Natural Hazards at Makarora

April 2007

Otago Regional Council
Private Bag 1954
70 Stafford Street
Dunedin

Ph: 0-3-474 0827
Fax: 0-3-479 0015

Executive Summary

Natural Hazards affecting the Makarora valley include flooding and seismic hazards. Flooding in the Makarora valley originates from two main sources – the Makarora River and the tributary creeks that flow into the Makarora River. The tributary creeks flow mostly on alluvial fans. Seismic hazards affecting the valley include liquefaction induced by ground-shaking and mass movement induced by ground shaking.

The hazards that affect alluvial fans are associated with fan erosion and deposition processes, flow path uncertainty and flood hazard severity. There is a long history of alluvial fan flooding (including debris deposition) events affecting the Makarora valley. Severe earthquakes may also trigger high levels of alluvial fan erosion and deposition activity.

The township of Makarora West is constructed partially on the Pipson Creek alluvial fan and partially on the White Creek alluvial fan. The oldest trees dated in the forest on the Pipson Creek alluvial fan are two matai trees dating to approximately 1080AD and 1402AD. All other trees on the fan post-date 1722AD and a significant number post-date 1869AD. The five trees commencing growth in 1823-1853AD may be associated with the 1826AD Alpine Fault earthquake.

Two of the early tree establishment dates may be associated with known significant Alpine Fault earthquakes in 1717AD and 1445AD. The post-1869 tree establishment dates are associated with a major fire in the valley which was started artificially in 1860.

The Makarora valley was shaken by an earthquake of M6.2 in 2001, centred on the local segment of the Alpine Fault. The most confident estimates for a large (>M8) Alpine Fault rupture between Haast and Milford Sound are 0.54-0.87% in one year; 10-16% in 20 years; 24-35% in 50 years; and 41-56% in 100 years. These estimates account for the increasing probability of a fault rupture as time passes without a significant rupture.

Fan erosion and deposition episodes are triggered relatively frequently by hydrological events. There have been eighteen recorded flood events causing damage in the valley since 1950, originating from either the Makarora River or its tributaries. However, recent fan building events on Pipson Creek fan have occurred more frequently than once every two years, suggesting Pipson Creek has recently developed a higher propensity for this style of event.

Other alluvial fans in the Makarora valley will behave in a similar way to the Pipson Creek alluvial fan. It should be expected that infrequent severe earthquakes and relatively frequent flood events will induce significant alluvial fan activity.

Assessment of the areas of the Makarora valley subject to natural hazards indicates that the valley floor and the alluvial fans have a higher risk from natural hazards than the elevated land on the Makarora faces.

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1 Introduction

The Makarora valley is situated at the head of Lake Wanaka. It extends from the lake to the Haast Pass, which is the north-western boundary of the Otago region and the Queenstown-Lakes District. This report describes the range and significance of natural hazards that are known to be present in the valley. It supersedes an earlier report dated January 2007 by providing more refined hazard information (Section 3 and Figure 6).

The Makarora valley was formed in part by Quaternary glaciers. The glaciers of the Last Glacial Maximum (18,000 years ago) extended as far south as the settlements of Hawea and Wanaka. The sediments left behind by the glaciers are modified today by the Makarora River, which forms a braided river, flowing on the western side of the valley floor. Glacial till is evident along the valley and as high level lateral moraines. There are several rock features near the valley floor that may be roche moutonées (formed by advancing ice). The moraines are dissected by steep streams flowing down the faces of the Makarora valley, which have formed extensive alluvial fans.

The Makarora valley has long been used as a route to the West Coast by Maori and later by settlers. In 1860 explorer George Hassing travelled up the valley. His journal notes that “[t]he Makarora valley was at that period covered by an entangled, impenetrable mess of cabbage trees, flax and fern, growing to a height of 8 feet to 10 feet and the ground a jungle of dried and decayed vegetation, over which it was impossible to make any heading”. To clear the country for travel, Hassing started a fire at the head of Lake Wanaka. “This soon developed into one unbroken seething ocean of flame from hillside to hillside, and fanned by a southerly wind, it raged for three days and nights, travelling up the valley 20 miles. It was a terrific blaze, that levelled everything in its course…” (Hassing, 1929).

Further later impacts from logging and additional fires resulted in the almost entirely tree-free lower valley seen today. Hassing’s fire did not remove all forest in the valley, because “[t]he upper Makarora valley was afforested down the fans on the valley floor. Saw milling commenced in 1861, when pit sawing began and subsequently three sawmills operated in the valley. The deafforestation (sic) was severe until around 1900 and has subsequently been almost completed through fire, particularly along the eastern slopes” (Ritchie, 1976). However, in the early part of the twentieth century, the forest on Pipson Creek’s alluvial fan was still extant (Figure 4) and it has probably survived through to today without significant further modification (Figure 5).

The valley remains a significant communications corridor from Otago to the West Coast, with State Highway 6 (SH6) experiencing an annual average of 770 vehicle movements a day in 2005, just south of the Makarora valley (Transit, 2005).

2 Flooding

Flooding in the Makarora valley originates from two main sources – the Makarora River and the tributary creeks that flow into the Makarora River. The creeks joining from the eastern side of the valley are the most significant for human use of the area. Since deglaciation approximately 15,000 years ago, most of these creeks have constructed alluvial fans where they debouch onto the Makarora valley floor. However, during significant floods steep creeks in this area also flow over apparently 'safe' locations such as isolated buttresses (Figure 10). Flooding from these alluvial fans has been experienced several times in recorded history. The hazards associated with alluvial fans are more extensive than simple flooding by inundation, so these features are dealt with separately here.

Flooding from the Makarora River and its tributaries has been experienced regularly. Photographs from some of these events are in Appendix 1. Recorded instances of these events are:

- 1948, when Lake Wanaka rose 12 feet above normal (ORC, 1993)
- 1950, when serious flooding occurred and 2,000 sheep were lost in the Makarora valley (SCRCC, 1957)
- 1952, when a flood of the Makarora River caused severe erosion and major damage was sustained by tributary creeks
- 1967 (March), when 35 hectares of farmland was isolated by the development of a side channel in the Makarora River, a short distance upstream of the lake (ORC, 1993)
- 1967 (December), when Township, Flaxmill, Station and Brady's Creeks filled with gravel during high flows (ORC, 1993)
- 1976, when gravel and trees blocked Flaxmill Creek (ORC, 1993)
- 1978, when there was very extensive flooding in the Makarora valley (Gillies, 1995) and 200 ewes and 1100 lambs were lost from Makarora Station, 5 km of fencing destroyed and 100 hectares covered by silt (ORC, 1993)
- 1979, when flood levels were higher from the Makarora River than during the 1978 event and floodwaters reached the doorstep of K Blanc's house (ORC, 1993)
- 1983, when the bridge over Waterfall Creek washed out and SH6 was closed (ORC, 1993)
- 1984/1985, when half of Wattie Cameron's property adjacent to the lake was flooded (ORC, 1993)
- 1986, when Flaxmill Creek was badly affected by boulders, gravel and silt deposited in the stream bed from the confluence with the Makarora River to a distance 300 metres upstream of the State Highway. The stream banks were overtopped in several locations (ORC, 1993).
- 1989/1990, when debris flows in Pipson Creek affected the SH6 bridge (Opus, 2004a).
- 1994, when six bridges between the Neck and Makarora were washed out and extensive sediment deposits left by the alluvial fan tributaries of the Makarora River (ORC, 1999). Debris flows in Pipson Creek also affected the SH6 bridge (Opus, 2004a).
- September 1995, when debris flows in Pipson Creek affected the SH6 bridge and laterally affected the area either side of the bridge (Opus, 2004a).
- December 1995, when debris flows in Pipson Creek affected the SH6 bridge and the side rail was damaged (Opus, 2004a).
- 1998, when debris flows in Pipson Creek affected the SH6 bridge and laterally affected the area either side of the bridge (Opus, 2004a).
- 2004, when Pipson Creek buried the SH6 bridge (Opus, 2004a).
- 2006, when Pipson Creek again buried the SH6 bridge and broke out from its channel on the left and right of the alluvial fan (ORC, 2006)

The house previously situated near the Country Café had floods from the Makarora River through the property so frequently that the floor was built up and doors shortened to cope with the higher floors (Gary Charteris, pers. comm. 2006).
The area of the Makarora valley potentially subject to flood hazard was previously identified from the observations of Catchment Board and Otago Regional Council employees, historical accounts and inspection of the catchment (ORC, 1999). The extents of this area are illustrated in Figure 2.

The catchment area of the Makarora River is approximately 710 km^2 (ORC, 1999). No flow records are available for the Makarora River or any of its tributaries. Rainfall information has been collected at Makarora since 1925 (Figure 1). The ten-year running mean annual rainfall increased from approximately 1700 mm in the 1940s to approximately 2500 mm today, an increase of 47% in about 60 years. This increase in annual rainfall will not necessarily be associated with an increase in the intensity of severe rainfall events, but wetter conditions have probably resulted in more frequent flood events and associated mass failures in the valley (Mojzisek, 2005).

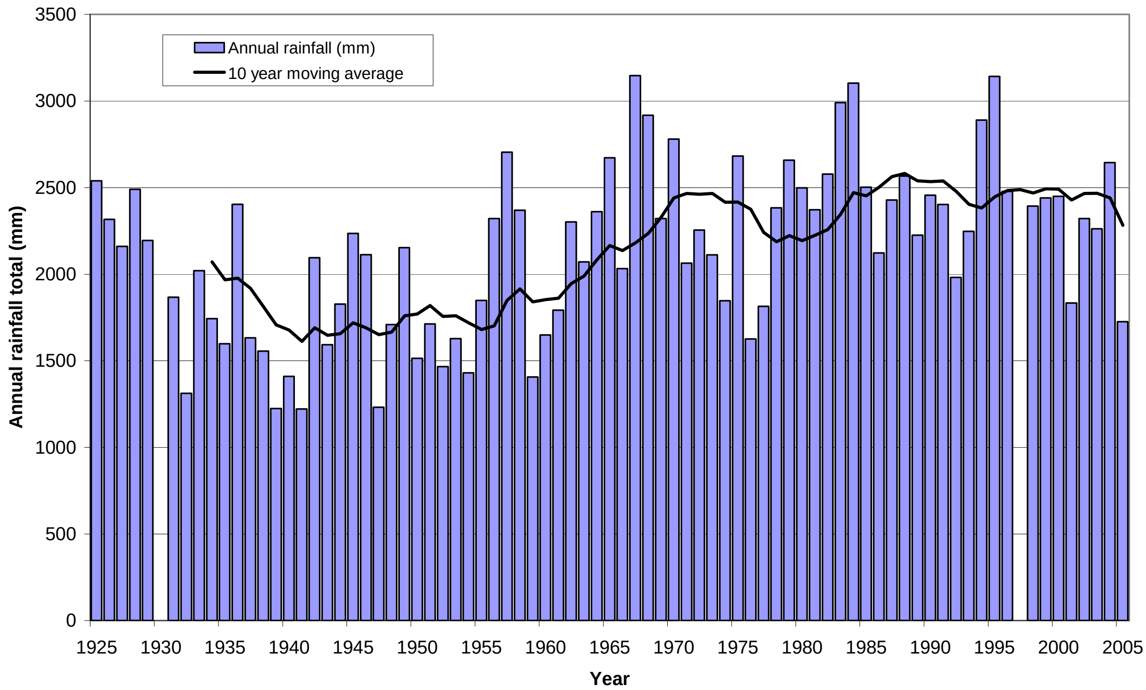

Figure 1: Annual rainfall at Makarora, 1925-2005

3 Alluvial Fans

The hazards that affect alluvial fans are associated with fan erosion and deposition processes, flow path uncertainty and flood hazard severity. In Figure 2 the flood hazard on the alluvial fan tributaries of the Makarora River has been identified on the basis of historical information and personal experience. However, alluvial fan landforms in the Makarora valley were constructed during fan depositional events in the historical past. These events have at one time or another occupied the whole surface of each alluvial fan. Except where it can be shown that the alluvial fan surface may no longer be occupied by the fan-forming stream, the whole alluvial fan should be considered as subject to alluvial fan hazards. This work has not been undertaken for any of the alluvial fans in the Makarora area.

