REPORT

Mt Lyford Village

Geological Assessment for Slope Hazards

Submitted to:

Hurunui District Council
PO Box 13
Amberley 7441

Submitted by:

Golder Associates (NZ) Limited
Level 1, 214 Durham Street, Christchurch 8011, New Zealand

+64 3 377 5696

1895571_7407-003-R-Rev0

December 2018

Record of Issue

Company	Client Contact	Version	Date Issued	Method of Delivery
Hurunui District Council	Monique Eade	Rev 0	21 December 2018	Email

Table of Contents

TABLES

FIGURES

APPENDICES

1.0 INTRODUCTION

1.1 Background

Hurunui District Council (HDC) engaged Golder Associates (NZ) Limited (Golder) to conduct a review of the slope instability hazards affecting the Mt Lyford Village area in Hurunui District. The goal is to better understand the slope instability mechanisms and the expected future performance of the slopes affecting existing or new development at Mt Lyford Village. Additionally, investigations were undertaken for ground truthing of several mapped faults within Mt Lyford Village.

During the magnitude 7.8 Kaikōura earthquake of 14 November 2016 strong ground shaking and associated slope instability processes damaged a number of properties at Mt Lyford Village. A study of 'land damage and natural hazards' following the 2016 Kaikōura earthquake (GNS 2018a), described slope instability effects that occurred at Mt Lyford Village and redefined Fault Avoidance Zones around a number of active fault traces. An additional report (GNS 2018b) made some recommendations to HDC regarding potential methods for mitigating slope instability hazards. In this report we have reviewed the 'Land Class' map presented in GNS (2018b) and provided further guidance on the appropriate geotechnical assessments to be undertaken in each zone and general geotechnical considerations for development within the village.

Local government considerations for managing slope instability hazards in the development and redevelopment of sites in the district include the Building Act 2004, the Resource Management Act 1991, the Local Government Act 2002, and the Civil Defence and Emergency Management Act 2002. The information presented in this report is also useful for planning by providing insight on the future implications of developing on a site with the potential for slope instability.

The assessment and investigations presented in this report were completed following a data review of available literature and information. The primary reference for the review is GNS (2018a) and associated information collected during that study, including airborne Light Detection and Ranging (LiDAR) data, records of geology, ground cracking and building damage. The current study supplements GNS (2018a) with additional field mapping and subsurface geotechnical investigations. The objectives of the new investigations were to collect geological data relevant to understanding the slope instability that affects Mt Lyford Village, to characterise the potential failure mechanisms, the implications for dwellings and infrastructure and give recommendations to mitigate the slope instability hazards affecting Mt Lyford Village. The expected effects of a Hope Fault earthquake and heavy rainfall events on Mt Lyford Village were also considered.

2.0 LOCATION

Mt Lyford Village is in the north of the Hurunui District and comprises approximately 100 residential lots and associated infrastructure. The village is bounded by Lulus Creek to the east and Unnamed Stream to the west. Inland Road is located south of the village and the Mt Lyford Ski area is to the north. The extent of Mt Lyford Village and the surrounding area included in this study are shown in the site plans included in Appendix B.

2.1 Geological Setting

Mt Lyford Village area is underlain by weak siltstone and sandstone of the upper Tertiary age (approximately 2 to 5 million years) which overlies calcareous mudstone and conglomerate of mid Tertiary age (approximately 5 to 24 million years) (Rattenbury et al 2006). The active Hope Fault is a major tectonic structure in this area that separates the much older greywacke rocks in the northwest from the young Tertiary rocks to the southeast. The Tertiary sequence of rocks is folded into a syncline on the southeastern side of the Hope Fault, known as the Wandle syncline. The fault zone is up to 2 km wide in the Mt Lyford area, and contains many active fault traces, scarps and lineaments. Based on the fault offsets and radio carbon dates within the near surface soils collected by GNS, the stream downcutting appears to have occurred in recent geological past (the Holocene epoch – the last 12,000 years).

2.2 Seismic Hazard

The average recurrence interval of the Conway Segment of the Hope Fault which crosses Mt Lyford Village is estimated to be 180-390 years (Langridge et al 2006). Given that the last surface rupturing earthquake of the Conway Segment is thought to have occurred in approximately 1780 AD, there is believed to be a relatively high probability of an earthquake occurring on the Hope Fault during the expected life of the residential buildings in Mt Lyford Village (i.e., within the 50-year building life under B2, Section 67 of the NZ Building Act).

2.3 Fault Rupture Hazard

GNS (2018a) define a number of fault traces that cross Mt Lyford Village. Ground rupture, of up to several metres of displacement, on one or more of these faults is expected to occur during a large earthquake on the Hope Fault. Such ground rupture could result in severe damage to overlying buildings. GNS (2018a) has defined Fault Avoidance Zones around the identified faults within which building should be avoided and recommends applying the guidelines set out by the Ministry for the Environment (Kerr et al 2003).

2.4 Slope Instability Hazard

Slope instability occurs when material moves downslope in response to gravity. Any unsupported material will be transported downslope, most commonly in response to an earthquake or significant rainfall. Most of the slope instability deformation styles observed at Mt Lyford Village following the 2016 Kaikōura earthquake comprised shaking induced ground cracks on slopes or near the crest of slopes. Subsequent creep movement that has been observed around Mt Lyford Village is thought to have occurred in response to ingress of surface water into the ground cracks. Deeper-seated landslides, where slide planes are tens of metres below surface, have also previously been recognized at Mt Lyford Village (GNS 2006, 2018a).

3.0 FIELD RECONNAISSANCE

3.1 Field Mapping

Summary of Daily Activities

29 October 2018 – Golder visited various lots including 1 Mt Lyford Avenue, 92 Tinline Terrace and 68 Tinline Terrace with Doug Simpson and Mike Powell to scope areas for test pitting for fault ground truthing. Scoped areas around Tinline Terrace for field mapping access to Unnamed Stream, the slopes were often too steep and forested. Visited site of ancient landslide with Ross Barnes and scoped areas to return for mapping along Unnamed Stream.

30 October 2018 – Drove around Lulus Lane and Mt Lyford Forrest Drive and took structural measurement and geological observations along road cuts and properties. Heavy rain made it difficult to access certain parts of the streams. Walked along the Foggy Lookout area looking for possible areas to conduct further drilling investigations. Visited lots 44 and 43 for access to Lulus Creek.

31 October 2018 – Visited the site of the prehistoric landslide, south of the village. Made structural measurements, geological observations and drone photography along banks of Unnamed Stream. Returned to Lulus Creek to make additional structural measurements and geological observations. Undertook drone photography at Foggy Lookout to capture areas on the western side of Unnamed Stream that were not accessible. Drone photography was also undertaken on the eastern side of Lulu's Creek from 40 Terako Terrace to capture footage of the landslide scarp east of Lulu's Creek. 87 Tinline Terrace was visited with Greg Baker who described damage that occurred during the earthquake and subsequently following rainfall. Photography and measurements of the tension cracks were taken. The area was scoped for possible drilling sites.

