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Project Number 28912.000.001

Geotechnical Assessment

Lighthouse Road Landslide, Akaroa,

Submitted to:
Christchurch City Council
PO Box 73016
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Executive Summary

ENGEO has assessed the recent reactivation of the Lighthouse Road landslide and its implications for slope stability and nearby assets. Our assessment based on desktop study, on-site testing and computational analysis indicate that the movement is slow and contained, with no immediate threat to downslope buildings. Based on site conditions and monitoring data, the likelihood of further escalation, such as debris flow or rapid failure, is considered low.

The Engineering Geological Model (EGM) was developed through geomorphic mapping, on-site borehole data, and computational analysis. The EGM identifies a broad, arcuate headscarp and a displaced mass extending downslope, consistent with historical movement patterns. Subsurface investigations suggest the failure is occurring within weathered pyroclastic material.

Monitoring data, including surface movement markers and a subsurface inclinometer, supports the interpretation that current movement is insignificant.

ENGEO recommends continuing the current monitoring regime for the next two to three months, including groundwater, surface movement, and inclinometer surveys. If movement remains minimal, monitoring frequency can be reduced, particularly during the drier summer months. The results of this ongoing monitoring, along with updated recommendations, will be provided to Council to support informed decisions regarding the need for continued observation or the initiation of remediation works.

Targeted pavement investigations are advised to inform pavement design. Damaged road sections should be reconstructed using geogrid-reinforced engineered fill to improve stability and load distribution. Surface water controls, including roadside swales and stormwater outfalls, should be enhanced to prevent infiltration and erosion.

While the overall risk to existing buildings downslope is considered low, it is important to note that the building platform at 41 Lighthouse Road is located closest to the active landslide area. Should future development be proposed at this location, further geotechnical assessment and potential mitigation works will be required to ensure safety and long-term stability.

1 Introduction and Scope of Work

ENGEO Ltd was requested by Christchurch City Council (CCC) to undertake a Geotechnical Assessment of the Lighthouse Road Landslide, Akaroa, (herein referred to as ‘the site’, shown in Figure 1). As background, the landslide reactivated in early May 2025, and as a result five properties downslope were evacuated. The affected properties (with the exception of the winery business) have all since been assessed as safe for occupation. The landslide is located in close proximity to an area that failed in 1994.

The objective of ENGEO's assessment was to evaluate the mechanisms causing landslide displacement in order to inform strategies for managing future landslide hazards. This work has been carried out under the conditions of our panel agreement with CCC (contract number 4600004844).

ENGEO have previously provided the following documents:

- Geotechnical Memorandum dated 16 May 2025 (reference: 28912.000.001_01) – Assessment of runout distance for various volumes of failure.
- Letter dated 12 June 2025 (reference: 28912.000.001_02) - Geotechnical and Risk Assessment. The purpose of the assessment was to produce a detailed geomorphological map and engineering geological model of the landslide to inform the basis for future analysis, risk assessment and geotechnical recommendations along with the future decision-making process.
- Draft Geotechnical Assessment Report dated 31 July 2025 (reference: 28912.000.001_03). The current report is an update of the 31 July report including the CCC quantitative risk assessment.

This current report updates and supersedes these previous documents and is intended to serve as the primary geotechnical reference for future decision making.

The combined scope of work undertaken by ENGEO over the course of the investigation has comprised:

- Geotechnical field reconnaissance.
- Drilling and logging of two geotechnical investigation boreholes.
- Development of a detailed geomorphological map and EGM of the landslide.
- Groundwater and inclinometer monitoring (on-going).
- Coordination of laboratory testing and assessment of test results.
- Slope stability and sensitivity analysis, as well as debris flow analysis.
- Development of recommendations for hazard mitigation.

Our scope of works has not included quantitative risk assessment or detailed design of mitigation measures. However, a quantitative risk assessment has been completed by Christchurch City Council (CCC) which is discussed in this report.

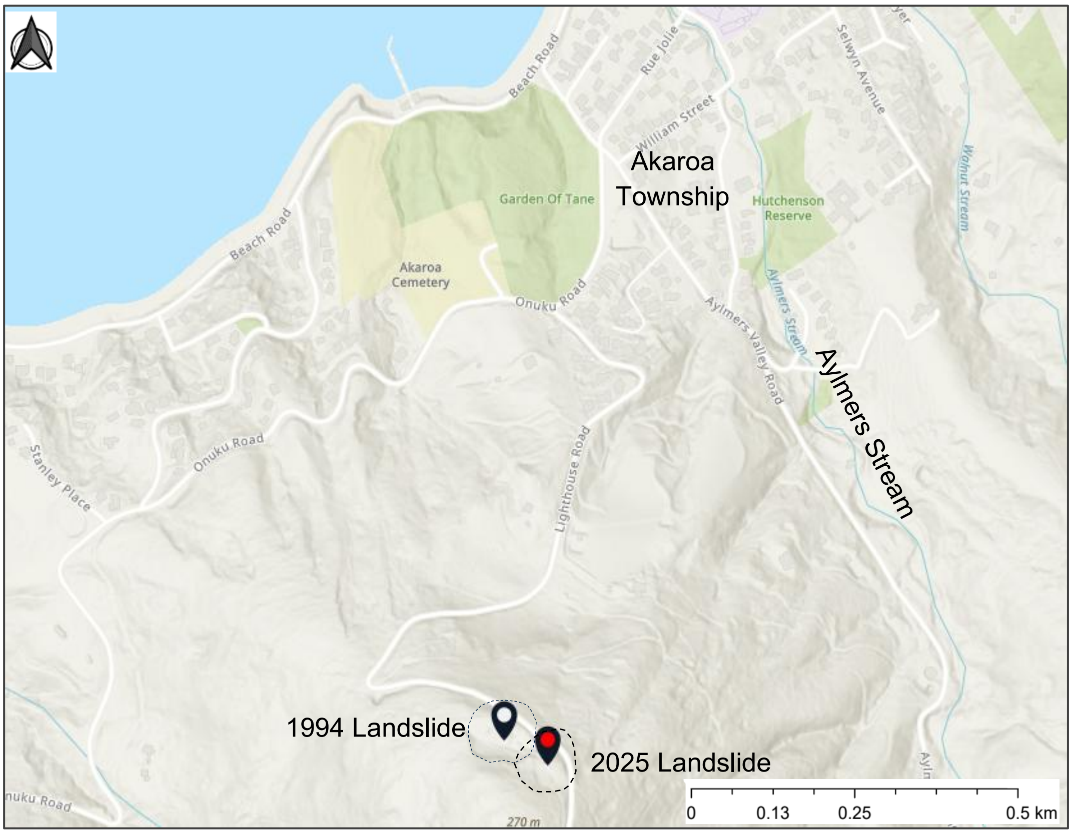
2 Site Description and Regional Topography

Both the recent and 1994 landslides are situated at approximately 280 metres above mean sea level (m asl) on Lighthouse Road, overlooking the township of Akaroa (Figure 1). The overall site faces north-northeast and lies just downslope of a north-trending spur (Aylmers Hill), which descends from the Akaroa Crater Rim.

Below the landslides, the terrain slopes steeply toward Aylmers Stream, with well-defined drainage channels incised into the hillside. The immediate downslope gradient ranges between 25° and 35°, featuring a prominent ridge and plateau at mid-slope. Gullies extend from this plateau into Akaroa Township, which is primarily located on moderately sloping terrain (<15°) that continues down to sea level.

A mountain bike track has been recently constructed through the area of both landslides (in 2018/2019).

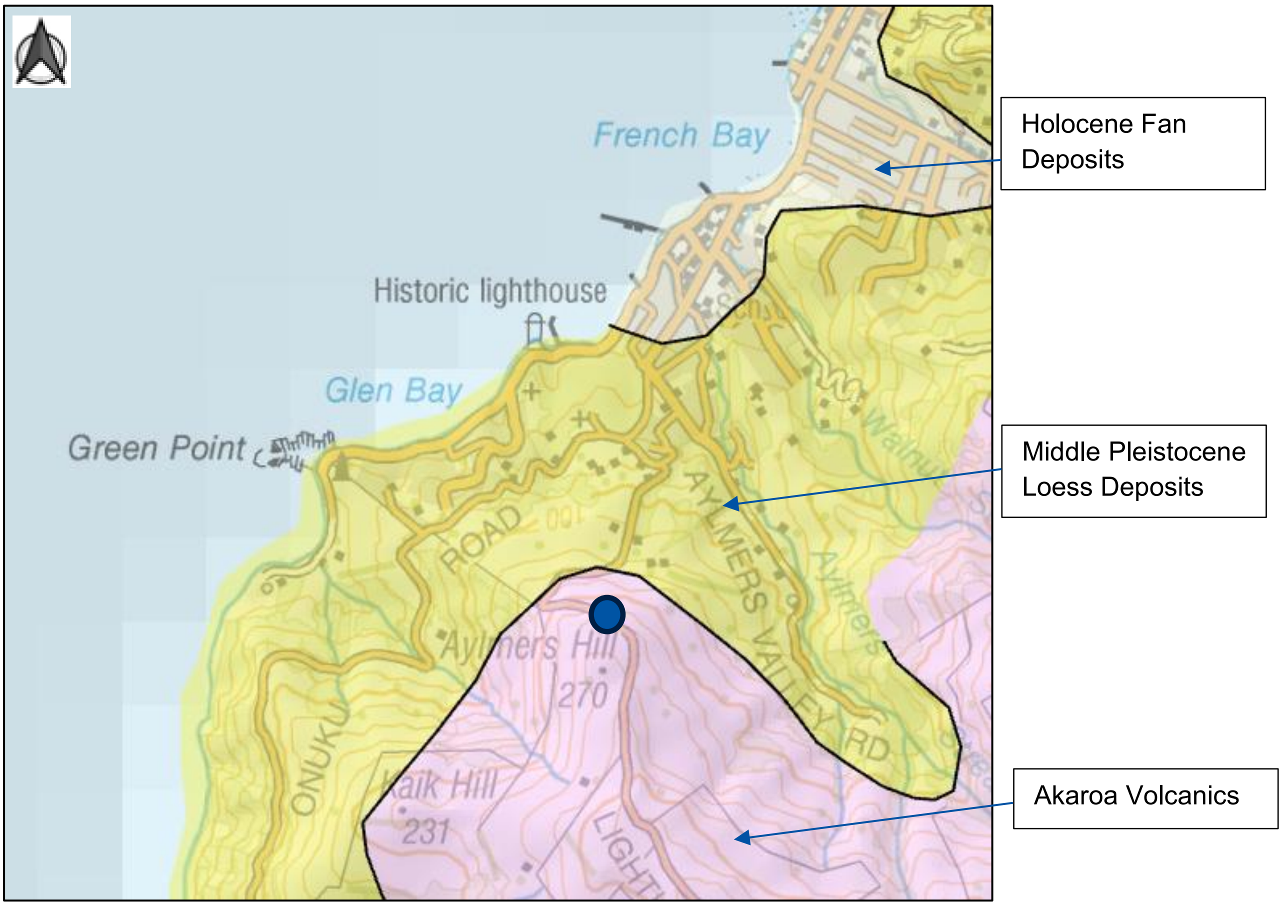
Figure 1: Site Location



3 Geological Setting

Both the 1994 and 2025 landslides are hosted in Akaroa Volcanics; described by GNS[1] as 'Basalt to trachytic lava flows intercalated with tuff pyroclastic breccia and agglomerate' (Figure 2).

Figure 2: Geological Setting (GNS online map).



Note: 2025 Landslide location shown in blue.

Aecom (2025)[2] provides the following notes:

- The rock mass at the site is predominantly highly weathered, with some areas approaching completely weathered pyroclastic material containing large basalt clasts within a finer groundmass of devitrified volcanic ash.
- The weathering of the ash matrix has resulted in the formation of clays, making the material weak to extremely weak. The basalt blocks, although harder, are also weathered and can be easily crushed between fingers.
- Evidence of sulfurous deposition suggests that hydrothermal alteration is the primary driver behind the weathering of the rock mass.

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[1] https://data.gns.cri.nz/geology/

[2] Aecom Letter to Jesse Dykstra (Christchurch City Council), 17 July 2025. Attached in Appendix 1.

- The highly weathered rock mass extends westward along the road cut and ends abruptly about 110 metres northwest of the mapped landslide. The extent of the weathered rock in other directions is not fully known due to limited exposure.

Loess is mapped on the lower slopes but does not mantle the topography in any significant thickness at the elevation of the landslides. Side cast fill associated with road construction is inferred to be present in some locations along the outside edge of Lighthouse Rd.

4 1994 Lighthouse Road Landslide

In 1994 a landslide occurred immediately adjacent to the area of recent movement (Figure 1). We have been provided with two reports in relation to the 1994 landslide as follows.

- 24 September 1994 **-** Geotech Consulting Ltd. Lighthouse Road Slide, Akaroa – Description of the landslide and a review of remedial work required for road reinstatement. Report for Banks Peninsula District Council. (Geotech, 1994).

- 17 April 1997 **-** Lighthouse Road landslide, Akaroa – monitoring during remedial work. Submitted to IPENZ Transactions, Vol 24, No. 1/CE, 1997. (Ekanayake and Phillips, 1997).

These two reports have been reviewed with key findings applicable to the 2025 landslide presented in the sections below.

4.1 Rate of Movement

The 1994 landslide was triggered following a 275 mm rainfall event that occurred over a three-day period[3] during the winter of 1994. The initial recorded slip rate was 6 mm/hr, which decreased to 4.5 mm/hr within 24 hours of the failure event (Yetton, 1994). Fourteen days later, the slip rate had reduced to 80 mm/day (equivalent to approximately 3.3 mm/hr) and continued to move at this rate with no additional rainfall recorded.

A decision was made to unload the landslide by removing 3,000 m^3 of material from the head of the landslide. Two days after completion of these earthworks (27 days following the initial failure; Yetton, 1994) the landslide stopped moving and as far as we are aware, has not moved since. Additional works were completed over the year following these earthworks which included further unloading and installing horizontal drains with the aim to reduce ground water pressure within the remainder of the landslide mass.

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[3] This corresponds to a rainfall event with an Average Recurrence Interval (ARI) of between 10 and 20 years

4.2 Landslide Morphology and Geology

The 1994 landslide was estimated at approximately 150 m wide and 80 m long with an estimated volume of 40,000 m^3. Ekanayake & Phillips (1997) inferred that the basal slide plane to be approximately 20 m deep and aligned subparallel to the dip of the slope. They write that the exact geological structure of the slide was unknown with the stratigraphy inferred from surface expressions and shallow excavations (deepest being 6 m).

Ekanayake & Phillips interpreted the toe of the landslide to daylight above a basalt layer downslope of Lighthouse Road that dips into the slope, with the main body of the landslide within pyroclastic material. They note a loess and colluvium mantle over the pyroclastic rock between approximately 5 and 10 m thick (inferred from their cross-section). A soil sample from the inferred base of the landslide showed high clay content (57%) with laboratory testing undertaken at the University of Canterbury giving the material a friction angle of 14° and residual apparent cohesion of 12 kPa4, although it is not clear how this was tested.

4.3 Landslide Hydrology

Ekanayake & Phillips (1997) attempted to define the hydraulic regime within the landslide mass by installing a series of piezometers in the slide mass. They found significant variability between pore-water pressures in respect to the piezometer locations and interpreted this as evidence of a series of perched water tables within a chaotic landslide mass separated by internal discontinuities. They concluded that the landslide hydrology was complex and that any phreatic surface chosen in subsequent stability analysis needed to be adopted cautiously.

5 2025 Lighthouse Road Landslide

5.1 Background

Christchurch City and Banks Peninsula experienced prolonged, intense rainfall between 30 April and 2 May 2025, resulting in flooding and multiple landslides across the region . On 1 May, cracks appeared along Lighthouse Road at the base of the landslide, prompting closure of the road. Evacuation of downslope residents occurred on the morning of Friday 2 May, when aerial reconnaissance revealed the extent of the cracking on the hillside. Following closer observation, tension cracks were observed extending from the crest of the historic landslide southeast for approximately 70 m, then east down to the road for approximately 35 m (Figure 3).

Movement of the landslide followed heavy rainfall that occurred between 30 April and 1 May 2025. The Akaroa EWS Rainfall gauge (Earth Sciences New Zealand) record that 262 mm of rain fell in the 24-hour period prior to 3:30 pm on 1 May 2025, equating to an approximately 70-year ARI according to HiRDS[5]. Crack monitoring was installed on 2 May, however little evidence of movement was noted in any of the monitoring pins to 29 May 2025 (by this stage, Kurloo sensors had been installed as discussed in Section 5.5.1).

Residents have now returned, and the road has since been reopened on the week of 13 August 2025.

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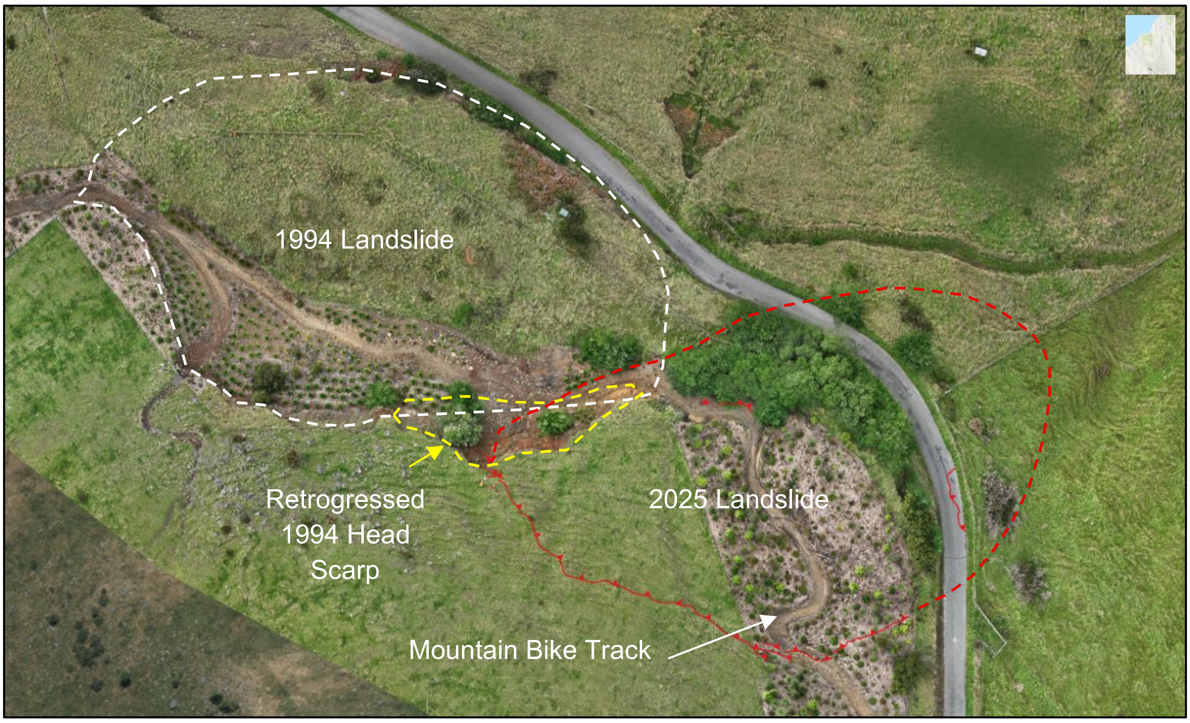
[4] This is a very high value – residual cohesion is 0, or very close to it. This value may represent a partially saturated soil state, and should be treated with caution

[5] High Intensity Rainfall System for Akaroa Armstrong Crescent gauge

Figure 3: 2025 Imagery with the Recent 2025 Landslide and 1994 Landslides Locations Annotated



5.2 Field Reconnaissance

ENGEO visited the site on 29 May 2025 to undertake geomorphic mapping of the landslide. The results of this exercise are shown in Appendix 2 with site photos attached in Appendix 3. We made the following observations at the time of our visit.

Landform

Immediately upslope of the road is an approximately 8 m high, steep, vegetated cut slope. Above this, a recently landscaped and planted mountain bike track descends from the south, traverses a moderately sloping bench, and continues westward with steep bends to accommodate the terrain. Further upslope, grassed and fenced farmland rises to the crest of a spur at approximately 280 m asl.

The 1994 landslide scarp is clearly visible, along with a more recent retrogressive failure within the eastern portion of the original scarp (Figure 3).

Landslide Features

- **Road Deformation**: Tension cracks were observed within Lighthouse Road. These had recently been infilled with road seal, but some appear to have since re-opened, with dilated cracks up to 10 mm wide visible within the infill material. The road surface which rises from 240 and 250 m asl shows slight bulging on the upslope side in two locations. On the downslope side, cracks up to 30 mm wide run sub-parallel to the road seal.

- **Head Scarp and Surface Expression:** A prominent head scarp extends from the centre of the retrogressed 1994 scarp westward through the grassed farmland, intersecting the mountain bike track and landscaped area. It becomes indistinct on the vegetated slope above the road to the east, with only minor tension cracks continuing down the 1994 scarp to the west.

- **Fence Line Distortion**: The fence line along the downslope side of Lighthouse Road was noted to be taut and straight. In contrast, the fence line running perpendicular to the road is buckled and slackened downslope to approximately 233 m asl, indicating differential ground movement. A fence line intersecting the head scarp was observed to be taut with a post pulled up out of the ground by approximately 300 mm.
- **Internal Deformation:** Within the landslide mass between the head scarp and Lighthouse Road a cluster of small scarps and tension cracks indicates ongoing ground movement. These features undulate with the landscaped bike track and show vertical offsets dipping both to the south / southwest and north / northeast. A small upthrown graben feature is visible in the central eastern portion of the landslide mass.

Subsurface Geology

A cross-section through the upper landslide subsurface was visible in the retrogressed 1994 earthworks slope. This slope is approximately 8 m high and contained a series of approximately metre-thick basalt flows interbedded with reddish brown and grey volcanic pyroclastic material which was weathered to a clayey silt / silty clay[6]. Overlying these volcanic sequences was an approximately 0.8 m thick mantle of loess with approximately 0.2 m of surficial topsoil.

We took structural measurements on two defect sets within the pyroclastic material, with one set measuring subvertical / 072°[7] and the other measuring 60° / 014°. Both defects showed evidence of movement, and were dilated to between 30 and 40 mm.

Landslide Hydrology

It was raining lightly during our site visit, and we did not note any springs or major seepage within the landslide mass. It may be that seepage was occurring but was concealed within the vegetated areas. However, CCC have observed three springs in the vicinity of the landslide in the immediate aftermath of the landslide event, and their locations are shown on the interpreted geomorphology map in Appendix 2.

5.3 Subsurface Investigations

Pro-Drill Limited were subcontracted to complete two machine boreholes, named MB01 and MB02, to 14 m and 22 m below ground level (bgl) respectively. Drilling began on 30 June and ended on 9 July 2025. ENGEO Engineering Geologists oversaw the borehole investigations and logged the recovered core in general accordance with the NZGS (2005) Field Description of Soil and Rock Logging Guideline. Borehole locations are shown on the Geomorphology Plan provided in Appendix 2 while the full logs are provided in Appendix 4.

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[6] Materials are logged behaviourally in accordance with the NZGS field description for Soil and Rock.

[7] Defect measurements are recorded as dip / dip direction towards True North.

The following provides a summary of results from the investigations.

Machine Borehole 1:

- MB01 was drilled in the lower part of the landslide mass. MB01 encountered a profile of 0.4 m of fill above pyroclastic soil containing gravel, sand, silt, and clay extending to 4.95 m below ground level (bgl). Below this, weathered volcanic and pyroclastic, moderately strong rock was logged. The rock appeared highly weathered down to 6.5 m bgl, transitioning to slightly weathered material.

- Drilling had poor core recovery between the surface and approximately 4.5 m depth. This was inferred to be primarily associated with fines being washed out by drilling fluid.

- The volcaniclastic rock encountered to 7.5 m was relatively competent and had a Rock Quality Designation (RQD) from 50% to 100%. From 7.5 m bgl, the rock mass was highly fractured, with a RQD of 0% from 7.5 m bgl and many logged discontinuities.

- Sheared fabric and potential crush zones were observed between 7.9 m to 10.7 m bgl and 12.6 m to 12.9 m bgl, as well as slickensided surfaces at around 8.8 m depth, suggesting possible basal shear zones along which the landslide moved.

- SPT N values in the upper 6.5 m profile ranged from 11 to 35 and below this N values of 50+ were recorded.

- Groundwater was measured at 1.4 m bgl at the end of drilling.

Machine Borehole 2:

- MB02 was drilled in the central part of the landslide mass and recorded 0.3 m of topsoil above stiff silt, consistent with loess, to 1.3 m bgl. Beneath the silt, zones of pyroclastic silts, sands, and volcanic rock were recorded, extending to 16.2 m bgl. Thinner interbedded layers of gravel, sand, and clay were encountered between 12.0 m and 13.7 m bgl.

- From 16.2 m bgl to the end depth of 22 m, layers of slightly weathered, moderately strong pyroclastic rock were present. The rock encountered was generally fresh to slightly weathered with pockets of moderately weathered to completely weathered material.

- The pyroclastic rock encountered to a depth of 14.8 metres was generally highly fractured with RQD values largely around 0%. The rock encountered below 14.8 m was comparatively less fractured and had RQD values from 47% to 100%.

- Sheared fabric and potential crush zones were observed between 5.4 m to 9.5 m bgl and 13.5 m to 15.7 m bgl, suggesting possible basal shear zones along which the landslide moved.

- SPT N values in the upper 12.5 m profile ranged from 4 to 22 and below this SPT N values of 50+ were recorded.

- Groundwater was measured at 7.3 m bgl at the end of drilling.

5.4 Laboratory Testing

Two samples, one each from MB01 and MB02 were collected for Particle Size Distribution (PSD), and Index testing (Atterberg Limits and Plasticity Index). The results of assessment are provided in Appendix 5 and summarised in Table 1. For completeness, we have also included data recorded in Ekanayake & Phillips (1994) in Table 1.

Table 1: Results of Laboratory Testing

	Grading (% of Dry Mass)				**Index Tests**		
Sample Number	**Gravel**	**Sand**	**Silt**	**Clay**	**PL(%)**	**LL(%)**	**PI**
MB01 2.95 -3.45 m	4	24	53	19	58	33	25
MB02 3.20 – 3.60m	2	25	36	37	73	34	39
Ekanayake & Phillips (1994)	NR	NR	NR	57	104	47	57

Notes: NR – Not recorded

5.5 Instrumentation and Monitoring

5.5.1 Rainfall Gauge

On 8 May 2025, a rainfall gauge was installed by NIWA up slope of the landslide, near cell phone towers located at the crest of Aylmers Hill. Records to 21 August show that no significant rainfall event has occurred since the gauge was installed, with a maximum rainfall of 38 mm falling between 8th-12th August. A total of 274 mm of cumulative rainfall has been recorded between 9th May (when the gauge was installed) and 21st August.

5.5.2 Surface Monitoring

Kurloo GPS movement sensors were installed by CCC on 8 May 2025. These sensors comprise autonomous GNSS-based devices capable of measuring displacement and settlement to ~2 mm accuracy. Six sensors have been installed as shown on Figure 4.

Figure 4: Location of Surface Monitoring Sensors

At the time of writing, Sensor 003 has reliably picked up about 14 mm of net movement in the horizontal direction (towards the northeast) and approximately 10-15 mm in the vertical direction (downwards). Around half of this movement occurred during and immediately after the earthworks for the pads for the drill rig (i.e. the two boreholes).

None of the other sensors have recorded more than about 5-10 mm of net displacement.

5.5.3 Subsurface Monitoring

Inclinometer monitoring was undertaken at borehole MBH02 to assess ground movement over time. The baseline survey was conducted on 18 July 2025, with a follow-up survey completed on 15 August 2025. The results are presented for two orthogonal directions: A0–A180 (40°) and B0–B180 (130°) in Appendix 7.

Both the A0-A18 and B0-B180 direction survey results show negligible movement (< 2 mm) over the approximately one month recording period.

5.5.4 Groundwater Monitoring

At the completion of the drilling program, two standpipe piezometers along with continuous groundwater loggers were installed, one each in MB01 and MB02. ENGEO also installed continuous groundwater loggers with the 1994 landslide piezometers.

The MB01 and MB02 piezometer construction details are summarised in Table 2.

Table 2: New Piezometer Construction Details

Piezometer	Total Depth (m bgl)	Screened Interval (m bgl)
MBH01	5.0	1.0 – 4.0 (1.0 m sump at base)
MBH02	12.3	1.0 – 12.3 (0.5 m sump at the base)

ENGEO attended site multiple times to carry out manual dips of the standing water within the piezometers and collect the groundwater data from the continuous monitors, summarised in Tables 3 and 4 below.

Table 3: Manual Groundwater Level Measurements m RL

Piezometer	11/6/2025	9/7/2025	18/07/2025	1/8/2025	15/8/2025
D4-A	231.079	229.849	229.699	229.409	228.809
D4-B	231.84	230.89	230.67	229.9	231.125
D5	231.644	231.164	231.184	231.064	231.114
MBH01	-	240.402	240.402	240.362	240.362
MBH02	-	-	245.518	245.423	245.453

Table 4: Groundwater Level Logger Data

Piezometer	Piezometer Depth m bgl	Dates Measured	GWL Range m (bgl / b TOC)	[3]GWL Range m RL
D4-A[1]	18	11/6/2025 – 15/8/2025	11.110 – 11.797	231.634 – 230.947
D4-B[1]	N/A	11/6/2025 – 15/8/2025	11.198 – 13.004	231.181 – 229.375
D5[1]	14	11/6/2025 – 15/8/2025	10.645 - 11.989	231.765 -230.421
MBH01[2]	5	8/7/2025 – 15/8/2025	3.242 – 4.599	241.490 – 240.133
MBH02[2]	12.3	18/7/2025 – 15/8/2025	7.197 – 7.604	245.596 -245.189

1. Surveyed and measured from Top of Case (TOC).
2. Surveyed and measured from ground level (bgl)
3. Measurements in m RL are based on survey points taken on site

Results of groundwater monitoring to date are included in Appendix 6.

