NHRP Kaikōura Earthquake Short-Term Project

Co-seismic and ongoing land deformation at Mt Lyford Village, North Canterbury

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Organisation: GNS Science

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DISCLAIMER

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ABSTRACT

The M_w 7.8 2016 Kaikōura earthquake caused considerable damage to land and buildings at Mt Lyford Village, north Canterbury. In light of this event, the Natural Hazards Research Platform (NHRP) along with the Hurunui District Council (HDC) and Environment Canterbury (ECan) have jointly funded a study of the earthquake damage caused to Mt Lyford Village. This project was designed by these stakeholders and the Department of the Prime Minister and Cabinet (DPMC) and led by GNS Science (GNS). GNS built a team that included expertise in engineering geology, structural engineering and log cabin engineering with members from Golder Associates Ltd. and PTL (NZ) Ltd. The results of the project have been presented as a GNS Science Consulting Report (Langridge et al., 2018; GNS CR 2017/227) along with GIS map layers to HDC. That report has been followed up by a GNS Science Letter Report (Langridge & Townsend, 2018; GNS CR 2018/104 LR) that details how the application of Land Classes could assist future planning decisions. The key findings of these two reports are:

Post-earthquake field reconnaissance and follow-on science using post-earthquake airborne LiDAR led to the evaluation of new locally-relevant land classes based on slope and erosion criteria, and to active fault avoidance zones.

The Land Classes are:

- Mt Lyford Land Class 1 (i.e. ML LC 1): slopes of <25°, and outside of any other land class definition, including active fault avoidance zones;
- ML LC 2: a mixed slope class, having a combination of very steep (≥25° slope), and less steep slopes (<25°);
- ML LC 3: comprising land with slopes of >25° (very steep slopes);
- ML LC 3a: comprising a ±20 m wide setback zone around the upper edge of ML LC 3 areas; and
- ML LC 4: comprising areas related to pre-existing landslide deposits

Land Class ML LC 4 was established because mapping in the Langridge et al. (2018) report highlighted that large landslide deposits may be susceptible to future movement or re-mobilisation and may be susceptible to material falling onto them from their own headscarp area.

Active faults have been mapped and buffered for fault avoidance according to the MfE guidelines relating to building on or adjacent to active faults (Kerr et al., 2003).

The recommended treatment of areas within each of these land classes and their associated risk profiles are discussed in the GNS Letter Report (Langridge & Townsend, 2018).

Engagement with the community of Mt Lyford has occurred frequently before, during and after the response investigations, and has been one of the most important and successful components of this project. The project team, encompassing GNS, HDC, ECan and Golder Associates have been involved in engagement in a united way, providing certainty for the villagers of Mt Lyford.

KEYWORDS

Mt Lyford Village, 2016 Kaikōura earthquake, land damage, log cabins, slope classes, active faults

1.0 INTRODUCTION

1.1 Background

The Natural Hazards Research Platform (NHRP) along with the Hurunui District Council (HDC) and Environment Canterbury (ECan) have jointly funded a study of the damage caused by the M_w 7.8 2016 Kaikōura earthquake to Mt Lyford Village in North Canterbury. This project was designed by these stakeholders and the Department of the Prime Minister and Cabinet (DPMC) and led by GNS Science (GNS). GNS built a team that included expertise in engineering geology, structural engineering and log cabin engineering with members from Golder Associates Ltd. and PTL (NZ) Ltd. The purpose of this multi-partisan team was in part to avoid any polarising or organisational opinions dating from earlier hazard studies at Mt Lyford (ECan, 2005; Hancox et al., 2006).

The M_w 7.8 Kaikōura earthquake struck at 12:02 a.m. on the 14th November 2016. The epicentre of the earthquake was south of the town of Waiau, north Canterbury (Figure 1.1; Kaiser et al., 2017). Strong to extreme seismic shaking caused extensive damage to both land and built structures across a large region spanning north Canterbury, Marlborough and Wellington City (Bradley et al., 2017). The earthquake ruptured an unprecedented number of geologic faults in the region, with rupture propagating from the epicentral area in the southwest, toward the northeast, as far as Cook Strait (Hamling et al., 2017; Litchfield et al., 2018).