3.2 Observed Slope Instability

During our field programme at Mt Lyford Village, we made the following observations regarding slope instability:

- Multiple tension cracks were observed at 87 Tinline Terrace and neighbouring sites near the crest of the slope. The cracks were observed within the near surface silty soil materials and up to approximately 2 m deep. South of the dwelling at 87 Tinline Terrace, in the wooded area, a 2 m high slip was observed (Figure 1 A). According to the land owner, the cracks occurred during the 2016 Kaikōura earthquake and are widening with exposure to rainfall. One of the tension cracks adjacent to the dwelling was located where stormwater drains down from the roof (Figure 1 B).
- Terraced slumping with multiple scarps and cracks near the slope crest on the north eastern side of Lulu's Creek (Figure 1 C). This is the largest landslip feature currently undergoing active deformation that we observed in proximity to the village.
- No evidence of recent movement of cracking was observed in the ancient landslide south of the village (see Figure 3 for location of ancient landslide). This is corroborated by the observations made by GNS (2018a) and from discussions with the landowner.
- Settlement and deformation were observed in areas of fill material at sites along Lulu's Lane and Terako Terrace (Figure 1 D).

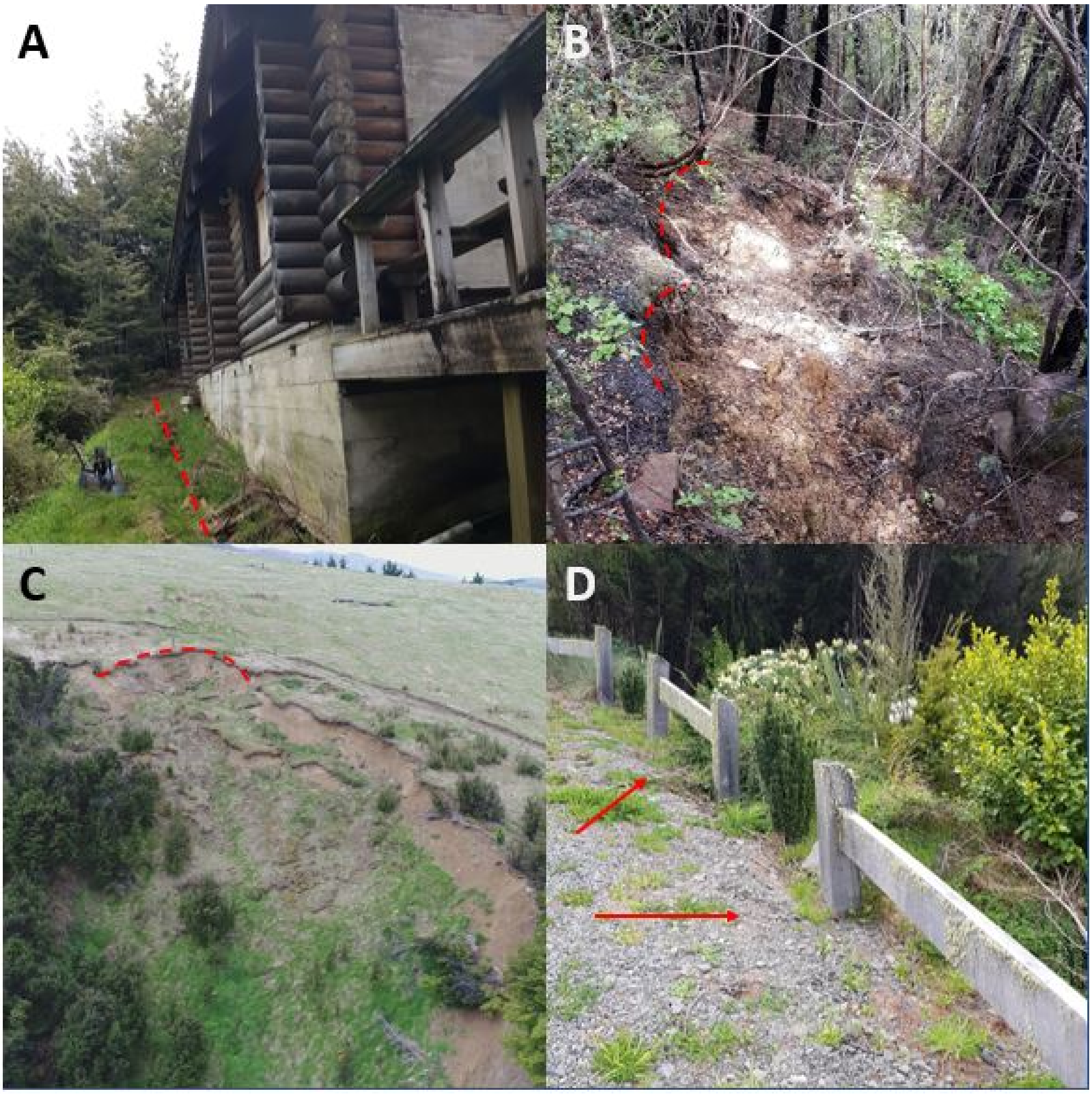

Figure 1: A) Dashed line represents ground crack observed at 87 Tinline Terrace where stormwater drained from the roof. B) Scalloped crests approximately 2 m high where landslide occurred south of the dwelling at 87 Tinline Terrace. The homeowner confirmed that the slumping and cracking occurred during the earthquakes but worsened following heavy rainfall. C) Slip with scalloped cracks north east of Lulu's Creek. The dashed line represents approximately 10 m in length. D) Settlement of fence due to movement of the fill material at 42 Terako Terrace. Arrows show approximate direction of the movement.

3.3 Ground Investigations

A field programme comprising test pitting and drilling investigations was undertaken between 23 November 2018 and 7 December 2018. The investigation locations are shown in Figure 2 and in the site plans included in Appendix B.