5.6 Engineering Geological Model

5.6.1 Units

Loess / Topsoil

The slope is covered by topsoil underlain by a thin mantle of loess. The depth of these materials likely varies, with thin layers near the crest of the spur where bedrock is exposed at the surface, and slightly deeper layers in valleys and areas of the slope that dip at shallower angles.

Basalt Flows

We observed weathered basalt outcrops near the crest of the spur, above the landslide head scarp. Additionally, basalt outcrops are apparent within the road cuttings downslope of the landslide on Lighthouse Road. According to Geotech (1994), a competent basalt flow is located below Lighthouse Road, dipping into the slope.

Based on the structure and relative location of the Akaroa Volcanic Centre, we believe that the large basalt flows dip into the slope, approximately towards the south. Due to the weathered nature of the outcrops, no suitable lithological planes were found to take structural measurements and confirm the dip. This is consistent with Geotech's conclusions.

Pyroclastic Material

Pyroclastic material was found within the retrogressed 1994 landslide scarp. The surface of this pyroclastic material was weathered to a reddish-brown colour, while the unweathered material appeared light grey. The weathered material was a clayey silt with an estimated strength of very stiff. Isolated metre-scale basalt flows are present within the pyroclastic material, forming more competent beds within the rock mass. Two defect sets were also identified and may be exerting some structural control within the rock mass.

5.6.2 Model Description

The observational EGM has been developed based on our site geomorphic mapping, structural measurements and subsurface information, along with the findings from the Geotech (1994) and Ekanayake & Phillips (1997) reports, and Aecom (2025) and Jacobs (2025)[8]. The geomorphological map of the landslide area is attached in Appendix 2. Appendix 8 presents the interpreted EGM of the landslide and a cross-section orientated in the inferred direction of movement.

Geomorphic evidence suggests that the landslide has been present in the landscape for some time prior to the recent reactivation. An arcuate feature is apparent in the LiDAR hillshade DEM as shown on Figure 5, which is interpreted to represent the headscarp of the landslide. During our field reconnaissance, this feature was noted to be rounded and subdued, suggesting that the landslide was inactive for many years to decades prior to movement in May.

The basal shear surface is modelled based on the slope stability back analysis and subsurface information from the machine boreholes. It is anticipated that the EGM and analysis will be continually reassessed as further data becomes available from future surface and subsurface monitoring.

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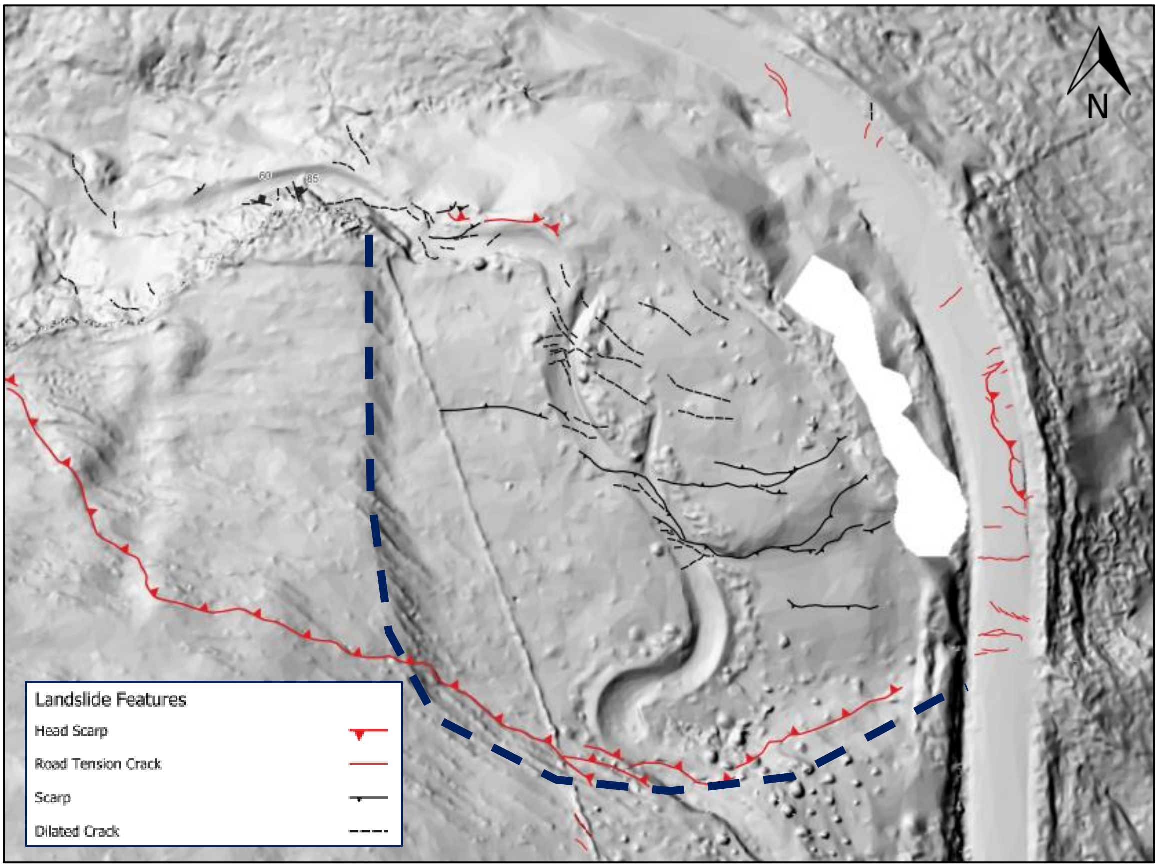
[8] Mr Charlies Watts, pers comm

Figure 5: Geomorphology Overlain on Hillshade Image



Note: Inferred headscarp of previous landslide shown by blue dashed line.

We have classified the landslide body into four zones based on compressional or extensional geomorphic evidence as follows (refer Engineering Geological Map in Appendix 2).

Zone A and **Zone B** denote areas where the land has displaced downslope and cover the areas immediately below the landslide head scarp. Zone B is located to the west of an inactive scarp that trends approximately north-south. We interpret Zone B to be a result of sympathetic movement between the previous landslide (described above) and the face of the 1994 earthworks as the main landslide body was displaced. We observed much less evidence of tension cracking and internal movement within Zone B compared to Zone A.

Zone C denotes a displaced extensional area where back scarps form slight upthrown graben features typical of extensional settings. This zone has a high concentration of tension cracks aligned subparallel to the main head scarp and to the orientation of the defects measured in outcrop (as described in Section 4.1).

Zone D denotes the compressional zone around the toe of the landslide where material has been translated horizontally rather than the relative vertical translation within Zone A and Zone B. We see evidence of this with the slackened downslope fence line and slight oversteepening of the road fill platform (Zone D1).

The landslide appears to be partially structurally controlled and partially mass controlled. The failure plane of the landslide is likely a defect or transition between a pyroclastic and a basaltic (lava flow) layer, with residual weathered clays along this horizon facilitating the movement of the slide (Aecom 17 July 2025 letter). This aligns approximately with a slickensided fracture at 8.8 m depth in MB01 and a clay seam encountered at approximately 12.1 m depth in MB02.

A solid volume of approximately 20,000 m^3 is inferred to be involved in the 2025 slide mass.

5.6.3 Hydrology

As outlined in Section 5.5.3, piezometric data has been continuously recorded over the last several weeks in MB01 and MB02 (as well as within the 1994 piezometers). Standing water levels ranging between approximately 243.36 and 241.98 m RL (approx. 3.64 to 5.03 m deep) in MB01 and 243.07 to 242.74 m RL (approx. 6.93 to 7.26 m deep) in MB02 have been recorded over this period.

Given that the landslide is developed within a variably weathered and altered pyroclastic rock mass, it is likely that secondary permeability (the permeability due to defects within the rock mass) is a significant control on groundwater. In addition, it is also likely that pre-existing crushed zones and shears within the rock mass have 'compartmentalised' the groundwater table to some degree. It is therefore difficult to predict the groundwater level in the slide mass with any degree of certainty. This has implications for potential remedial solutions that involve dewatering as discussed in Section 8.

5.6.4 Debris Flow Initiation

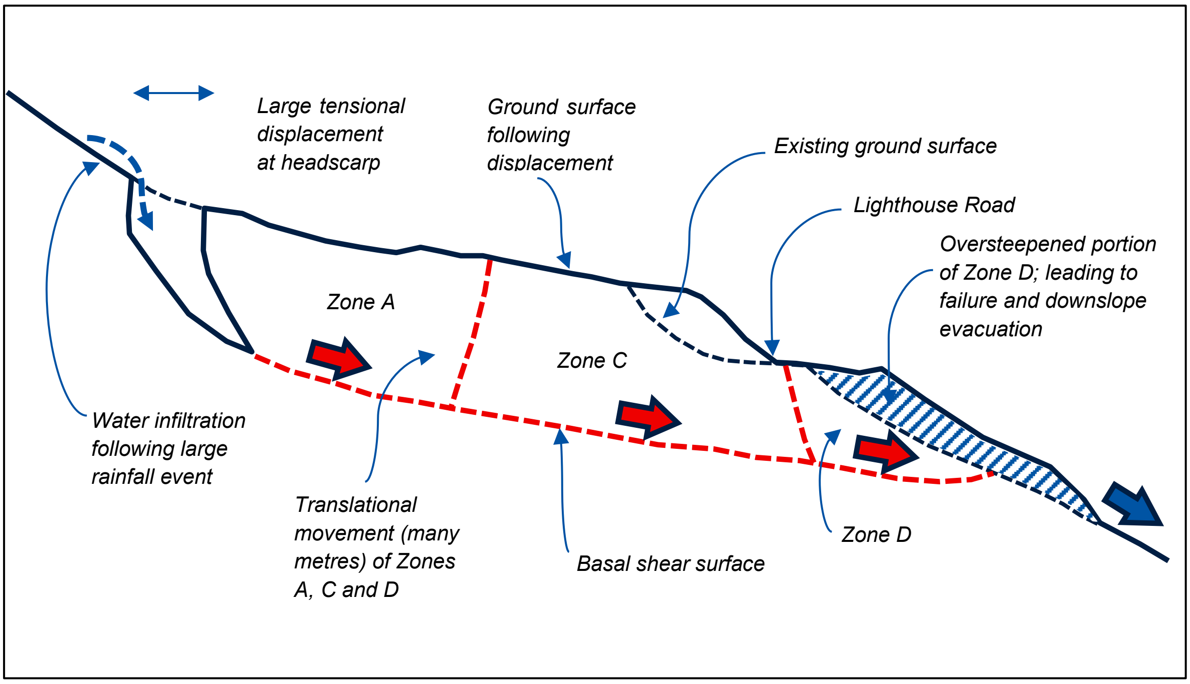
For debris flow failure to occur, we consider that several precursor events would need to happen in sequence, as shown in Figure 6 and described below.

1. A large and long-duration rainfall event (spanning days rather than hours) would be required to generate the hydrostatic pressures necessary to initiate debris flow failure within the landslide mass. While it is difficult to precisely define the recurrence interval of such an event, it is reasonable to assume that it would need to be significantly larger than the 70-year event that triggered the May 2025 failure. This assumption is based on the understanding that the May 2025 event reactivated a pre-existing landslide rather than initiating a new debris flow, and thus the basal shear surface was already within soils at their residual strengths.
2. Downslope displacement of many metres of the whole of the landslide mass.
3. As a result of this landslide displacement, the compressional zone (Zone D) must lurch forward, again by several metres, resulting in oversteepening and evacuative downslope travel.

Although the slide base may now be more susceptible due to recent movement and disturbance, the transition from a reactivated slide to a full debris flow typically requires more extreme hydrological conditions. The current morphology and material properties suggest that additional triggering mechanisms such as prolonged saturation, elevated pore pressures, and potential loss of basal resistance would need to coincide (depicted in Figure 6). Ongoing inclinometer and groundwater data will help clarify whether susceptibility has increased and inform whether this assumption remains valid.

With this inferred mechanism, we consider that it is most unlikely (or implausible) that the whole of the landslide volume could evacuate downslope as a single event. Rather we estimate that a 'Reasonable Worst Case' (RWC) event could involve the majority of Zone D.

Figure 6: Inferred Mechanism for Debris Flow Initiation



Conservatively assuming that all of the length of the toe were to fail, a solid failure volume of 3,000 m^3 is inferred, with a more likely event being on the order of 1,000 m^3. The distance that these volumes of material could move downslope is assessed in Section 6.2 following.

6 Analysis

6.1 Material Flow Potential

The material involved in the landslide is typically described (both by ENGEO and Aecom) as pyroclastics, comprising weathered ash and weak volcanic rock.

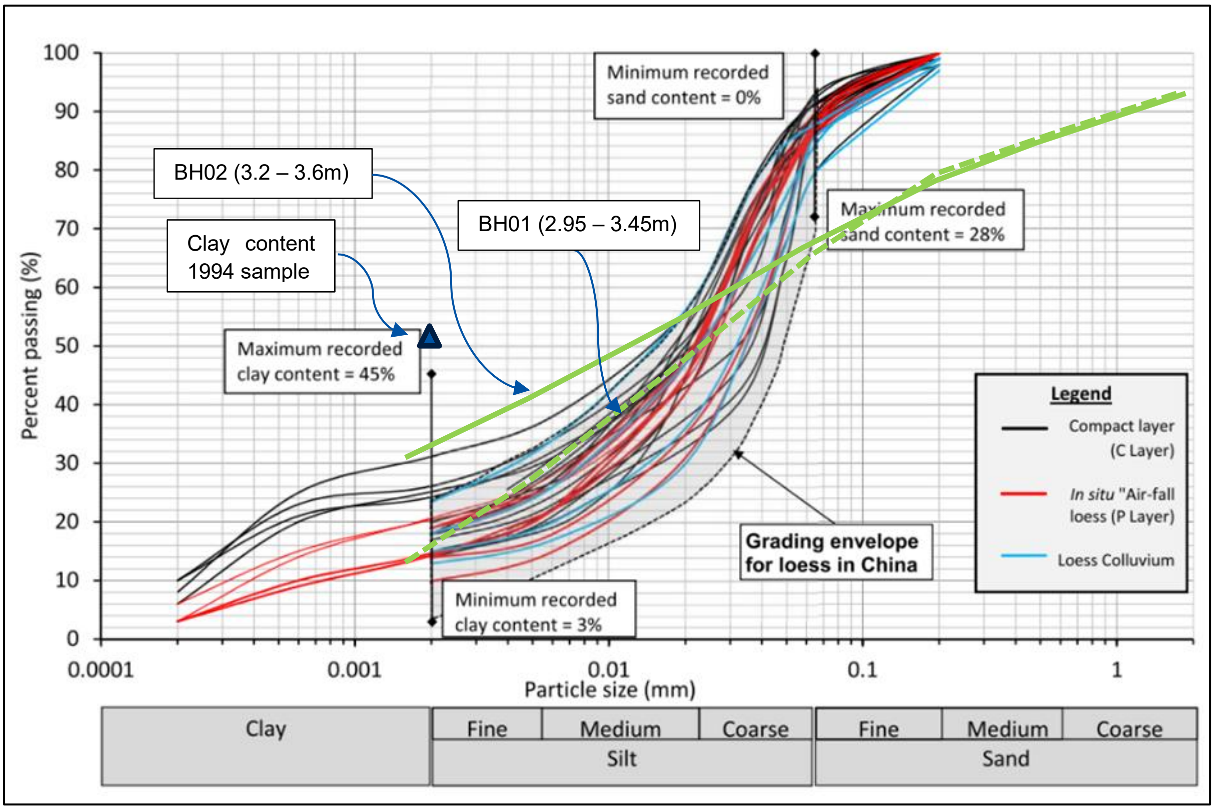
Much of the shallow soils on the Port Hills and hills descending from the Akaroa Crater Rim consist of loess (predominantly silt-sized sediment formed by the accumulation of wind-blown dust). As described by Hungr et al (2014), loess and similar materials can be subject to flow, described as a "*Very rapid to extremely rapid flow of sorted or unsorted saturated granular material on moderate slopes, involving excess pore-pressure or liquefaction of material originating from the landslide source.* "

However, this type of behavior is not as apparent in finer grained (i.e. clay-dominated) materials which are not subject to liquefaction behavior on saturation. The particle size distributions of the recovered borehole samples (refer Section 5.4) are shown on Figure 7 in comparison to a range of measured distributions for loess (Yates et al, 2018). Also included in this figure is the value reported in Ekanayake & Phillips (1997) (refer Section 5.4).

It is apparent that both samples from recent investigations, and the 1994 investigations have higher clay content compared to that typical for loess, particularly the value recorded in Ekanayake & Phillips (1997). Both recent samples are also more well graded (larger range of particle sizes) compared to the particle size envelope for loess.

In addition, the recent samples have higher liquid and plastic limits (LL and PL) and plasticity index (PI) than typical for Loess. Yates et al (2018) note values of LL between 24-30%, PL 15-20% and PI of 4-12, and, Moase (2011) suggests that the fines content of the flow must have a PI less than 5% to maintain the ‘debris flow’ classification; significantly lower than the values provided for the weathered pyroclastic material in Table 1. This suggests that the pyroclastic material is more likely to behave as a cohesive soil and is therefore not subject to the same degree of flow behavior compared to loess.

Figure 7: Particle size distribution for Canterbury Loess deposits (Yates et al, 2018) compared to pyroclastic material.



Note: Clay content in the 1994 sample is taken from Ekanayake and Philips (1997)

6.2 Runout Analysis

Potential runout distances were assessed for the likely range of release volumes described in Section 5.9. The debris flow modelling was undertaken with HEC-RAS 6.6 using Canterbury – Banks Peninsula LiDAR 1 m DEM (2023) (LINZ, 2024) with a 2 m by 2 m mesh extending from the toe of the landslide.

The debris flow volumes were released as a triangular hydrograph inflow boundary condition at the toe of the landslide. The debris flow was released over 30 seconds with a peak flow at 15 seconds. Based on field analysis, a yield stress value of 3,000 Pa was used in the HEC-RAS model relating to the cohesion value of rubbly basalt flows. A user defined viscosity of 250 Pa-s was used in the model relating to approximate the viscosity of the clay-dominated pyroclastic material. The O’Brien rheological model was used with an assumed representative particle size of 3 mm. The O’Brien quadratic equation combines and accounts for stresses due to cohesion, internal friction between sediment and fluid, turbulence, and inertial impact between particles and is the model recommended to simulate debris flows (HEC-RAS, 2025).

An assumed concentration volume of 68% relating to a mixture density of approximately 1,800 kg/m3 was also used as a model input.

The estimated extent of inundation from the model are presented in Appendix 9.

In summary:

- With a 1,000 m^3 release volume, material is modelled to extend approximately 70 m (as measured in plan view) downslope of the inferred toe of the landslide. This stops short of the building platform (identified to ENGEO by CCC) on the neighbouring property downslope (41 Lighthouse Road).
- Under a 3,000 m^3 release volume, material is modelled to flow 160 m downslope of the toe of the landslide. This is sufficiently far to inundate the building platform on 41 Lighthouse Road but does not reach properties further downslope. At the location of the building platform at #41, the flow is modelled to have height of up to 1.0 to 1.5 m. Impact velocities are modelled to be up to 3 m/s which could result in significant damage to any house built here without mitigation.

6.3 Slope Stability Analysis

We have undertaken limit equilibrium assessment of the effect on stability of:

(1) Unloading the headscarp of the recent failure by earthworks.

(2) Dewatering the landslide mass assuming the installation of horizontal drains

The assessment considered the subsurface conditions interpreted in the current Engineering Geological Model. The results of the assessment are provided in Appendix 8 and are described in the following sections.

6.3.1 Factor of Safety

In slope stability analysis, Factor of Safety (FoS) is a measure of how stable a slope is. It compares the forces that resist movement (like soil strength) to the forces that cause movement (like gravity). A higher FoS means a more stable slope.

FoS < 1.0: The slope is considered unstable, and failure is likely or already occurring.

For a typical residential slope in New Zealand the following FoS are generally accepted:

- Long-term static condition (normal groundwater depth): FoS ≥ 1.5
- Transient groundwater condition (high groundwater): FoS ≥ 1.3
- Seismic condition: FoS ≥ 1.2 or deformations demonstrated to be acceptable

6.3.2 Material Parameters

The following geotechnical parameters have been adopted in our analyses. These are based on our current understanding of the EGM (Section 6) and should be re-evaluated during subsequent stages of design and / or when further geotechnical data becomes available.

In both scenarios, the interpreted failure geometry was back-analysed assuming a low strength layer along the basal slide plane at a state of marginal stability (FoS = 1.0). No specific groundwater surface was included in head-unloading analysis, as the effect on the groundwater table would need to be judged for every analysis. Rather the analysis here implicitly assumes the same groundwater regime that existed at the time of the May 2025 movement.

Material parameters are provided in Table 5.

Table 5: Table of Geotechnical Parameters

EGM Unit	**Unit Weight (kN/m^3)**	**Effective Stress Parameters**	
		Ø' (°)	c (kPa)
Loess	19	30	3
Fill	19	30	2
Pyroclastic Material	19	32	5
Basal Shear Surface	19	14 (no gw)[1] 21 (gw)	0[2]
Basalt below slide mass	23	45	50

Notes:

[1]. The calculated friction angle varies between the analyses due to the analysis methodology (no specific groundwater surface was included in the assessment of head unloading, but was for dewatering analysis)

[2]. Assumes residual shear strength conditions exist along the basal slide plane

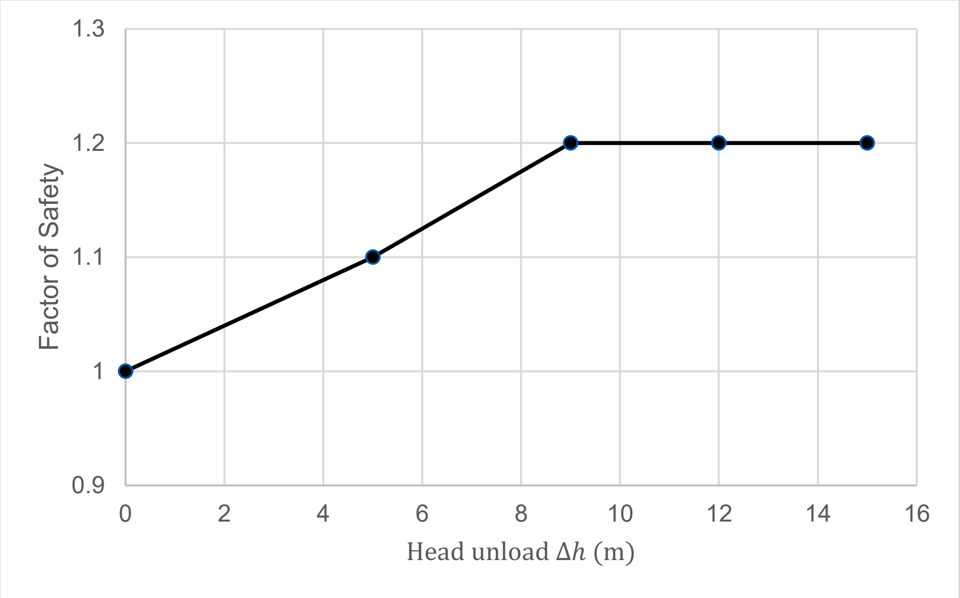
6.3.3 Analysis Results

Head Unloading

The scenarios consider the effect of a change in vertical excavation height (∆h) of 5, 9, 12 and 15 m respectively. As can be seen in Figure 8 there is some improvement to a 9 m high cut; but no significant improvement is gained by increases beyond this.

Head unloading slope stability outputs are included in Appendix 10.

Figure 8: Results of Slope Stability Analysis - Head unloading (Refer text for additional description)



Effect of Dewatering

Dewatering can reduce landslide movement by lowering pore water pressures, typically resulting in an increase in FoS. We assessed two drainage options in our slope stability analysis. Option 1 has a 20 m drain inclined at 10° discharging at road level, and Option 2 has the same drain geometry discharging at the base of the landslide on the property of 41 Lighthouse Road.

Option 1 - discharging at road level limits the potential effectiveness of dewatering. This is because the drain can only intercept the water table near the central portion of the landslide mass as the road is located above the landslide toe. As a result, much of the landslide remains saturated, and the water table remains relatively high. Slope stability modelling reflects this limitation where the maximum achievable drawdown from Option 1 increases the FoS only marginally, to 1.02.

Option 2 - which drains from the base of the landslide is a more effective at lowering the FoS as more of the landslide mass is dewatered. Modelling shows a FoS of 1.2 is achieved using the Option 2 geometry.

The results of this analysis are attached in Appendix 10. This model only analyses a re-activation case of the original inferred failure surface.

7 Hazard Assessment

Based on our assessment as described in the previous sections, the Lighthouse Road landslide is interpreted to be a partially structurally controlled and a partially mass controlled failure. There is evidence for both a rotational component close to the head of the failure and extensional / translational movement in the central part of the slide mass.

We make the following comments:

1. There is geomorphic evidence that the landslide has been present in the landscape for some time. The subdued morphology of the headscarp suggests that there had been no significant movement for years or decades prior to the recent movement.

2. We consider that landslide mass as a whole has moved in a north-eastern direction. Whilst this has not yet been confirmed based on GPS or inclinometer data (due to the lack of further movement recorded to date), it is supported by the orientation of the subdued headscarp, described above.

3. It is likely that the landslide movement pattern is one of stick-slip, with the recent period of slip having started and stopped in the hour or days following the rainfall event in late April, with no movement being recorded since this date.

4. A large storm event (on the order of 70-year recurrence interval) was required to initiate the recent failure. We expect that a significantly large event, or events would be required to mobilise the landslide to a greater distance than occurred as a result of the late April 2025 rainfall event (see Section 5.6.4).

5. The landslide is developed substantially within pyroclastic material, which has a higher clay content than the overlying loess, which is silt-dominated. We consider that the material characteristics limit the potential for debris flow run out, as the material is significantly more cohesive with higher clay content than typical loess-dominated debris flows common around Banks Peninsula.

6. The extent of the weathered pyroclastic material is not well defined. This material is known to be susceptible to failure following our investigation, and future instability within or near the 2025 landslide area remains possible. Although no morphological evidence of recent displacement was observed in the pyroclastic layer outside the 2025 failure zones during site inspections, the pyroclastic deposits may still pose a risk as a potential source of future failures.

7. The mechanism of debris flow initiation likely involves metres of displacement of the landslide mass, resulting in oversteepening of some portion of the landslide toe and downslope evacuation.

8. Debris flow modelling scenarios with this failure mechanism suggest that there is some potential for the current building platform at 41 Lighthouse Road to be inundated should a large failure volume evacuate. However, even with this large volume, properties further downslope do not appear to be affected.

The summary provided above suggests that the level of hazard posed by the recent landslide to existing buildings (with the exception of 41 Lighthouse Road) is not particularly high. ENGEO has not completed a formal quantitative risk assessment, but we consider that the level of risk to building occupants is most likely *tolerable* in the context of the AGS 2007 guidelines, which define tolerable risk as falling within the ALARP (As Low As Reasonably Practicable) region. This implies that while the risk is not negligible, it is sufficiently low that further mitigation may not be justified unless the cost of doing so is proportionate to the risk reduction achieved.

This conclusion is based on:

- A low probability of debris flow initiation, requiring a rainfall event significantly more extreme than the 70-year event that triggered the May 2025 failure (see Section 5.6.4).
- A very low probability of debris flow travel reaching existing buildings, given the current slope morphology and material properties.
- Low expected velocities and flow heights except the platform at 41 Lighthouse Road.

While the term "acceptable" could be considered, it typically implies that no further action is required, which may not be appropriate given the residual uncertainties and the lack of a formal risk quantification. Therefore, "tolerable" remains the more appropriate term unless further assessment demonstrates that the risk is sufficiently low to be deemed acceptable under AGS guidelines.