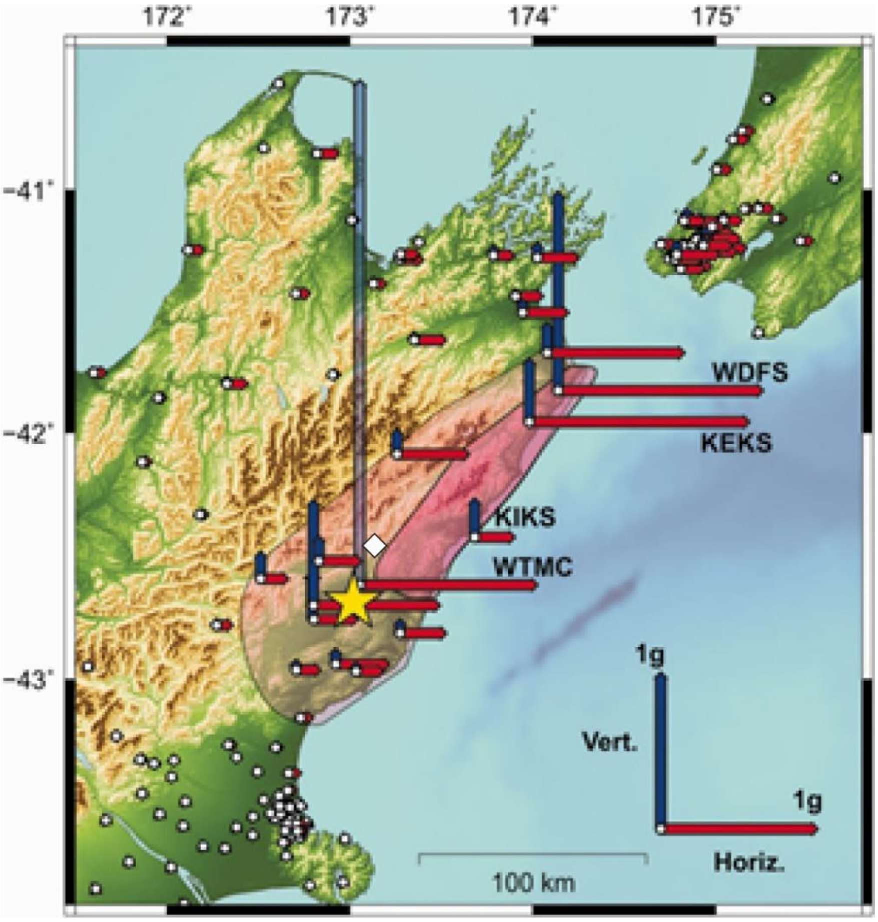

Figure 1.1 Peak ground accelerations in the horizontal (red) and vertical (blue) directions recorded at GeoNet strong-motion stations (from Kaiser et al., 2017). The epicentre of the Kaikōura earthquake is shown as a yellow star and Mt Lyford Village as a white diamond. The approximate extent of mapped landslides is shown as pink shaded area, with the majority occurring in the darker shaded region.

One of the major effects of the earthquake was to cause very extensive small-to-moderate landslides (as well as several very large landslides), and at least 200 landslide-dammed lakes in the hillier terrain (Dellow et al., 2017; Massey et al., 2018). Damage occurred to houses and other buildings in the main towns of North Canterbury and widespread damage occurred to infrastructure including roads, bridges, railways and utility networks (Stirling et al., 2017; Stringer et al., 2017; Van Dissen et al., 2018). Ground motions from seismic shaking were variable across the affected regions (Figure 1.1).

1.2 Scope of this report

This report primarily summarises the NHRP-funded component of the project, the field reconnaissance, follow-on science using post-earthquake airborne LiDAR, and reporting (Langridge & Townsend, 2018; Langridge et al., 2018). HDC and ECan provided additional funding for a more complete engagement with the townsfolk of Mt Lyford Village, both before and after the field reconnaissance and report writing stages of the project. Parts of the science assessment were funded by ECan to make the science goals of the project more complete. This report focuses on the NHRP-funded component of the project. Further details are available in the report by Langridge et al. (2018), which will be available on the HDC and ECan website.

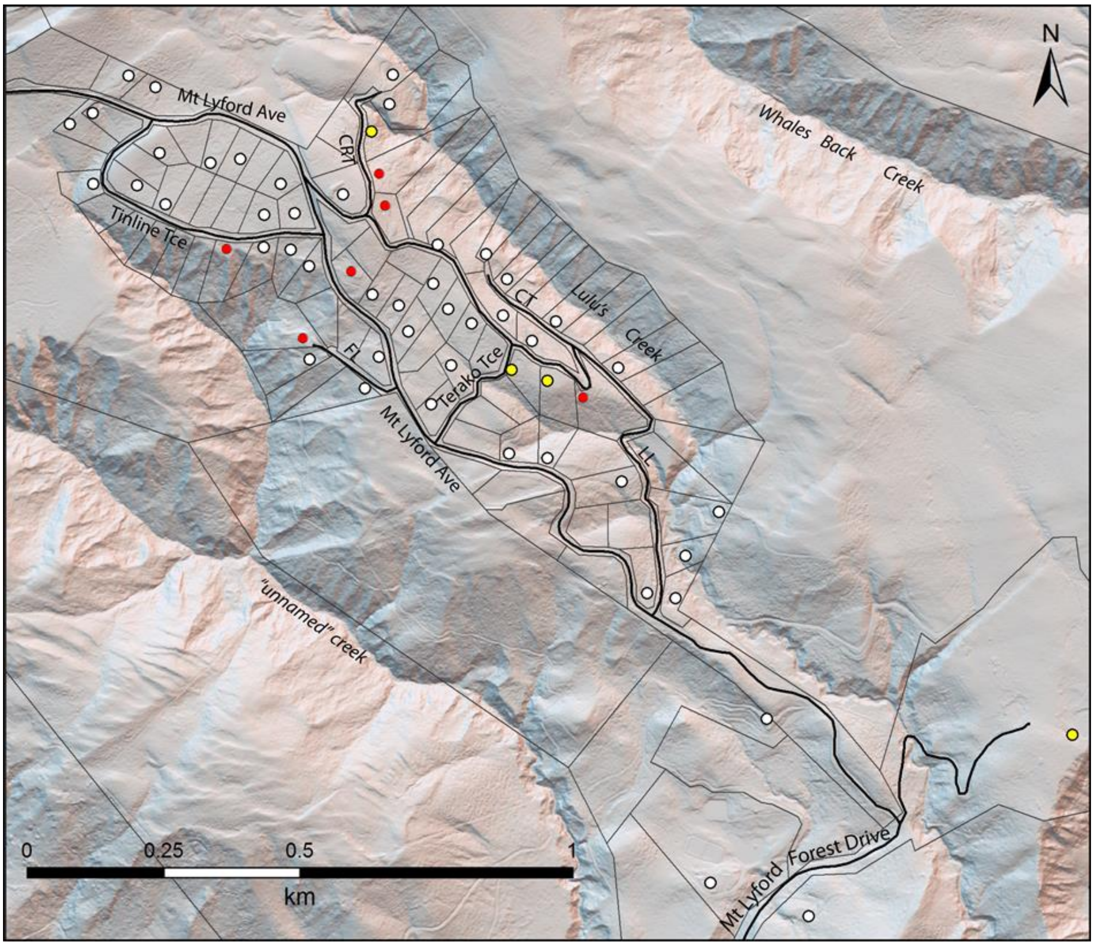

Figure 1.2 Airborne LiDAR-derived hillshade model of the Mt Lyford Village area highlighting street names, property boundaries, and post-earthquake rapid assessment placarding on houses. Dots are house sites, and the colours correspond to red, yellow and white 'placarding'. Abbreviations for street names are: FL, Foggy Lookout; LL, Lulus Lane; CT, Charwell Terrace; CRT, Cloudy Range Terrace.