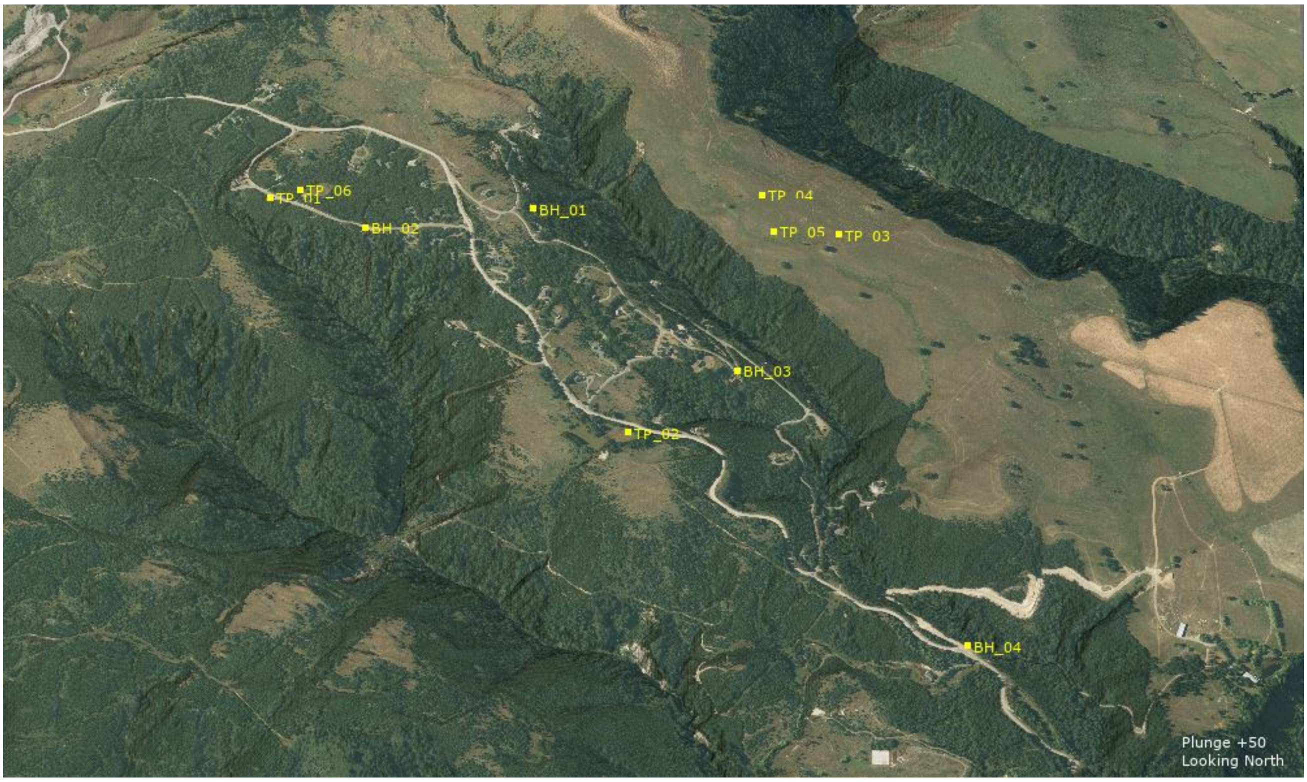

Figure 2: Oblique aerial photo looking North of Mt Lyford area showing investigation locations.

Summary of Daily Activities

23 November 2018 – Visited each planned test pitting and drilling location with an underground service clearance specialist. Verified each site for absence of underground services using a hand-held device and ground penetrating radar (GPR).

28 November 2018 – Following a postponement due to wet weather, TP_01 was excavated despite often persistent rainfall. TP_01 was photographed and then surveyed using an automatic level. TP_01 was logged as best as possible in the rain but planned to be further investigated later in the week.

29 November 2018 – TP_02 was excavated at 1 Mt Lyford Avenue, surveyed with an automatic level and photographed during a drone flight. TP_03 was excavated in a paddock east of Lulu's Creek, surveyed with an automatic level and photographed with a drone flight. Geologists from Davis Ogilvie (DO) arrived in the afternoon. TP_04 and TP_05 were excavated and surveyed. TP_04 was photographed during a drone flight.

30 November 2018 – Monique Eade from HDC and Tim McMorran from Golder arrived. TP_03, 04 and 05 east of Lulu's Creek were reviewed by geologists from Golder and DO. HDC and Golder go to TP_01 where water is removed from the existing test pit. TP_01 was enlarged as the weather is favourable. DO left the group and went to visit other site areas. Drone photography was undertaken at TP_01; TP_02 inspected.

3 December 2018 – Water for drilling organised, BH_01 at 40 Terako Terrace commenced.

4 December 2018 – Finished drilling BH_01 and start setting up BH_02 at 87 Tinline Terrace.

5 December 2018 – Finished drilling BH_02 and setting up BH_03 at 17 Lulus Lane.

6 December 2018 – Finished drilling BH_03 and setting up BH_04 at the south of Mt Lyford Village.

7 December 2018 – Completed drilling BH_04.

Test Pitting

Test pitting was undertaken by Mt Lyford Contracting between 28 November – 30 November 2018 under the supervision of geologists from Golder. Geologists from Davis Ogilvie were given the opportunity to review the test pits on site along with staff from Golder. TP_01,02,06 were sited to investigate locations where faults had been previously mapped by GNS (2018a). TP_03, 04 and 05 were sited to assess lineaments trending approximately in the 300º NW direction previously mapped by GNS (2018a). Test pit locations are shown in the site plans in Appendix B and approximate depths are outlined in Table 1. Logs and test pit photographs are included in Appendix C.

Table 1: Test pit details.

ID	Location	Approximate Depth	Geology	Evidence of faulting
TP_01	92 Tinline Terrace	2.1 m	Gravelly silt alluvial fan deposits (inferred age 24 – 59 ka) overlain by silt (inferred age 12 – 24 ka). Truncated by a deformation zone dipping 80º towards 115°. Tertiary siltstone of the Greta formation was exposed at the base of the southern end of the trench.	Change in lithology across steeply dipping deformation zone.
TP_02	1 Mount Lyford Avenue	2.4 m	Gravelly silt alluvial fan deposits (inferred age 24 – 59 ka) with inclined bedding overlain by silt (inferred age 12-24 ka)	Inclined bedding in silty gravel
TP_03	Paddock east of Lulu's Creek	2.9 m	Gravelly silt alluvial fan deposits (inferred age 24 – 59 ka) truncated by an abrupt change in lithology across an inclined plane dipping 70º towards 190°. Change in lithology to silt (inferred age 12-24 ka) truncated by a second change in lithology across an inclined plane dipping 60º towards 010°. Change in lithology to gravelly silt alluvial fan deposits (inferred age 24 – 59 ka).	Abrupt change in lithology across two inclined planes.
TP_04	Paddock east of Lulu's Creek	2.9 m	Silt (inferred age 12-24 ka) underlain by gravelly silt alluvial fan deposits (inferred age 24 – 59 ka) with inclined bedding planes and underlain by siltstone of the Greta formation.	Inclined bedding

ID	Location	Approximate Depth	Geology	Evidence of faulting
TP_05	Paddock east of Lulu's Creek	2.0 m	Silt (inferred age 12-24 ka) underlain by siltstone of the Greta formation.	No evidence
TP_06	68 Tinline Terrace	1.5 m	Silt (inferred age 12-24 ka) underlain by siltstone of the Greta formation.	No evidence

Borehole Drilling

Triple tube rotary core drilling was undertaken by Speight Drilling between 3 December and 7 December 2018 under the supervision of a geologist from Golder. Drilling was undertaken to better understand the stratigraphic profile of the underlying material and to characterise the geomechanical properties of the materials including rock strength, discontinuities and permeability. Borehole locations are shown in the site plans in Appendix B and approximate depths are outlined in Table 1. Borehole logs are included in Appendix D and core photographs are included in Appendix E.

Table 2: Borehole details.