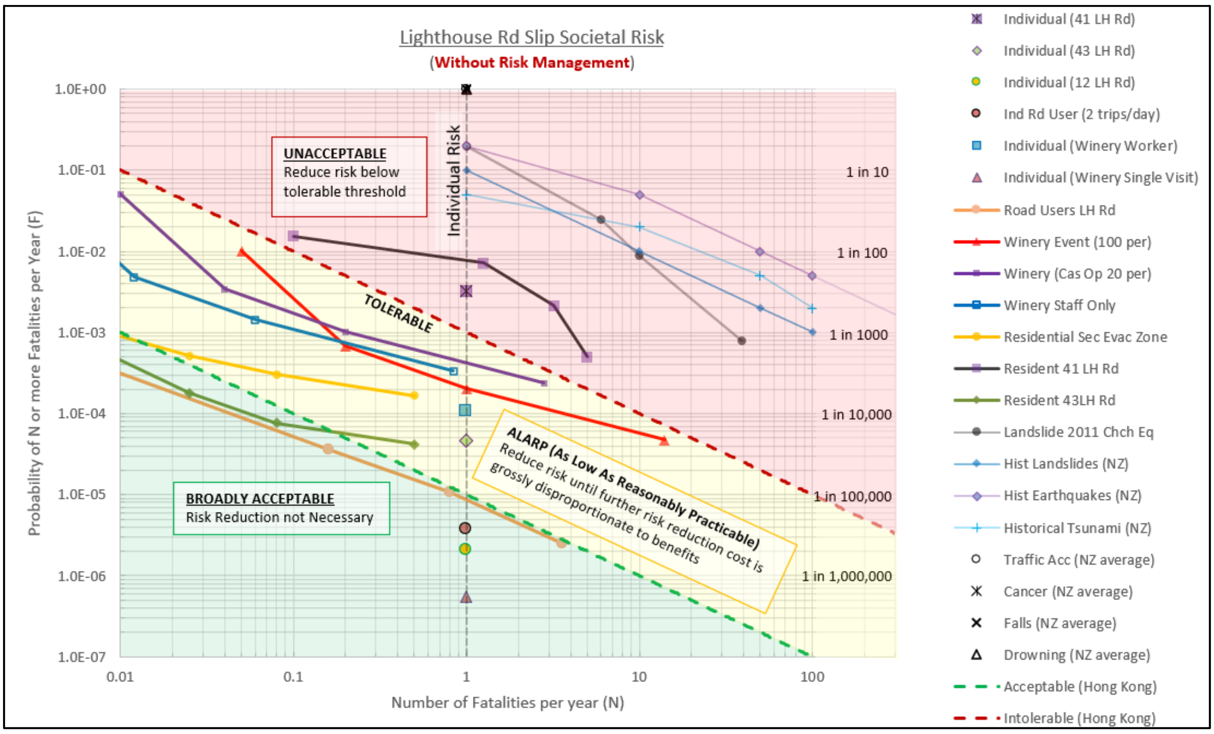
Subsequent to this assessment, CCC completed a Quantitative Risk Assessment following the AGS 2007 guidelines. The findings of this assessment broadly match the findings described above. A summary of the CCC risk assessment is as follows (note that this assessment assumes no risk management in place (i.e. no displacement monitoring, TARP, etc.), and no physical remediation works have been undertaken):

- Individual risk (AIFR) – the risk to the individual person most exposed to the hazard:
  - all calculated individual risks (AIFR) are considered tolerable or acceptable, except that an individual living at 41 Lighthouse Road (recent excavated building site downslope) would be exposed to Unacceptable level of personal risk (AIFR = 3.2×10^{-3}),
  - the next highest individual risk would be to a winery worker (assumed on-site 200 days / year), AIFR = 1.1×10^{-4},
    - this is about the same as the current criteria generally accepted for individual life safety risk due to rockfall in the Port Hills and is broadly similar to the AIFR associated with driving in New Zealand.
- Societal Risk (F-N pairs) – the risk that someone could be seriously injured or killed by a future landslide event:
  - The theoretical societal risk for residents living at the current building platform on 41 Lighthouse Rd is considered Unacceptable, indicating that it is not safe for people to live there without implementing some hazard mitigation and / or ongoing risk management.

- ○ Societal risk curves for winery operations and those living within the secondary evacuation zone are within the Tolerable (ALARP) region, indicating that the risk is acceptable in the short-term, but should be reduced as much as reasonably practicable over the longer-term.
- ○ Societal risk for general road users (Lighthouse Rd at and below the slip area) and residents at 43 Lighthouse Road are typically within the Acceptable region - no specific further action is required to mitigate these risks, but any action to minimise the risks in the previous bullet points will further reduce these risks as well.

Figure 9, below, shows an extract of the results of this risk assessment and the full assessment is included as Appendix 11.

Figure 9: Risk Assessment Results (Without Risk Management) with information known as of August 2025.



Note that the societal risk curve for residents within the secondary evacuation zone indicates higher risk there compared to that for 43 Lighthouse Rd – this is due to the greater population exposed within the secondary evacuation zone. Hence, while the individual risk within the secondary evacuation zone (e.g. at 12 Lighthouse Rd) is acceptably low, the societal risk is within the ALARP (tolerable) region.

7.1 Rockfall

We understand that some concern has been raised by the local community regarding rockfall hazard. Whilst we have not assessed this hazard in detail we make the following points:

- We anticipate that the rockfall source area is located above the crest of the 1994 earthworks.
- This source area is located approximately 300 m horizontally and 120 m above the closest building, resulting in a shadow angle of 22°.
- As outlined in Table 8.4 of Unit 1 of the Slope Stability Guidance, there is a mean probability of 0.8% of boulders reaching or passing this shadow angle. This is likely an overestimation given the large flat area that exists from the 1994 earthworks that would tend to arrest most boulders initiated from this source area.

Based on this, we consider the rockfall risk to occupants of existing buildings to be tolerably low, consistent with the AGS 2007 framework where “tolerable” risk falls within the ALARP region. We consider that the recent landslide movement has not significantly altered this risk profile. We have used “tolerable” rather than “acceptable” here to reflect the residual uncertainty and the absence of a detailed quantitative rockfall risk assessment. Should further assessment confirm that the risk is negligible, the terminology could be revisited.

8 Hazard Mitigation Options

We consider that there are two main options for long term hazard management of the landslide mass. These involve either construction of engineered solutions and / or establishment of a long-term monitoring strategy. In addition to these options, supplementary measures including infill of the head scarp which has been partially completed to date, and re-vegetation of the slope may provide some increased stability and reduced surface water ingress (which are discussed below).

Engineered options may involve:

1. Earthworks to reduce the driving force of the landslide (as was undertaken on the adjacent slope in 1994). However, the results of stability assessment suggest that head unloading results in some, but limited improvement in the level of stability of the landslide, and by itself would be unlikely to result in a suitable long-term factor of safety (i.e. close to 1.5).

2. Installing drainage is likely less disruptive to the landform, however due to geometric limitations, the groundwater table cannot be lowered sufficiently (if drained to the cut slope above Lighthouse Road) to meaningfully increase the modelled factor of safety along the basal failure surface. The second option for dewatering where drainage is installed to discharge at the base of the landslide onto a neighbouring property (41 Lighthouse Road) shows an increase in FoS along the basal slide plane to 1.2. We note that this does not meet the FoS 1.5 for normal conditions or FoS 1.3 level for transient high groundwater conditions for residential slopes. However, the modelling results indicate an improvement in stability if this option is selected. Further modelling and investigations could refine the effectiveness of this option. Additionally, as outlined in Section 5.6.3, the groundwater profile is likely to be complex and instability may be partly due to hydrostatic pressures developed in defects in the pyroclastic material (as noted by Aecom), the extent of the highly weathered material and the routes of water infiltration must be considered. Further, due to the generally low permeable soils (as discussed in Section 5.6.3), the drainage network would likely need to be dense to effectively drain the landslide mass. Therefore, a dewatering remediation option would require specific design.

Either / or a combination of these options will likely result in an improvement in the stability of the landslide mass, more detailed consideration and analysis is required. Any significant cut would result in excavation into the steep slope above the headscarp of the existing failure and its stability will need to be carefully considered as part of any detailed earthworks design (i.e. would require specific slope stability analysis and permanent batter design to limit the risk of further slope instability). In addition, the likely complexity of the groundwater table may mean that there is low confidence that a dewatering strategy would effectively and uniformly lower the groundwater level to gain the improvement in stability that the modelling suggests.

Long-term monitoring. The low likelihood of large displacement of the landslide and the mechanism of displacement suggest that there is an opportunity to have significant forewarning of critical landslide movement (i.e. movement large enough to damage Lighthouse Road or result in debris flow initiation). Combined with the low likelihood of inundation of downslope properties even if a debris flow were to occur, this is our recommended option. Conceptually, the monitoring plan would involve:

1. Awareness of future large rainfall events predicted in weather forecasts (this is already occurring as part of CCC’s current trigger action response plan).

2. Retaining the existing GPS sensors and establishing alert levels should displacement be recorded. (this is already occurring as part of CCC’s current trigger action response plan and would be refined as part of the monitoring plan).

3. Development of a suitable response plan in the event that threshold levels are exceeded (this is already occurring as part of CCC’s current trigger action response plan and would be refined as part of the monitoring plan).

4. Regular monitoring of the piezometers and inclinometer (this would be an extension of the monitoring that is already occurring as part of the response plan monitoring regime).

We envisage that the monitoring program would need to be in place for a number of years, such that the long-term patterns of movement (if there are any) are well known and understood by all Stakeholders.

We anticipate that monitoring will continue under the current regime—including ongoing Kurloo monitoring, fortnightly inclinometer surveys and groundwater data collection—for approximately two to three months. If the results from this period continue to indicate minimal or no significant movement, the monitoring frequency would be reduced to monthly intervals and potentially extended further during the drier summer months.

Slope revegetation. Slope revegetation may provide localised stabilisation benefits within the landslide mass (Masi, Segoni, & Tofani, 2021), particularly in areas that may be prone to shallow secondary failures such as the road cut. Through their root systems, vegetation can improve near-surface soil cohesion, reduce erosion, and enhance shallow drainage. However, revegetation is unlikely to significantly influence the overall stability of the wider landslide mass, where failure mechanisms are governed by deeper geological and hydrological conditions.

We consider that the close proximity of the building platform at 41 Lighthouse Road means that some form of engineered mitigation should be constructed upslope of the platform should this site be developed in future. A reinforced earth bund or similar structure would likely be appropriate in this case.

For the remediation of Lighthouse Road, ENGEO recommends the following measures:

- Conduct further pavement investigations to better understand subsurface conditions. This should include machine-excavated test pits to penetrate the existing pavement and underlying hardfill, hand-auger boreholes to assess shallow subsurface materials (1 to 2 metres deep), and Scala penetrometer testing to gather data that will inform California Bearing Ratio (CBR) recommendations.
- Undertake a specific civil engineering pavement design based on the findings of these investigations. This design should incorporate geogrid reinforcement to interlock with surrounding fill, thereby enhancing lateral resistance and improving load distribution across the road base. The pavement design will likely be conservatively specified to accommodate the landslide risk.
- Remove damaged sections of the road and underlying hardfill, excavating either to native soil or to a depth suitable for placing the bottom layer of geogrid.
- Reconstruct the road using a conservative design that includes geogrid reinforcement and engineered fill to ensure long-term stability and performance.
- Install geogrid perpendicular to the slope, extending from the road cut face to the outer edge. In areas requiring greater confinement, closer spacing and higher-strength geogrids should be considered.
- Repair and enhance roadside swales to effectively direct surface water away from the affected area. Stormwater outfalls should be specifically designed to prevent erosion or destabilisation of existing slopes.

9 Limitations

i. We have prepared this report in accordance with the brief as provided. This report has been prepared for the use of our client, Christchurch City Council, their professional advisers and the relevant Territorial Authorities in relation to the specified project brief described in this report. No liability is accepted for the use of any part of the report for any other purpose or by any other person or entity.

ii. The recommendations in this report are based on the ground conditions indicated from published sources, site assessments and subsurface investigations described in this report based on accepted normal methods of site investigations. Only a limited amount of information has been collected to meet the specific financial and technical requirements of the client's brief and this report does not purport to completely describe all the site characteristics and properties. The nature and continuity of the ground between test locations has been inferred using experience and judgement and it should be appreciated that actual conditions could vary from the assumed model.

iii. Subsurface conditions relevant to construction works should be assessed by contractors who can make their own interpretation of the factual data provided. They should perform any additional tests as necessary for their own purposes.

iv. This Limitation should be read in conjunction with the Engineering NZ / ACENZ Standard Terms of Engagement.

v. This report is not to be reproduced either wholly or in part without our prior written permission.

We trust that this information meets your current requirements. Please do not hesitate to contact the undersigned on (03) 328 9012 if you require any further information.

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10 References

Ekanayake, J. C., & Phillips, C. J. (1997). *Lighthouse Road landslide, Akaroa – Monitoring during remedial work*. IPENZ Transactions, 24(1/CE)

Geotech Consult (1994). *Lighthouse Road Slide, Akaroa – Description of the landslide and a review of remedial work required for road reinstatement*. Geotech Consult Ltd. Report prepared for Banks Peninsula District Council.

Hungr, O, Leroueil, S & Picarelli, L (2014). *The Varnes Classification of Landslide Types, an Update*. Landslides (2014) 11:167–194

Moase, E (2011). Guidance for Debris Flow and Debris Flood Mitigation Design in Canada. PhD Thesis, Simon Fraser University

Masi, E. B., Segoni, S., & Tofani, V. (2021). Root reinforcement in slope stability models: A review. *Geosciences, 11*(5), 212. https://doi.org/10.3390/geosciences11050212

Yates, K, Fenton, C. H., Bell, D. H., (2018) *A review of the geotechnical characteristics of loess and loess-derived soils from Canterbury, South Island, New Zealand*. Engineering Geology, Volume 236 (2018): 11-21.

APPENDIX 1:

Aecom Letter 17 July 2025

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17 July 2025

Jesse Dykstra
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Dear Jesse

Following the Lighthouse Road Slip site visit on 11 June with yourself and Charlie Watts, I would like to share some observations. I'll not repeat those observations already completed regarding the slip morphology, or the site description already recorded by Charlie, but will add some observations and thoughts regarding the slip extents and why the slip is occurring.

Deep seated landslides in the Banks Peninsula Volcanics are far less common than shallow failures within the overlying loess. Rockfall and cliff collapse are more common failure modes, and were widespread during the 2011 Canterbury Earthquake Sequence (CES), but deeper rotational or translational failures within the rockmass are not a typical failure mode in these units. Where these do occur, they typically do so in highly weathered rock, and in response to rainfall events. For example, of the >1300 failures recorded in the 2021 Banks Peninsula Eastern Bays storm, only three were deeper-seated, all of which occurred in highly weathered rock of the Akaroa Volcanics in Goughs Bay (Yates et al, 2025). For this reason, I anticipated that the Lighthouse Road slip was likely to have occurred in an area subject to a high amount of weathering.

Exposure of the rockmass at the Lighthouse Road Slip is present in the road cut that crosses the slip. In the mapped landslide location the rock mass is 'highly weathered' at best, with localised areas approaching 'completely weathered'. The rock at this location is a pyroclastic layer, with large basalt clasts present in a finer groundmass of devitrified volcanic ash. The size of some of the bigger clasts suggests a location within 50 - 200 metres of the vent from which they were ejected. The ash matrix has weathered to clays, and can easily be penetrated with a rock hammer, or dug into by hand (NZGS field strength: weak to extremely weak) (Figure 1). The basalt blocks present within the rockmass appear harder, but are similarly weathered, and can easily be crushed between fingers. Recent insect burrows penetrate both the pyroclastics and the relict basalt blocks, illustrating how soft they are. Evidence of sulphurous deposition is also present, suggesting hydrothermal alteration is the driver behind the weathering of the rockmass. This is also suggested by the contact between the highly weathered material and the adjacent more moderately weathered rock of the same unit. The highly weathered rockmass extends westward along the road cut and ends abruptly about 110 m northwest of the mapped landslide (Figure 2). This area of highly weathered rock outside of the mapped landslide includes part of the area "unloaded" through earthworks in the 1990's, to mitigate a previous landside at this site. To the south of the landslide the highly weathered rock is visible in the road cut for some distance up the road – the furthest extent is unknown as this was not actively mapped during the site visit.

The extents of the highly weathered rock in other directions are not apparent due to limited exposure of outcrop. Nevertheless, the existence of much less weathered rock to the immediate west of the landslide is consistent with the mechanism of hydrothermal alteration, whereby discrete areas can be affected by fluids rising from depth, resulting in weathered areas bounded by much less weathered areas within the same unit. This mechanism would imply that the highly weathered material extends more deeply than the landslide base (noting that we have not seen the results of the drilling yet).

Figure 1 Highly weathered pyroclastic layer visible in the road cut. Basalt clasts are visible in the deposit, presenting as the obvious grey areas, within the browner matrix material

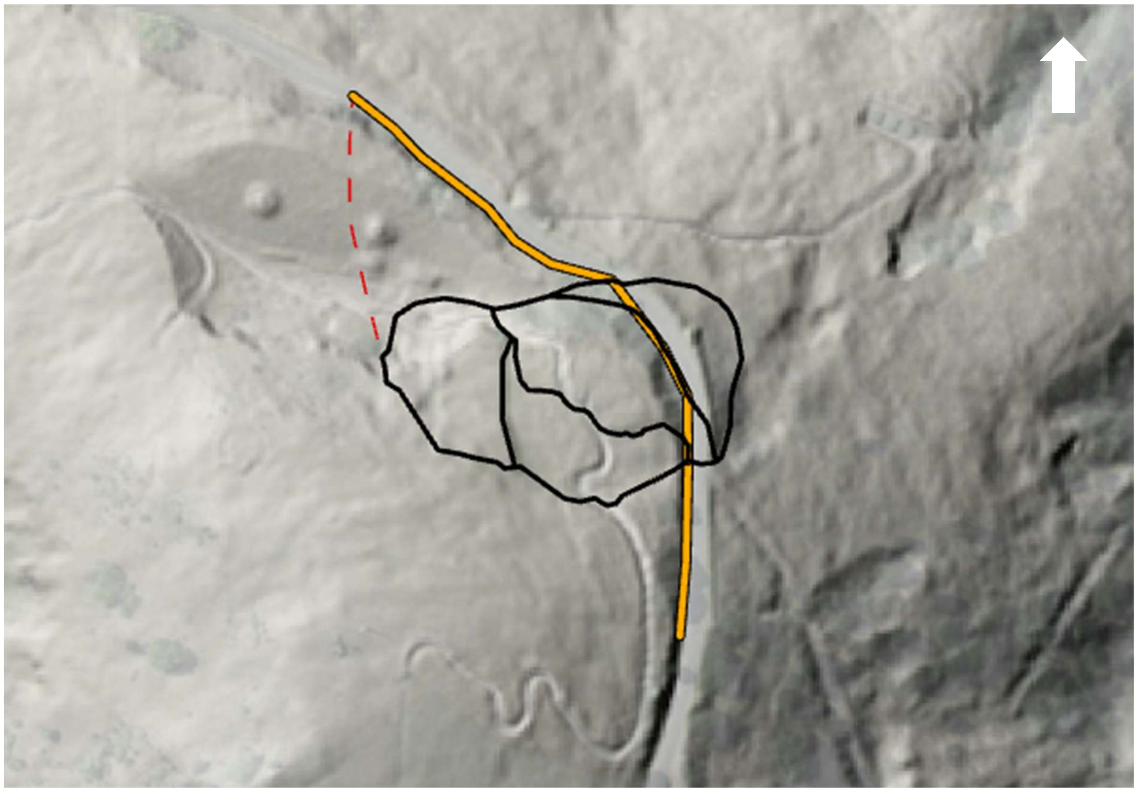


Figure 2 Mapped extent of landslide from Engeo study (black lines). The site slopes generally from SW to NE. The approximate extent of the weathered material is illustrated on the west side of the mapped landslide by the red dashed line. The observed extent of the weathered material in the road cut is indicated by the orange line. It may extend past this to the south but was not investigated in detail during the brief site inspection.

It is clear that the landslide has occurred in the highly weathered rock material. There is no sign of movement in the less weathered material to the west (though previous landslides have occurred near here – possibly also in highly weathered rock units). Mapping of the landslide extent is based on areas that moved this year, all of which are located within the observed extent of the highly weathered material. There is little observed (mapped) movement in the area previously unloaded, however the preliminary cross section from Engeo implies that that area still has several metres of material remaining above the inferred failure plane. As such it may be prudent to regard the extent of weathered material as the possible landslide extent – even if outside of the currently active lobe. Further site investigation could confirm the distribution of the highly weathered rock. The failure plane of the landslide is likely a defect or transition between a pyroclastic and a basaltic (lava flow) layer, with residual weathered clays along this horizon facilitating movement of the slide.

Current discussions around dewatering of the slope as a possible mitigation method for reducing the landslide hazard are appropriate for this hypothesis. However, should this methodology be applied, it is important that the extent of the area that the dewatering is applied to considers how far the highly weathered material extends and the routes of water infiltration into the mass. Design of remediation/stabilisation works should therefore take into account the potential for movement within not just the current slide mass but potential areas of further instability as defined by the highly weathered rock extent..

Yours faithfully

Scott Barnard

References

Yates, K., Dykstra, J., Hampton, S. and Chan, M., 2025. Landslides triggered by the December 2021 Eastern Bays storm, Banks Peninsula, New Zealand. *New Zealand Journal of Geology and Geophysics*, pp.1-15.

APPENDIX 2:

Geomorphic Map

Legend

Landslide Features

- Head Scarp
- Scarp
- Tension Crack
- Compressional Tension Crack
- Inactive Scarp, subdued
- Convex Sharp Break in Slope
- Convex Break in Slope
- Concave Sharp Break in Slope
- Concave Break in Slope
- Compressional Movement in Fence
- Extensional Movement in Fence
- Bulging In Road
- Extent of 1994 Earthworks
- Cross Section A
- 10 m Contours
- 2 m Contours
- Spring
- Discontinuity
- Photo Location

Notes:
Imagery 03/05/2025
10 m & 2 m Contours from Lidar 05/05/2025

N

0 10 20 m

Client: Christchurch City Council

Title: Lighthouse Road Landslide Geomorphic Interpretaion

Appendix No. 1
Size: A3
Sheet

Project: Lighthouse Road Landslide

Drawn: ID

Date: 12/06/2025

Checked: RJ

Proj No: 28912.000.001

Scale: 3,400 @ A3

Version: 1.0

Legend

Landslide Features

Head Scarp	▼▼
Scarp	▾
Tension Crack	—
Compressional Tension Crack	┈
Bulging In Road	—
Cross Section A	⊏⊐
10 m Contours	—
2 m Contours	—
Spring	⌖

Interpreted Landslide Areas

Zone A - Displaced, Downthrown Region	🟥
Zone B - Area of Sympathetic Displacement	🟧
Zone C - Displaced, Extensional Zone	🟨
Zone D - Compressional Zone	🟦
Zone D1 - Fill Failure	▨
Zone D2 - Fill Failure	▨
Potential Zone of Incipient Movement	┈
Inferred Direction of Movement	→

1994 Landslide Features

Extent of 1994 Earthworks	┈

Notes:
Imagery 03/05/2025
10 m & 2 m Contours from Lidar 05/05/2025

N

0 10 20 m

Client: Christchurch City Council

Title: Lighthouse Road Landslide Zone Interpretaion

Appendix No.

Project: Lighthouse Road Landslide

Drawn: ID

Size: A3 Sheet

Date: 11/06/2025

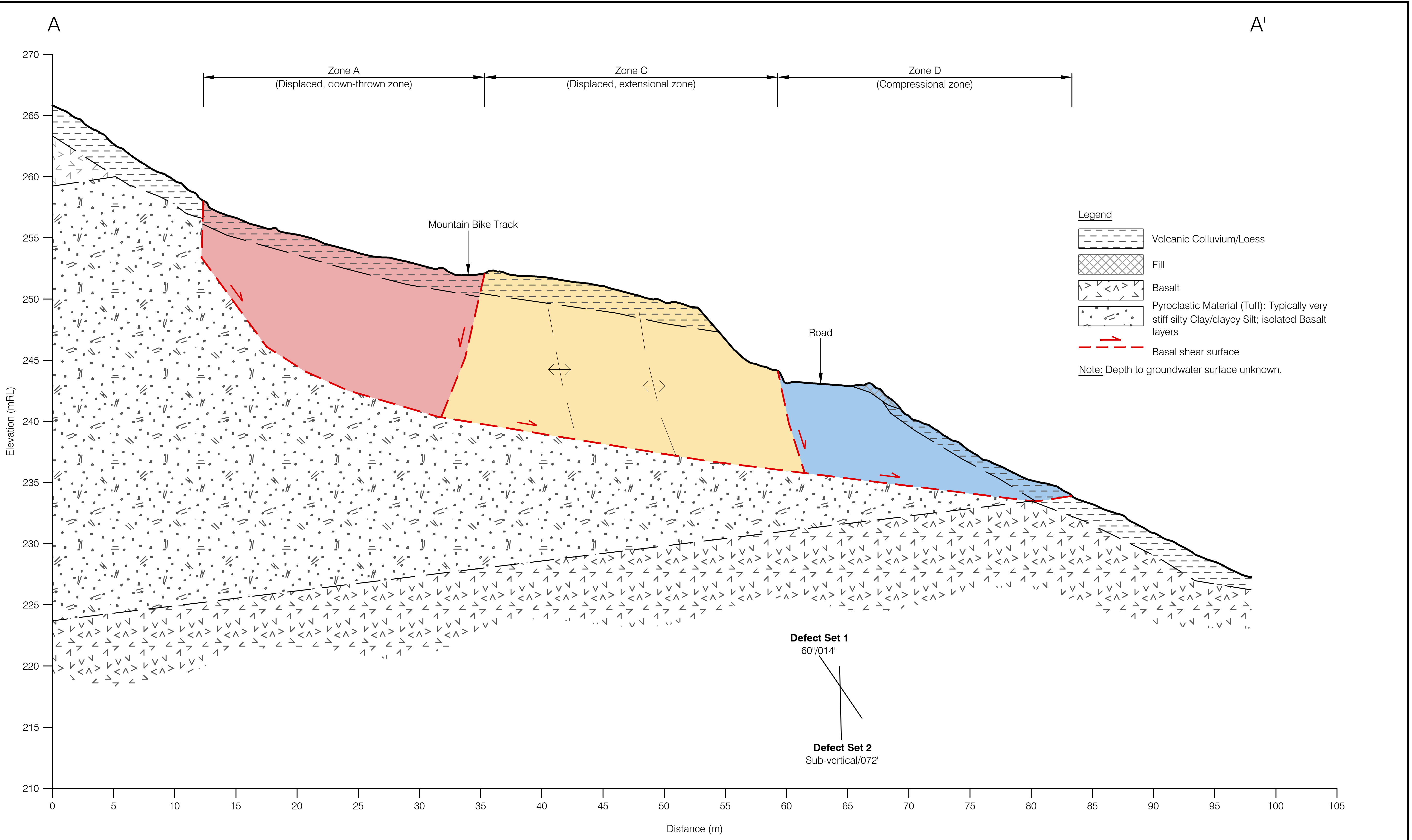
Checked: RJ

Proj No: 28912.000.001

Scale: 3,400 @ A3

Version: 1.0

DATE PLOTTED: 4 June 2025 2:00 pm BY : DOUG FINLAY



CROSS SECTION A-A'

Rev	Date	Description	Drwn	Chkd
A	04.06.25	Issued for information	DF	RJ

ENGEO

Christchurch Office
124 Montreal St
Sydenham
Christchurch, 8023
Tel: 03 328 9012
www.engeo.co.nz

Title:

GEOLOGICAL CROSS SECTION

Client: Christchurch City Council

Project: Lighthouse Road Landslide
Akaroa

Proj No: 28912.000.001

Designed: ID
Drawn: DF
Checked: RJ
Date: 04.06.25
Scale: 1:300

Figure No: 1
Size: A3
Rev: A

CAD File: Z:\Drafting\28001 to 29000\28912 - Lighthouse Road, Akaroa\DWG Files\01-Geological XS\V1-28912-GXS-300525.dwg
XREF's:

ORIGINAL FIGURE PRINTED IN COLOUR

APPENDIX 3:

Site Photographs

Photo 1. Landslide head morphology. Photo taken looking west from within the mountain bike area.

Photo 2. Slacked fence line below Lighthouse Road.

Photo 3 & 4. Evidence of continued movement in tension cracks within Lighthouse Road.

Photo 5. Basalt sub-crops above head scarp.

Photo 6. Tension cracks within Zone C.

Photo 7. Tension Cracks within Zone D2.

Photo 8. Volcanic Tuff material with open defects (Dip/Dip Direction Measured).

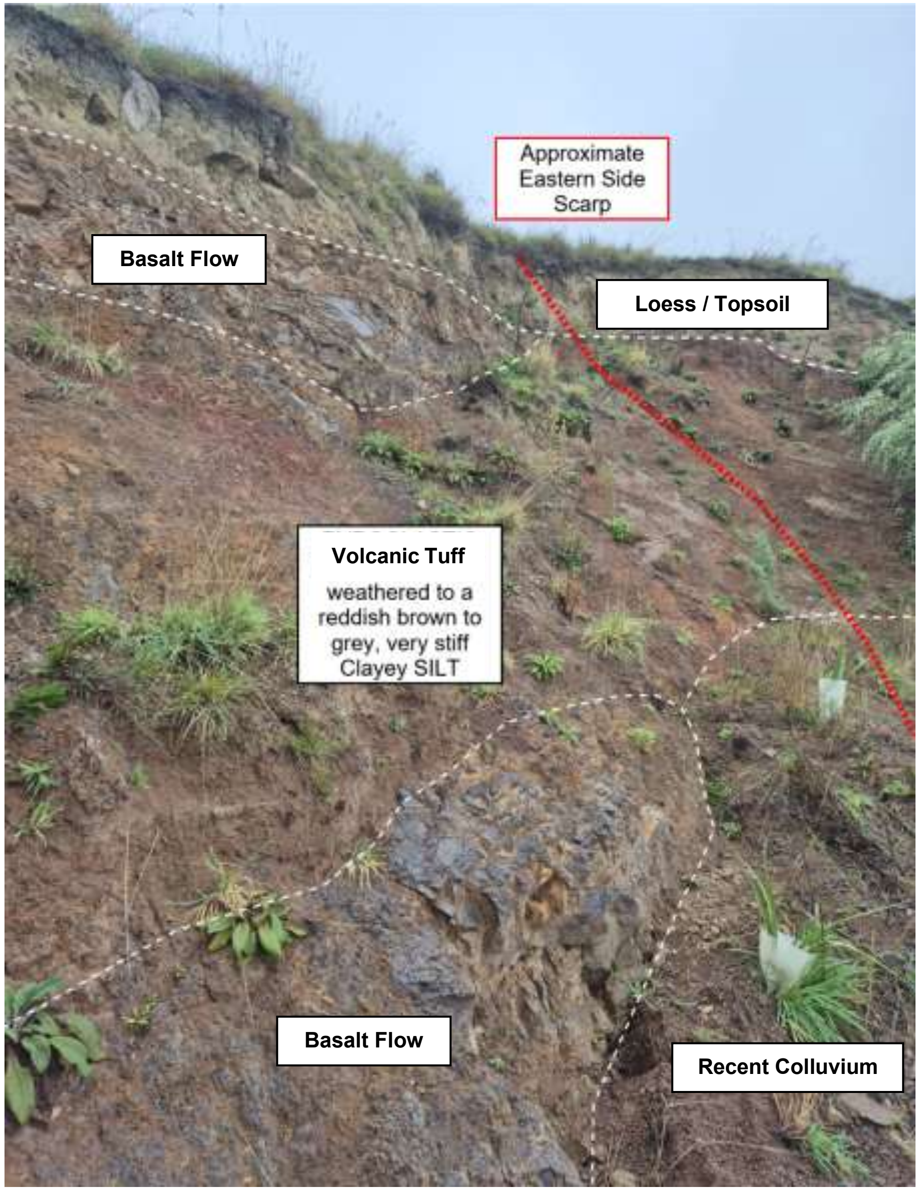


Photo 9. Cross-sectional geology of the landslide, shown as a representative face within the regressed 1994 landslide.