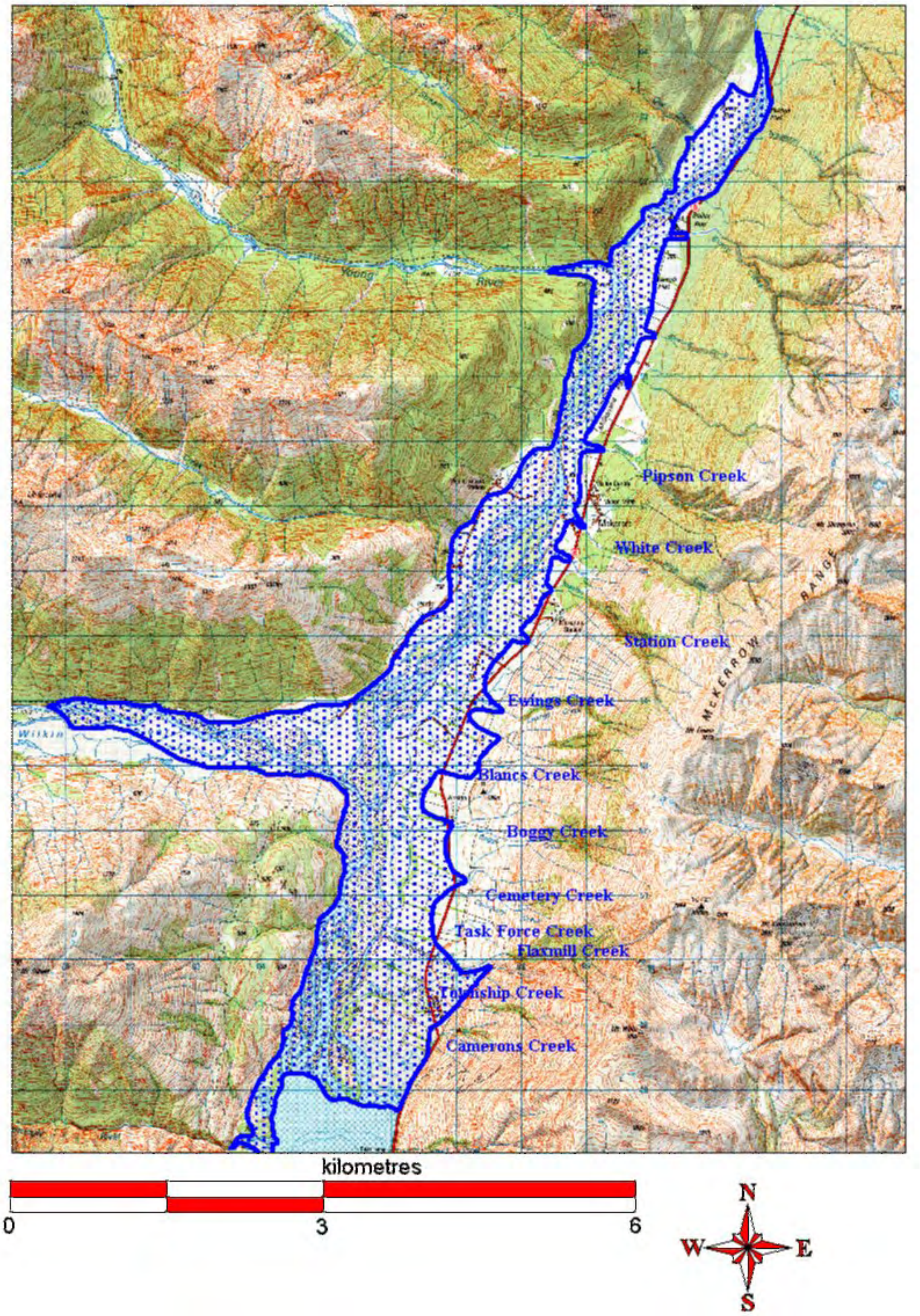

Figure 2: Area of Makarora valley potentially subject to flood hazards (ORC, 1999).

The probability of any one portion of each alluvial fan experiencing a flood/debris flow event can not easily be predicted due to the uncertain nature of alluvial fan flow paths. However, proportional risk generally increases towards the head of the fan as fan width decreases. The alluvial fan hazard is derived not only from flowing water, but also from the material transported in water as debris slurries, or as debris flows. The large concentration of debris in fan-forming flows in the Makarora area greatly increases the likelihood of flows destroying property, compared to water-only flows. This type of event is illustrated in Appendix 1.

There is a long history of alluvial fan flooding (including debris deposition) events affecting the Makarora valley. In the 1930s Station Creek flowed through where the manager’s house is situated today. At the turn of the nineteenth century the house was well above the ground. Today the ground has aggraded up to the floor joists as a result of flood events. In 1944 a local resident observed the fence upstream of the highway buried by debris from Boggy Creek. This was the second fence to be built on this site (Ian Turnbull, pers. comm. 2006). There existed previously at Wharf Creek a pub that was destroyed by a flood in the area (Ian Turnbull, pers. comm. 2006). During the events of 1978 and 1979 Ewings Creek was so high that a car was washed into a willow tree near the Country Café on the downhill side of the road. This was approximately 2.5 m above the normal ground level. During the 1994 event the manager’s house at Station Creek had the creek running underneath it. The velocity of the water and associated debris was so high that the house was shaking (Gary Charteris, pers. comm. 2006).

The identification of the area subject to these hazards in Makarora is by interpretation of aerial photographs flown in 1953, 1986 and 1999; oblique photographs obtained during floods (see Appendix 1 – mostly from the collection of Clinton O’Brien, by kind permission); and from general field interpretation in the period 2004-2006. In Figure 6 the parts of the Makarora River floodplain and alluvial fans affected by historic flooding is shaded in light blue and outlined in dark blue. The extent of relatively recently active (last 200 years) alluvial fans is shaded in light blue without outlining.

Also shown in Figure 6 are three classes of area considered to be possibly more suitable for settlement than the remainder of the Makarora valley.

1) Class 1: These areas outlined in green are predominantly between the State Highway and the Makarora River. They are areas where the risk of inundation by debris flows from eastern tributaries of the Makarora River is slightly reduced because sediment is trapped behind the State Highway during floods and because the gradient of the alluvial fans is lower – causing deposition of sediment at lower velocities during flood and debris flow events. The risk of inundation from the Makarora River is also reduced in these areas because they are relatively distant from the main riverbed. However, historic floods and debris flows have affected these positions (for examples, see photographs in Appendix 1). It may be feasible to identify parts of these areas where structural and non-structural measures may reduce the risk of inundation and debris flows to a level acceptable for settlement. However, site-specific analysis will be required to identify the magnitude and frequency of historic flood and debris flow events affecting these areas. It may not be feasible to mitigate the risks of flooding and debris flow events to an acceptable level, despite the lower risk in these areas. The

exception in this group is a rock knoll situated just north of Cemetery Creek, where elevation has created a site relatively secure from flooding and debris flows.