ID	Location	Approximate Depth	Stratigraphic Sequence
BH_01	40 Terako Terrace	14.8 m	■ Nominal thickness of fill material underlain by silt (inferred age 12-24 ka) from surface to approximately 2.3 m below ground level (bgl); with an approximately 300 mm wide sandstone boulder at a depth of approximately 1.2 m. ■ Silty gravel inferred to be alluvial fan deposits (inferred age 24-59 ka) from approximately 2.3 m bgl to 6.5 m bgl. ■ Siltstone of the Greta Formation from approximately 6.5 m bgl to the end of hole (EOH) at 14.8 m bgl.
BH_02	87 Tinline Terrace	9.0 m	■ Silt and silty gravel from surface to approximately 5.5 m bgl. ■ Siltstone of the Greta Formation from approximately 5.5 m bgl to EOH at 9.0 m bgl.
BH_03	17 Lulus Lane	7.5 m	■ Nominal thickness of fill underlain by silt inferred to be 12-24 ka in age from surface to a depth of approximately 1.9 m bgl.

			- Siltstone of the Greta Formation from approximately 1.9 m bgl to EOH at 7.5 m bgl.
BH_04	At driveway entrance across the road from 227 Mt Lyford Forest Drive.	28.6 m	- Nominal thickness of fill underlain by silt inferred to be 12-24 ka in age to a depth of approximately 0.6 m bgl. - Silty gravel inferred to be alluvial fan deposits 24-59 ka in age from 0.6 m bgl to approximately 2.3 m bgl. - Siltstone of the Greta Formation from approximately 2.3 m bgl to EOH at 28.6 m bgl.

4.0 DISCUSSION

4.1 Geological Model

Figure 3 shows a summary of important geological features in the Mt Lyford Village area.

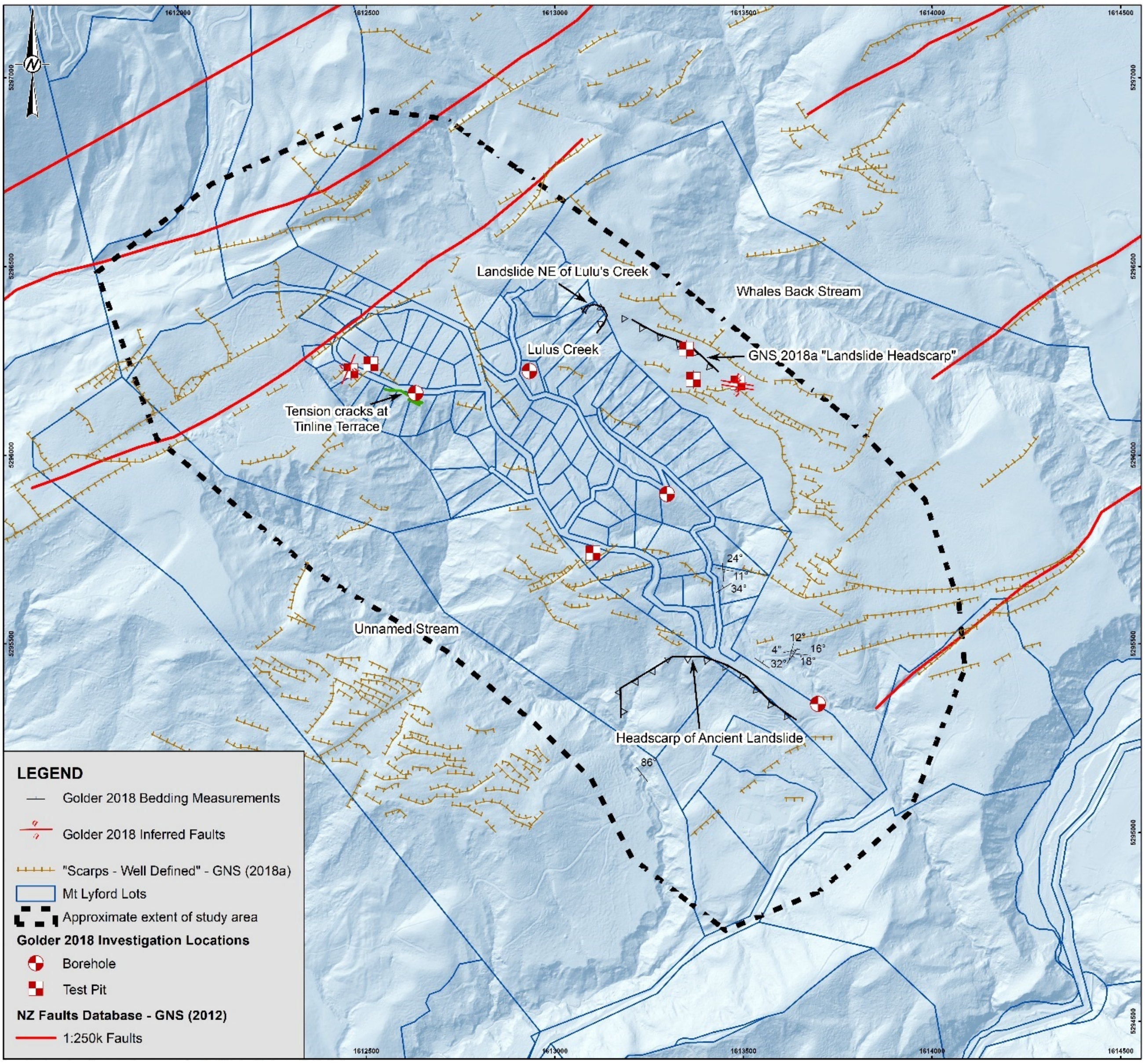

Figure 3: Geological features of Mt Lyford Village and field observations by Golder.

4.2 Typical Stratigraphy

The typical stratigraphy found at Mt Lyford Village is shown in Figure 4. As was confirmed in the drilling, the general stratigraphy of the area comprises silty soils overlying silty gravels (inferred to be alluvial fan materials), which are underlain by Tertiary age siltstone of the Greta Formation. The deposits are folded in what is known as the Wandle Syncline. Our observations of bedding within the siltstone are consistent with the presence of a syncline. However, the bedding orientation did not seem to have an influence on slope instability.

Figure 4: Typical stratigraphy at Mt Lyford Village. Photo taken at the south of Mt Lyford Village near Unnamed Stream.

Generally, the interpretation of the borehole data from the current investigation, the materials encountered during test pitting and the observations made during field mapping, indicate that the subsurface material at Mt Lyford Village comprises the following typical stratigraphic sequence:

- Silty soil: topsoil, quaternary soil deposits, generally less than 1 m thick.
- Silt: well sorted (poorly graded), soft, may be dispersive and susceptible to erosion when exposed to surface water, inferred to be 24-12 ka in age.
- Silty gravel: alluvial fan deposits, angular to subangular gravel, poorly sorted (well graded), loose, containing fines which may be dispersive and susceptible to erosion when exposed to surface water, inferred to be 59-71 ka in age.
- Siltstone: inferred to be of the Greta Formation, very weak to weak rock, bedding is distinct in some cases due to varying grain size, contains shallow marine fossils, no major shear planes observed in drilling. Competent and relatively strong as a foundation bearing material. Observed at a depth of approximately 2 m bgl in the northern part of the village (Tinline Terrace) and appears shallower (less than 2 m depth) as you head south. This is consistent with the overlying silty gravel being an alluvial fan deposit. The siltstone is of low permeability and may act as a slipping surface for overlying silty/gravel material, given the presence of extremely weak material at the contact in some drillholes.