APPENDIX 4:

Borehole Logs

BOREHOLE LOG MB01

Lighthouse Road Landslide

Akaroa
28912.000.001

Client : CCC
Date : 30-06-25
Hole Depth : 14 m
Drilling Method : Mud Rotary
Drilling Contractor : Prodrill Ltd
Core Diameter : 63.5 mm
Energy Transfer Ratio : 76%
Logged By/Reviewed By : ID / RJ
Latitude : -43.8201811
Longitude : 172.9599373

Material	DESCRIPTION	Log Symbol	Strength	Depth (m BGL)	Elevation (mRL)	SPT N-Value / Vane Shear Strength	Sample Type	TCR (%) 25 50 75	RQD (%) 25 50 75	Defect Description	Moisture	Water Level	Piezometer Construction
FILL	[FILL PLATFORM BUILT FOR DRILLING] Sandy fine to coarse GRAVEL; grey. Well graded. 0.2 m to 0.4 m: No recovery.		L		244							▽	
VOLCANICLASTIC	[ORIGINAL GROUND LEVEL, Fines washed out] GRAVEL with trace cobble; dark grey. Poorly graded, subangular; fine grained volcanic. 0.6 m to 1.4 m: No recovery.	NR	MD	1	243								
	SILT with minor sand and minor gravel and trace clay; greyish brown. Low plasticity. Gravel is subangular, volcanic; sand is fine to coarse, subangular volcanic; gravel is fine to medium, volcanic.		VSt MD F			1/2/2/1/4/4 N=11				1.65-1.7 m: Potential shear plane?			
	Fine to coarse SAND with minor fine gravel and trace silt; red. Well graded, subangular, volcanic; gravel is fine, subangular, volcanic.		MD	2									
	Silty CLAY with trace angular concretion; whitish light brown with orange banding. High plasticity.												
	Silty fine to coarse SAND with minor fine gravel; reddish brown. Well graded, subangular, volcanic; gravel is fine, subangular, volcanic.		MS		242								
	[Fines washed out] Fine to coarse GRAVEL with minor cobble; dark grey. Well graded, subangular, fine grained volcanic.												
	Silty CLAY with minor coarse gravel; light yellowish brown to orange red. High plasticity; gravel is subangular, fine grained volcanic.		F	3		2/2/3/4/7/9 N=24							
	[Sharp contact] SILT; grey with orange vertical banding and light brown staining along subhorizontal discontinuities. Low plasticity, highly dispersive.		S		241								
	[Fines washed out] Coarse GRAVEL; grey. Poorly graded, subangular, fine grained volcanic. 3.5 m to 4.5 m: No recovery.	NR	MS	4									

Borehole met target depth
Dip test showed standing water at 0.3 m bgl (30 June 2025).
Angles are measured from the horizontal

Locations from hand help GPS
Vertical Datum = NZVD2016, long / lat in WGS84

ENGEO

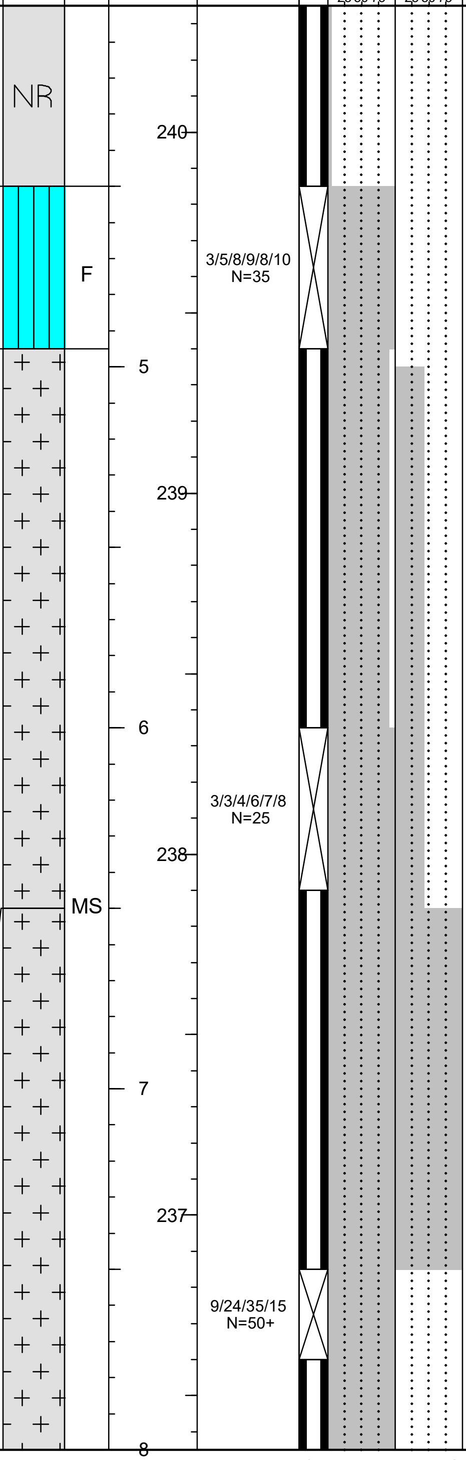
BOREHOLE LOG MB01

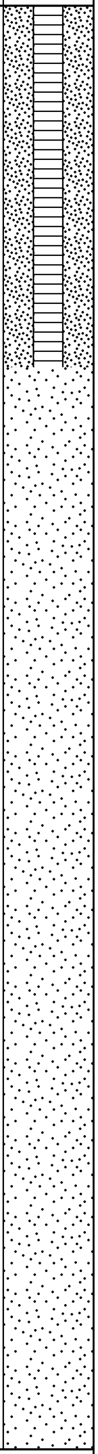
Lighthouse Road Landslide

Akaroa
28912.000.001

Client : CCC
Date : 30-06-25
Hole Depth : 14 m
Drilling Method : Mud Rotary
Drilling Contractor : Prodrill Ltd
Core Diameter : 63.5 mm
Energy Transfer Ratio : 76%
Logged By/Reviewed By : ID / RJ
Latitude : -43.8201811
Longitude : 172.9599373

Material	DESCRIPTION	Log Symbol	Strength	SPT N-Value / Vane Shear Strength	Defect Description
VOLCANICLASTIC	3.5 m to 4.5 m: No recovery.	NR			
	SILT with trace fine sand; dark grey with minor white yellow and orange mottles (completely weathered minerals). Low plasticity, highly dispersive. 4.75 m: Completely weathered mineral content increases to some.		F	3/5/8/9/8/10 N=35	
	Highly weathered, porphyritic, welded, dark grey with some orange red and greyish white mottles (weathered minerals) fine grained VOLCANICS; moderately strong. 5.75 m to 5.80 m: Orange red (Iron Stained). 5.85 m to 6.0 m: Orange red (Iron Stained) 6.5 m: 50 mm alteration zone, dark purplish grey zoning through light grey.		MS	3/3/4/6/7/8 N=25	5.25 m: Weathered fracture surface with iron staining. Dip 55° and 72°, rough undulating.
	Slightly weathered, porphyritic, greyish black with orange red and greyish white mottles VOLCANICS; moderately strong. Minerals weathered to iron oxide. 7.15 m: Becoming grey. 7.5 m: Becoming light grey.			9/24/35/15 N=50+	7.1 m: Weathered fracture surface with black staining. 20° rough undulating 7.48 m: Weathered fracture surface with black staining. 40° rough undulating. 7.8 m: Weathered fracture surface with black staining, 20°. Rough undulating. 7.85 m: Weathered





Borehole met target depth
Dip test showed standing water at 0.3 m bgl (30 June 2025).
Angles are measured from the horizontal

Locations from hand help GPS
Vertical Datum = NZVD2016, long / lat in WGS84

ENGEO

BOREHOLE LOG MB01

Lighthouse Road Landslide

Akaroa
28912.000.001

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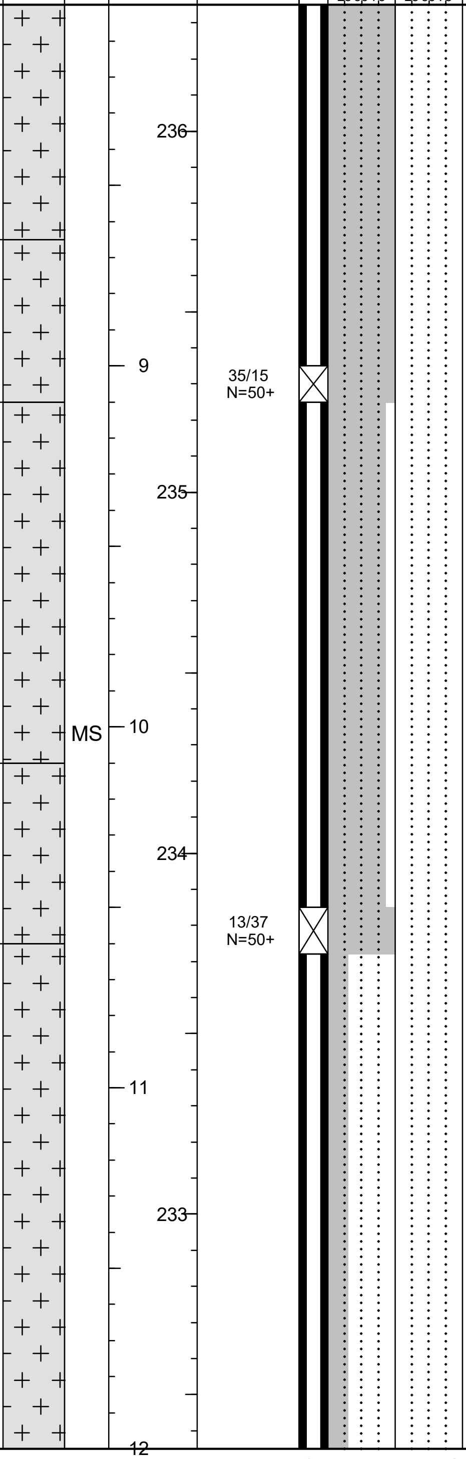
Drilling Method : Mud Rotary
Drilling Contractor : Prodrill Ltd

Core Diameter : 63.5 mm
Energy Transfer Ratio : 76%
Logged By/Reviewed By : ID / RJ
Latitude : -43.8201811
Longitude : 172.9599373

Material	DESCRIPTION	Strength	Depth (m BGL)	Elevation (mRL)	SPT N-Value / Vane Shear Strength
VOLCANICLASTIC	Slightly weathered, porphyritic, greyish black with orange red and greyish white mottles VOLCANICS; moderately strong. Minerals weathered to iron oxide. 8.4 m to 8.5 m: Light yellow and red horizontal staining with trace vesicles.	MS		236	
	Slightly weathered, massive, red and black banded, fine grained VOLCANICLASTIC; moderately strong.		9		35/15 N=50+
	Slightly weathered, massive, dark grey with light yellow and orange banding and red zoning, fine grained VOLCANICLASTIC; moderately strong. Becoming grey with orange and yellow mottles.		10	235	
	Slightly weathered, grey with purplish grey and black fine grained clasts <40 mm and iron stained veining, fine grained VOLCANICLASTIC; moderately strong.			234	13/37 N=50+
	Slightly weathered, massive, dark grey with light yellow and orange banding and red zoning, fine grained VOLCANICLASTIC; moderately strong. 10.65 m: Slightly weathered fracture with black and iron staining, rough undulating. 10.7 m to 11.2 m: No recovery. 11.45 m to 12.5 m: Core stuck in barrel. Poor recovery.		11 12	233	



Defect Description

fracture surface with black and iron staining. Sub parallel, rough undulating.
7.9-8.3 m: Highly fractured with trace shear fabric and iron oxidation. Red, yellow, light yellow and black. Crush Zone?
8.3-8.4 m: Weathered fracture surfaces with black orange light yellow staining / precipitate.
8.5-8.65 m: Horizontal mechanical fractures.
8.8 m: Slickensided fracture, red and grey with light yellow mottles. Dip 30°.
8.9-9 m: Mechanical fractures along rock discontinuities.
9-9.1 m: Shear fabric? Extremely closely spaced stepped smooth sub horizontal discontinuities.
9.2 m: Subhorizontal slightly weathered fracture with iron staining.
9.3 m: Subhorizontal slightly weathered fracture, rough stepped.
9.45 m: Slightly weathered fracture, rough planar with minor iron staining. Dip 40°.
9.5 m: Mechanical fracture.
9.6 m: Slightly weathered fracture, rough planar with iron staining. Dip 20°.
9.75 m: Slightly weathered fracture, rough undulating with iron staining. Dip 20°.
9.8 m: Slightly to unweathered fracture, rough planar with trace iron staining. Dip 40°.
10-10.1 m: Crush zone?
10.2 m: Mechanical fracture along vein fabric.
10.3 m: Slightly weathered fracture with black and iron staining, rough planar. Dip 80°.
10.5 m: Slightly weathered fracture with black and iron staining, rough planar, subhorizontal.
10.7 m: Crush zone?
11.25 m: Slightly weathered fracture with black and iron staining planar stepped, dip 30°
11.3 m: Slightly weathered fracture with black and iron staining, planar rough, dip 10°
11.2-11.45 m: Slightly weathered fracture planar rough, vertical with iron infill.
11.35-11.45 m: Slightly weathered fracture with iron and black staining,

Moisture | Water Level | Piezometer Construction

Borehole met target depth
Dip test showed standing water at 0.3 m bgl (30 June 2025).
Angles are measured from the horizontal

Locations from hand help GPS
Vertical Datum = NZVD2016, long / lat in WGS84

ENGEO

BOREHOLE LOG MB01

Lighthouse Road Landslide

Akaroa
28912.000.001

Client : CCC
Date : 30-06-25
Hole Depth : 14 m
Drilling Method : Mud Rotary
Drilling Contractor : Prodrill Ltd

Core Diameter : 63.5 mm
Energy Transfer Ratio : 76%
Logged By/Reviewed By : ID / RJ
Latitude : -43.8201811
Longitude : 172.9599373

Material	DESCRIPTION	Log Symbol	Strength	Depth (m BGL)	Elevation (mRL)	SPT N-Value / Vane Shear Strength	Sample Type	TCR (%)	RQD (%)	Defect Description	Moisture	Water Level	Piezometer Construction
VOLCANICLASTIC	Slightly weathered, massive, dark grey with light yellow and orange banding and red zoning, fine grained VOLCANICLASTIC; moderately strong.									planar rough, Dip 50°			
					232								
						24/26 N=50+							
										12.6-12.9 m: Mechanical crush zone from SPT.			
	12.9 m: Becoming red.												
			MS	13						13-13.2 m: Closed fractures with iron and black staining. Mechanically fractured.			
	13.2 m: Becoming dark grey.												
					231								
						20/30 N=50+				13.6-13.8 m: Open fracture with 2 mm iron infill. Subvertical, branching. Crushed between 13.7 m and 13.75 m			
				14									

End of Hole Depth: 14 m
Termination: Target depth

Borehole met target depth
Dip test showed standing water at 0.3 m bgl (30 June 2025).
Angles are measured from the horizontal

Locations from hand help GPS
Vertical Datum = NZVD2016, long / lat in WGS84

BOREHOLE LOG MB02

Lighthouse Road Landslide

Akaroa
28912.000.001

Client : CCC
Date : 03-07-25
Hole Depth : 22 m
Drilling Method : Mud Rotary
Drilling Contractor : Prodrill Ltd
Core Diameter : 63.5 mm
Energy Transfer Ratio : 76%
Logged By/Reviewed By : ID / RJ
Latitude : -43.820361
Longitude : 172.9596956

Material	DESCRIPTION	Log Symbol	Strength	Depth (m BGL)	Elevation (mRL)	SPT N-Value / Vane Shear Strength	Sample Type	TCR (%)	RQD (%)	Defect Description	Moisture	Water Level	Piezometer Construction
TS	[TOPSOIL] SILT with trace sand; dark brown. Low plasticity.		St										
LOESS	SILT with trace sand; light yellow brown. Low plasticity.		St	1	251								
VOLCANICLASTIC	1.3 m to 1.6 m: No recovery.	NR											
	Unweathered, massive, dark grey BASALT; very strong. 1.8 m to 1.85 m: Highly fractured with Silt infill.		VS							1.7 m: Mechanical fracture.			
	Slightly weathered, massive, dark grey, fine grained VOLCANICS; moderately strong.		MS	2	250					1.95 m: Slightly weathered fracture with iron staining dip 30°			
	SILT with trace sand; brown. Low plasticity.		VSt										
	2.1 m to 2.7 m: No recovery.	NR											
	SILT with minor sand; brown. Low plasticity. Sand is black and light brown, fine, subangular, volcanic. 2.8 m to 3.0 m: Becoming orange with black mottles. 3.2m: Becoming dark brown with black and orange mottles, with trace weathered gravel and trace slightly weathered fine grained volcanic cobbles, subrounded.		S	3 4	249 248	2/0/1/1/1/1 N=4 1/1/1/1/2/2/ N=6		25 50 75	25 50 75				

Borehole met target depth
Dip test showed standing water at 7.3 m bgl (3 July 2025).
Angles are measured from the horizontal

Locations from hand help GPS
Vertical Datum = NZVD2016, long / lat in WGS84

ENGEO

BOREHOLE LOG MB02

Lighthouse Road Landslide

Akaroa
28912.000.001

Client	: CCC	**Core Diameter**	: 63.5 mm
Date	: 03-07-25	**Energy Transfer Ratio**	: 76%
Hole Depth	: 22 m	**Logged By/Reviewed By**	: ID / RJ
Drilling Method	: Mud Rotary	**Latitude**	: -43.820361
Drilling Contractor	: Prodrill Ltd	**Longitude**	: 172.9596956

Material	DESCRIPTION	Strength	SPT N-Value / Vane Shear Strength	Defect Description
VOLCANICLASTIC	SILT with minor sand; brown. Low plasticity. Sand is black and light brown, fine, subangular, volcanic.	S	1/1/1/1/2/2/ N=6	
	Unweathered, fractured, dark grey, fine grained VOLCANICS; very strong. Mechanically rounded to cobbles. 5.2 m to 5.4 m: Mechanically fractured by SPT. 5.5 m: Becoming completely weathered with relic rock fabric, iron stained and black mottled fractures with alteration zonation, highly fractured.	VS		5.4-5.45 m: Shear zone. Highly weathered sheared fabric with orange clay infill. 6.05 m: Completely weathered fracture with silty clay infill. Dip 30°.
	Slightly weathered, light grey with black veins and orange mottles, fine grained VOLCANICLASTIC; very weak.	VW		
	Slightly weathered, light grey with orange silty clay infill, sheared VOLCANICLASTIC; extremely weak.	EW		6.1-6.4 m: Shear Zone?
	Slightly weathered, light grey with open fractures infilled black and orange, fine grained VOLCANICLASTIC; weak along fractures.	W		6.7-6.8 m: Shear zone? Shear fabric, extremely closely spaced sub horizontal.
	Sandy SILT with trace gravel and trace clay; dark purplish grey mottled with orange clay. Low plasticity; sand is fine to coarse, subangular, volcanic; gravel is fine to coarse, subangular, volcanic. 7.2 m: Becoming mottled with black and red, gravel becoming minor.	L	4/3/2/2/1/2 N=7	7.4 m: Fracture with orange clay infill, slickensided dip approximately 20° 7.5-7.55 m: Weathered fracture with orange clay infill dip approximately 20° 7.8 m: Weathered fracture with iron staining, dip approximately 20°

Depth (m BGL)	Elevation (mRL)
	247
5	
	246
6	
	245
7	
	244
8	

Borehole met target depth
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Angles are measured from the horizontal

Locations from hand help GPS
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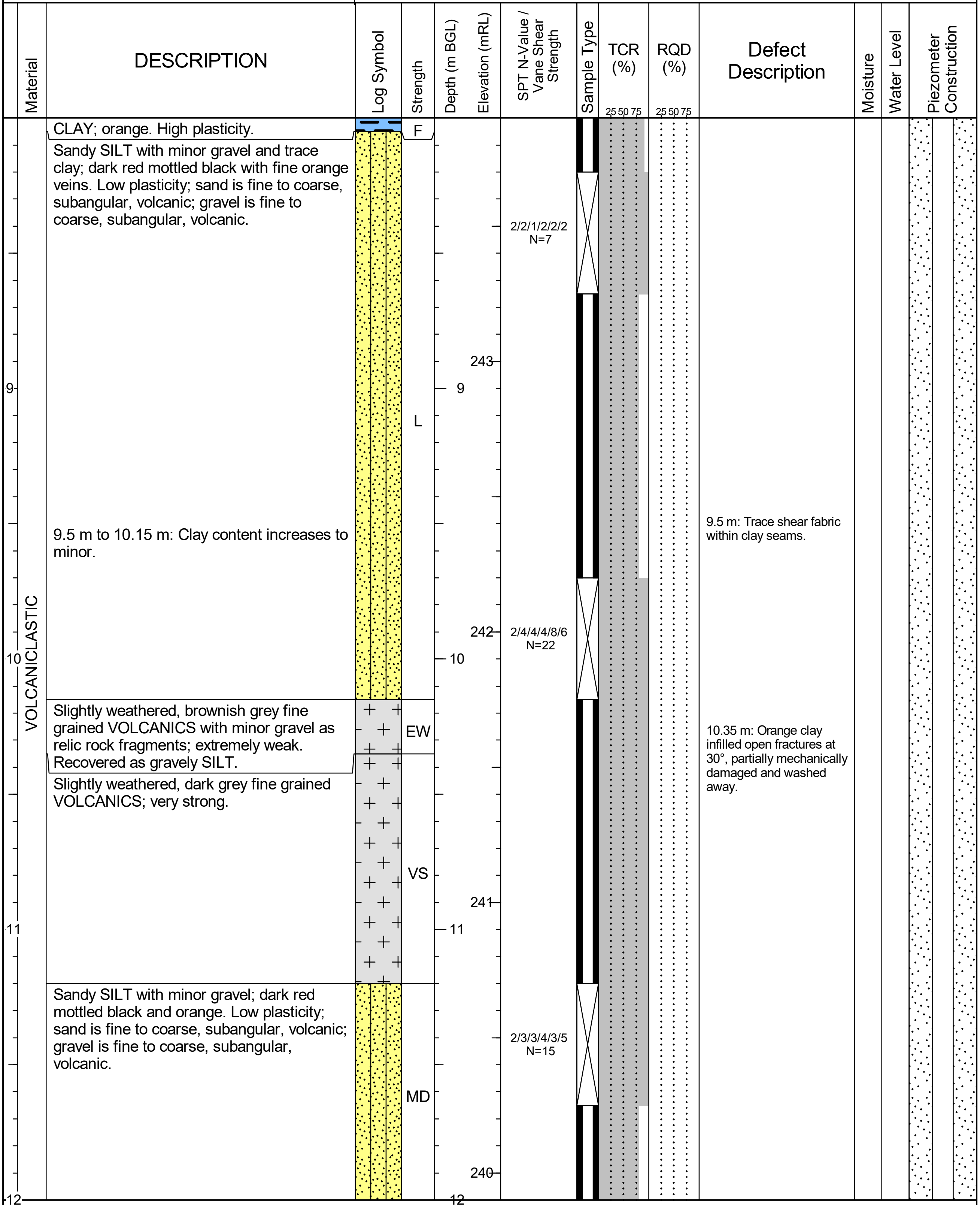
BOREHOLE LOG MB02

Lighthouse Road Landslide

Akaroa
28912.000.001

Client	CCC	**Core Diameter**	63.5 mm
Date	03-07-25	**Energy Transfer Ratio**	76%
Hole Depth	22 m	**Logged By/Reviewed By**	ID / RJ
Drilling Method	Mud Rotary	**Latitude**	-43.820361
Drilling Contractor	Prodrill Ltd	**Longitude**	172.9596956



CLAY; orange. High plasticity.

Sandy SILT with minor gravel and trace clay; dark red mottled black with fine orange veins. Low plasticity; sand is fine to coarse, subangular, volcanic; gravel is fine to coarse, subangular, volcanic.

9.5 m to 10.15 m: Clay content increases to minor.

Slightly weathered, brownish grey fine grained VOLCANICS with minor gravel as relic rock fragments; extremely weak. Recovered as gravelly SILT.

Slightly weathered, dark grey fine grained VOLCANICS; very strong.

Sandy SILT with minor gravel; dark red mottled black and orange. Low plasticity; sand is fine to coarse, subangular, volcanic; gravel is fine to coarse, subangular, volcanic.

SPT N-Value:

2/2/1/2/2/2
N=7

2/4/4/4/8/6
N=22

2/3/3/4/3/5
N=15

Defect Description:

9.5 m: Trace shear fabric within clay seams.

10.35 m: Orange clay infilled open fractures at 30°, partially mechanically damaged and washed away.

Borehole met target depth
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Angles are measured from the horizontal

Locations from hand help GPS
Vertical Datum = NZVD2016, long / lat in WGS84

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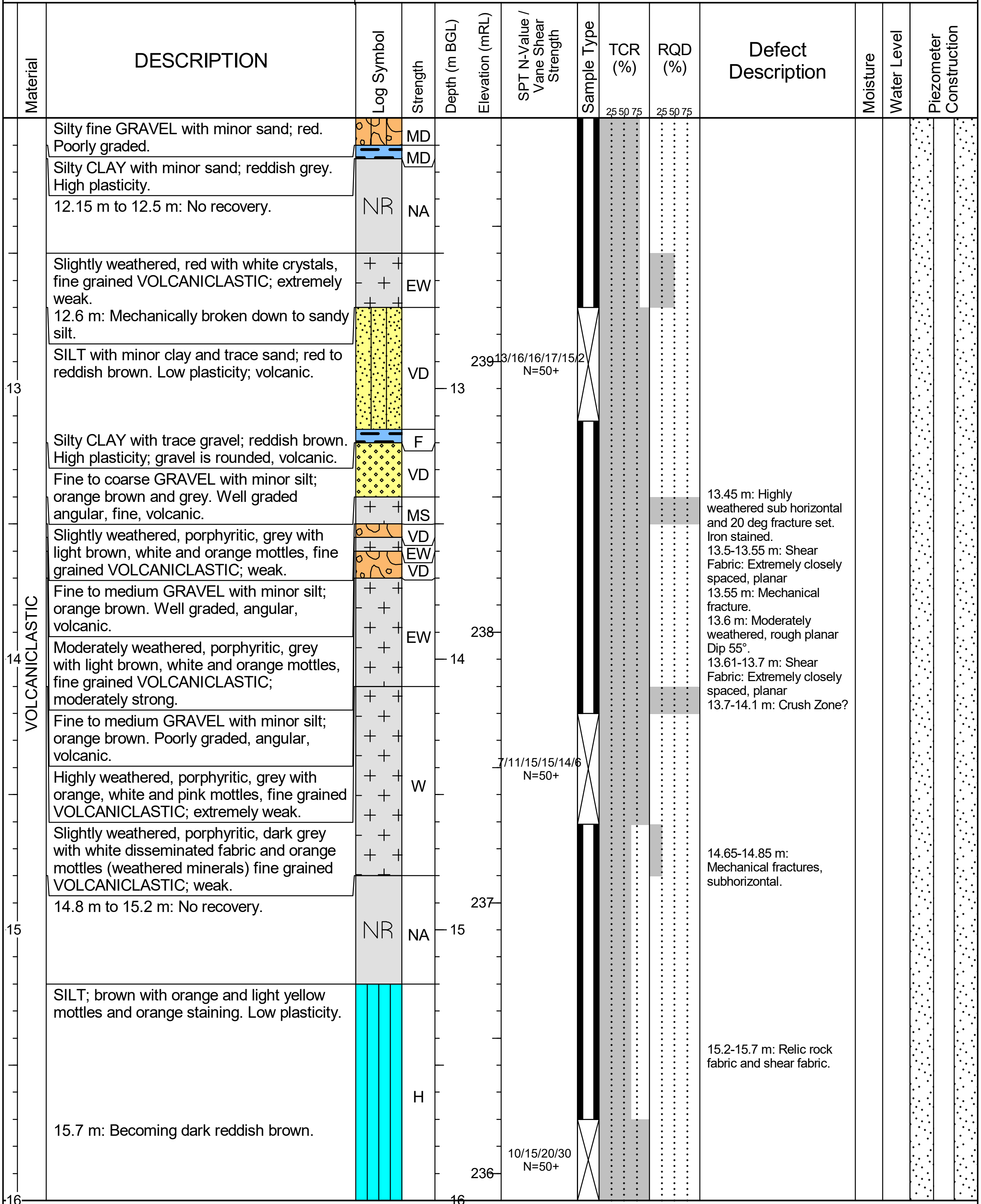

DESCRIPTION

- Silty fine GRAVEL with minor sand; red. Poorly graded.
- Silty CLAY with minor sand; reddish grey. High plasticity.
  12.15 m to 12.5 m: No recovery.
- Slightly weathered, red with white crystals, fine grained VOLCANICLASTIC; extremely weak.
  12.6 m: Mechanically broken down to sandy silt.
- SILT with minor clay and trace sand; red to reddish brown. Low plasticity; volcanic.
- Silty CLAY with trace gravel; reddish brown. High plasticity; gravel is rounded, volcanic.
- Fine to coarse GRAVEL with minor silt; orange brown and grey. Well graded angular, fine, volcanic.
- Slightly weathered, porphyritic, grey with light brown, white and orange mottles, fine grained VOLCANICLASTIC; weak.
- Fine to medium GRAVEL with minor silt; orange brown. Well graded, angular, volcanic.
- Moderately weathered, porphyritic, grey with light brown, white and orange mottles, fine grained VOLCANICLASTIC; moderately strong.
- Fine to medium GRAVEL with minor silt; orange brown. Poorly graded, angular, volcanic.
- Highly weathered, porphyritic, grey with orange, white and pink mottles, fine grained VOLCANICLASTIC; extremely weak.
- Slightly weathered, porphyritic, dark grey with white disseminated fabric and orange mottles (weathered minerals) fine grained VOLCANICLASTIC; weak.
  14.8 m to 15.2 m: No recovery.
- SILT; brown with orange and light yellow mottles and orange staining. Low plasticity.
  15.7 m: Becoming dark reddish brown.

