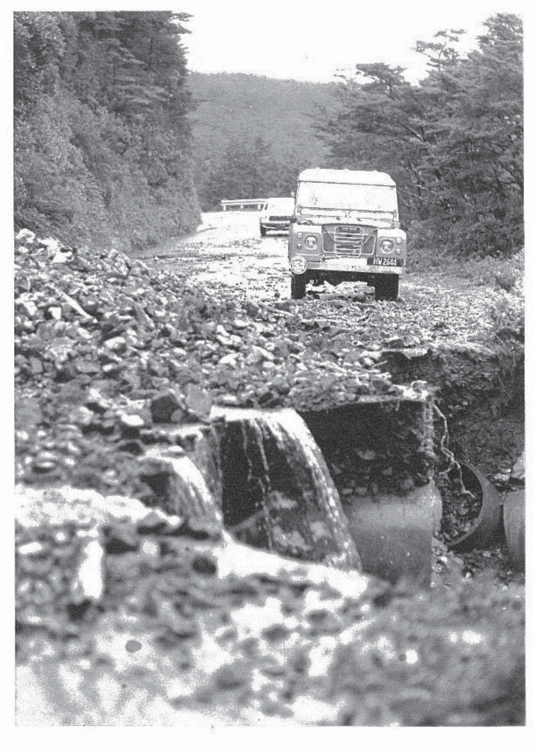

Figure 21: Flood and debris flow damage to SH73 at Snow Creek, 3 December 1979.

Figure 22: Erosion of road formation due to flooding near Snow Creek, 3 December 1979.

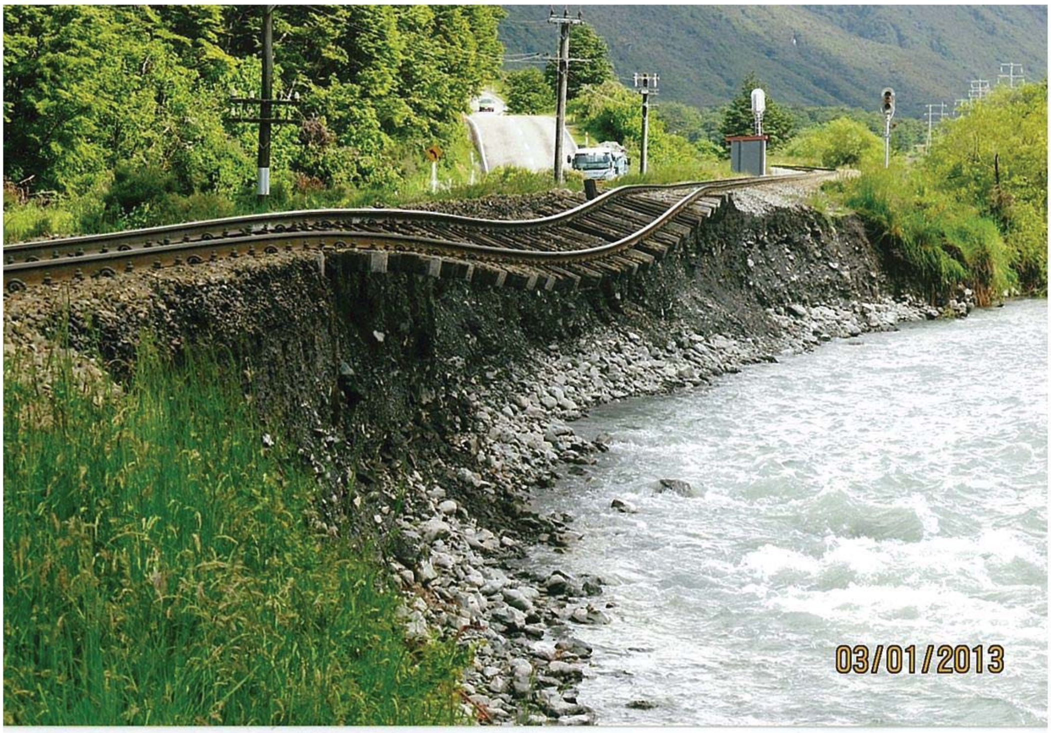

Figure 23: Erosion of railway formation by Bealey River north of Halpin Creek.

Figure 24: Debris flow in rail formation north of Halpin Creek.

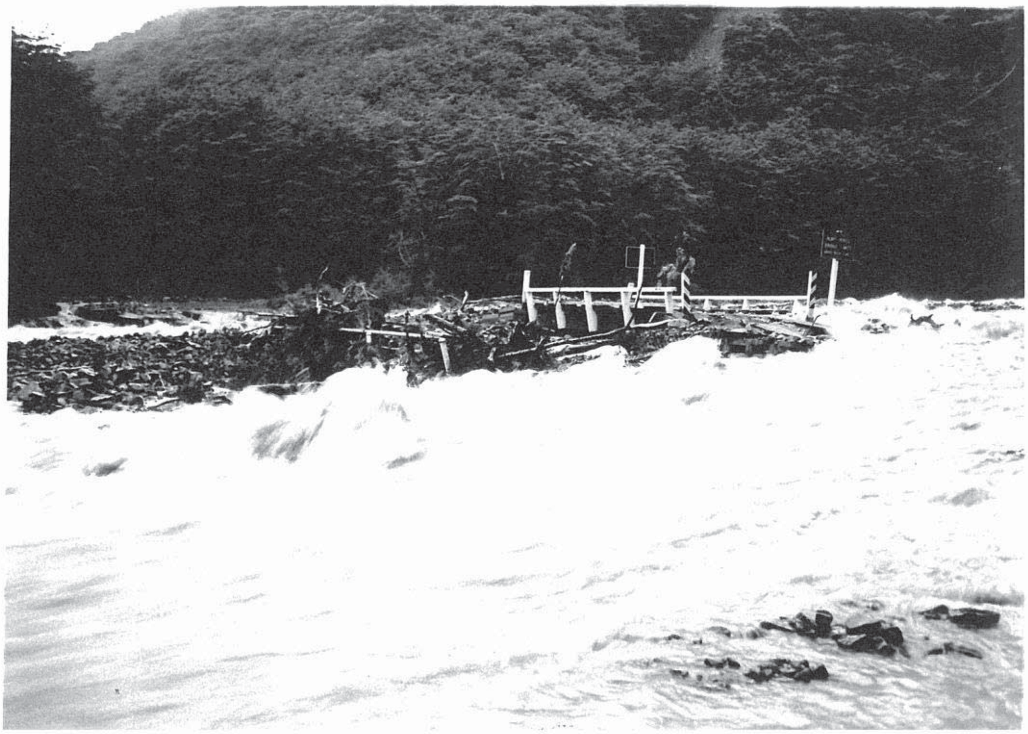

Figure 25: Flood aggradation and debris flow damage at Halpin Creek, 1979.

Figure 26: Clean-up of damage to bridge and channel capacity reduction at Halpin Creek, 1979.

Figure 27: Erosion of rail formation by Bealey River near Halpin Creek.

Figure 28: Sluicing of debris flow material at site of buried camp near Klondyke Corner, 1979.

Figure 29: Debris flow material near Klondyke Corner.

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