4.3 Erosion

The silty material encountered at the site may be susceptible to erosion when exposed to water ingress and are considered dispersive. Dispersive characteristics of these soils were observed during our field mapping programme during heavy rain Water ingress may widen any existing cracks or cause gully erosion within the silty deposits.

4.4 Mechanisms of Slope Instability

Figure 1 illustrates the different styles of slope instability observed in our field programme. The results of our investigation suggest that the most common mechanism for slope instability and deformation at Mt Lyford Village is deformation within the silty and gravelly layers overlying the siltstone and within colluvial soils or fill materials on slopes. During the 2016 Kaikōura earthquake, cracking was observed within the silt and gravelly layers. Water ingress into the cracks has been observed to worsen the deformation. The competent siltstone beneath the silty and gravelly layers is relatively impermeable. The interface may form the slip surface for some slope instability and appears to behave as a slip surface for the overlying material. Therefore, the stability seems to be controlled by the thickness of the silty and gravelly layers, the proximity to the slope edge and the orientation of the soil to siltstone contact.

During our investigation, we did not find evidence to suggest that deep-seated instability, for instance within the siltstone, is a common feature. The ancient landslide south of the Mt Lyford Village shows that the failure of the siltstone is possible, but our findings suggest that this is not a widespread mechanism affecting the consenting of residential dwellings in Mt Lyford Village. The siltstone observed in the boreholes, specifically in BH_04 located in proximity of the head scarp of the ancient landslide, did not show evidence of obvious planes of weakness (such as weak bedding layers, defects or shear planes) that could be interpreted as a potential deep-seated slipping surface. Our results show that deep-seated land slips are not considered to cause significant large-scale deformation throughout the Mt Lyford Village.

4.5 Fault Ground Truthing

Golder has undertaken test pitting to investigate a sample of faults which had been previously mapped by GNS (2018a). The test pit locations are shown in the site plans in Appendix B. Logs and test pit photographs are included in Appendix C.

TP_01, excavated at 92 Tinline Terrace, contained a zone of deformation oriented dipping approximately 80º towards 115° at an abrupt horizontal change in lithology (yellow silt inferred to be 12-24 ka in age to grey gravelly silt juxtaposed against alluvial fan deposits 24-59 ka in age). Additionally, the inclined gravel bedding suggests tectonic displacement.

TP_02 at1 Mount Lyford Avenue showed inclined gravel beds dipping towards the inferred fault scarp. The LiDAR data and observed topography indicate a gently inclined surface dipping towards a linear feature inferred to be a fault scarp. Due to site constraints (a mature row of Pine trees along the inferred fault scarp), the test pit could not be extended across the inferred fault. However, the inclined gravel bedding suggests tectonic displacement which is typical close to a fault.

TP_06 was excavated at 68 Tinline Terrace. The site constraints meant that only a small test pit could be excavated; however, the test pit did cross the lineament shown in the LiDAR which suggested that a fault may be present. Despite crossing the lineament shown in the LiDAR, no evidence of a fault, such as a sudden change in lithology, a sheared surface or steeply dipping bedding, was found.

4.6 Secondary Lineament Features

Test pits were excavated in the paddocks east of Lulu's Creek, where lineaments previously mapped as "well defined scarps" (GNS 2018a) are present. The results of TP_03 and TP_04 showed lineaments and dipping bedding within the alluvial fan deposits suggest that secondary faults are present outside of the main trend of the Hope Fault. The dipping bedding may result from tectonic processes or as a result of a mass movement or gravitational process. However, given the age of the geomorphic surfaces affected, such processes appear to be relatively slow.

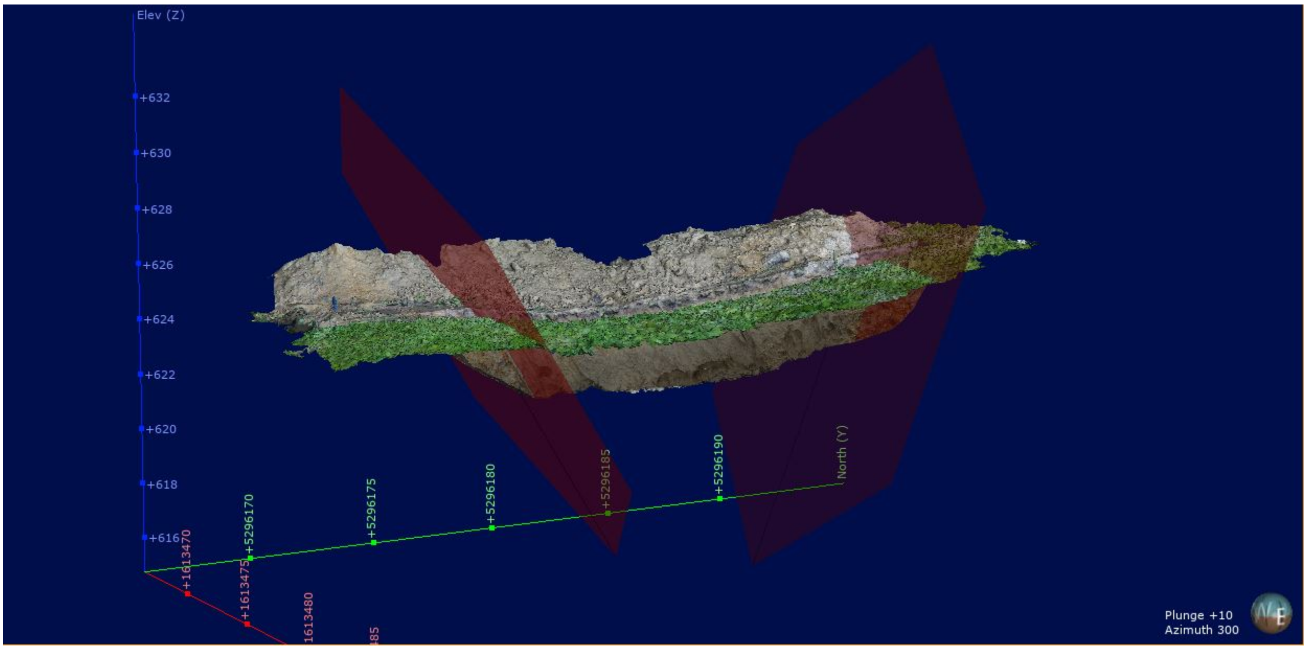

Figure 5: 3D model and cross section of TP_03 showing inferred faults which trend outside of the main trend of the Hope Fault. Looking to 300 and plunging 10º.