Strength (top to bottom): MD, MD, NA, EW, VD, F, VD, MS, VD, EW, VD, EW, W, NA, H

SPT N-Value

- 13/16/16/17/15/2 N=50+
- 7/11/15/15/14/6 N=50+
- 10/15/20/30 N=50+

Defect Description

13.45 m: Highly weathered sub horizontal and 20 deg fracture set. Iron stained.
13.5-13.55 m: Shear Fabric: Extremely closely spaced, planar
13.55 m: Mechanical fracture.
13.6 m: Moderately weathered, rough planar Dip 55°.
13.61-13.7 m: Shear Fabric: Extremely closely spaced, planar
13.7-14.1 m: Crush Zone?

14.65-14.85 m: Mechanical fractures, subhorizontal.

15.2-15.7 m: Relic rock fabric and shear fabric.

Borehole met target depth
Dip test showed standing water at 7.3 m bgl (3 July 2025).
Angles are measured from the horizontal

Locations from hand help GPS
Vertical Datum = NZVD2016, long / lat in WGS84

BOREHOLE LOG MB02

Lighthouse Road Landslide

Akaroa
28912.000.001

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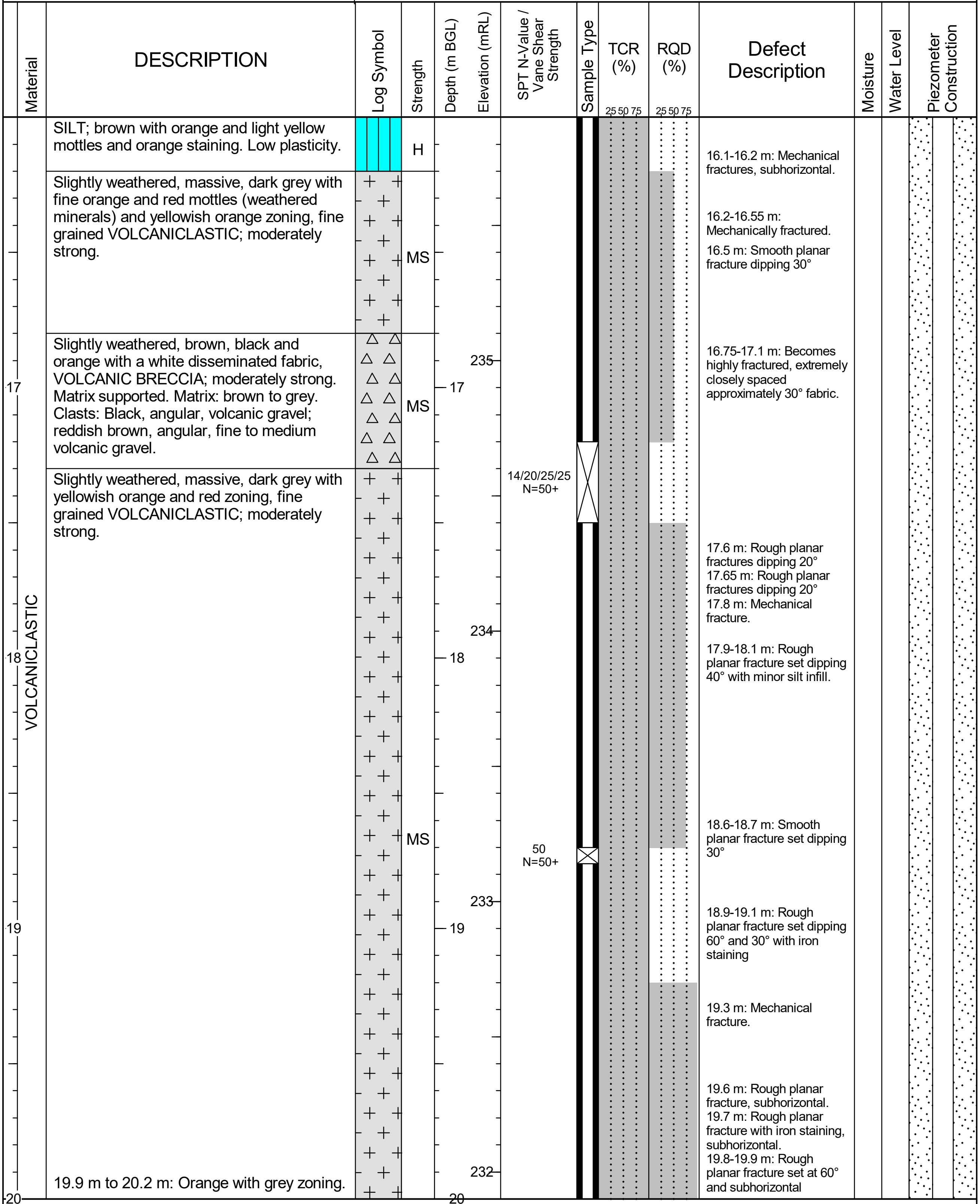


SILT; brown with orange and light yellow mottles and orange staining. Low plasticity.

Slightly weathered, massive, dark grey with fine orange and red mottles (weathered minerals) and yellowish orange zoning, fine grained VOLCANICLASTIC; moderately strong.

Slightly weathered, brown, black and orange with a white disseminated fabric, VOLCANIC BRECCIA; moderately strong. Matrix supported. Matrix: brown to grey. Clasts: Black, angular, volcanic gravel; reddish brown, angular, fine to medium volcanic gravel.

Slightly weathered, massive, dark grey with yellowish orange and red zoning, fine grained VOLCANICLASTIC; moderately strong.

19.9 m to 20.2 m: Orange with grey zoning.

16.1-16.2 m: Mechanical fractures, subhorizontal.

16.2-16.55 m: Mechanically fractured.

16.5 m: Smooth planar fracture dipping 30°

16.75-17.1 m: Becomes highly fractured, extremely closely spaced approximately 30° fabric.

17.6 m: Rough planar fractures dipping 20°
17.65 m: Rough planar fractures dipping 20°
17.8 m: Mechanical fracture.

17.9-18.1 m: Rough planar fracture set dipping 40° with minor silt infill.

18.6-18.7 m: Smooth planar fracture set dipping 30°

18.9-19.1 m: Rough planar fracture set dipping 60° and 30° with iron staining

19.3 m: Mechanical fracture.

19.6 m: Rough planar fracture, subhorizontal.
19.7 m: Rough planar fracture with iron staining, subhorizontal.
19.8-19.9 m: Rough planar fracture set at 60° and subhorizontal

Borehole met target depth
Dip test showed standing water at 7.3 m bgl (3 July 2025).
Angles are measured from the horizontal

Locations from hand help GPS
Vertical Datum = NZVD2016, long / lat in WGS84

ENGEO

BOREHOLE LOG MB02

Lighthouse Road Landslide

Akaroa
28912.000.001

Client : CCC
Date : 03-07-25
Hole Depth : 22 m
Drilling Method : Mud Rotary
Drilling Contractor : Prodrill Ltd

Core Diameter : 63.5 mm
Energy Transfer Ratio : 76%
Logged By/Reviewed By : ID / RJ
Latitude : -43.820361
Longitude : 172.9596956

Material	DESCRIPTION	Log Symbol	Strength	Depth (m BGL)	Elevation (mRL)	SPT N-Value / Vane Shear Strength	Sample Type	TCR (%) 25 50 75	RQD (%) 25 50 75	Defect Description	Moisture	Water Level	Piezometer Construction
VOLCANICLASTIC	Slightly weathered, massive, dark grey with yellowish orange and red zoning, fine grained VOLCANICLASTIC; moderately strong. 20.6 m: Becomes grey with iron stained defects.		MS	21 22	231 230	40/10 N=50+				20.1 m: Mechanical fracture. 20.3 m: Mechanical fracture. 20.6 m: Fracture zone with iron staining - extremely closely spaced discontinuities potentially mechanically broken. 20.7 m: Smooth planar fracture set at 60° and 40° 20.8 m: Mechanical Smooth planar fracture dipping 20° 20.9 m: Mechanical Smooth planar fracture dipping 20° 21 m: Mechanical Smooth planar fractures dipping 30° and 80° 21.01-21.5 m: Mechanically fractured along existing closely spaced discontinuities. 21.5-21.6 m: Mechanical Smooth planar fracture dipping 20° 21.6-21.8 m: Mechanically fractured along existing closely spaced discontinuities. 21.8-22 m: Closely spaced subhorizontal fracture set with iron staining.			

End of Hole Depth: 22 m
Termination: Target depth

Borehole met target depth
Dip test showed standing water at 7.3 m bgl (3 July 2025).
Angles are measured from the horizontal

Locations from hand help GPS
Vertical Datum = NZVD2016, long / lat in WGS84

APPENDIX 5:

Results of Laboratory Testing

BGL
Babbage Geotechnical Laboratory

Babbage Geotechnical Laboratory
Level 4
68 Beach Road
Auckland 1010
Telephone
E-mail

P O Box 2027
New Zealand
64-9-367 4954
wec@babbage.co.nz

Please reply to: W.E. Campton

ENGEO LTD.
PO Box 33-1527
Takapuna
Auckland 0740

Attention: **JAKE CORNALL**

Job Number: 66273#L
BGL Registration Number: 3064
Checked by: WEC

31st July 2025

HYDROMETER PARTICLE-SIZE DISTRIBUTION TESTING

Dear Sir,

Re: LIGHTHOUSE ROAD, AKAROA, CANTERBURY

Your Reference: 28912
Report Number: 66273#L/AL Lighthouse Road

The following report presents the results of hydrometer particle-size distribution testing at BGL of soil samples delivered to this laboratory on the 25th of August 2025. Test results are summarised below, with the following pages showing graphs and detailed results.

Test standards used were:

Water Content:	NZS4402: 1986: Test 2.1
Wet Sieve Test:	NZS4402: 1986: Test 2.8.1
Hydrometer Test:	NZS4402: 1986: Test 2.8.4

Borehole Number	**Sample Number**	**Depth (m)**	**Hydrometer Grading (% of Dry Mass)**			
			GRAVEL (2 – <9.50mm)	**SAND** (0.06 – 2mm)	**SILT FRACTION** (0.002 – 0.06mm)	**CLAY FRACTION** (< 0.002mm)
BH01 ◆	**BAG**	**2.95 – 3.45**	**4**	**24**	**53**	**19**
BH02	**BAG**	**3.20 – 3.60**	**2**	**25**	**36**	**37**

◆ = *The soil fraction passing a 9.50mm sieve was used for this hydrometer test.*

The whole soils were used for these hydrometer tests, except for the samples with a diamond (◆) beside them, where the soil fractions passing a 9.50mm sieve were used. For the samples passing a 9.50mm sieve ;

- approximately 84% wet mass passed the 9.50mm sieve for sample BH01 / 2.95 – 3.45m

NZS4402: 1986: Test 2.8.4 uses a 2.00mm sieve as the separation point for obtaining the hydrometer sample, therefore the use of the whole soils & the soil fractions passing a 9.50mm sieve represents a departure from the test standard.

As the organic content of the soils tested was very low, peroxide pretreatment was not carried out. A solid density of 2.65t/m^3 was assumed for these hydrometer tests, and is not part of the IANZ endorsement for this report.

As per the reporting requirements of NZS4402: 1986: Test 2.1: water content is reported to two significant figures for values below 10%, and to three significant figures for values of 10% or greater. Test 2.8.1: wet sieve & Test 2.8.4: hydrometer, the 'percentages passing' and 'percentages finer than' are reported to nearest 1%.

Please note that the test results relate only to the samples as-received, and relate only to the samples under test.

Thank you for the opportunity to carry out this testing. If you have any queries regarding the content of this report please contact the person authorising this report below at your convenience.

Yours faithfully,

Justin Franklin
Key Technical Person
Assistant Laboratory Manager
Babbage Geotechnical Laboratory

Nº 126

All tests reported herein have been performed in accordance with the laboratory's scope of accreditation. This report may not be reproduced except in full & with written approval from BGL.

BGL Babbage Geotechnical Laboratory	**Job Number:**	66273#L	**Sheet 1 of 1**	**Page 3 of 4**
	Registration Number:	3064		
	Report Number:	66273#L/HYD Lighthouse Road		
	Project:	**LIGHTHOUSE ROAD, AKAROA, CANTERBURY**		

PARTICLE-SIZE DISTRIBUTION BY HYDROMETER

Test Methods: NZS4402: 1986: Test 2.1, Test 2.8.1, Test 2.8.4

Tested By:	JL	29-Jul-25
Compiled By:	JL	30-Jul-25
Checked By:	JF	31-Jul-25

Version Number:	7	**Version Date:**	July 2022	**Authorised By:**	W. Campton

Borehole No: **BH01** ***Sample No:*** **BAG** ***Depth:*** **2.95 - 3.45m**

Water Content (%): **45.6**

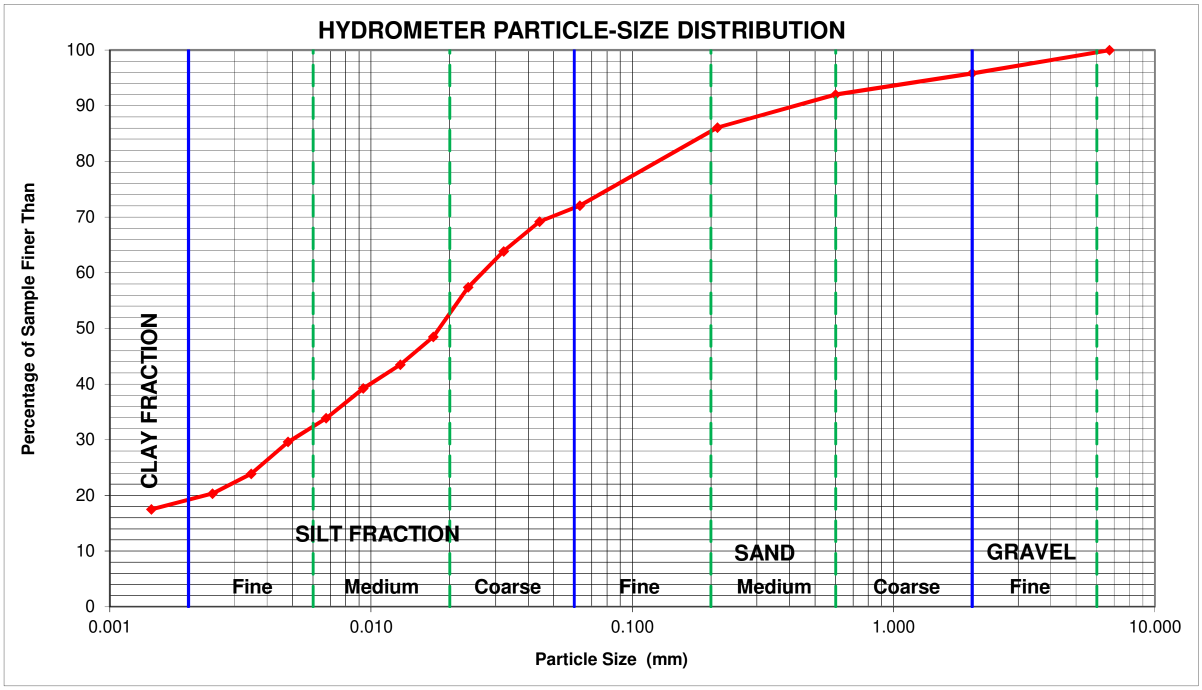
Sample History: ~~Natural / Air Dried / Oven Dried /~~ Unknown

pH of sedimentation suspension: 8.2

Particle-size (mm)	% Finer Than
6.70	100
2.00	96
0.600	92
0.212	86
0.063	72
0.044	69
0.032	64
0.024	57
0.017	48
0.013	44
0.0093	39
0.0067	34
0.0048	30
0.0035	24
0.0025	20
0.0014	17

HYDROMETER ANALYSIS (% of dry mass)				**TOTAL**	
GRAVEL	Medium	*< 9.5 - 6mm*	0	**4**	**%**
	Fine	*6 - 2mm*	4		
SAND	Coarse	*2.0 - 0.6mm*	4	**24**	**%**
	Medium	*0.6 - 0.2mm*	7		
	Fine	*0.2 - 0.06mm*	13		
SILT FRACTION	Coarse	*0.06 - 0.02mm*	20	**53**	**%**
	Medium	*0.02 - 0.006mm*	20		
	Fine	*0.006 - 0.002mm*	13		
CLAY FRACTION		*< 0.002mm*		**19**	**%**
				100%	

HYDROMETER TEST WAS CARRIED OUT ON THE ~~WHOLE SOIL~~ / SOIL FRACTION PASSING A 9.50mm SIEVE



BGL
Babbage Geotechnical
Laboratory

Job Number:	**66273#L**	**Sheet 1 of 1**	**Page 4 of 4**
Registration Number:	**3064**		
Report Number:	**66273#L/HYD Lighthouse Road**		
Project:	**LIGHTHOUSE ROAD, AKAROA, CANTERBURY**		

PARTICLE-SIZE DISTRIBUTION BY HYDROMETER

Test Methods: NZS4402: 1986: Test 2.1, Test 2.8.1, Test 2.8.4

Tested By:	JL	29-Jul-25
Compiled By:	JL	30-Jul-25
Checked By:	JF	31-Jul-25

Version Number:	7	**Version Date:**	July 2022	**Authorised By:**	W. Campton

Borehole No: **BH02** ***Sample No:*** **BAG** ***Depth:*** **3.20 - 3.60m**

Water Content (%): **51.3**

Sample History: ~~Natural / Air Dried / Oven Dried /~~ Unknown

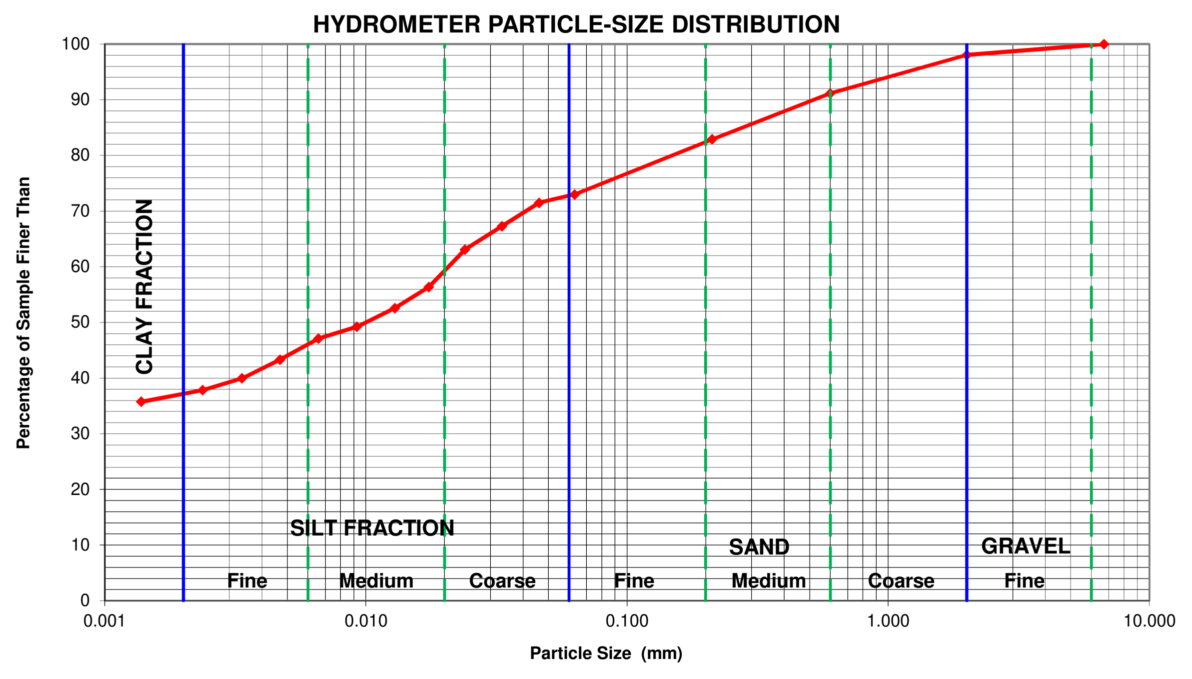
pH of sedimentation suspension: 8.2

Particle-size (mm)	% Finer Than
6.70	100
2.00	98
0.600	91
0.212	83
0.063	73
0.046	71
0.033	67
0.024	63
0.017	56
0.013	53
0.0092	49
0.0066	47
0.0047	43
0.0034	40
0.0024	38
0.0014	36

HYDROMETER ANALYSIS (% of dry mass) **TOTAL**

GRAVEL	Medium	*< 9.5 - 6mm*	0		
	Fine	*6 - 2mm*	2	**2**	**%**
SAND	Coarse	*2.0 - 0.6mm*	7		
	Medium	*0.6 - 0.2mm*	9	**25**	**%**
	Fine	*0.2 - 0.06mm*	9		
SILT FRACTION	Coarse	*0.06 - 0.02mm*	14		
	Medium	*0.02 - 0.006mm*	13	**36**	**%**
	Fine	*0.006 - 0.002mm*	9		
CLAY FRACTION		*< 0.002mm*		**37**	**%**
				100%	

HYDROMETER TEST WAS CARRIED OUT ON THE WHOLE SOIL / ~~SOIL FRACTION PASSING A 9.50mm SIEVE~~



BGL
Babbage Geotechnical Laboratory

Babbage Geotechnical Laboratory
Level 4
68 Beach Road P O Box 2027
Auckland 1010 New Zealand
Telephone 64-9-367 4954
E-mail wec@babbage.co.nz

Please reply to: W.E. Campton

ENGEO LTD.
PO Box 33-1527
Takapuna
Auckland 0740

Attention: **JAKE CORNALL**

Job Number: 66273#L
BGL Registration Number: 3064
Checked by: WEC

1st August 2025

ATTERBERG LIMITS & LINEAR SHRINKAGE TESTING

Dear Sir,

Re: LIGHTHOUSE ROAD, AKAROA, CANTERBURY

Your Reference: 28912
Report Number: 66273#L/AL Lighthouse Road

The following report presents the results of Atterberg Limits & Linear Shrinkage testing at BGL of soil samples delivered to this laboratory on the 25th of July 2025. Test results are summarised below, with page 3 showing where the samples plot on the Unified Soil Classification System (Casagrande) Chart.

Test standards used were:

Water Content:	NZS4402: 1986: Test 2.1
Liquid Limit:	NZS4402: 1986: Test 2.2
Plastic Limit:	NZS4402: 1986: Test 2.3
Plasticity Index:	NZS4402: 1986: Test 2.4
Linear Shrinkage:	NZS4402: 1986: Test 2.6

Borehole Number	Sample Number	Depth (m)	Water Content (%)	Liquid Limit	Plastic Limit	Plasticity Index	Linear Shrinkage (%)*
BH01	BAG	2.95 – 3.45	45.6	58 ◆	33 ◆	25 ◆	11 ◆
BH02	BAG	3.20 – 3.60	51.3	73 ◆	34 ◆	39 ◆	18 ◆

**The amount of shrinkage of the sample as a percentage of the original sample length.*

◆ = *The soil fraction passing a 0.425mm sieve was used for the liquid limit, plastic limit & linear shrinkage tests.*

The whole soils were used for the water content tests (the soils were in an unknown state), and for the liquid limit, plastic limit & linear shrinkage tests without a diamond beside them. The soil fractions passing a 0.425mm sieve were used for the liquid limit, plastic limit & linear shrinkage tests with a diamond (◆) beside them. The soils were wet up and dried where required for the liquid limit, plastic limit & linear shrinkage tests.

As per the reporting requirements of NZS4402: 1986: Test 2.1: water content is reported to two significant figures for values below 10%, and to three significant figures for values of 10% or greater. Test 2.2: liquid limit, test 2.3: plastic limit, and test 2.6: linear shrinkage are reported to the nearest whole number.

Please note that the test results relate only to the samples as-received, and relate only to the samples under test.

Thank you for the opportunity to carry out this testing. If you have any queries regarding the content of this report please contact the person authorising this report below at your convenience.

Yours faithfully,

Justin Franklin
Key Technical Person
Assistant Laboratory Manager
Babbage Geotechnical Laboratory

ACCREDITED
IANZ
TESTING LABORATORY
Nº 126

All tests reported herein have been performed in accordance with the laboratory's scope of accreditation. This report may not be reproduced except in full & with written approval from BGL.

Babbage Geotechnical Laboratory

Job Number:	**66273#L**	**Sheet 1 of 1**	**Page 3 of 3**
Registration Number:	**3064**		
Report Number:	**66273#L/AL Lighthouse Road**		
Project:	**LIGHTHOUSE ROAD, AKAROA, CANTERBURY**		

DETERMINATION OF THE LIQUID LIMIT, PLASTIC LIMIT & THE PLASTICITY INDEX

Test Methods: NZS4402: 1986: Test 2.2, Test 2.3 and Test 2.4

Tested By:	JL	July 2025
Compiled By:	JF	1/08/2025
Checked By:	JF	1/08/2025

Version Number:	7	**Version Date:**	July 2022	**Authorised By:**	Wayne Campton

SUMMARY OF TESTING

Borehole Number	Sample Number	Depth (m)	Liquid Limit	Plastic Limit	Plasticity Index	Soil Classification Based on USCS Chart Below
BH01	**BAG**	**2.95 - 3.45**	58	33	**25**	MH
BH02	**BAG**	**3.20 - 3.60**	73	34	**39**	CH / MH

The chart below & soil classification terminology is taken from ASTM D2487-17^{e1} "Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System)", April 2020, & is based on the classification scheme developed by A. Casagrande in the 1940's (Casagrande, A., 1948: Classification and identification of soil. Transactions of the American Society of Civil Engineers, v. 113, p. 901-930). The chart below & the soil classification given in the table above are included for your information only, and are not included in the IANZ endorsement for this report.