2.0 PROJECT STRUCTURE AND FINDINGS

2.1 Mt Lyford Village

Mt Lyford Village is located on a broad, gently sloping spur that is part of a deeply dissected range-front fan surface between the Wandle and Mason rivers on the southeast flank of the Amuri Range (Figure 1.2). It lies c. 20 km northeast of Waiau at an altitude of 500-730 m above sea level, and is accessed via the Inland Road (formerly State Highway 70) and Mt Lyford Forest Drive. The village area is bounded by deeply (50–100 m) incised streams which drain the highly dissected fan apron flanking the base of the Amuri Range – to the northeast by Lulus Creek, and southwest by an “unnamed” creek referred to in Hancox et al. (2006). The spur on which Mt Lyford Village is located and the spur northeast of Lulus Creek are broad-crested and slope gently (5–15°) to the southeast. These spurs are crossed by a number of ‘slope rents’ and active faults (ECan 2005; Hancox et al., 2006; Langridge et al., 2018).

Along with other towns in North Canterbury, including Waiau, Cheviot and Kaikōura, the village suffered considerable damage from the Kaikōura earthquake to built structures and utilities. Mt Lyford Village is a rural-lifestyle village with a house construction covenant centred around the concept of log cabin building design. Within Mt Lyford Village, the impacts of the earthquake were variable. There is no doubt that intense coseismic shaking was experienced throughout the village with anecdotal evidence suggesting that ground motions exceeded 1.0 g (a road grader in the village was apparently lifted off the ground and moved c. 2 m away).

As part of the earthquake response, HDC dispatched engineers to the village to assess and categorise the damage to built structures. The result of this assessment was a standard classification of red/yellow/white placarding being assigned to each dwelling in the village (Figure 1.2). These designations were later reviewed as part of the shift from post-earthquake response to council-led Section 124 notices under the Building Act 2004 (dangerous building, prohibited access) being placed on some log cabin homes. The log cabins in the village had a variable response to the strong shaking. Seven of the buildings within the village were given red placards (dangerous building, no access) and four yellow placards (damaged building, limited access) for a variety of reasons. Forty-five other dwellings were given a white placard designation (undamaged building, no access restrictions). A preliminary assessment of the performance of the log cabin buildings was undertaken by PTL (NZ), a private log cabin engineering company (Buchanan and Moroder, 2017). Dr. Daniel Moroder of PTL (NZ) was invited to be part of the project team to provide advice on the performance of log cabins relative to land damage and ground conditions.

2.2 Field reconnaissance

Field reconnaissance of Mt Lyford Village took place from 21 to 25 August 2017. Reconnaissance was primarily undertaken by Drs. Langridge and Townsend (GNS). Tim McMorran and Clive Anderson of Golder Associates Ltd. were present on 22 August, and Daniel Moroder was present on 25 August. Drs. Langridge and Townsend stayed in the village throughout the week so that they had the greatest opportunity to engage with villagers.

Field reconnaissance involved investigating areas where houses had been damaged by any kind of process - land damage, shaking, or from structural failure - and areas where land damage had occurred around steep gullies and along active faults within the village. Attention

was also given to areas where there was a lesser amount of land and building damage to understand why these areas were more stable relative to others. Typical examples of damage are shown in Figures 2.1-2.4.

Figure 2.1 Typical foundation settling adjacent to a split-level log house at Mt Lyford Village.Note the subsidence of the ground and ground cracking extending away from the house (concrete pad).

Figure 2.2 Typical ground extension observed at the downhill-facing edge of a log cabin at Mt Lyford Village.

Figure 2.3 Arcuate ground cracking related to slope extension within scrub above 'unnamed' stream.

Figure 2.4 Ground cracking and extension causing subsidence in a yard at a property on Lulus Lane, adjacent to a steep cut bank edge.

2.3 Mapping of geomorphic features

Airborne Light Detecting and Ranging (LiDAR) data collected before and after the Kaikōura earthquake was invaluable for high resolution geomorphic mapping, and the mapping was ground-truthed by the field reconnaissance. LiDAR data also allowed for the creation of digital slope maps, which were used to define slope categories. For example, very steep slopes with slope angles of ≥25° include steep gully sides at the edges of the main rangefront spur upon which much of the village was constructed (Figure 2.5). The geomorphic map (Figure 2.6) was combined with geological information to estimate rates of landscape change including active fault slip rate, depositional ages for surfaces, and rates of erosion.

The LiDAR data was also used to map active faults traces throughout the village. Active fault mapping (Figure 2.7) and the development of Fault Avoidance Zones as part of this project supersedes previous active fault mapping and Fault Awareness Areas in the Mt Lyford area (Hancox et al. 2006; Barrell and Townsend 2012). In addition to new active fault mapping, the Langridge et al. (2018) report provided new recurrence interval data based on: radiocarbon dates from two trenches excavated in 2006; and geologic slip rates defined from the geomorphic mapping combined with estimated ages from local alluvial surfaces.