The observations made in TP_03 suggest that some ground displacement is possible in the Mt Lyford Village area outside of the known active mapped faults. The observations are in line with the model of the area set out by Eusden et al (2000) shown in Figure 5. This emphasises that the Mt Lyford Village area is a complex fault zone rather than a series of discrete features. Deformation, either from tectonic or slope instability processes, is possible in areas away from the delineated GNS Fault Avoidance Zones. Active faults mapped by GNS are likely to be where the maximum deformation may occur during a Hope Fault earthquake, but it should be considered that deformation may occur away from the mapped faults.

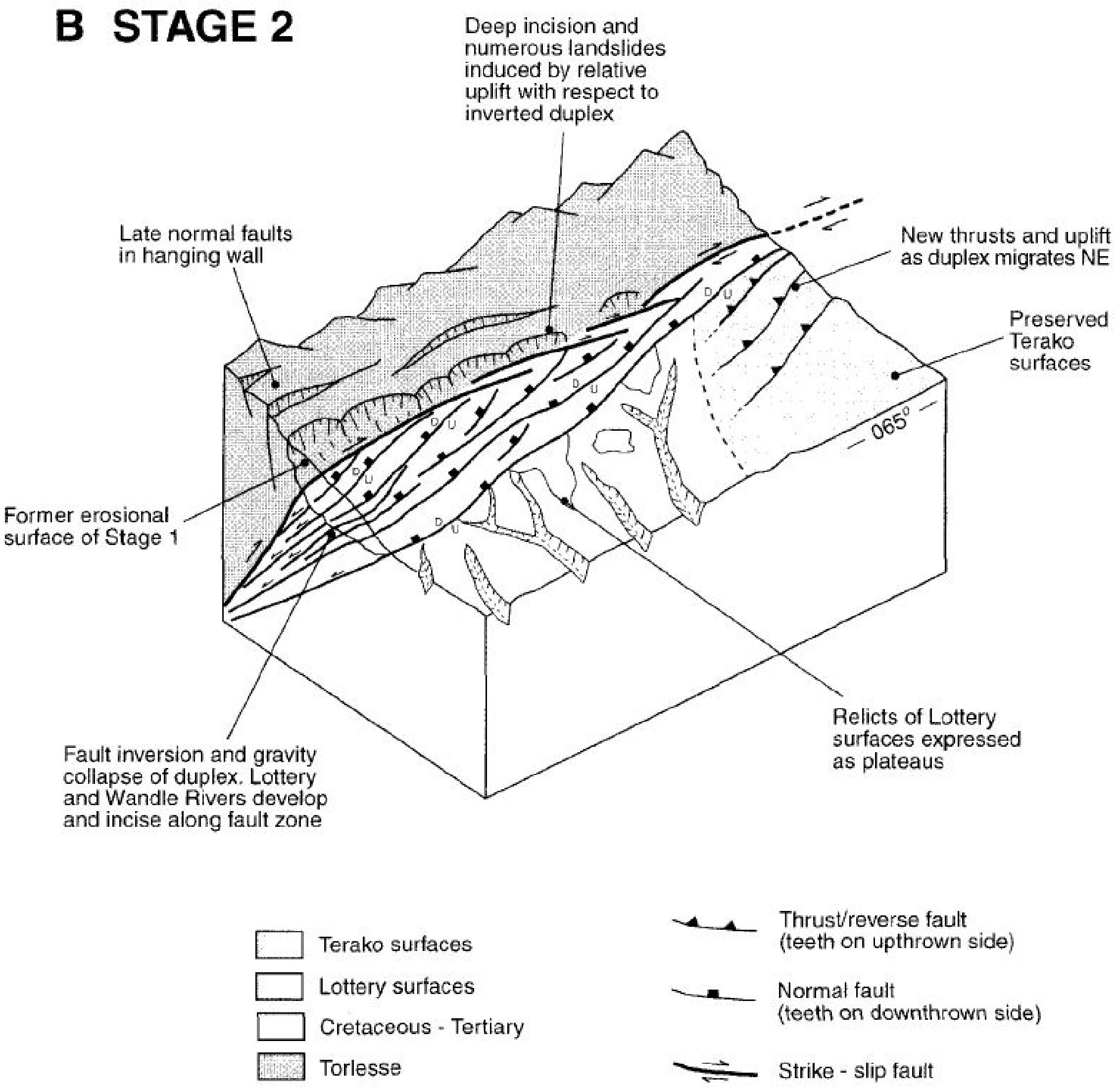

Figure 6: Faults inferred in TP_03 and TP_04 may represent new thrusts and uplift as duplex migrates. From Eusden et al 2000.

5.0 CONSIDERATIONS FOR DEVELOPMENT

It is our opinion that if the recommendations below, which follow the considerations outlined in the NZ Building Act 2002, are followed and adhered to then continued development in the Mt Lyford Village is appropriate.

Stormwater Management

The upper silty soils overlying the competent siltstone at Mt Lyford Village are dispersive judging by the suspended sediment observed in standing water bodies. These soils are likely susceptible to erosion. Therefore, when developing a site at Mt Lyford Village, consideration must be given to stormwater management and the effects of drainage on the building platform, foundations and stability of the area. The water must be drained in a controlled manner, as it can affect the stability of the site and neighbouring downhill sites. Geotechnical input should be sought when designing the building platform (whether there are earthworks or not) and foundations.

Earthworks

Earthworks, such as cutting and filling, has the potential to adversely affect the stability of a site and its neighbouring properties both upslope and downslope. Geotechnical input should be sought to confirm that any proposed land reshaping is appropriate for the works in question and that the earthworks do not adversely affect the stability of the slope. Any building platforms, especially when incorporating fill material, should be constructed to statutory engineering controls and reinforced when necessary. Any existing fill platforms should be assessed prior to redevelopment. Retaining walls should be designed according to the NZ Building Code and using the guidance recently issued by the Ministry of Business, Innovation and Employment (MBIE) and the New Zealand Geotechnical Society (NZGS) (2017). For instance, any retaining walls in the vicinity of the dwelling, over 1.5 m in height and/or supporting a surcharge must be specifically designed with engineering controls considering static and seismic loadings.

Construction and Repairability

The Mt Lyford Village is susceptible to movement due to slope instability and fault rupture hazards. Whether it be deformation caused by an earthquake or by rainfall events, consideration should be given to a building construction method which can withstand some flex and be relevelled as required. Planned use and any required ongoing maintenance (as is needed with log cabins) should be considered at the design stage. Following discussions with the residents, it appears that some of the earthquake damage experienced at Mt Lyford Village was due to poor maintenance of the log cabins. For dwellings where occupants may be away for much of the year, such as vacation homes, consideration should be given to a construction method that requires less maintenance than the current log cabins.