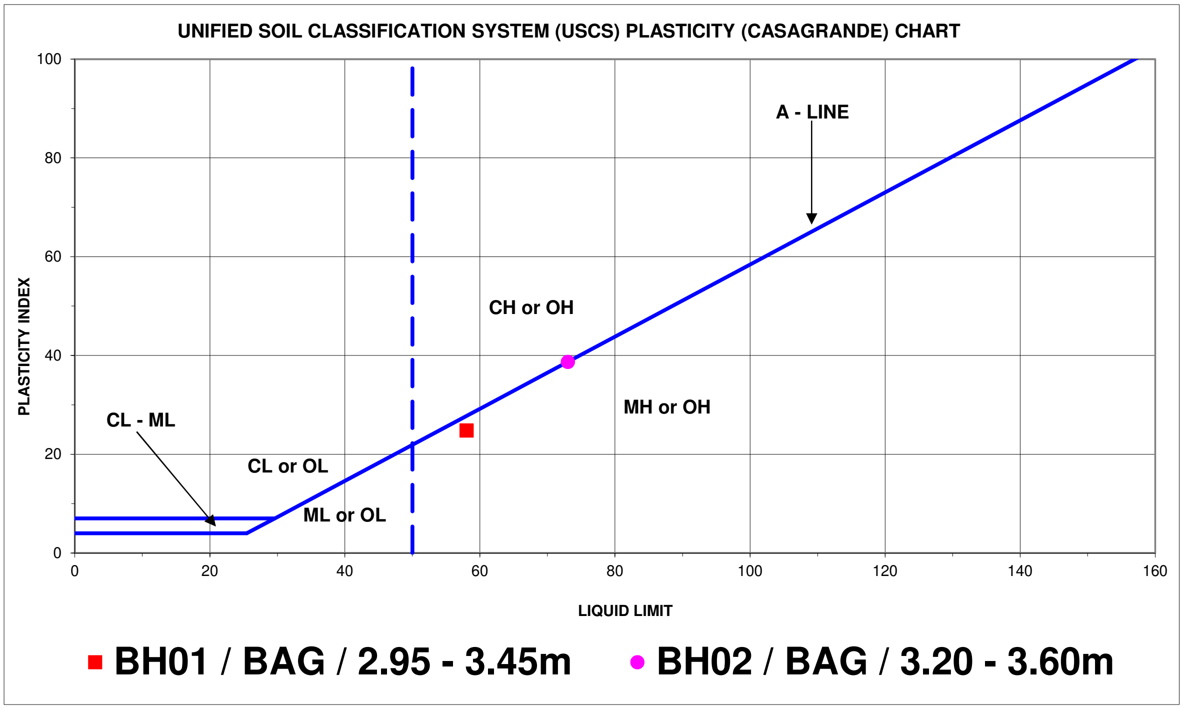


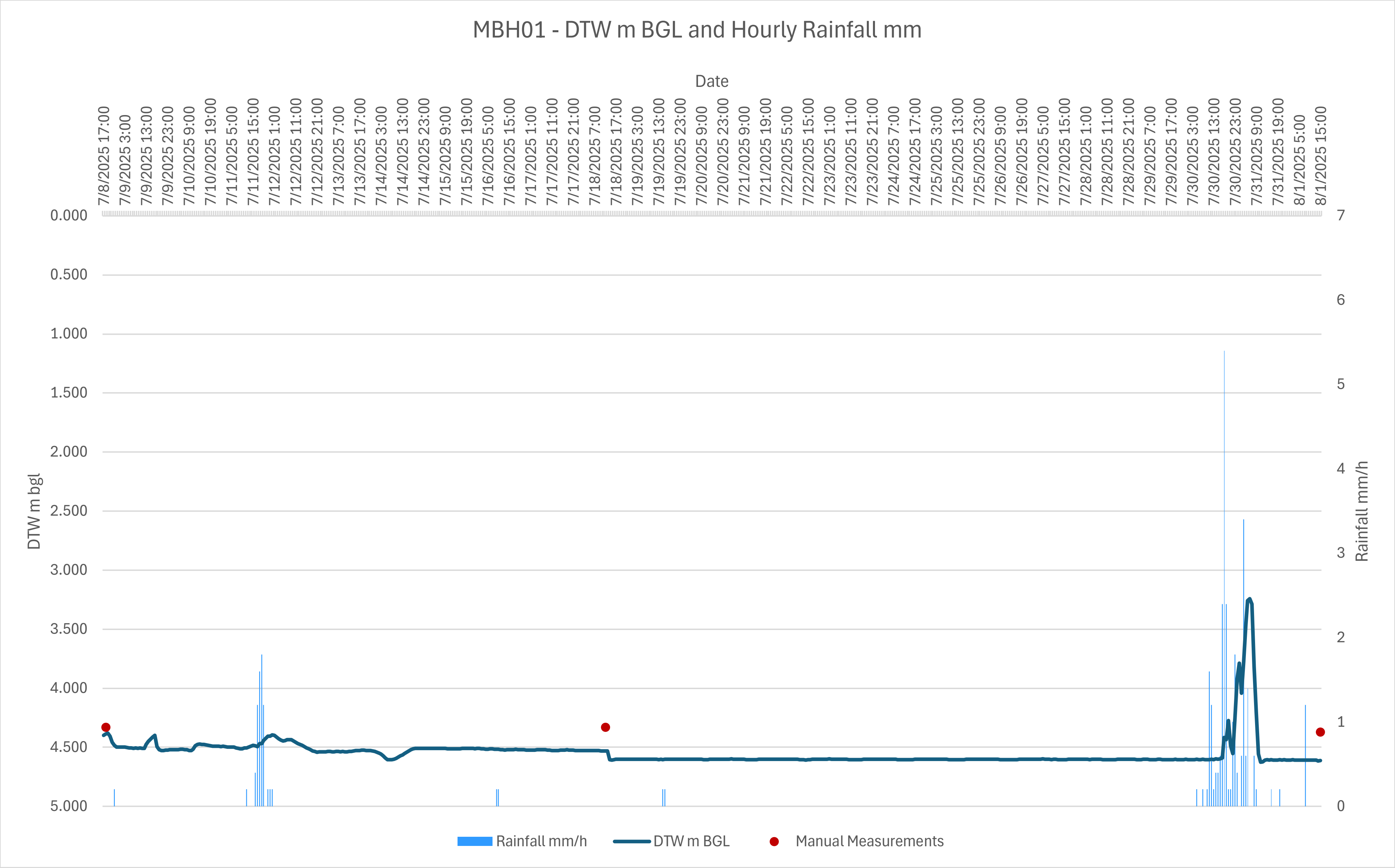
CHART LEGEND

CL = CLAY, low plasticity ('lean' clay)
OL = ORGANIC CLAY or ORGANIC SILT, low liquid limit
ML = SILT, low liquid limit
CL - ML = SILTY CLAY

CH = CLAY, high plasticity ('fat' clay)
OH = ORGANIC CLAY or ORGANIC SILT, high liquid limit
MH = SILT, high liquid limit ('elastic silt')

APPENDIX 6:

Groundwater Monitoring Results



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7/9/2025 13:00
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7/10/2025 9:00
7/10/2025 19:00
7/11/2025 5:00
7/11/2025 15:00
7/12/2025 1:00
7/12/2025 11:00
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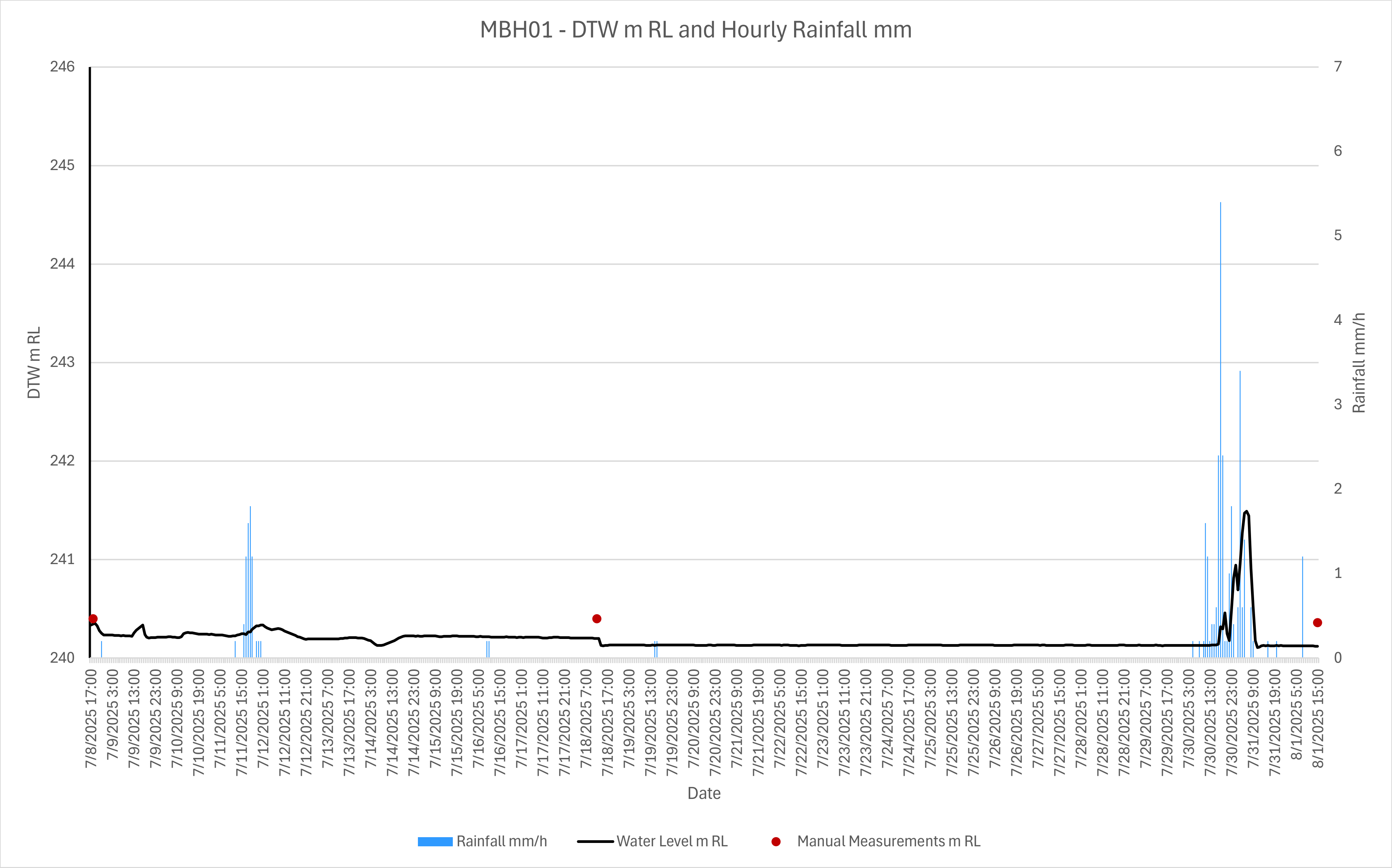
7/31/2025 9:00
7/31/2025 19:00
8/1/2025 5:00
8/1/2025 15:00
DTW m bgl
0.000
0.500
1.000
1.500
2.000
2.500
3.000
3.500
4.000
4.500
5.000
Rainfall mm/h
7
6
5
4
3
2
1
0
Rainfall mm/h
DTW m BGL
Manual Measurements


MBH01 - DTW m RL and Hourly Rainfall mm
DTW m RL
246
245
244
243
242
241
240
Rainfall mm/h
7
6
5
4
3
2
1
0
Date
7/8/2025 17:00
7/9/2025 3:00
7/9/2025 13:00
7/9/2025 23:00
7/10/2025 9:00
7/10/2025 19:00
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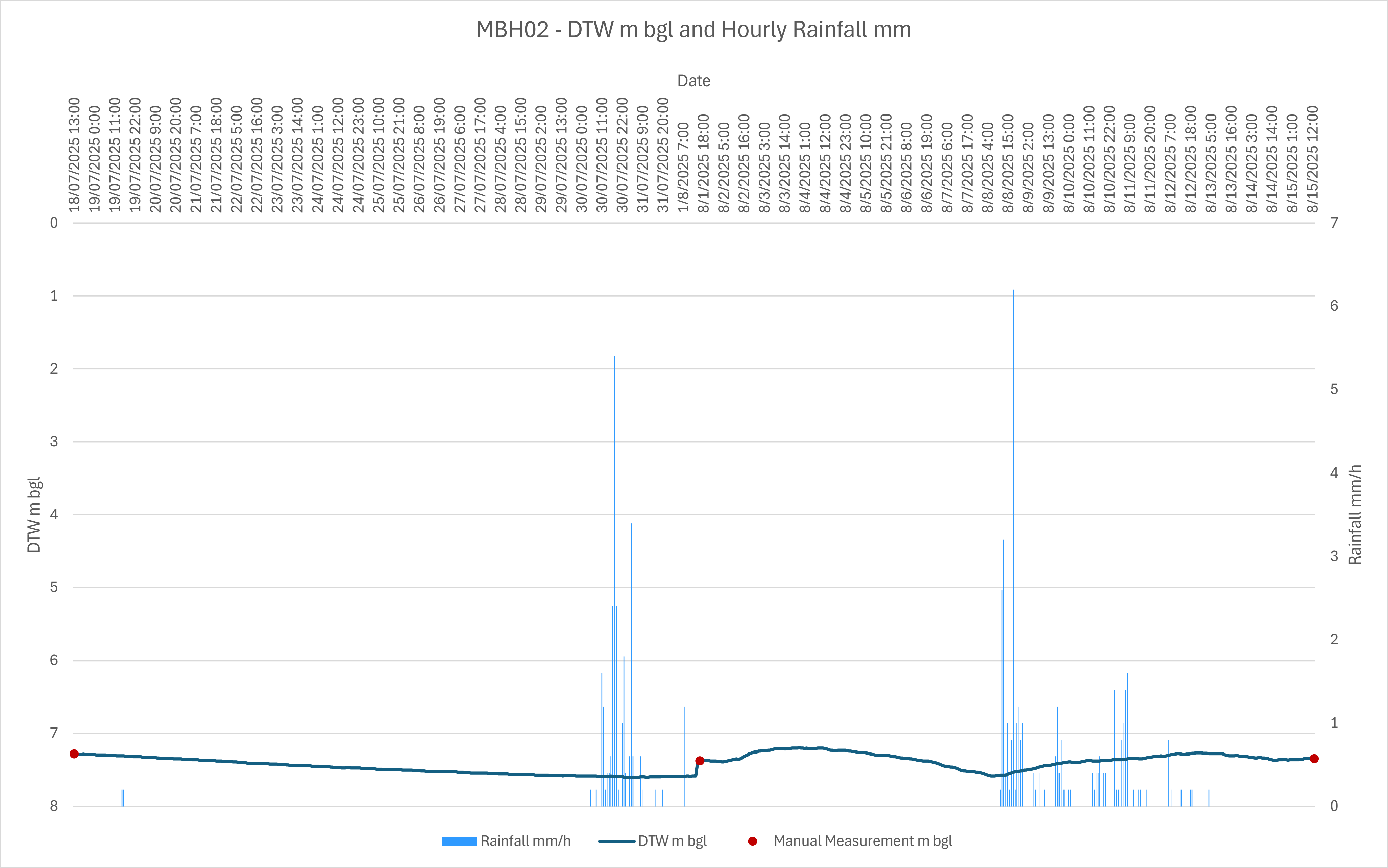
Rainfall mm/h
Water Level m RL
Manual Measurements m RL


MBH02 - DTW m bgl and Hourly Rainfall mm
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19/07/2025 0:00
19/07/2025 11:00
19/07/2025 22:00
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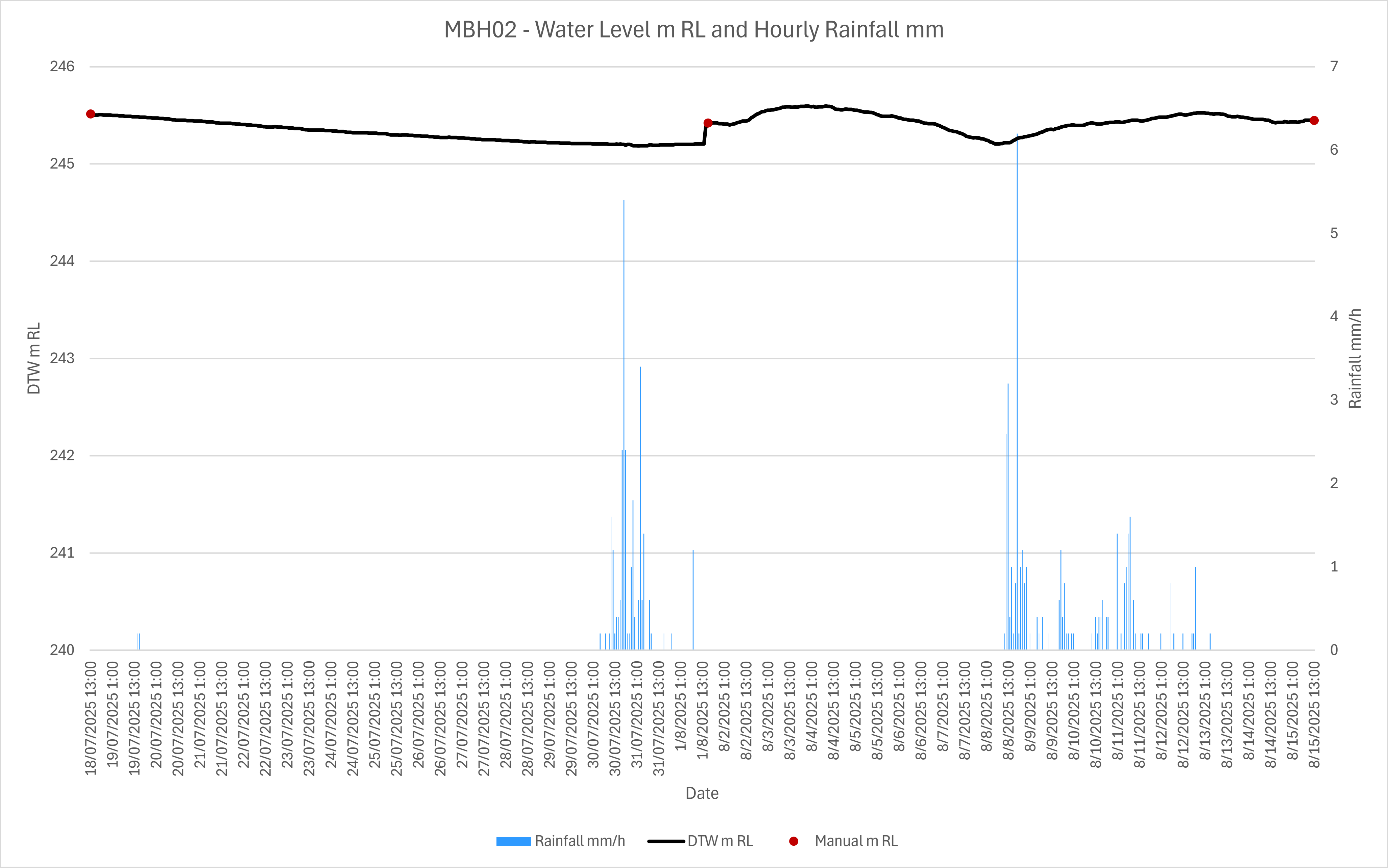
DTW m bgl
0
1
2
3
4
5
6
7
8
Rainfall mm/h
7
6
5
4
3
2
1
0
Rainfall mm/h
DTW m bgl
Manual Measurement m bgl