2) Class 2: The area outlined in orange is a semi-plateau of land situated on the eastern slopes the Makarora valley between Ewings Creek in the north and Boggy Creek in the south. The risk of inundation by debris flows or floods is slightly reduced in this location because the creeks appear to change their courses less frequently, possibly because the slope of the land is steeper than the alluvial fans. However, in 1994 Cemetery Creek changed and broadened its course in a similar situation to this (Figure 20). Although the risk of inundation may be proportionally lower here because the creeks flow more rapidly, high velocity flows would do more damage to buildings than at lower gradient sites. Careful site-specific investigation would be required to identify whether the risk of channel avulsion (switching) could be mitigated to the extent necessary to make parts of this area sufficiently safe to build.
3) Class 3: This area of land is situated to the east of the State Highway and south of Blancs Creek, around trig station “B”. This area is elevated and relatively protected from debris flows and flooding, although site specific assessment may be required to identify whether creeks flowing west from Mount Ernest had the potential to run up over the site.

3.1 Pipson Creek

In 2004 and 2006 debris from floods in Pipson Creek buried the SH6 bridge, just north of the Makarora West township. The township of Makarora West is constructed partially on the Pipson Creek alluvial fan and partially on the White Creek alluvial fan. Historically, the White Creek alluvial fan was more active, but in floods of the 1980s water from Pipson Creek was observed flowing down the nature walk on the true left of its fan (Gary Charteris, pers. comm. 2006).

The age of historical alluvial fan forming events may be identified by dating the erosion and deposition surfaces on the fan. One commonly used method is dendrochronology – tree dating. Erosion and deposition events affect trees by directly destroying them and disturbing their growth. New trees are established following the disturbance and the oldest of these trees will give an age for the period immediately following the disturbance. On an alluvial fan the disturbance may be localised in response to a narrowly-focussed event such as a single channel avulsion event; or it may be more widespread, reflecting general erosion and deposition on the fan.

Trees were chosen for dating from the Pipson Creek alluvial fan by systematic identification of locations on the alluvial fan, followed by selection of the largest tree in each location. The oldest trees dated in the forest on the Pipson Creek alluvial fan are two matai trees dating to approximately 1080AD and 1402AD. The oldest beech trees in the forest are found at the margins of Pipson Creek and in the centre of the fan. These trees range in age from approximately 1722AD to about 1853AD. The next cohort of ages is of trees established after 1869AD, with most dating to the 1880s. These are found around the margins of the forest. The final cohort is a group of twentieth century trees found in the forest margins and in the palaeochannel feature on the south-east margin of the fan (Figure 3).

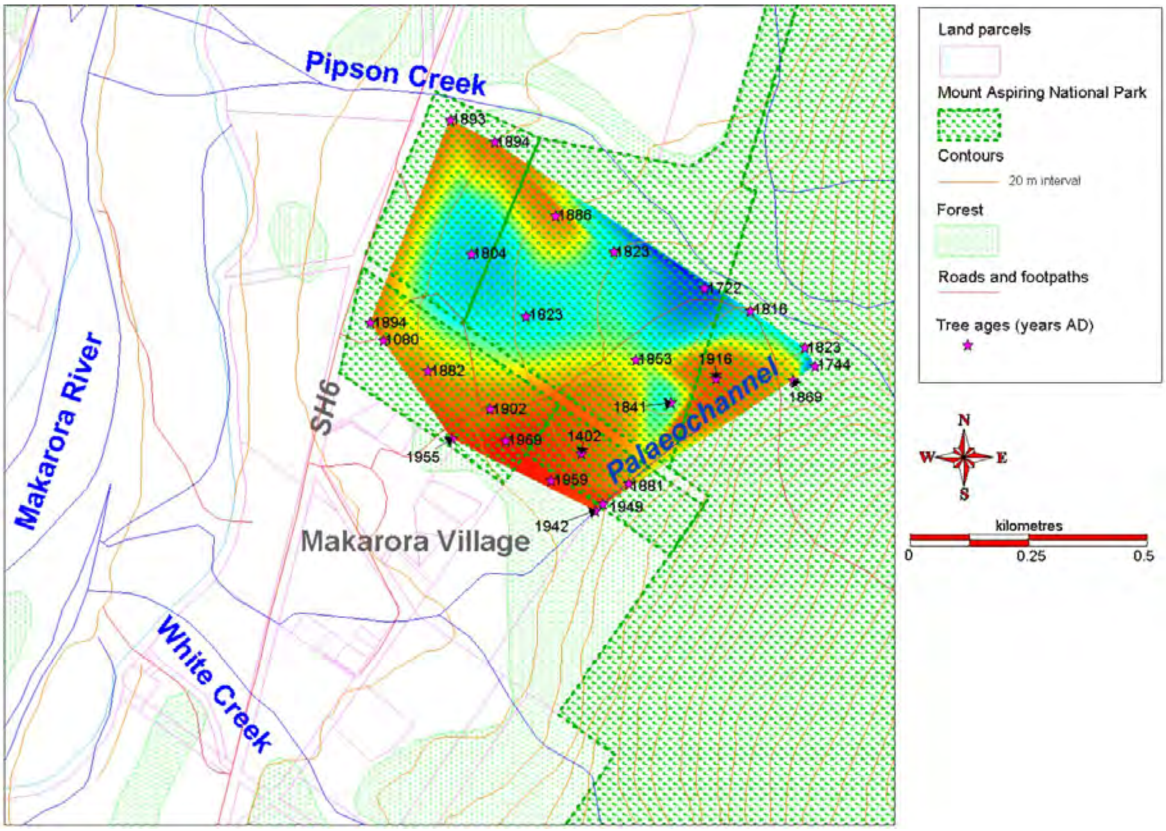

Figure 3: Age of trees on the Pipson Creek alluvial fan. Colour shading indicates age – orange is young.

The known events that may have affected forest growth on Pipson Creek alluvial fan are Hassing's burning of the valley floor and logging in the years following 1861. However, early photographs of the Pipson Creek alluvial fan show that the forest survived at least until the early twentieth century (Figure 4) and the forest present today is substantially similar (Figure 5). Earthquakes on the Alpine Fault (Figure 7) may also have caused sediment inputs to the alluvial fan from seismic-induced mass movement in the catchment.

Figure 4: Makarora Township and forest on the Pipson Creek alluvial fan, early 20th century (1902?).

Figure 5: Substantially the same view as Figure 4, October 2006.

Alpine Fault earthquakes are known to have occurred in 1826AD and 1717AD. The 1826 event was probably focussed in the offshore segment of the Alpine Fault south of the latitude of Pipson Creek (Wells & Goff, 2006). The 1717AD event is expected to have caused displacement of approximately 8 m near Haast. In general on the Alpine Fault additional events are reported as occurring in 1620±10AD, 1445±20AD and in 1100-1200AD (Norris et al. 2001). In the southern segment of the fault from Haast to Milford Sound, these latter two events have been revised more recently to 1450±100AD and 1210±50AD (Rhoades & Van Dissen 2003). All these events may also have caused approximately 8 m displacement on the Alpine Fault near Haast. Norris et al. (2001) do not identify the 1620AD and 1445AD events near Haast, but note that they are found further north on the Alpine Fault (Norris et al. 2001).