Post-earthquake LiDAR was re-processed alongside pre-earthquake LiDAR acquired in 2012 to develop a differential elevation model (Figure 2.8; Langridge et al., 2018). Such a differential or D-LiDAR model can display the amount of change in the landscape due to tectonic activity, landsliding and alluvial processes. A D-LiDAR model of the rangefront of the Amuri Range

along which the Hope fault runs, shows that there was significant (metre-scale) uplift of the land to the north and south of the Hope Fault. Uplift was higher to the south of the Hope Fault, in proximity to the Leader and Conway-Charwell faults that ruptured in the 2016 Kaikōura earthquake (Litchfield et al., 2018; Nicol et al., 2018). This result matches well with reoccupations of LINZ trig stations following the Kaikōura earthquake, which also show metre-scale vertical uplift and translation of trig monuments to the north-northeast compared with before the earthquake (Langridge et al. 2018).

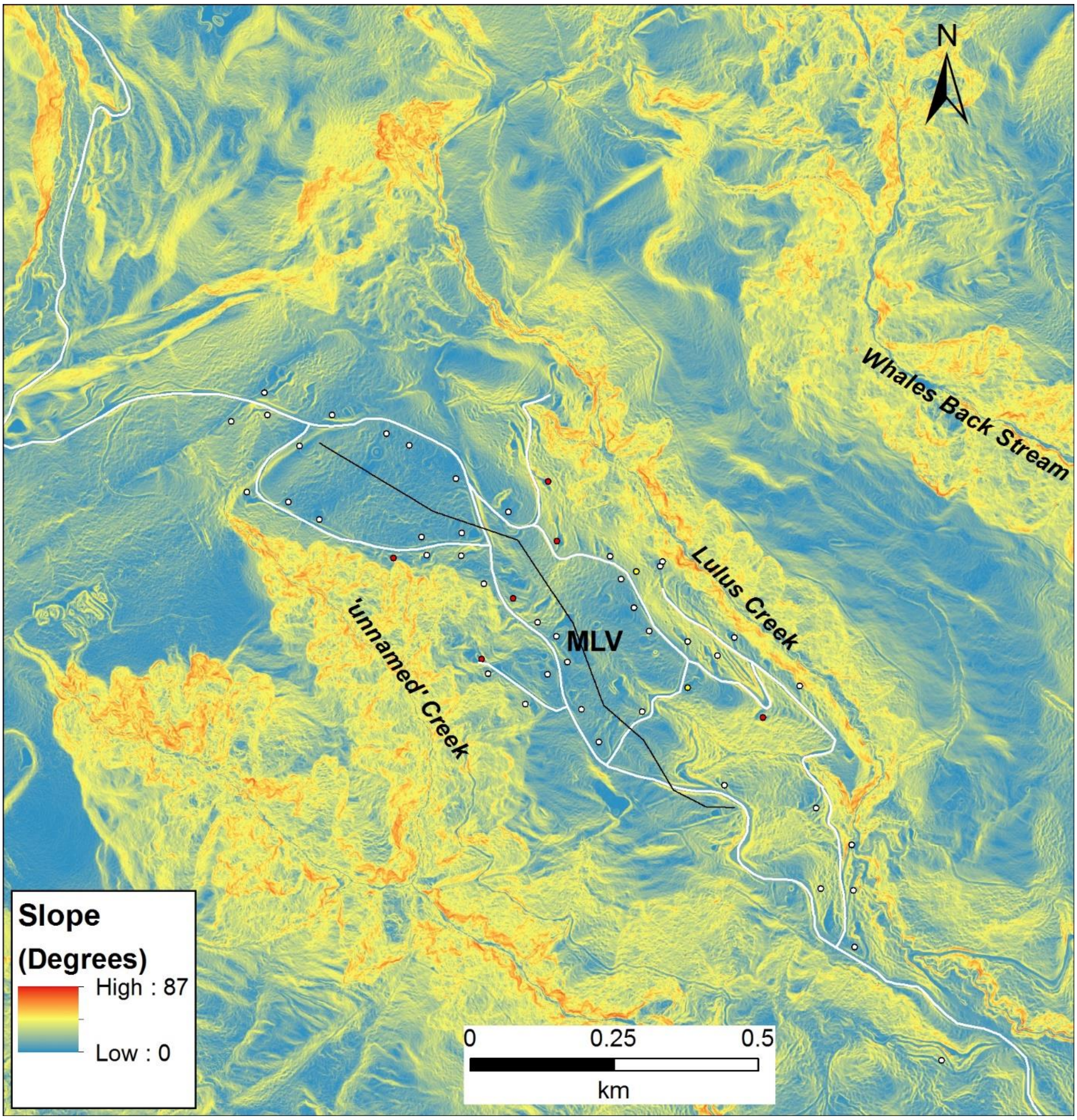

Figure 2.5 A digital Slope map of the wider Mt Lyford Village area derived from post-earthquake airborne LiDAR data. Slopes in bluish colours are between c. 0 and 20º, while slopes in yellow and orange are c. >25º. The village road network is shown in white and post-earthquake response placards are shown as coloured dots.