MBH02 - Water Level m RL and Hourly Rainfall mm
DTW m RL
246
245
244
243
242
241
240
Rainfall mm/h
7
6
5
4
3
2
1
0
18/07/2025 13:00
19/07/2025 1:00
19/07/2025 13:00
20/07/2025 1:00
20/07/2025 13:00
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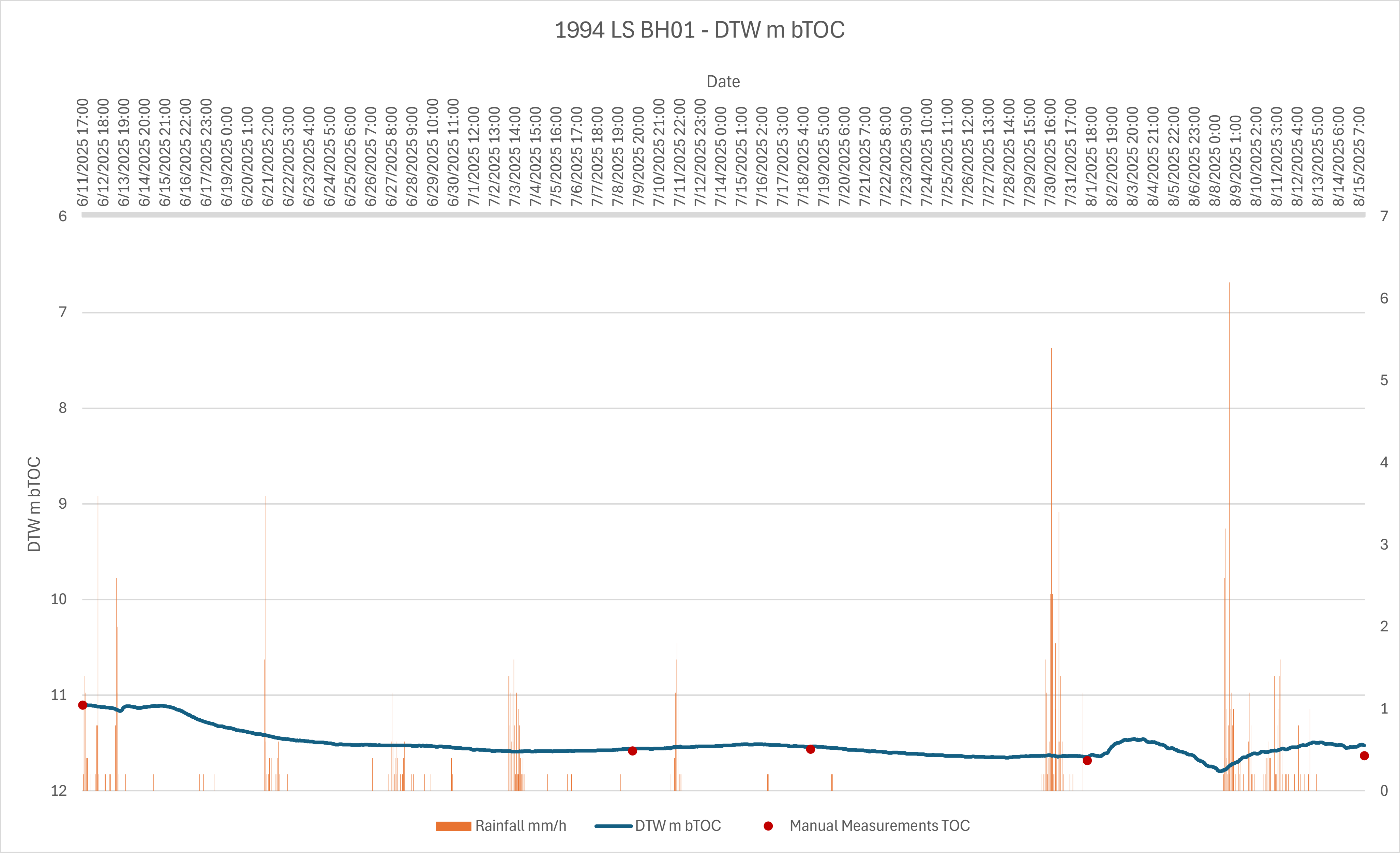
8/14/2025 13:00
8/15/2025 1:00
8/15/2025 13:00
Date
Rainfall mm/h
DTW m RL
Manual m RL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8/12/2025 4:00
8/13/2025 5:00
8/14/2025 6:00
8/15/2025 7:00
DTW m bTOC
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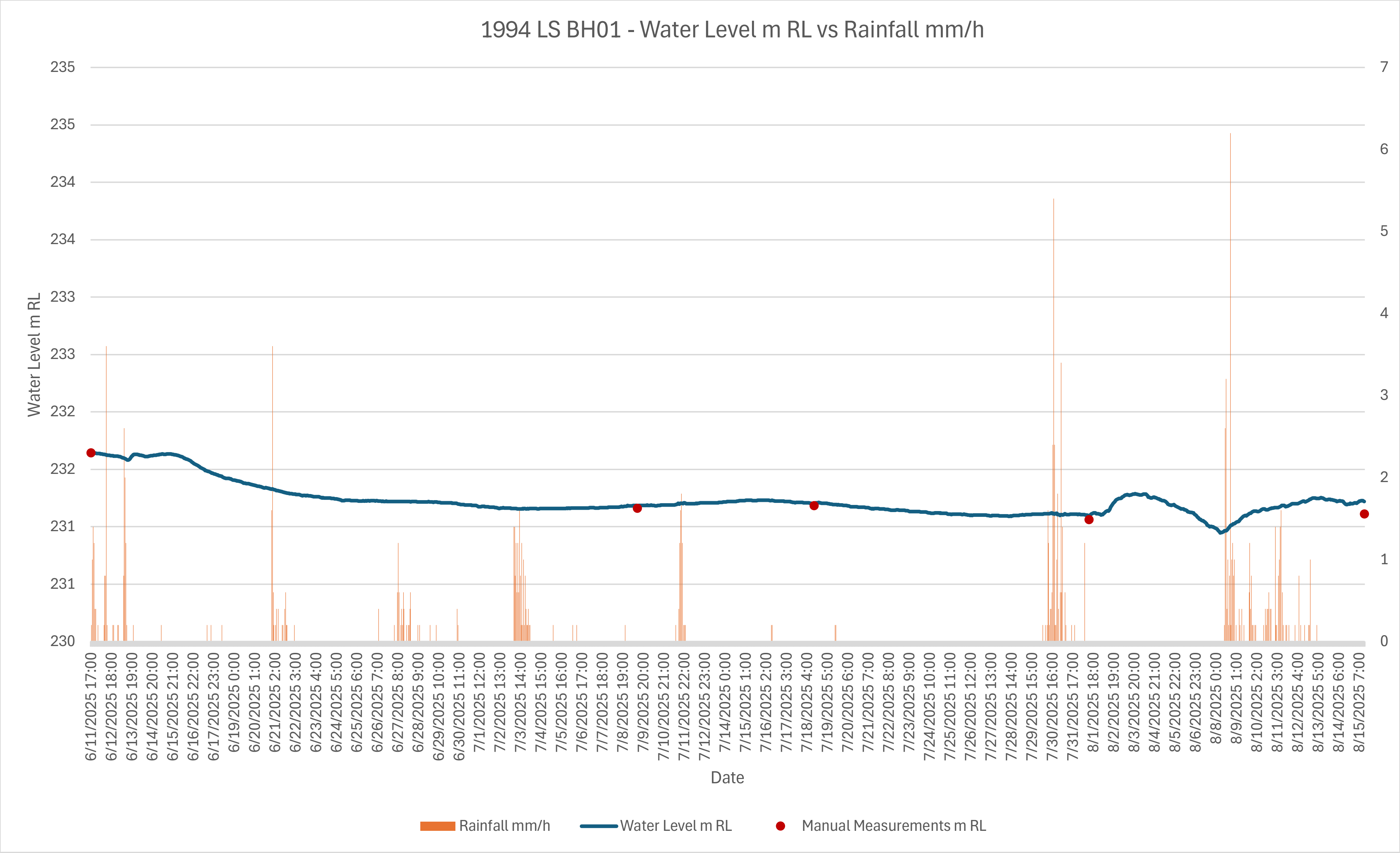
12
7
6
5
4
3
2
1
0
Rainfall mm/h
DTW m bTOC
Manual Measurements TOC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Water Level m RL
235
235
234
234
233
233
232
232
231
231
230
7
6
5
4
3
2
1
0
Date
6/11/2025 17:00
6/12/2025 18:00
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6/14/2025 20:00
6/15/2025 21:00
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8/12/2025 4:00
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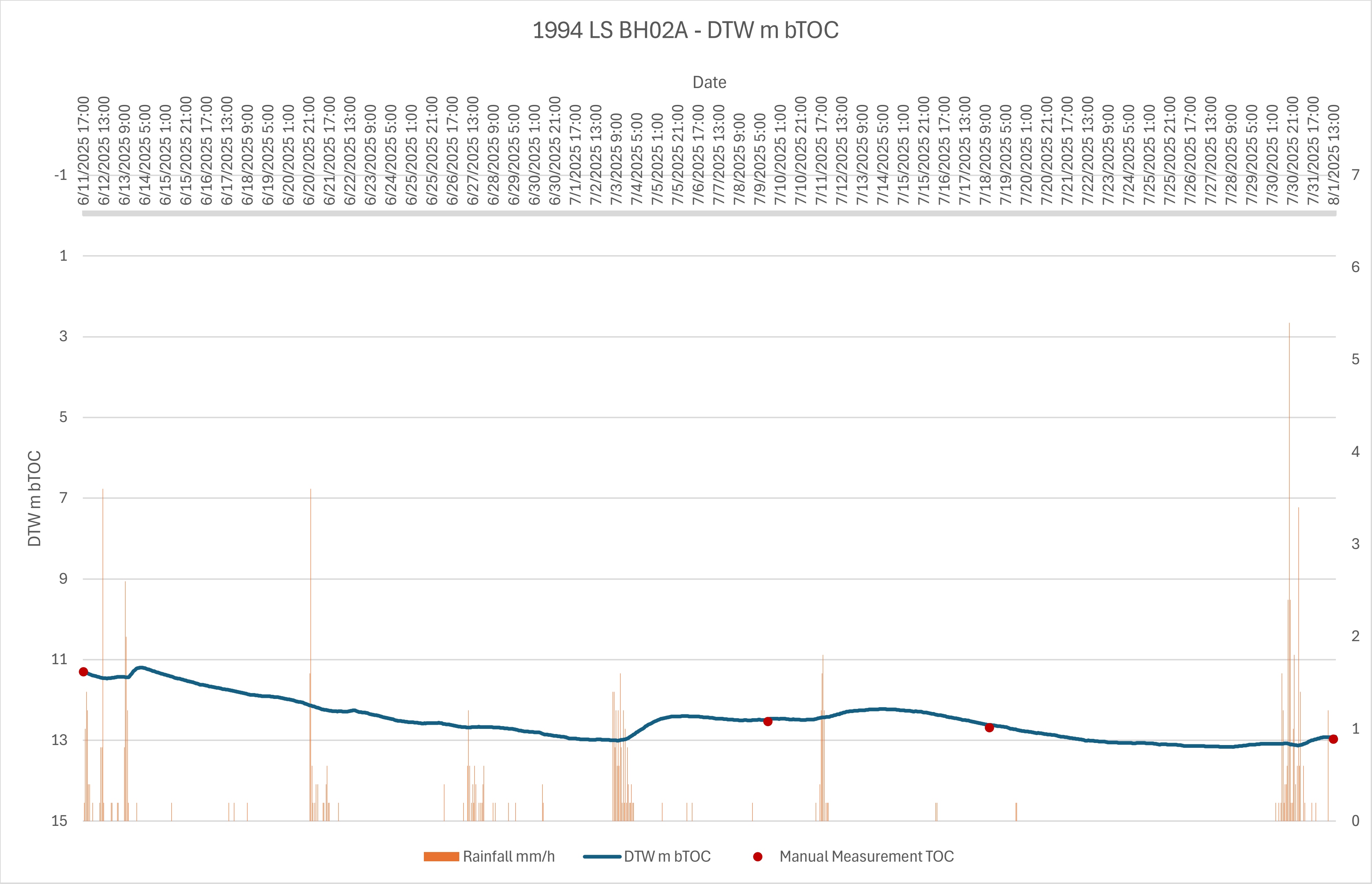
8/14/2025 6:00
8/15/2025 7:00
Rainfall mm/h
Water Level m RL
Manual Measurements m RL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7/30/2025 21:00
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8/1/2025 13:00
DTW m bTOC
-1
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9
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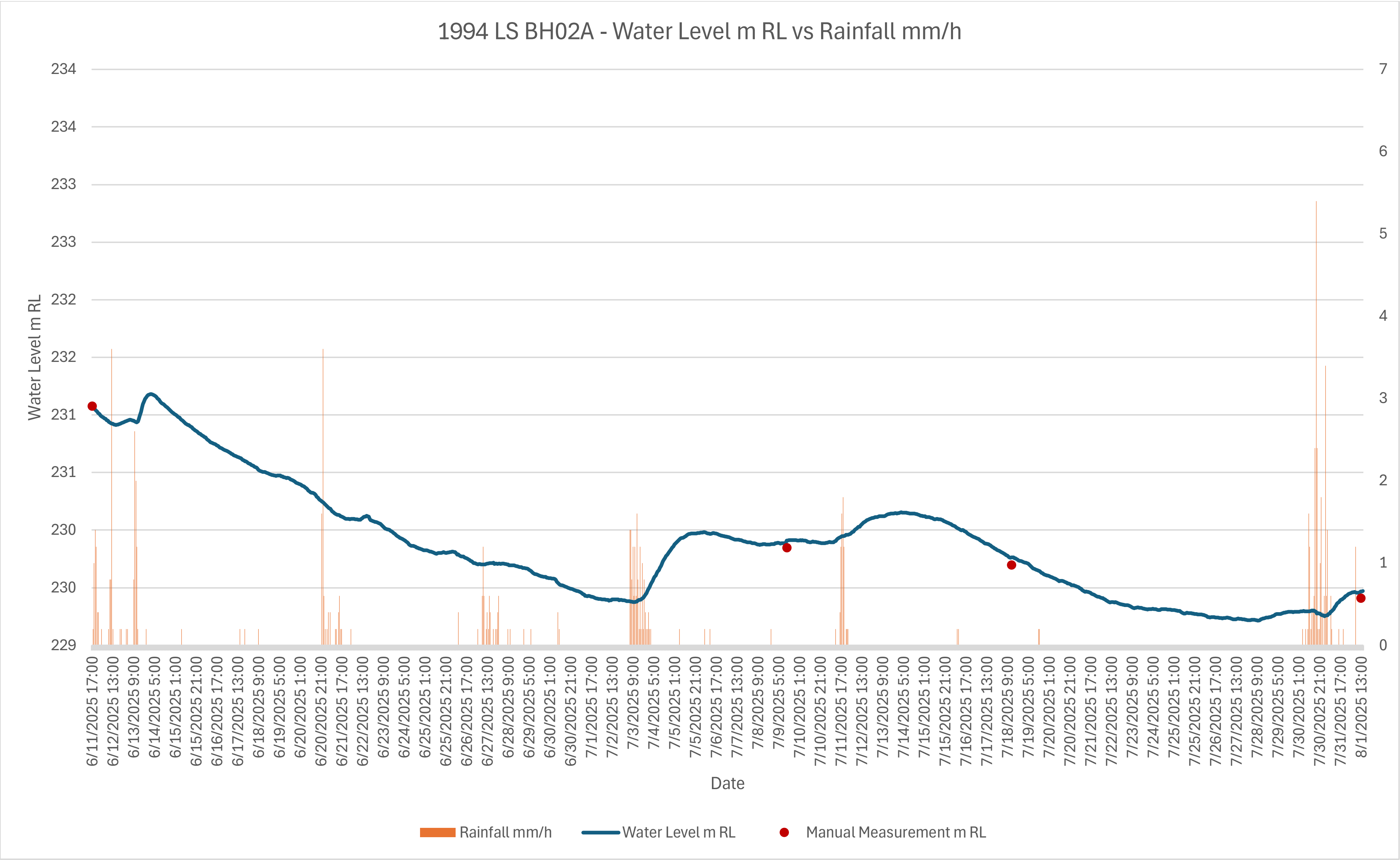
0
Rainfall mm/h
DTW m bTOC
Manual Measurement TOC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Water Level m RL
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234
233
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232
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230
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229
7
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7/29/2025 5:00
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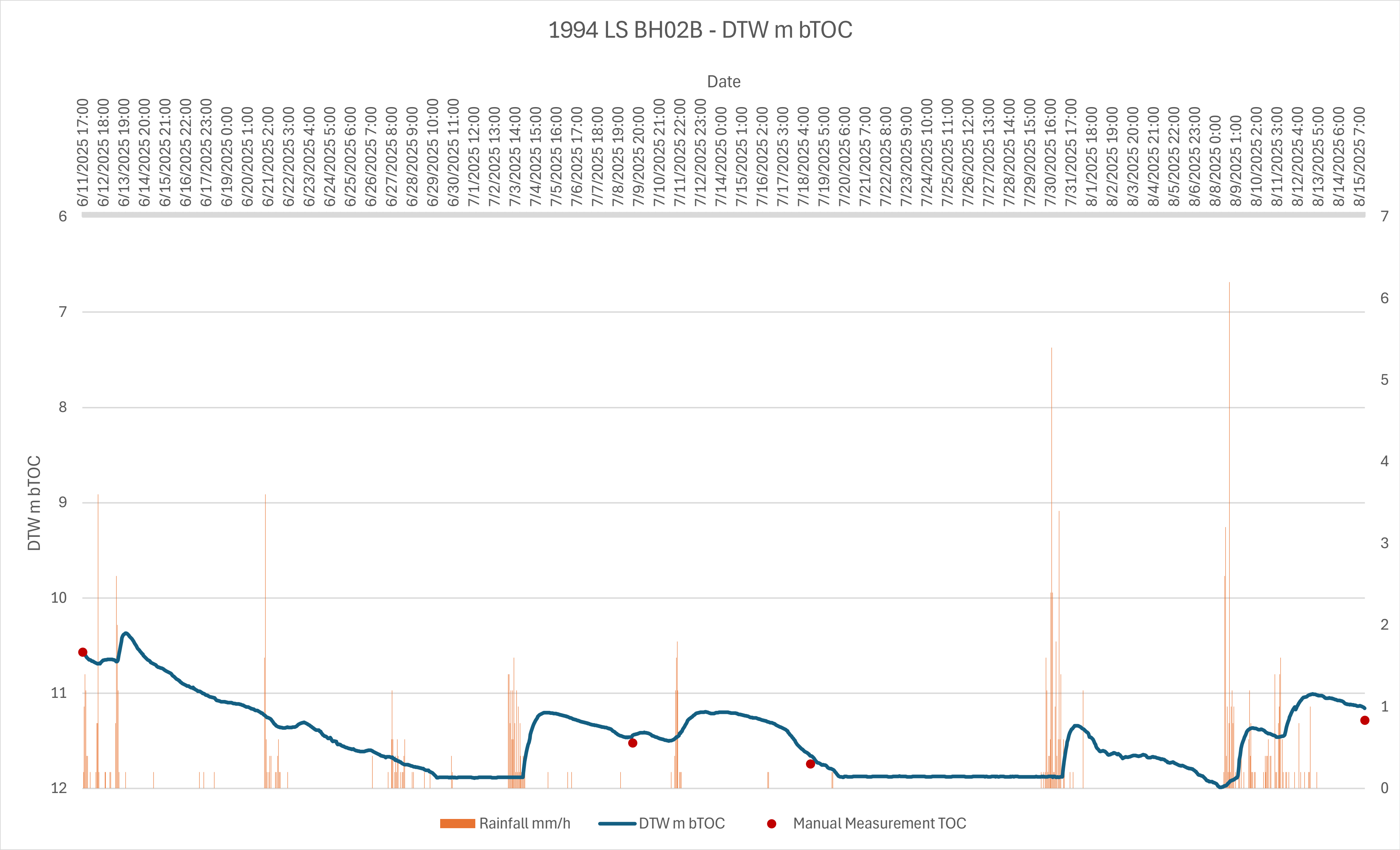
7/30/2025 21:00
7/31/2025 17:00
8/1/2025 13:00
Date
Rainfall mm/h
Water Level m RL
Manual Measurement m RL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DTW m bTOC
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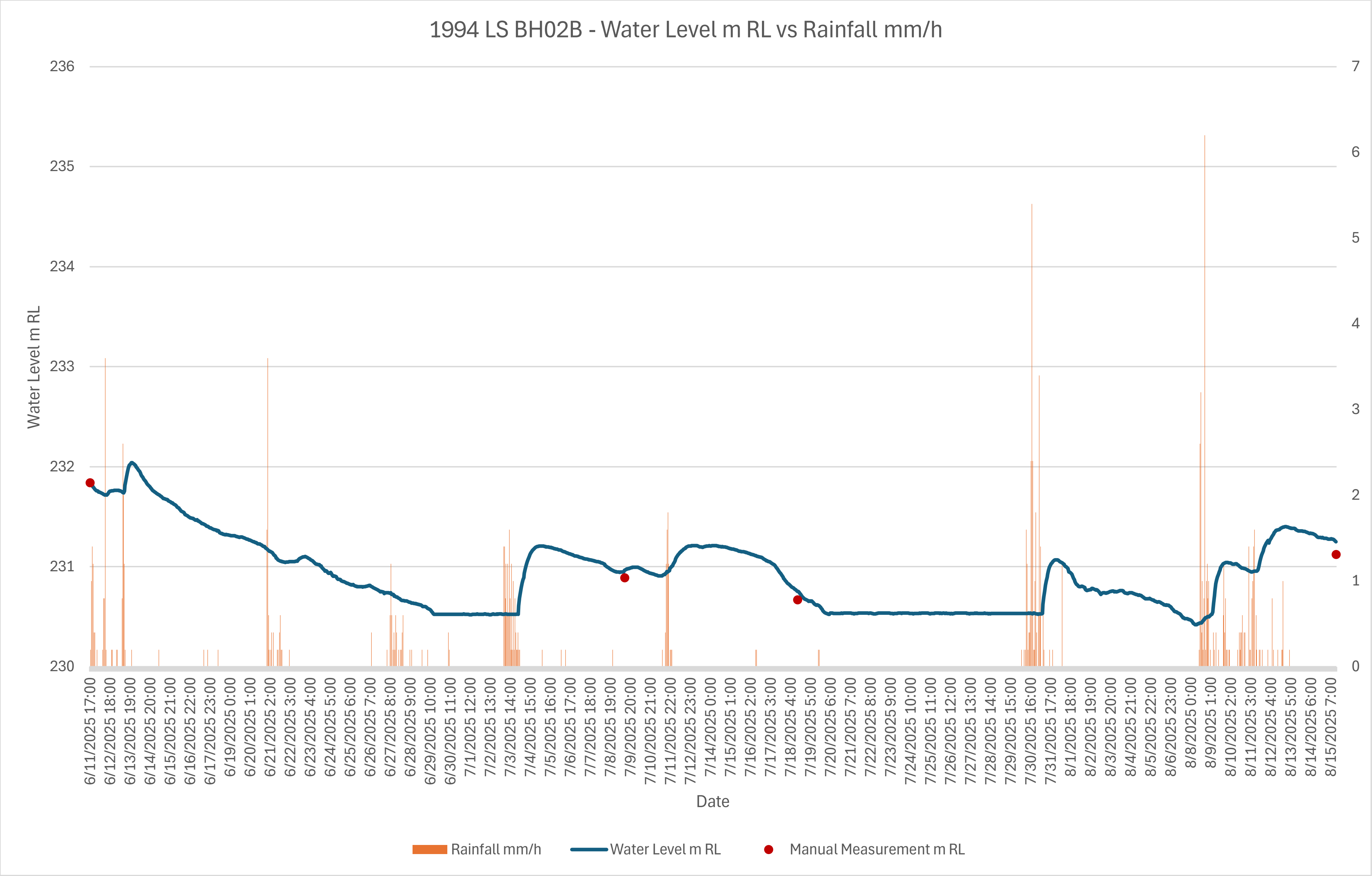
Rainfall mm/h
DTW m bTOC
Manual Measurement TOC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Water Level m RL
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232
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7
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2
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Date
6/11/2025 17:00
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8/12/2025 4:00
8/13/2025 5:00
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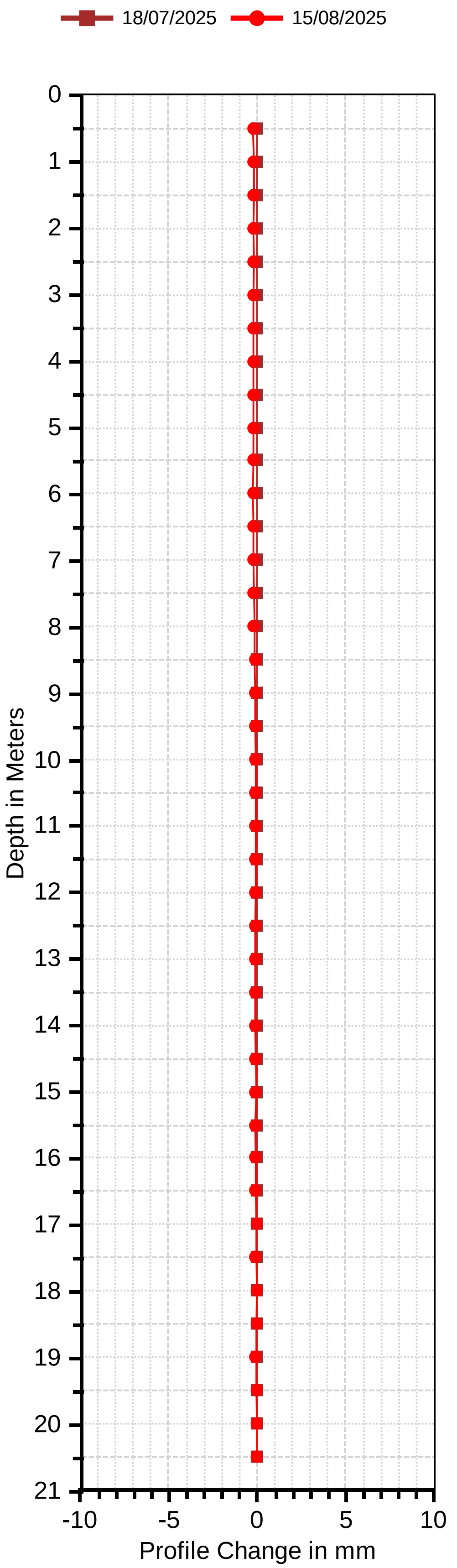
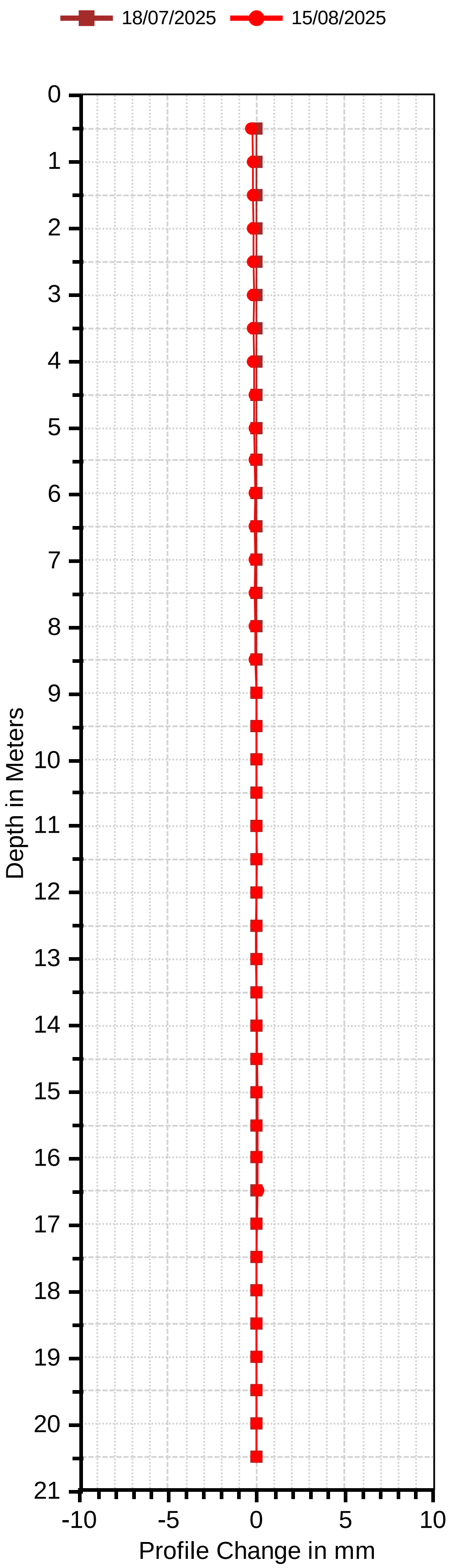
8/15/2025 7:00
Rainfall mm/h
Water Level m RL
Manual Measurement m RL

APPENDIX 7:

Inclinometer Monitoring Results



MBH02 - A0-A180 (40degs)

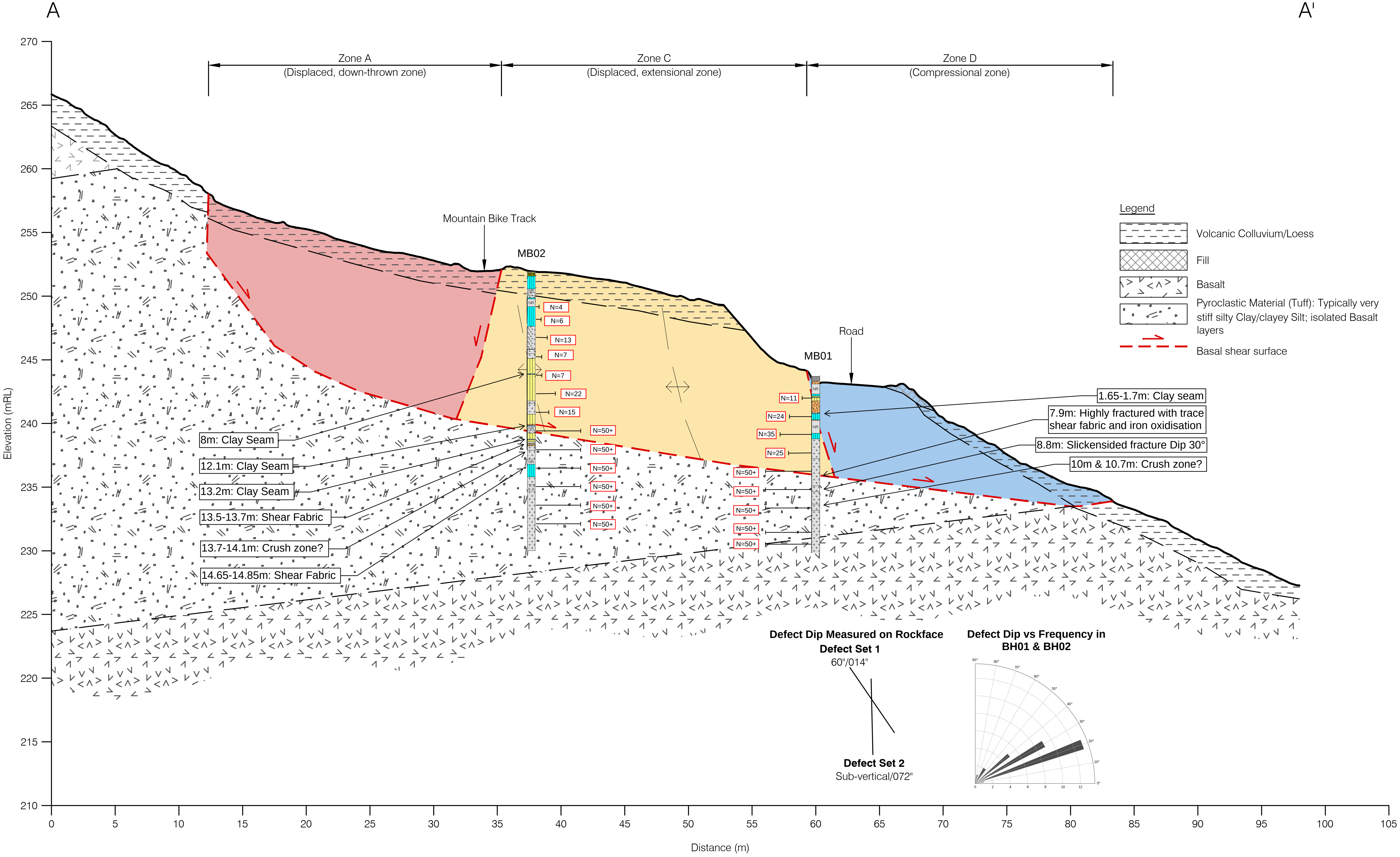


MBH02 - B0-B180 (180degs)

APPENDIX 8:

Engineering Geological Model

DATE PLOTTED: 4 June 2025 2:00 pm BY : DOUG FINLAY



CROSS SECTION A-A'

A	04.06.25	Issued for information	DF	RJ
Rev	Date	Description	Drwn	Chkd

ENGEO

Christchurch Office
124 Montreal St
Sydenham
Christchurch, 8023
Tel: 03 328 9012
www.engeo.co.nz

Title:

GEOLOGICAL CROSS SECTION

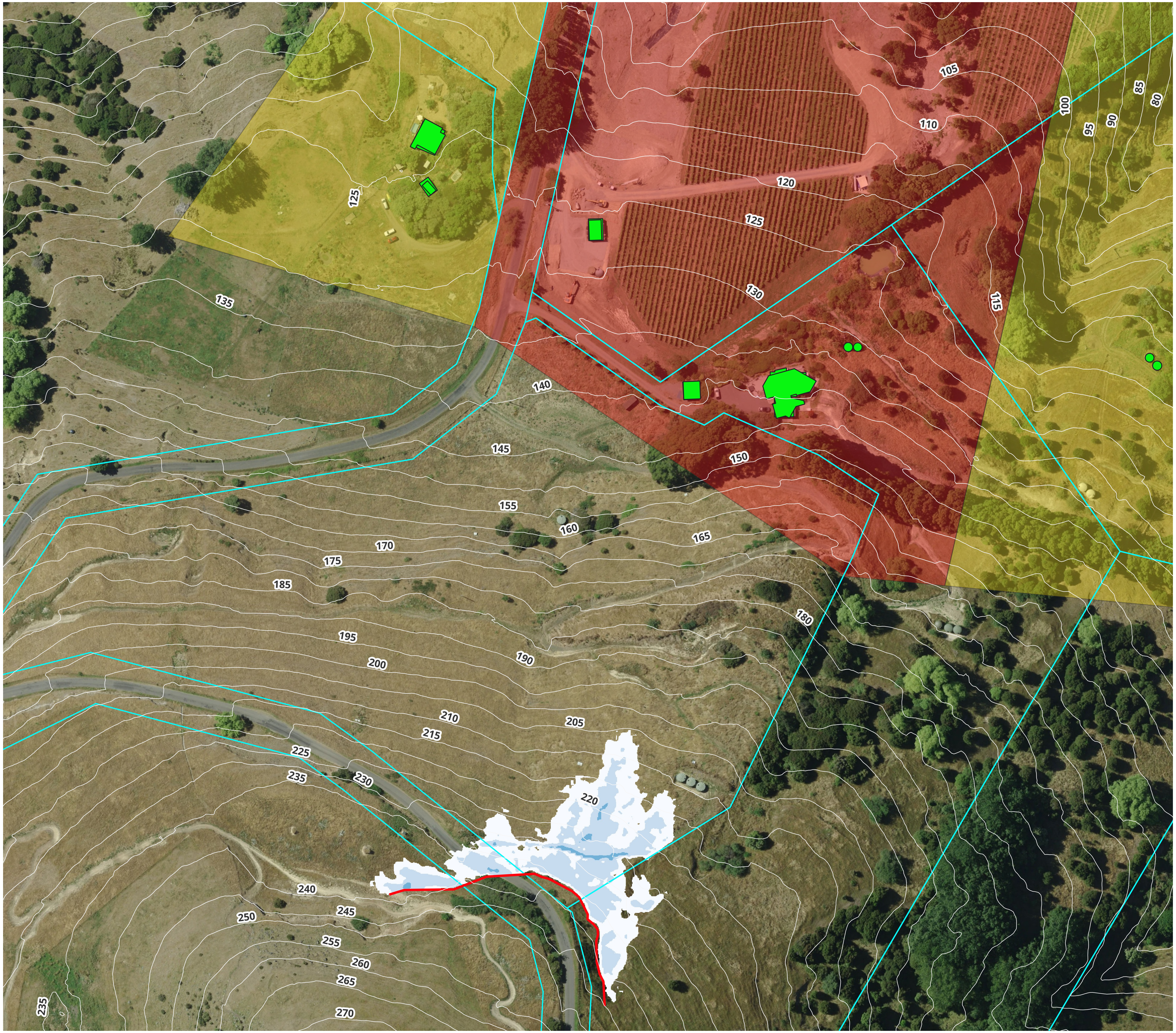
Client: Christchurch City Council
Project: Lighthouse Road Landslide Akaroa
Designed: ID
Drawn: DF
Checked: RJ
Date: 04.06.25
Scale: 1:300
Proj No: 28912.000.001
Figure No: 1
Size: A3
Rev: A

CAD File: Z:\Drafting\28001 to 29000\28912 - Lighthouse Road, Akaroa\DWG Files\01-Geological XS\V1-28912-GXS-300525.dwg
XREF's:

ORIGINAL FIGURE PRINTED IN COLOUR

APPENDIX 9:

Runout Analysis



— 5m Contours
— Landslide Toe
🟥 Primary Evacuation Zone
🟨 Secondary Evacuation Zone
🟩 NZ Building Outlines
☐ NZ Property Titles

Maximum Depth

(m)

⬜ <= 0.50
🟦 0.50 - 1.00
🟦 1.00 - 1.50
🟦 1.50 - 2.00
🟦 > 2.00

New Zealand Imagery

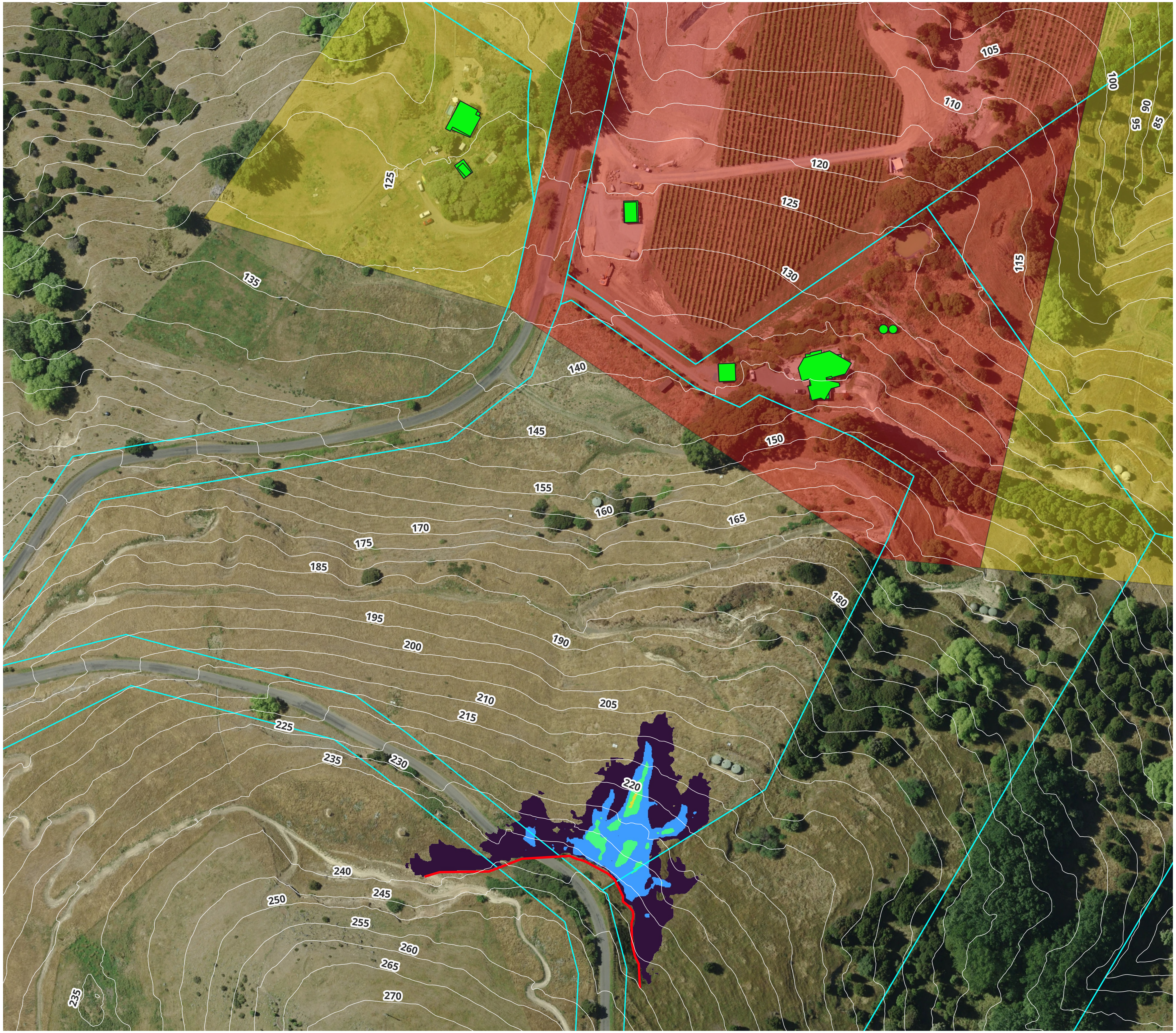
Notes:
1. The model terrain is derived from Canterbury Banks Peninsula LiDAR 1m DEM 2023.
2. Debris flow extent presented is a best estimate only.