Considerations for Piled Foundations

The preferred embedment layer for piles at the site is the competent siltstone unit. In our investigations, the top of the siltstone was encountered at depths ranging from less than 2 m to approximately 6.5 m. As a founding layer the siltstone was uniform, lacked discontinuities and appeared to be laterally extensive and thick (as shown in Figure 4). Consideration should be given to embedding foundation elements into the competent siltstone. Alternatively, design engineers may embed foundations in the shallower soils following an assessment of slope stability and the potential erosion and dispersion of the silty deposits.

Secondary Lineaments and Scarps

In our geotechnical investigations, specifically TP_03 – TP_05, we identified deformation zones, inferred to be faults or shear zones, which had not been previously investigated and that do not coincide with the trends or locations of previously identified active faults. Similar features had been mapped as “slope rents” and “scarps” in the past (Yetton 2005, GNS 2018a). It is important to consider for future proposed works that movement was identified in these features, which means that movement is possible in areas outside of the currently mapped Fault Avoidance Zones. For the purposes of future development, if an area is away from mapped active Fault Avoidance Zones, no topographical features with significant lineaments, scarps or slopes are identified on site, and there is no evidence of variability in the founding materials, then the risk of future deformation is considered low but not zero. Note that small fault displacements, ground tilting or slope instability related deformation may still occur. We recommend, however, that an assessment be undertaken prior to development to identify if the site is susceptible to future movement. As stated in Section 4.2, active faults mapped by GNS are likely to be where the maximum deformation may occur during a Hope Fault earthquake, but it should be considered that deformation may occur away from the mapped faults. We consider that the extent of deformation away from the active mapped faults is unlikely to cause severe damage to a dwelling, for instance where collapse would occur; and therefore, are within the tolerances of the NZ Building Act for an Ultimate Limit State (ULS) earthquake. For a serviceability limit state (SLS) earthquake, where some deformation is allowable but must be reparable, we consider that the hazard can be mitigated through engineering design as is outlined in the “Construction and Reparability” Section.

Fault Avoidance Zones

From our observations, the fault deformation zones at Mt Lyford Village may vary from discrete shear planes to broad zones of deformation with distributed shear and local tilting. The scale of deformation could vary from a few centimetres to many metres of ground surface rupture. We recommend avoiding building within the Fault Avoidance Zones, as detailed by GNS (2018a). However, building within a Fault Avoidance Zone could be acceptable subject to an appropriate investigation by a specialist geologist to mitigate the effects of future fault rupture on the structure. The building recommendations within a Fault Avoidance Zone would be at the discretion of the specialist geologist who has undertaken the investigation.

6.0 GEOTECHNICAL ASSESSMENT ZONE CLASSIFICATIONS

The geotechnical assessment zones are shown in Figure 7 and are included in Appendix F. These zones define a range of geotechnical assessments and recommendations that we believe are appropriate given the findings of our site investigation. The suggested geotechnical assessments for each zone are summarised below. It should be noted that development in all zones must follow the requirements of the NZ Building Code, take into account the Fault Avoidance Zones previously mapped by GNS (2018a) and take into account the considerations outlined in Section 5.0 of this report.

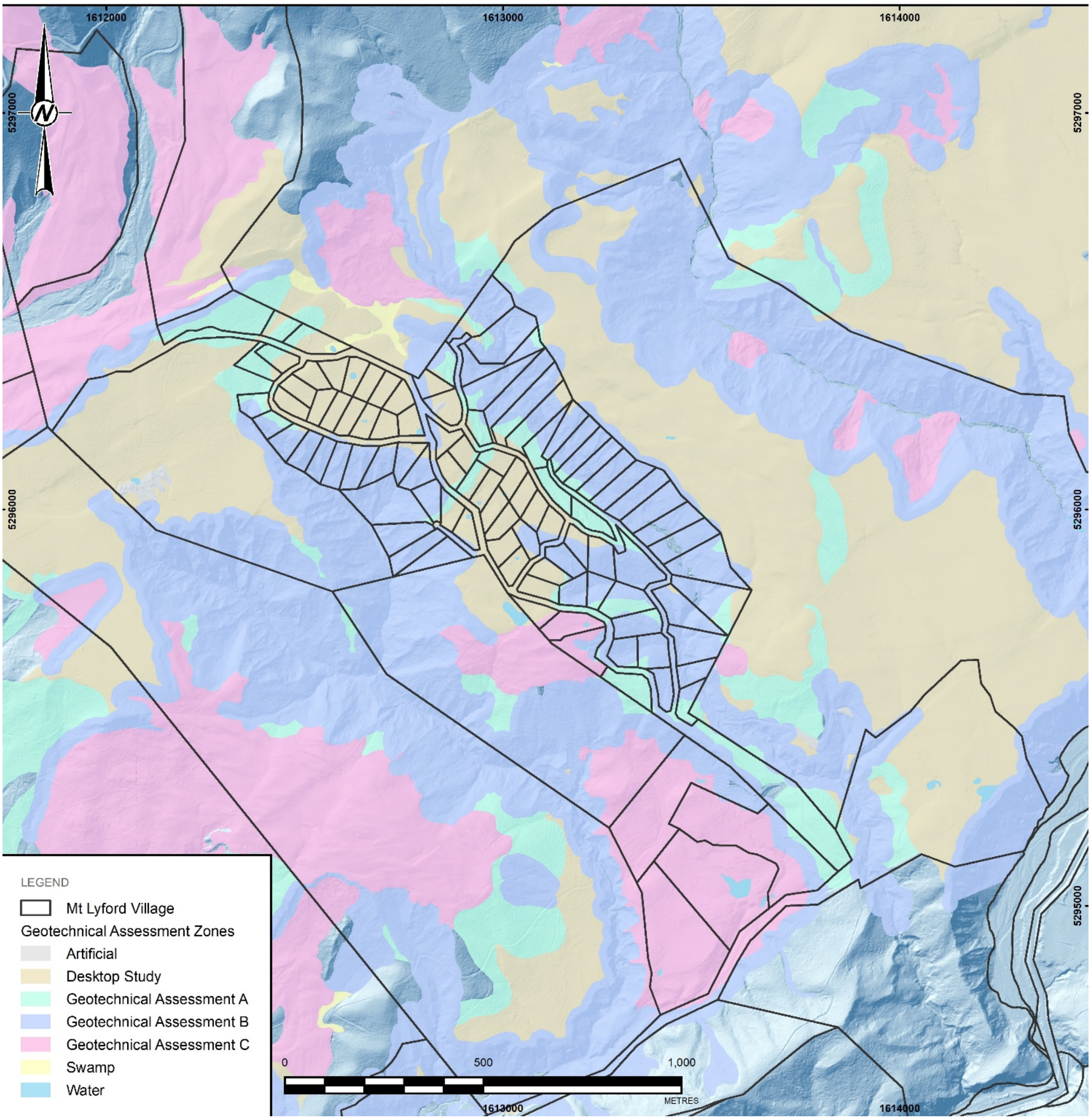

Figure 7: Geotechnical assessment Zones for Mt Lyford Village area.