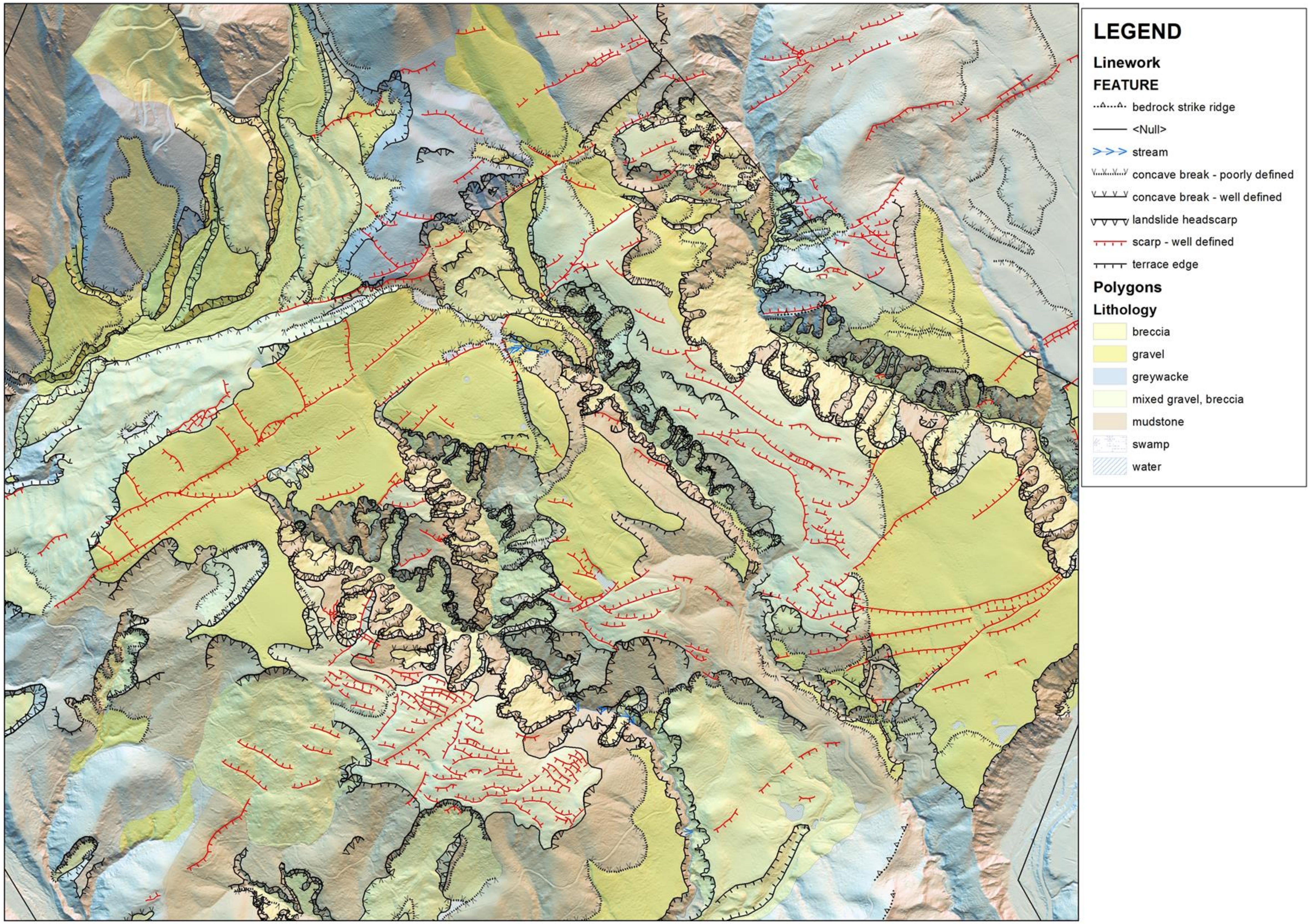

Figure 2.6 Geomorphic map of the Mt Lyford area. The map extends between the Wandle and Mason Rivers (top left to bottom right), and from the Hope Fault to the Inland Road. The geomorphic map identifies mainly: hill terrain – high (blue – mostly greywacke); hill terrain – low (orange – mostly mudstone); high terraces (dark yellow – constructional piedmont), mid-level terraces (yellow) and valley floor alluvium (pale yellow); hillslopes and hummocky ground (colluvium and landslide debris). Lines depict erosional processes such as breaks in slope (black), and tectonic and gravitational scarps (red lines). The rangefront spur on which most of the village is built is at centre.