The establishment ages for the two matai trees were obtained by linear extrapolation of growth rates based on tree ring counting in the youngest part of the tree. Neither tree was cored to the oldest rings. For these old trees, the accumulated errors in tree ring counting are likely to be of the order of several decades. The matai tree located near SH6 that dates to approximately 1080AD may have commenced growing following the 1210±50AD earthquake, although this is relatively unlikely. However, 303 years of the tree age were estimated from extrapolation of observed growth rates. The 1402AD matai tree located in the middle-south side of the fan may have commenced growing following the 1450±100AD earthquake. In this latter case the slightly older tree age is likely to be within the accumulated error for the tree ring counting and the error of the earthquake age. Only 11 years were added by extrapolation to the 1402AD tree's observed age.

The two beech trees that are estimated to have commenced growing in 1722AD and 1745AD respectively may have established following the 1717AD Alpine Fault earthquake. It is notable that no beech trees have been dated to older than 1722AD.

The five trees commencing growth in 1823-5AD (3), 1841 and 1853 may have grown following the 1826AD earthquake. The pre-1826 trees in the cohort may be saplings that were already established which grew strongly when competing trees were destroyed during the event. These five trees are situated at the head of the alluvial fan and in the central area of the fan west of the channel. The trees were sampled from the top surface of the alluvial fan, on depositional lobes and at the upper edge of the run-out zone (a zone with few gullies). The event causing tree disturbance was probably deposition of material shaken loose from the catchment by the earthquake.

The possible association of the tree establishment dates with three known significant Alpine Fault earthquakes (1826AD, 1717AD and 1445AD) and elevated levels of alluvial fan activity since the M6.2 earthquake in 2001 (Clinton O'Brien, pers. comm. 2006) suggest that the Pipson Creek alluvial fan experiences significant disturbance events during severe seismic events. This is probably as a result of mass movement induced in the upper catchment by seismic shaking, which causes subsequent sediment deposition on the alluvial fan during heavy rain. The two older matai trees may be situated in areas of the fan that did not experience disturbance during more recent fan building events.

Several beech trees from the late nineteenth century are found around the forest margins in the lower part of the forest. These may have grown following Hassing's fire of 1860 or

alternatively after disturbance from an alluvial fan depositional event around this time. Older, trees in the centre of the forest were probably protected from the fire and other events.
The tree located closest to the SH6 bridge over Pipson Creek includes damaged growth rings from 1910AD, which may indicate a period of damage from flooding around this time.

The mid-twentieth century ages for beech trees in the south-east corner of the fan may indicate that the palaeochannel that runs south from Pipson Creek towards the Makarora settlement was active prior to this time. However, no historical record has been found that identifies an event in this channel around this time. In addition, the proximal end of the palaeochannel (ie, at the top of the alluvial fan) has trees established in the period 1744-1910. It is more likely that the disturbance event causing tree re-growth is related to waterlogged ground at the margins of the hill or to selective felling at the margins of the forest in the 1940s and 1950s.

The palaeochannel may not have been active since the 1717AD earthquake. However, this does not mean that the palaeochannel will not be active again in the future – it offers a 'path of least resistance' to any debris flow exiting the channel at its upstream end. As sediment inputs change in the throat of the Pipson Creek alluvial fan, the potential exists for channel aggradation to trigger channel avulsion into any position on the fan. The high channel margins here indicate that reoccupation of the palaeochannel is less likely than avulsion in other places on the fan, but it should not be excluded as a potential breakout location.

3.2 Other Fans

The information obtained from the trees on Pipson Creek's alluvial fan indicates that significant fan building episodes in the Makarora valley may be related to earthquake events on the Alpine Fault. Recent debris flow events in 2004 and 2006 suggest that material supplied during mass failures may be transported during heavy rain events to also produce significant fan building episodes.

Evidence from elsewhere in the Makarora valley obtained during the widely-observed 1994 heavy rain event indicates that fan building episodes controlled by hydrology may be relatively frequent. No observations have been made for the impacts of earthquakes on these other fans.

There have been eighteen recorded flood events causing damage in the valley since 1950, originating from either the Makarora River or its tributaries, or one every three years on average. However, recent fan building events on Pipson Creek fan occur more frequently than once in two years, suggesting Pipson Creek has developed a higher propensity for these events in recent years.

Fan building episodes triggered by major earthquakes are much less frequent, with three significant events in the last 290 years (Table 1), or one every 97 years on average. The interval between major earthquakes on the Alpine Fault is one to two centuries. It is notable that Pipson Creek activity has been much more significant since the local M6.2 earthquake of 2001.

4 Seismic Activity

Seismic activity affecting the Makarora valley is most likely to originate on the Alpine Fault, which is situated to the north-west of the valley (Figure 7). Two significant seismic hazards for the Makarora valley are liquefaction as a result of ground shaking (Figure 8) and mass movement induced by ground shaking (Figure 9).

The distributions of ground potentially affected by these two hazards are shown in Figure 8 and Figure 9 respectively (data from Opus, 2004b). During the 2001 M6.2 earthquake on the Alpine Fault (Figure 7) an observer noted that during the event the valley floor had the appearance of “corrugated iron” (Clinton O’Brien, pers. comm. 2006). This was probably caused by surface waves propagating through alluvial sediments. However, little damage was caused to buildings in the valley.

In a similar way to the flood and alluvial fan hazard identification, seismic hazards should be considered as a general level identification of the potential hazard. Further localised study may identify areas in the Makarora valley where these hazards are less significant.

The probability of future seismic events on the southern section of the Alpine Fault has recently been examined by Rhoades & van Dissen (2003). They estimate that the probability of rupture of the Alpine Fault between Haast and Milford Sound from 2002AD onwards is 0.33-0.87% in one year; 6.3-16% in 20 years; 15-35% in 50 years; and 27-58% in 100 years.

Rhoades & van Dissen (2003) suggest the most confident estimates for a large Alpine Fault rupture between Haast and Milford Sound are 0.54-0.87% in one year; 10-16% in 20 years; 24-35% in 50 years; and 41-56% in 100 years. These estimates account for the increasing probability of a fault rupture as time passes without a fault rupture.