Desktop Study: Based on field observations and previously reported information by GNS (2018a, 2018b), the likelihood of future slope instability causing deformation that damages a dwelling or residence in this zone is considered low. However, it should be noted that currently unrecognised features may be present; and therefore, a desktop assessment confirming that there are no geomorphological features such as significant lineaments, slopes, or tension cracks within the building footprint should be completed as part of the documentation prepared for site development. This assessment should be conducted by a suitably qualified engineering geologist or geotechnical engineer and refer to previous reports (including this report), LiDAR data and/or the results of a site walkover. If any topographic features are identified that could result from tectonic deformation or landslide activity, the procedure outlined in Geotechnical Assessment A should be followed.

Geotechnical Assessment A: This zone comprises sites with mixed topography, some flat lying, some terraced and some of which have slopes greater than 25º. GNS defined that some of these properties have the potential for adverse slope instability issues. We recommend that a geotechnical report, prepared by a suitably qualified engineering geologist or geotechnical engineer, assessing land stability be provided for any development to these sites. Any earthworks in proximity to the proposed building footprint should be assessed by an experienced geotechnical professional to address the potential slope instability risks. Investigations should include a geomorphological assessment of whether any evidence of past slope movement (cracking, terraces, bulging etc) is present. If identified, then foundations should be designed accordingly. Consideration can be given to founding in the competent siltstone beneath surficial soil layers. A geotechnical investigation such as borehole drilling or test pitting should be undertaken to confirm the depth and lateral extent of a suitable founding layer.

Geotechnical Assessment B: The investigation procedures outlined for Geotechnical Assessment A should be followed for this zone with the following additional considerations. This zone comprises the steepest sites within Mt Lyford Village and includes a 20 m setback zone from the crest of the slope. This zone is considered a high hazard area in terms of slope instability. Golder considers that a 20 m setback from the crest is an appropriate configuration to delineate this high hazard area. As is outlined in GNS 2018b, damage to dwellings or residences experienced in this area during the 2016 Kaikōura earthquake and afterwards were due to ground shaking, which has been exacerbated by rainfall events. To develop in this zone, an assessment of slope instability will need to be undertaken. It is likely that mitigation works to reduce the slope instability hazard would be required, and any mitigation works should be designed with input from a geotechnical engineer or engineering geologist. As is outlined in Section 5.0, geotechnical input is needed to confirm the suitability of any earthworks for the land such as cutting and filling. Any retaining walls should be designed with input from a chartered professional engineer. In this geotechnical assessment zone, drainage is particularly important due to the dispersive nature of the surficial soils, especially on steep slopes. The geotechnical assessment report for the properties in this zone should address any potential gully erosion, slope retreat, landslip and inundation from landslip material. If any of these hazards are observed on the site, they must be addressed and mitigated in the specific engineering design.

Geotechnical Assessment C: This zone is characterised by previously recognised ancient landslide deposits. Because these sites are not “in situ” ground and have experienced movement in the recent past, it is considered to have the potential to experience further deformation that could cause unacceptable damage to buildings on the sites. These landslide deposits were mapped by Bell (1987) using aerial photography and more recently by GNS (2018a) using LiDAR digital elevation models. A site-specific geotechnical report using the procedures outlined for land zoned Geotechnical Assessment A should be applied. Special consideration should be given to determine if the property has experienced any movement or settlement in the recent earthquakes.

7.0 REFERENCES

Bell, DH, 1987. Mt Lyford Log Village Residential / Recreation Zone, Evidence presented at Town and Country Planning Hearing, 22 January 1987.

Bell, DH, 2006. Letter to Davis, Ogilvie and Partners regarding Mt Lyford Integrated Active Faults and Slope Features Map published on ECan website, 8 February 2006.

ECan, 2004. Letter to Hurunui District Council with recommendations regarding active faults and avoidance zones for inclusion in the Hurunui District Plan, 8 September 2004.

ECan, 2005. Letter to Hurunui District Council with recommendations regarding the ‘slope rents and zones of slope collapse at Mt Lyford Village, 14 November 2005.

ECan, 2005. Letter to Hurunui District Council with further comments regarding the ‘slope rents and zones of slope collapse at Mt Lyford Village, 12 December 2005.

Eusden, JD, Pettinga, JR, Campbell, JK, 2000. Structural evolution and landscape development of a collapsed transpressive duplex on the Hope Fault, North Canterbury,New Zealand. NZ Journal of Geology and Geophysics, 43: 391–404.

Hancox GT, Langridge RM, Townsend DB, 2006. Review and investigation of slope instability and active fault features in the Mt Lyford Village area, North Canterbury, Lower Hutt (NZ) GNS Science, Reference GNS Report 2006/26, 12 June 2006.

Kerr J, Nathan S, Van Dissen RJ, Webb P, Brunsdon D, King A, 2003. Planning for development of land, on or close to active faults: a guideline to assist resource management planners in New Zealand. Lower Hutt (NZ) GNS Science, GNS Report Reference 2002/124, 2003.

Langridge RM, Townsend DB, McMorran T, Anderson C, Moroder D, 2018a. Land damage and natural hazards in the Mt Lyford Village area following the 2016 Kaikōura earthquake, Lower Hutt (NZ) GNS Science, GNS Report Reference 2017/227, April 2018.

Langridge RM, Townsend DB, 2018b. Re: Land Class recommendations at Mt Lyford Village, Lower Hutt (NZ) GNS Science, Letter Report No: CR 2018/104 LR, 24 July 2018.

Ministry of Business Innovation and Employment (MBIE), New Zealand Geotechnical Society (NZGS) 2017. Earthquake geotechnical engineering practices, Module 6: Earthquake resistant retaining wall design. May 2017. Available from www.building.govt.nz

Rattenbury MS, Townsend DB, Johnston MR (compilers) 2006. Geology of the Kaikoura area. Institute of Geological & Nuclear Sciences 1: 250 000 geological map 13. 1 sheet + 70 p. Lower Hutt, New Zealand. GNS Science, 2006.

URS, 2005. Mt Lyford Village Active Fault Hazard Assessment Review. Peer review.

Letter to Environment Canterbury by Tim McMorran and Don Macfarlane, URS New Zealand Ltd, 23 November 2005.

Yetton, M, 2005. Updating of Active Fault database–Hurunui District – Waikari and Mt Lyford areas. Letter to ECan by Mark Yetton, 27 October 2005.

Yetton, M, 2005. Updating of Active Fault database–Mt Lyford area. Letter to ECan by Mark Yetton, 18 November 2005.

Yetton, M, 2006. Proposed investigation of slope rent features at Mt Lyford Village.

8.0 CLOSURE

We trust this meets your current requirements. Should you have any queries, or require further clarification, please do not hesitate to contact the undersigned.

Golder Associates (NZ) Limited

Marie-Claude Hébert	Tim McMorran
Engineering Geologist	*Principal Engineering Geologist* | *Associate*