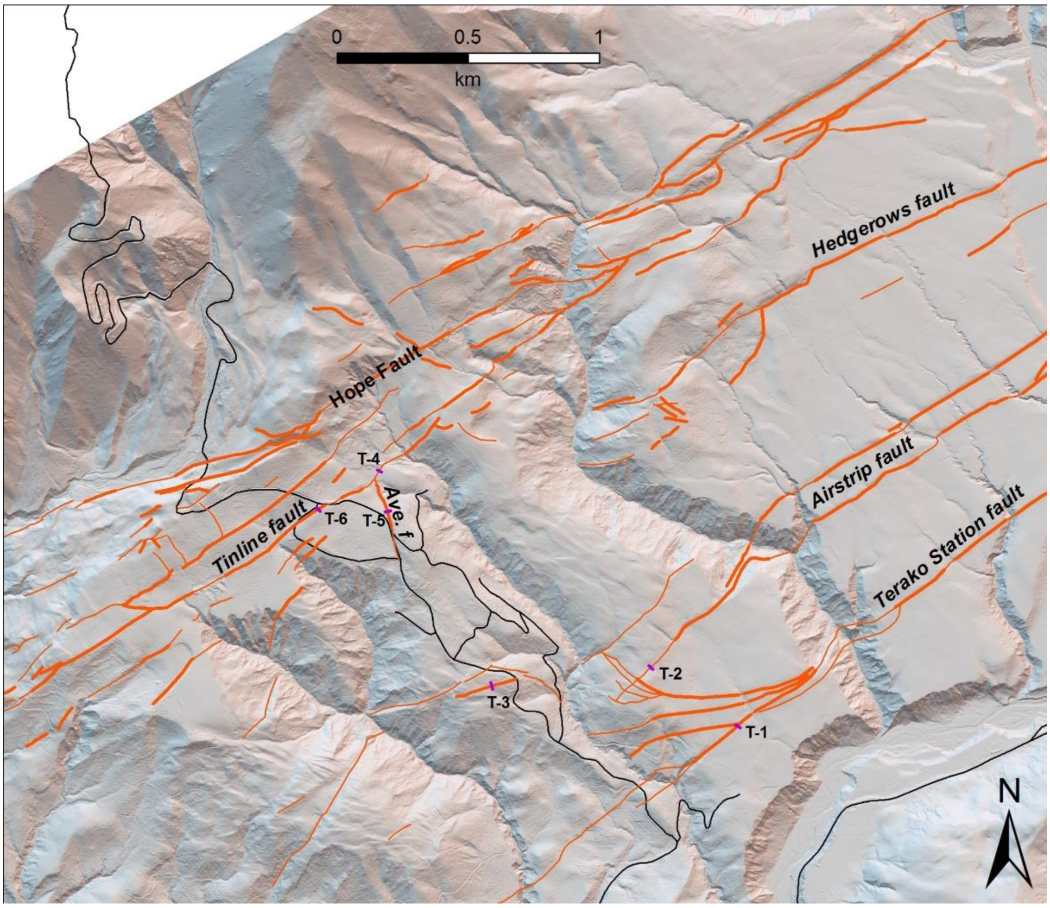

Figure 2.7 Updated active fault map for the Mt Lyford Village area. The Hope Fault is a distributed fault zone of up to 0.5 km width, and could be extended to include informally named faults (those in italics) such as the Tinline Fault. The accuracy of fault location is shown by the thickness of lines (accurate = thickest). The trenches excavated in 2006 are shown by purple dashes across faults and labels T-1, T-2 etc.

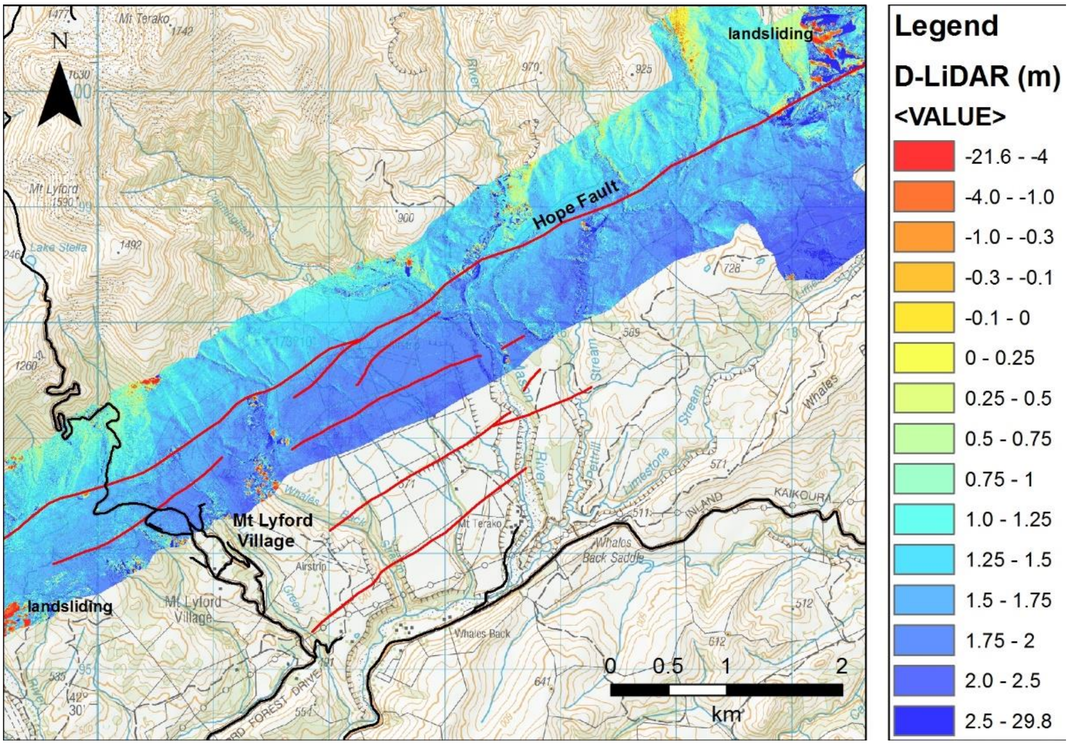

Figure 2.8 Map showing differential LiDAR coverage along the rangefront of the Amuri Range near Mt Lyford Village. The legend indicates the vertical change between the 2012 and 2016 acquisitions.

3.0 CHARACTERISING GEOLOGIC HAZARDS

Geomorphic mapping and analysis was used to characterise the ongoing hazard from slope instability and active faulting at Mt Lyford Village (Langridge et al. 2018).

3.1 Slope Hazards and Land Classes

Slope hazards were defined in such a way as they could be used directly for planning purposes. Previous work (Hancox et al. 2006) defined Land Stability Classes as:

- Class 1 – gentle to moderate slopes <15°;
- Class 2 – gentle to moderately steep areas 10-20°;
- Class 3 - steep slopes on sides of gullies 15-25°.

The approach in Langridge et al. (2018) was to re-map the area using airborne LiDAR data and to define Land Classes that were locally applicable to the Mt Lyford Village area. New Mt Lyford (ML) Land Classes were designed for the Langridge and Townsend Letter Report as follows:

ML Land Class 1: areas of gentle to steep slopes 0-25° that are not included as part of any other Land Class. Much of the central part of Mt Lyford Village is classed as ML LC 1. Exclusions to ML LC 1 areas, described below, are for areas mapped as large or extensive landslide deposits, or associated with fault avoidance zones.