Table 1: Pipson Creek alluvial fan disturbance events

Date (AD)	Trigger Event	Disturbance Location	Probable Cause
1100s?	Earthquake? (~M8)	W edge of fan	Debris flow on fan
~1445	Earthquake? (~M8)	S edge of fan	Debris flow on fan
1717	Earthquake (~M8)	W edge of channel	Debris flow in channel?
1826	Earthquake	Central part of fan	Debris flow on fan
1860	Fire	S & N edge of forest	Death of marginal trees
1910	Heavy rain?	W end of bridge	Debris flow?
1980s	Heavy rain	Fan surface at walkway	Water flow from Pipson Ck
2001	Earthquake (M6.2)	Channel & NE part of fan	Debris flows 2004 & 2006

Table 2: Susceptibility classification for liquefaction induced by seismic shaking (Opus, 2004b).

Susceptibility Class	Modified Mercalli Intensity of Shaking			
	MM6	MM7	MM8	MM9
Possibly Susceptible	Liquefaction and settlement are unlikely, no ground damage expected	Liquefaction and settlement of limited layers may occur resulting in minor ground damage	Liquefaction and settlement of some areas resulting in moderate ground damage	Liquefaction and settlement resulting in significant ground damage are possible
Low Susceptibility	Liquefaction and settlement are unlikely, no ground damage expected	Liquefaction and settlement are unlikely, no ground damage expected	Liquefaction and settlement of limited layers may occur resulting in minor ground damage	Liquefaction and settlement of some areas resulting in moderate ground damage
Not Susceptible	Liquefaction and settlement are unlikely, no ground damage expected	Liquefaction and settlement are unlikely, no ground damage expected	Liquefaction and settlement are unlikely, no ground damage expected	Liquefaction and settlement are unlikely, no ground damage expected

Table 3: Susceptibility classification for mass movement induced by seismic shaking (Opus, 2004b).

Susceptibility Category	Modified Mercalli Intensity				
	≤MM VI	*MM VI*	*MM VII*	*MM VIII*	*MM IX*
Low	Landslides and rockfalls are unlikely	Landslides and rockfalls are unlikely except for very small rock and soil falls		Localised small rock and soil falls on the most susceptible natural slopes, modified slopes and fill embankments	
Moderate	Landslides and rockfalls are unlikely	Landslides and rockfalls are unlikely except for very small rock and soil falls	Small landslides, soil and rockfalls may occur on more susceptible slopes		Small to moderate landslides and rockfalls
High	Landslides and rockfalls are unlikely	Small rock and soil falls	Significant small to moderate landslides and rockfalls		Widespread landslide and rockfalls

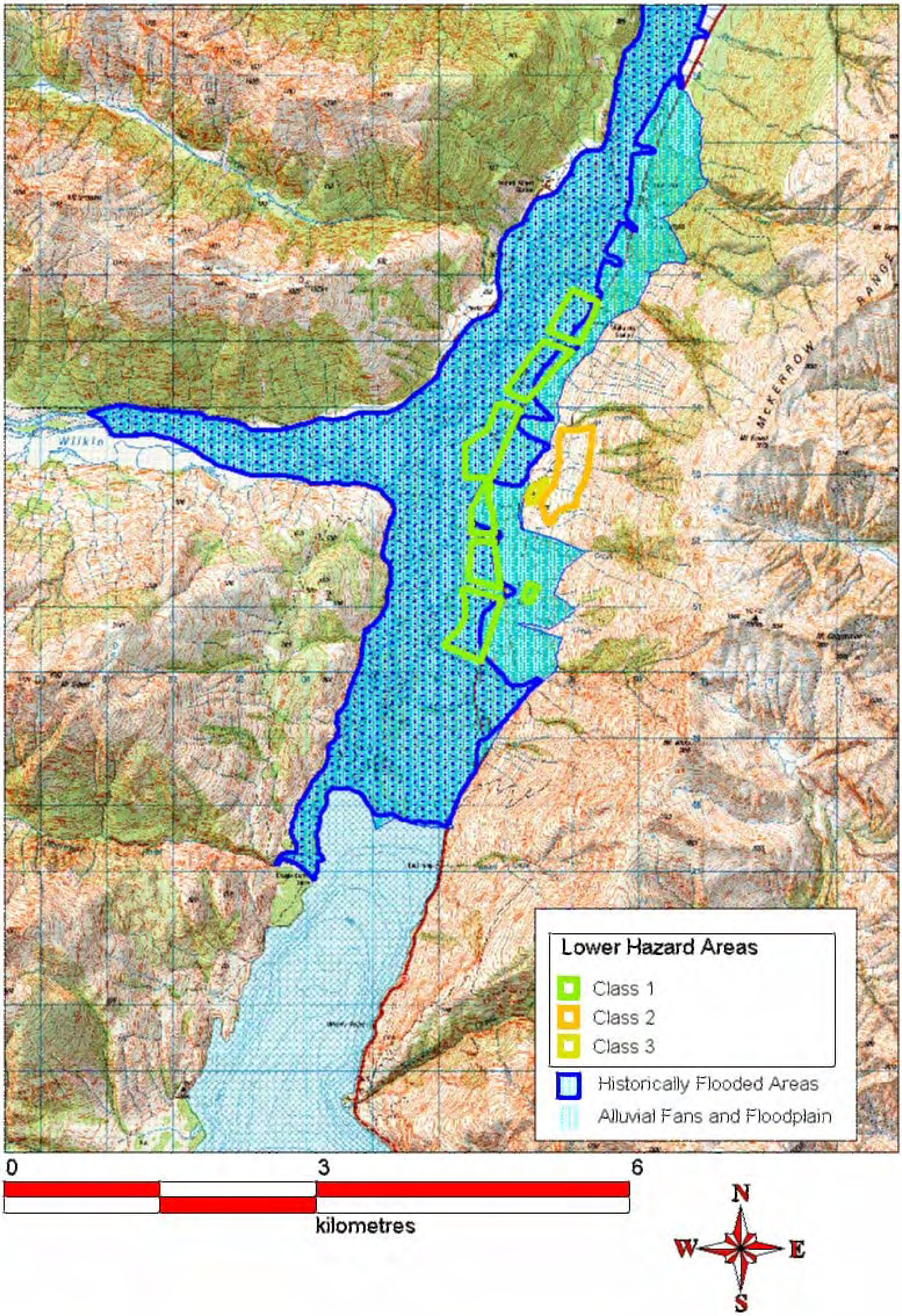

Figure 6: Combined flood and alluvial fan hazards, with lower hazard areas, Makarora valley.

5 Discussion

The general hazardscape of the Makarora valley is associated with the two major landforms – the valley floor and the valley slopes. The valley floor includes the floodplain of the Makarora River and the alluvial fans of its tributary streams. The valley slopes include the steep land above the alluvial fans.

The valley floor is subject to hazards from flooding, both from the Makarora River and from the alluvial fans. The alluvial fans are also subject to debris flow and debris flood hazards – these are the events that form alluvial fans. The soft sediments of the valley floor are also more prone to liquefaction during significant earthquakes, but they have a relatively low susceptibility to mass movement caused by earthquakes.

The Makarora valley slopes are less prone to flooding hazards, although some parts of the valley slopes experience overland flow during significant rainfall events. The valley slopes also have no susceptibility to liquefaction. However, on these slopes there is a high susceptibility to mass movement induced by earthquakes. Mass movement features are common on the slopes above the Makarora valley.

A summary of the major disturbance events that have affected trees on the Pipson Creek alluvial fan (Table 1) suggests that debris flow events associated with significant Alpine Fault earthquakes are a major cause of deposition on its alluvial fan. Channel-switching episodes of all origins may be relatively frequent, with at least five partial or complete switching events in the last 290 years.

The events affecting Pipson Creek alluvial fan are likely also to have affected other alluvial fans in the Makarora valley in a similar way.

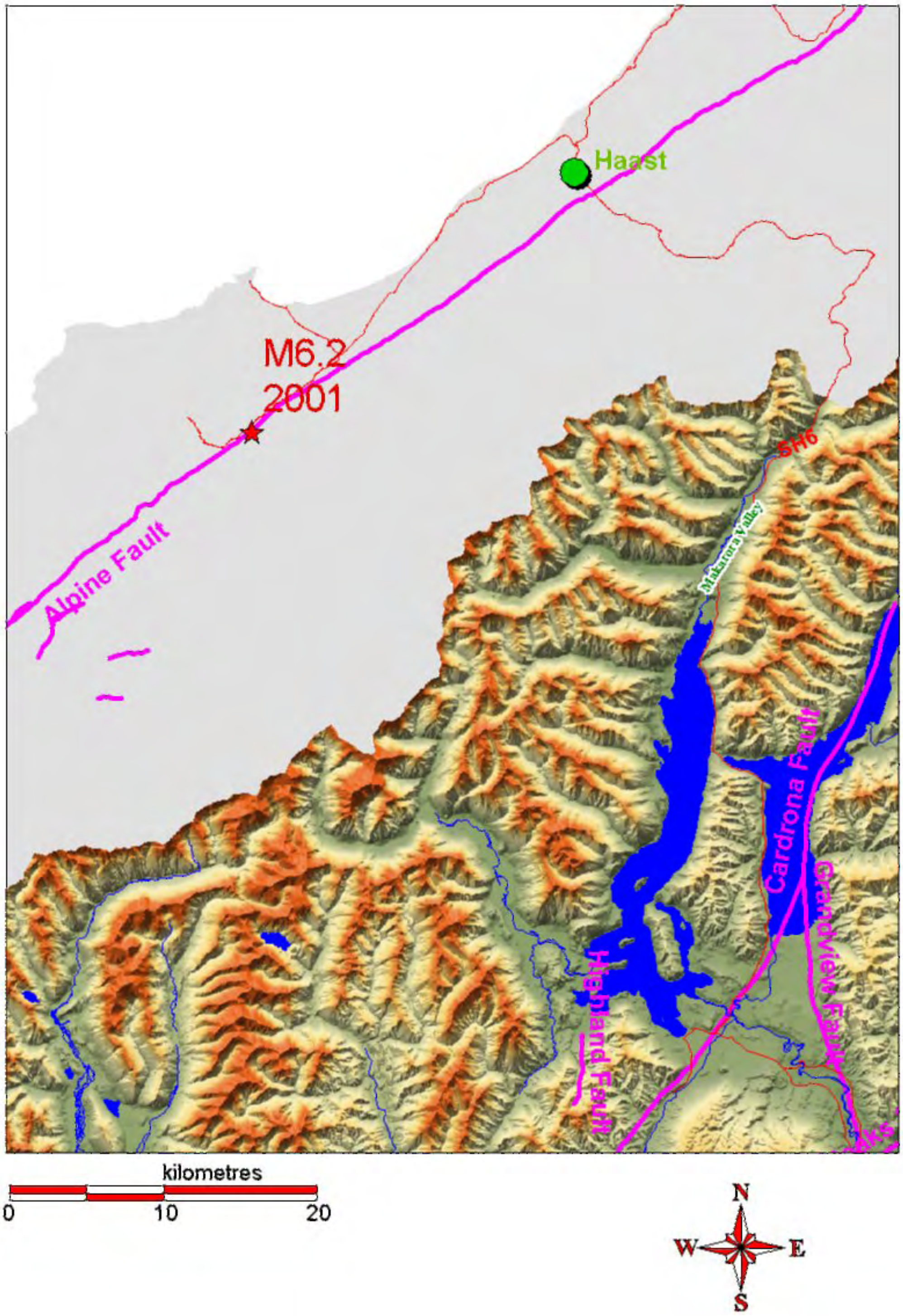

Figure 7: Faults (pink) and earthquake epicentres >M6.0 since 1980, local to the Makarora valley.