ML Land Class 2: Mixed or terracette slopes refer to slopes that have a mixed slope comprising alternating bands of very steep (≥25°) and less steep slopes (0-25°). Mixed slopes also occur on steep gully sides, often the northeast-facing slopes of the major southeast-draining streams. The upper parts of these slopes were originally cleared for pastoral farming. The mixed slopes may have been developed in part by animal tracking, e.g. sheep tracks. This is in contrast to ML LC 3 areas, which are often on the southwest-facing sides of the same gullies, and which often still have a cover of native forest.

ML Land Class 3: very steep slopes of ≥25° commonly located around the upper edges of gullies and landslide headscarps. The very steep slope designation coincided with an important cut-off at the top edges of active gullies related to Lulus Creek, Whales Back Stream and ‘unnamed stream’ locally.

ML Land Class 3a: a setback zone of ±20 m width is placed around the upper edge of Class 1 areas, acknowledging that headward retreat of gullying or gully erosion was observed as a consequence of strong ground motions in the Kaikōura earthquake, and following seasonal rains. This narrow buffer allows for a small amount of future slope retreat as a consequence of future earthquakes or seasonal rains and climate effects, and from slope instability below this top edge.

3.2 Landslide Deposits

A fourth land class (ML LC 4) was developed for the GNS Letter Report - Langridge & Townsend (2018), because landslide deposits represented another class of land that was not dealt with by slope angle.

Pre-existing landslide deposits (ML LC 4) include large rock avalanche deposits along the mountain front of the Amuri Range (Hope Fault), landslide deposits preserved in the sides and

floor of the major tributary gullies (e.g. Lulus, Whales Back and 'unnamed'), and some smaller surficial slump deposits.

For example, the largest landslide deposit in the area is a 'large pre-historic landslide' of c. 3 ha size in the southern part of Mt Lyford Village. This deposit had previously been mapped by Hancox et al. (2006) but was not included as a hazard area. Langridge and Townsend (2018) define this pre-historic landslide as an area of hazard because, since 2006 there has been an increasing recognition that active geomorphic settings (such as alluvial fans and landslide deposits) (Barrell et al., 2009) are fundamentally hazardous areas; and landslides have the potential to remobilise (slip) or be inundated by more debris from above. While we acknowledge that the slopes are generally low on this old landslide deposit, because the deposit is not 'in situ' ground, it has the potential to differentially settle during strong ground motion (shaking) and/or sliding and, therefore, there is a hazard associated with it.

Landslides are typically associated with a buried slide plane along which the landslide can mobilise. This is a low-angle surface that we can't easily see. Now that the land has been uplifted by the Kaikōura earthquake, the slide plane for this old slide could be undercut or exposed by future downcutting by the streams, allowing the slide to possibly reactivate due to shaking and/or high groundwater conditions. While its slopes are generally quite low, the old landslide does have steep slopes around its headscarp and potentially around where streams and gullies are cutting at its edges.

3.3 Active Faulting

Active faults have been mapped and Fault Avoidance Zones have been developed following methods outlined in the 'Ministry for the Environment Guidelines for building on or adjacent to active faults' (Kerr et al., 2003). Active fault mapping is attributed with the accuracy terms: accurate, approximate and uncertain, depending on the level to which a fault trace can be recognised and mapped (Figure 2.7). Fault Avoidance Zones are developed by establishing setback zones based on the accuracy terms. Fault recurrence intervals have been derived from paleoseismic trench data (including new radiocarbon dates) and from estimated slip rate data (Figure 3.1).

Due to the village's proximity to the Hope Fault, many of the active faults mapped in the upper part of the village have been designated as Recurrence Interval Class I (RI <2000 years). Faults in the lower part of the village (e.g., Airstrip and Terako Station faults) have been designated as Recurrence Interval Class II (RI <2000-3500 years).