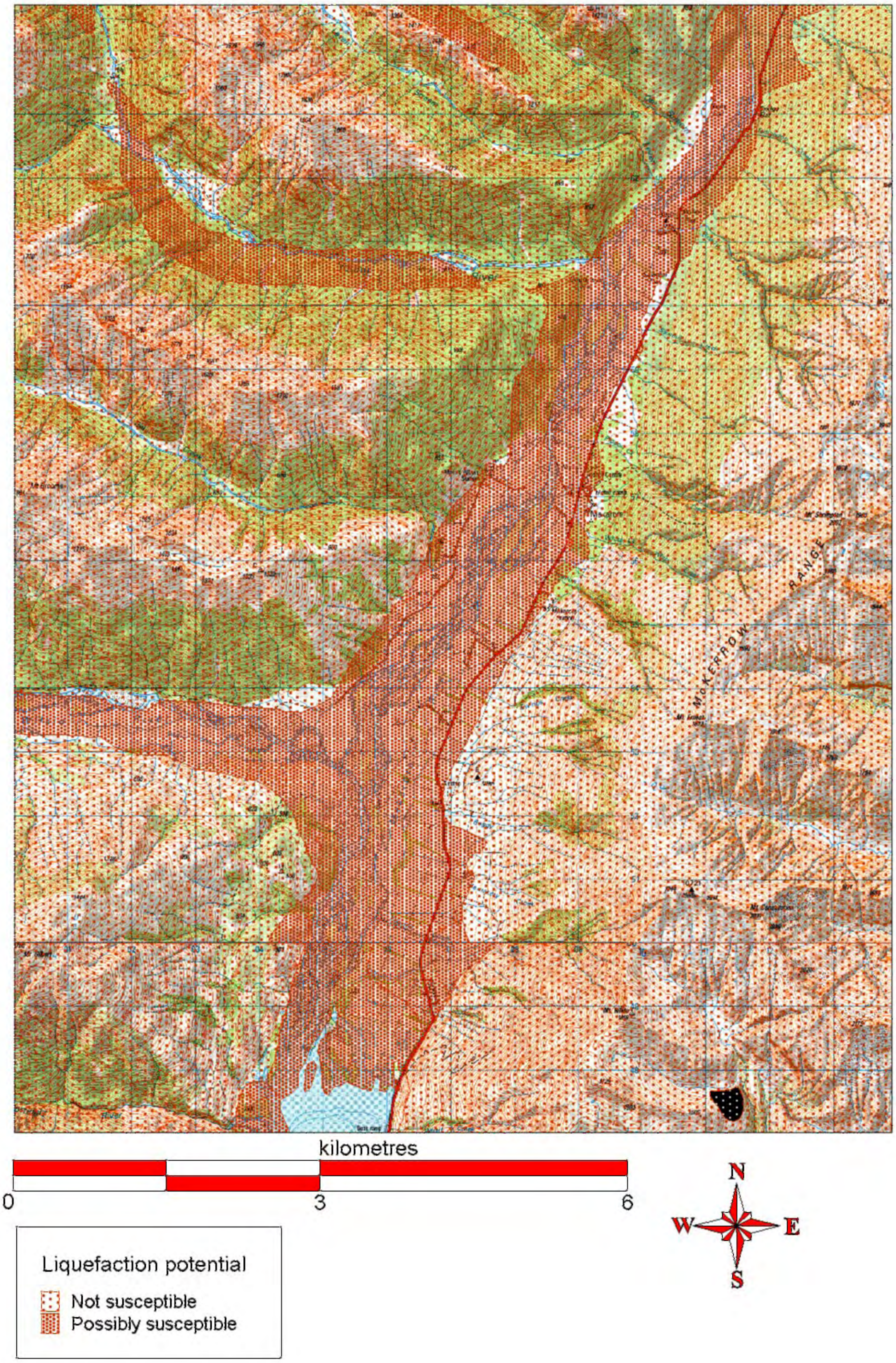

Figure 8: Land possibly susceptible to liquefaction induced by seismic shaking.

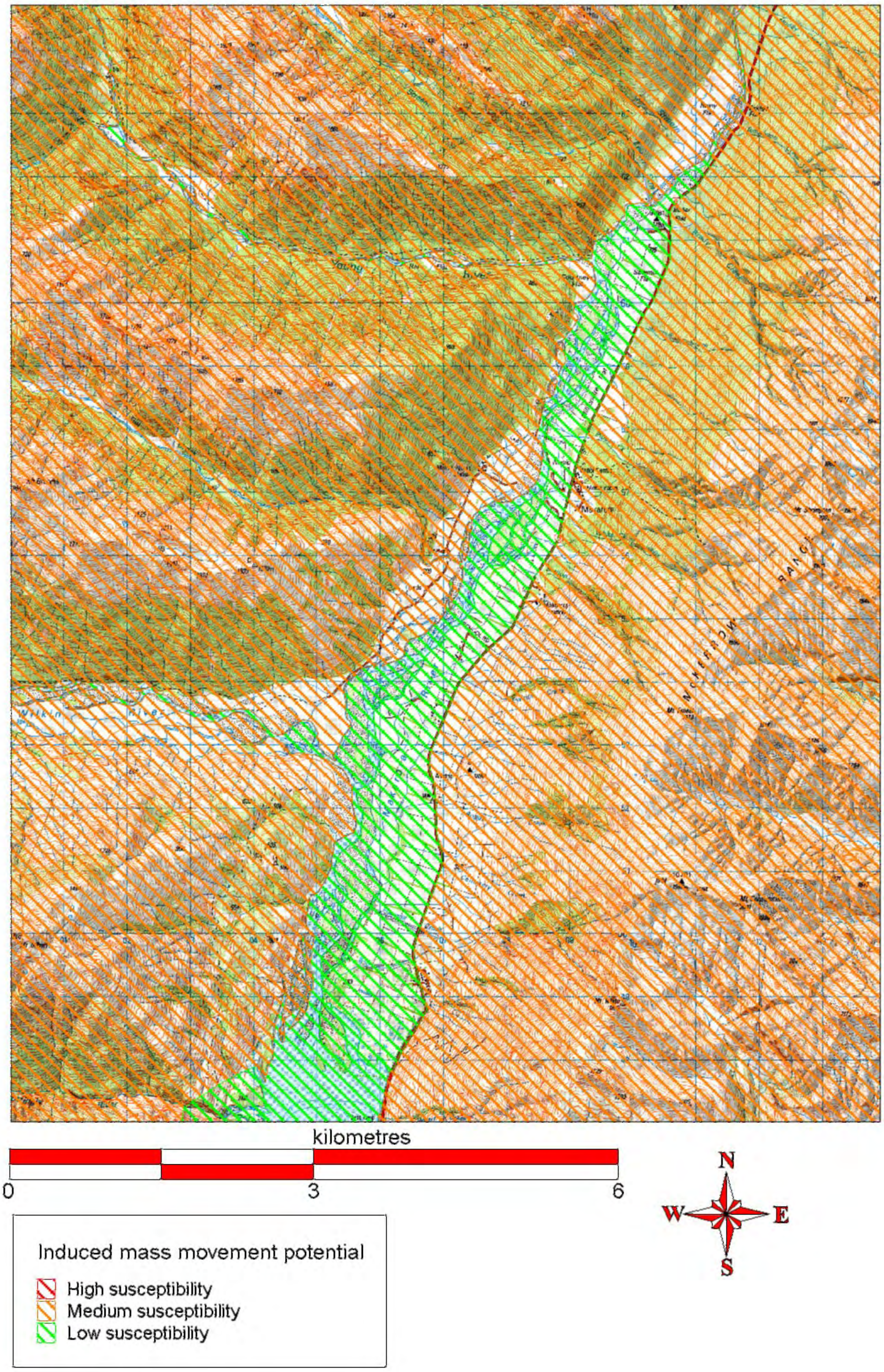

Figure 9: Susceptibility of land to mass movement induced by seismic shaking.

6 References

Charteris, Gary – Long-term resident of Makarora, living on the White Creek alluvial fan and owning land on the Pipson Creek alluvial fan. Employed by various agencies in land management in the Otago Alps.

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