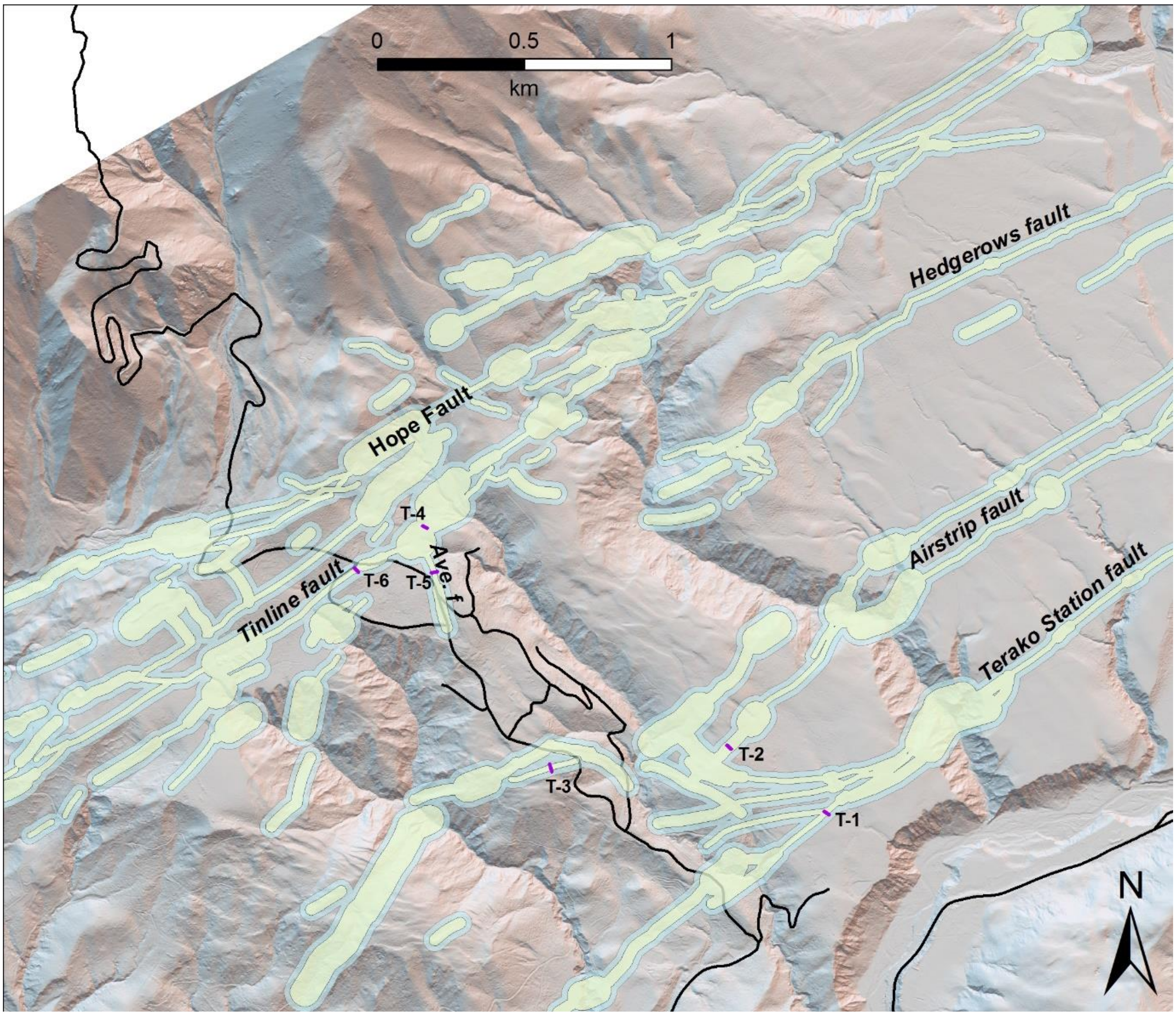

Figure 3.1 Fault Avoidance Zone (FAZ) map for Mt Lyford Village (from Langridge et al., 2018). FAZ 'sausages', based on accuracy of fault mapping, are shown with their associated active faults as labelled. Fault line data is intentionally left off this map to focus on the avoidance zones.

4.0 PUBLIC ENGAGEMENT

Public engagement was undertaken with the community at Mt Lyford both before and after the field reconnaissance and at the time that the final report was delivered to HDC. Public meetings were held at Mt Lyford Lodge on the Inland Highway on June 10th 2017 and on January 29th 2018. These meetings were attended by Dr. Langridge, planning staff from HDC, the Chief Executive of HDC, the Hazards Officer from ECan and ECan planning staff. Tim McMorran from Golders Associates attended the meeting in January 2018. These meetings were attended by an audience of c. 20-30 local landowners. The discussion regarding the current state and future of the village was rich and lively.

Community engagement is an ongoing process and we expect to attend another village meeting at Mt Lyford following landowner consideration of the GNS Letter Report (Langridge and Townsend, 2018). The Letter Report develops recommendations for the Mt Lyford land Class and hazard categories for land use that can be applied in upcoming district plan changes at HDC.

5.0 SUMMARY AND CONCLUSIONS

The NHRP-funded Mt Lyford project developed as a response to the impacts of the 2016 Kaikōura earthquake. The government, Councils, GNS Science and its collaborators have worked together effectively to provide outcomes for HDC and the landowners at Mt Lyford Village. The results of the project have been presented as a GNS Consulting Report (Langridge et al., 2018; GNS CR 2017/227) and subsequent Letter Report (Langridge and Townsend, 2018; CR 2018/104 LR) to HDC and ECan.

Reconnaissance and follow-on science using post-earthquake airborne LiDAR led to the evaluation of new land classes based on slope and active fault traces. The Mt Lyford Land Classes are as follows:

- Mt Lyford Land Class 1 (i.e. ML LC 1): slopes of <25°, and outside of any other land class definition, including active fault avoidance zones;
- ML LC 2: a mixed slope class, with banded strips of slope that are of ≥25° slope, with slopes of <25°;
- ML LC 3: comprising land with slopes of >25° (very steep slopes);
- ML LC 3a: comprising a ±20 m wide setback zone around the upper edge of ML LC 3 areas; and
- ML LC 4: comprising areas related to pre-existing landslide deposits

Landslide deposits (ML LC 4) may be susceptible to future movement or re-mobilisation or to material falling onto them from the headscarp area.

Active faults have been mapped and buffered for fault avoidance according to the MfE guidelines relating to building on or adjacent to active faults. Active faults in the upper part of the village are classified as Recurrence Interval Class I (RI <2000 years) and the lower part as Recurrence Interval Class II (RI <2000-3500 years).

Engagement with the community of Mt Lyford has occurred frequently, before, during and after the field reconnaissance, and has been one of the most important and successful components of this project. The project team, encompassing GNS, HDC, ECan and Golder Associates have been involved in engagement in a united way, providing certainty for the villagers of Mt Lyford.

6.0 ACKNOWLEDGMENTS

The authors wish to thank the villagers of Mt Lyford Village for access to properties and houses around the village. Claudine Barnes was particularly helpful and we thank her for meals cooked during our field visit. We acknowledge the assistance of Hurunui District Council and Environment Canterbury in facilitating this work. Sally Dellow and Dr Kelvin Berryman provided review comments on the Final Report prepared for Hurunui District Council (Langridge et al., 2018; CR 2017/227). Sally Dellow, Tim McMorran, and Emily Grace provided review comments on the Langridge & Townsend letter report (CR 2018/104 LR). Dr Nicola Litchfield provided review comments on this report. We thank them for their support in this project.

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