0 50 100 m

ENGEO

Projection: NZTM 2000NZGD2000 / New Zealand Transverse Mercator 2000

Client: Christchurch City Council		
Title: Lighthouse Road Landslide 1,000m3 Debris Flow (Maximum Depth)		Appendix No. Size: A3 Sheet
Project: Lighthouse Road Landslide	Drawn: ZS	
Date: 24/07/2025	Checked: RJ	
Proj No: 28912.000.001	Scale: 800 @ A3	Version: 1.0



― 5m Contours

― Landslide Toe

🟥 Primary Evacuation Zone

🟨 Secondary Evacuation Zone

🟩 NZ Building Outlines

☐ NZ Property Titles

Maximum Velocity

(m/s)

■ <= 1.00

■ 1.00 - 2.00

■ 2.00 - 3.00

■ 3.00 - 4.00

■ 4.00 - 5.00

■ > 5.00

New Zealand Imagery

Notes:
1. The model terrain is derived from Canterbury Banks Peninsula LiDAR 1m DEM 2023.
2. Debris flow extent presented is a best estimate only.

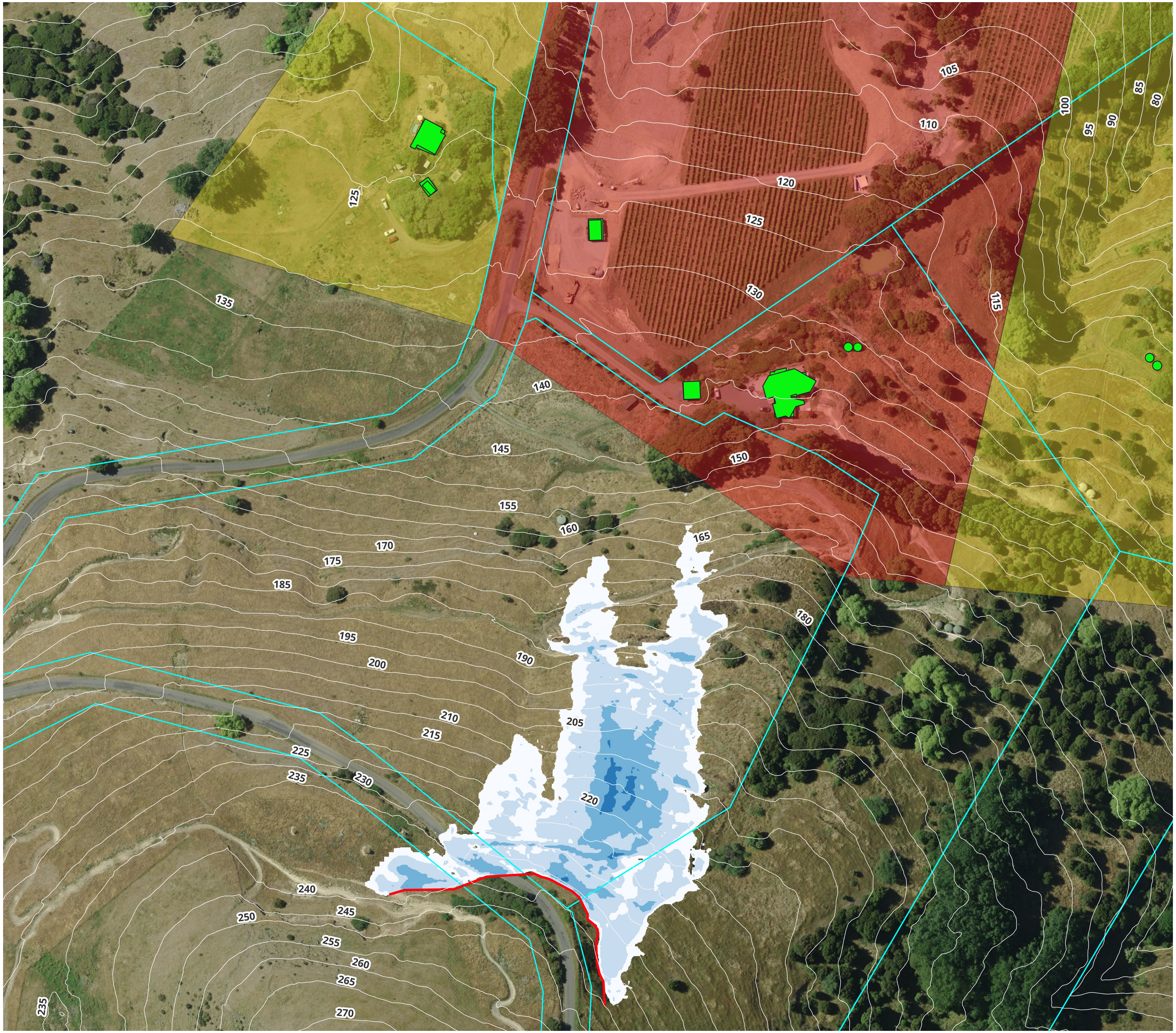
0 50 100 m

ENGEO

Projection: NZTM 2000NZGD2000 / New Zealand Transverse Mercator 2000

Client: Christchurch City Council

Title: Lighthouse Road Landslide 1,000m3 Debris Flow (Maximum Velocity)		Appendix No. Size: A3 Sheet
Project: Lighthouse Road Landslide	Drawn: ZS	
Date: 24/07/2025	Checked: RJ	
Proj No: 28912.000.001	Scale: 800 @ A3	Version: 1.0



- 5m Contours
- Landslide Toe
- 🟥 Primary Evacuation Zone
- 🟨 Secondary Evacuation Zone
- 🟩 NZ Building Outlines
- ☐ NZ Property Titles

Maximum Depth (m)

- ☐ <= 0.50
- ■ 0.50 - 1.00
- ■ 1.00 - 1.50
- ■ 1.50 - 2.00
- ■ > 2.00

New Zealand Imagery

Notes:
1. The model terrain is derived from Canterbury Banks Peninsula LiDAR 1m DEM 2023.
2. Debris flow extent presented is a best estimate only.

0 50 100 m

ENGEO

Projection: NZTM 2000NZGD2000 / New Zealand Transverse Mercator 2000

Client: Christchurch City Council

Title: Lighthouse Road Landslide 3,000m3 Debris Flow (Maximum Depth)

Project: Lighthouse Road Landslide

Drawn: ZS

Date: 24/07/2025

Checked: RJ

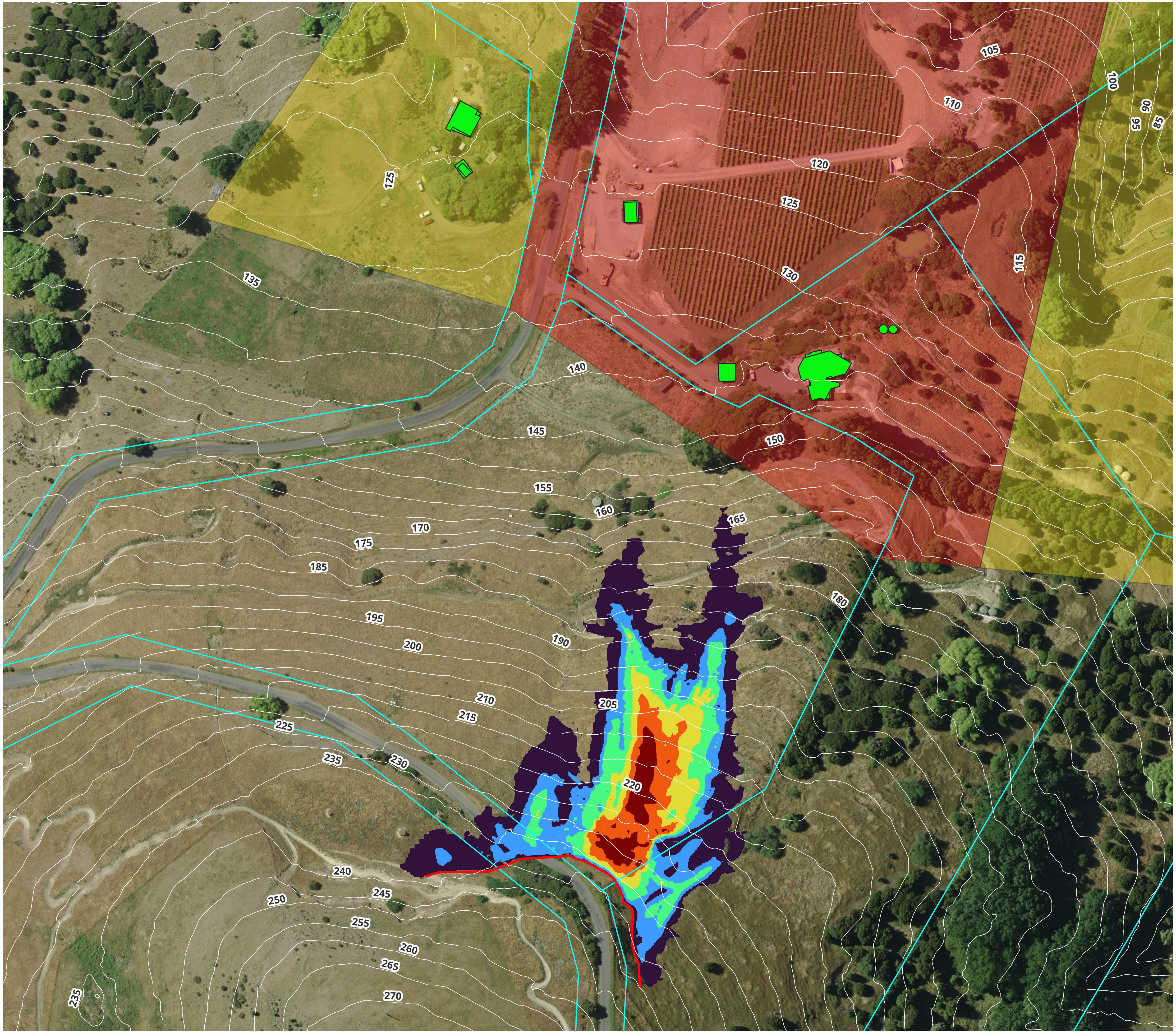
Appendix No.

Size: A3 Sheet

Proj No: 28912.000.001

Scale: 800 @ A3

Version: 1.0



— 5m Contours
— Landslide Toe
🟥 Primary Evacuation Zone
🟨 Secondary Evacuation Zone
🟩 NZ Building Outlines
☐ NZ Property Titles

Maximum Velocity (m/s)

■ <= 1.00
■ 1.00 - 2.00
■ 2.00 - 3.00
■ 3.00 - 4.00
■ 4.00 - 5.00
■ > 5.00

New Zealand Imagery

Notes:
1. The model terrain is derived from Canterbury Banks Peninsula LiDAR 1m DEM 2023.
2. Debris flow extent presented is a best estimate only.

0 50 100 m

ENGEO

Projection: NZTM 2000NZGD2000 / New Zealand Transverse Mercator 2000

Client: Christchurch City Council

Title: Lighthouse Road Landslide 3,000m3 Debris Flow (Maximum Velocity)

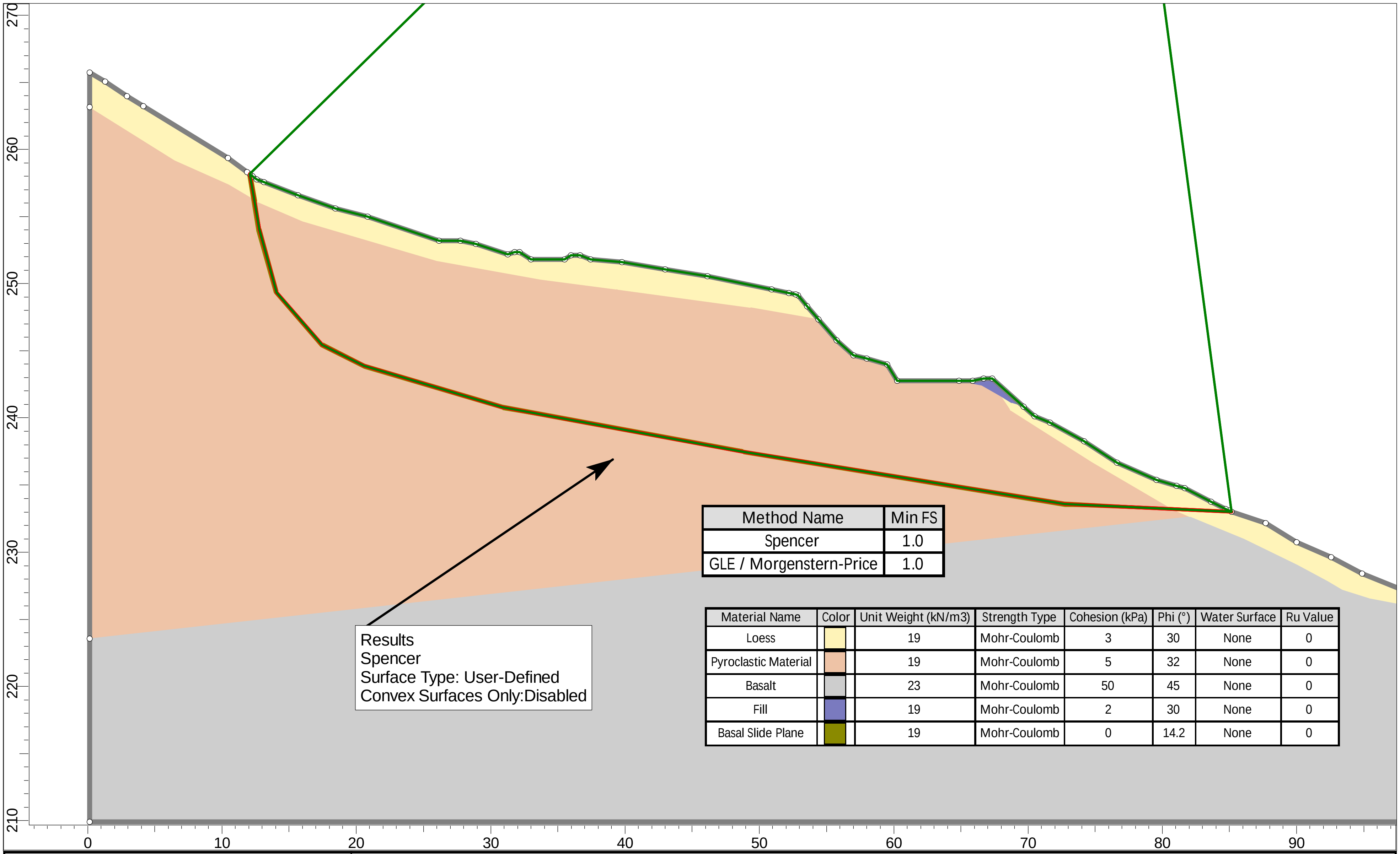
Project: Lighthouse Road Landslide
Drawn: ZS
Appendix No.
Size: A3 Sheet

Date: 24/07/2025
Checked: RJ

Proj No: 28912.000.001
Scale: 800 @ A3
Version: 1.0

APPENDIX 10:

Slope Stability Analysis



Results
Spencer
Surface Type: User-Defined
Convex Surfaces Only:Disabled

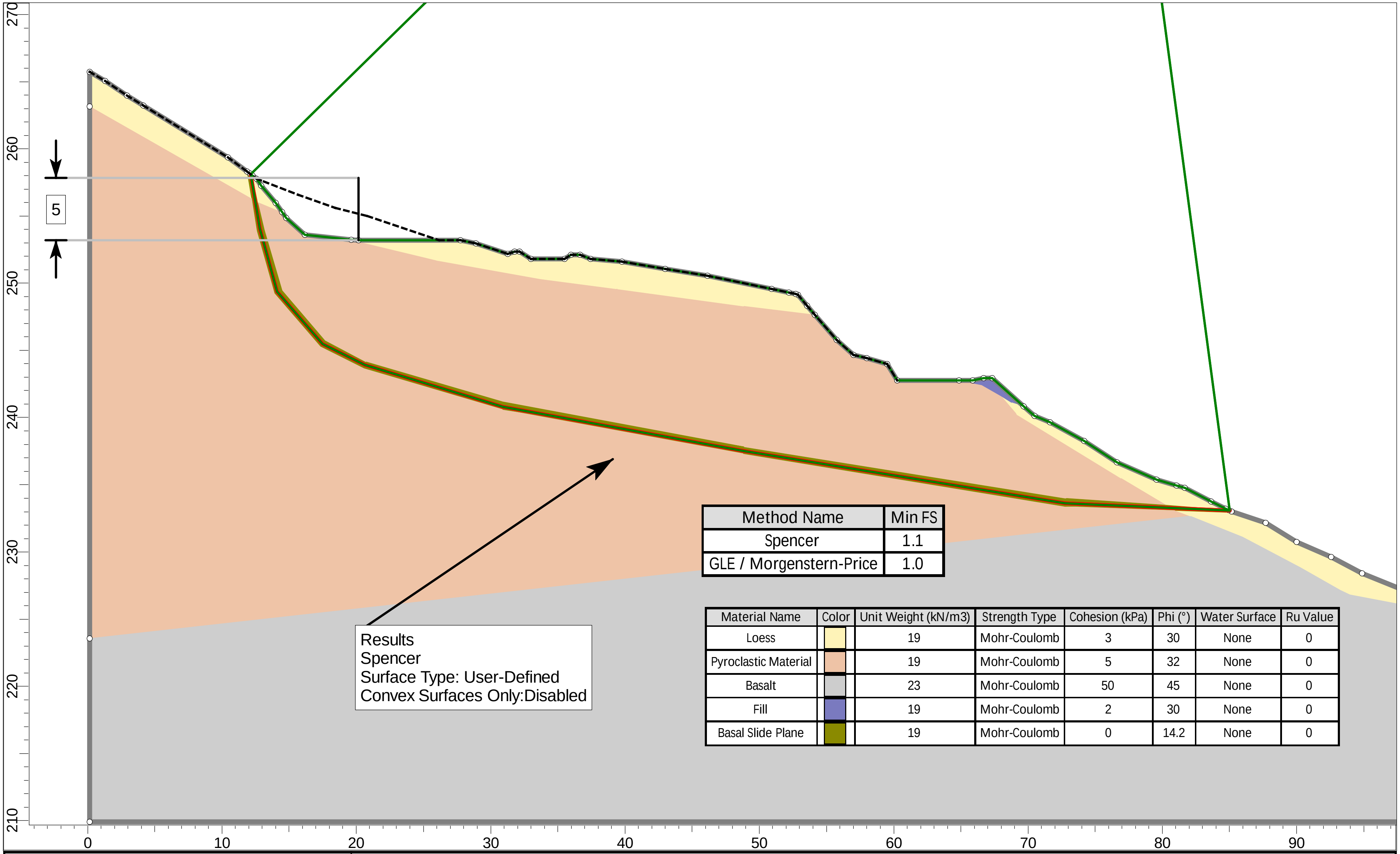
Method Name	Min FS
Spencer	1.0
GLE / Morgenstern-Price	1.0

Material Name	Color	Unit Weight (kN/m3)	Strength Type	Cohesion (kPa)	Phi (°)	Water Surface	Ru Value
Loess	🟨	19	Mohr-Coulomb	3	30	None	0
Pyroclastic Material	🟧	19	Mohr-Coulomb	5	32	None	0
Basalt	⬜	23	Mohr-Coulomb	50	45	None	0
Fill	🟪	19	Mohr-Coulomb	2	30	None	0
Basal Slide Plane	🟩	19	Mohr-Coulomb	0	14.2	None	0

ENGEO

SLIDEINTERPRET 9.036

Project	28912.000.001 Lighthouse Road Landslide - Slope Stability		
Section	1	*Scenario*	Unmodified Slope
Drawn By	ID / DD	*Reviewed By*	JC
Date	07 August 2025	*Scale*	1:400



Method Name	Min FS
Spencer	1.1
GLE / Morgenstern-Price	1.0

Results
Spencer
Surface Type: User-Defined
Convex Surfaces Only:Disabled

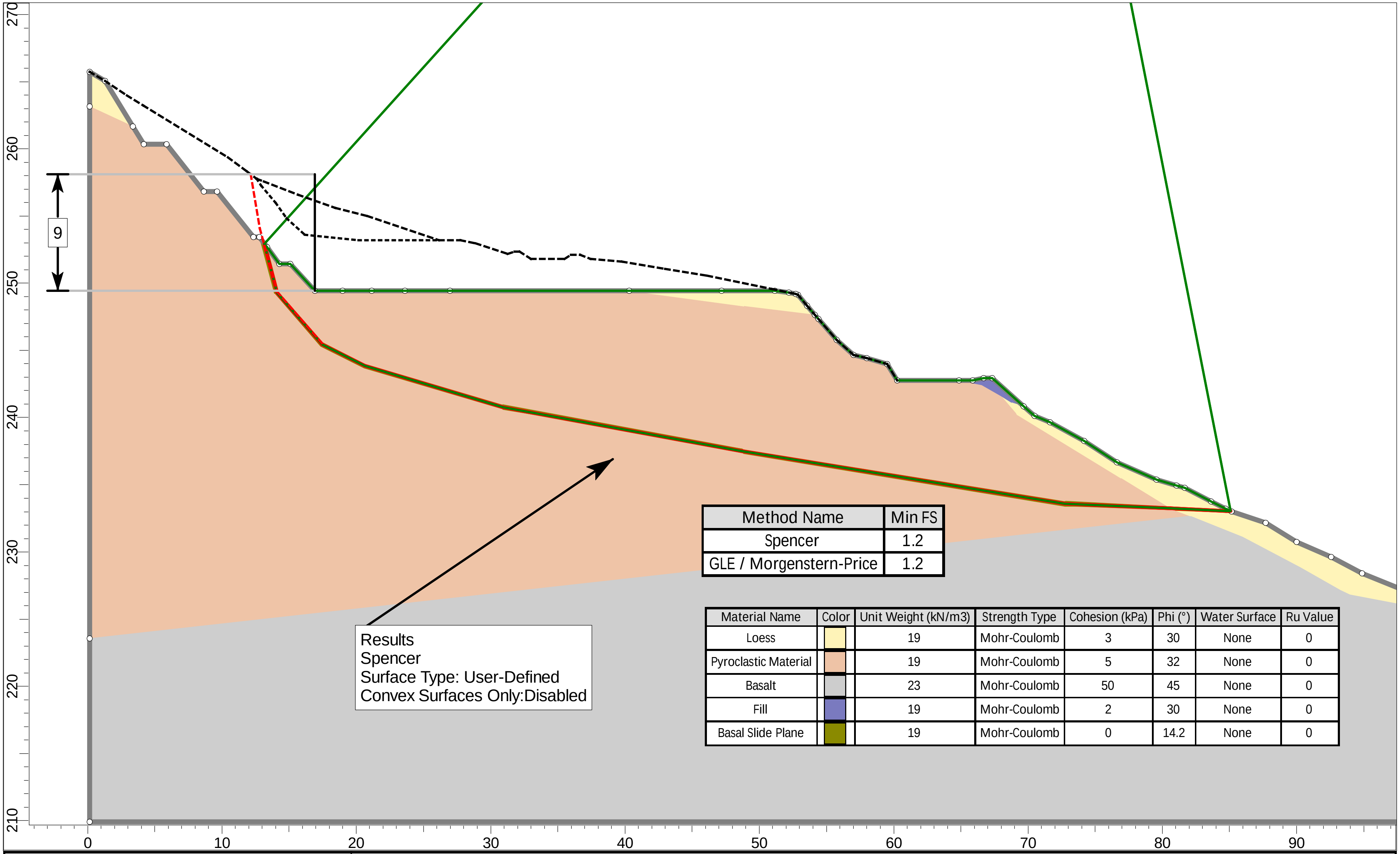
Material Name	Color	Unit Weight (kN/m3)	Strength Type	Cohesion (kPa)	Phi (°)	Water Surface	Ru Value
Loess	🟨	19	Mohr-Coulomb	3	30	None	0
Pyroclastic Material	🟧	19	Mohr-Coulomb	5	32	None	0
Basalt	⬜	23	Mohr-Coulomb	50	45	None	0
Fill	🟪	19	Mohr-Coulomb	2	30	None	0
Basal Slide Plane	🟩	19	Mohr-Coulomb	0	14.2	None	0

ENGEO

SLIDEINTERPRET 9.036

Project	28912.000.001 Lighthouse Road Landslide - Slope Stability

Section	1	*Scenario*	Modified Slope 5 m Cut
Drawn By	ID / DD	*Reviewed By*	JC
Date	07 August 2025	*Scale*	1:400



Method Name	Min FS
Spencer	1.2
GLE / Morgenstern-Price	1.2

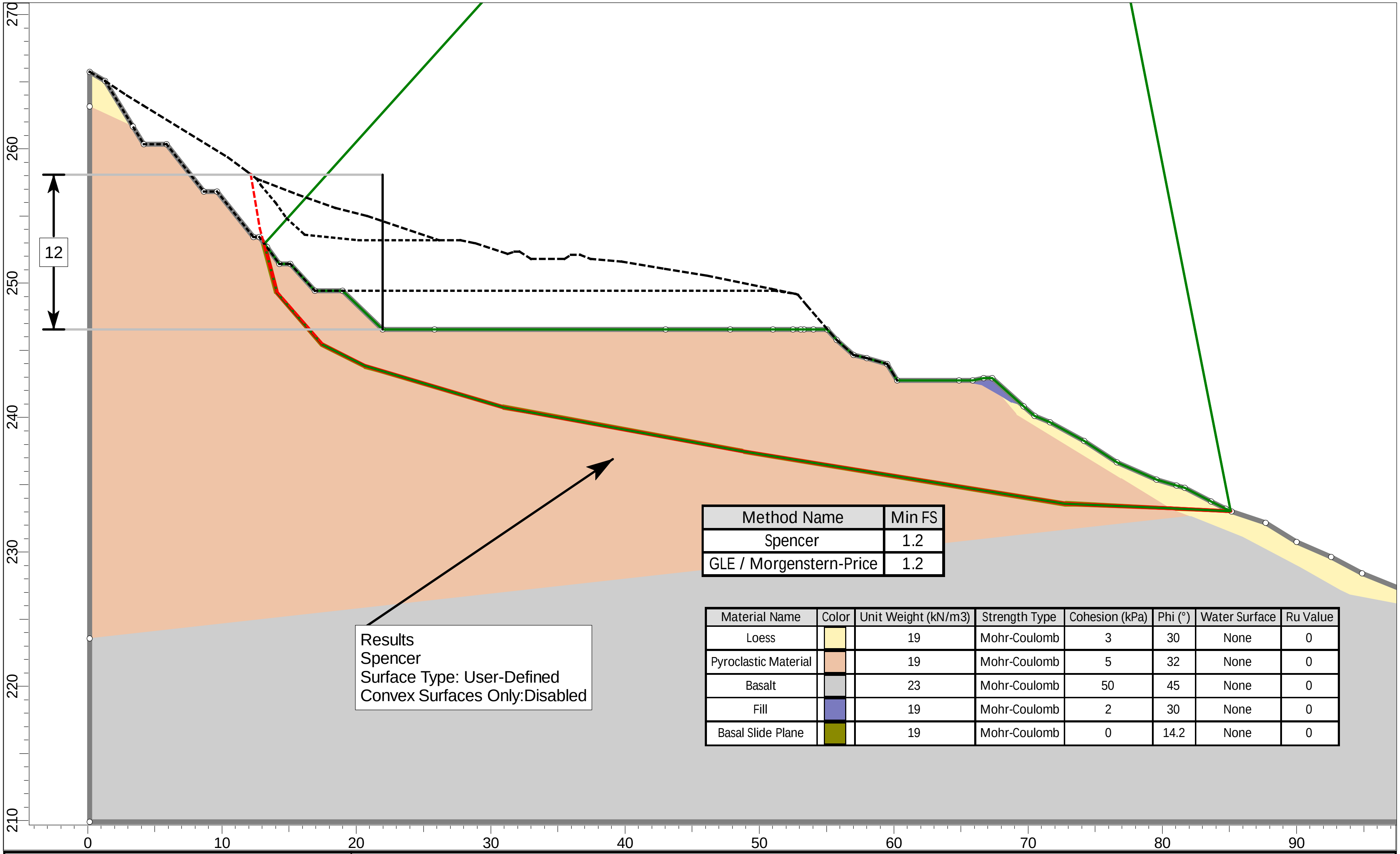
Results
Spencer
Surface Type: User-Defined
Convex Surfaces Only:Disabled

Material Name	Color	Unit Weight (kN/m3)	Strength Type	Cohesion (kPa)	Phi (°)	Water Surface	Ru Value
Loess	🟨	19	Mohr-Coulomb	3	30	None	0
Pyroclastic Material	🟧	19	Mohr-Coulomb	5	32	None	0
Basalt	⬜	23	Mohr-Coulomb	50	45	None	0
Fill	🟪	19	Mohr-Coulomb	2	30	None	0
Basal Slide Plane	🟫	19	Mohr-Coulomb	0	14.2	None	0

ENGEO

SLIDEINTERPRET 9.036

Project	28912.000.001 Lighthouse Road Landslide - Slope Stability		
Section	1	*Scenario*	Modified Slope 9 m Cut
Drawn By	ID / DD	*Reviewed By*	JC
Date	07 August 2025	*Scale*	1:400



Results
Spencer
Surface Type: User-Defined
Convex Surfaces Only:Disabled

Method Name	Min FS
Spencer	1.2
GLE / Morgenstern-Price	1.2

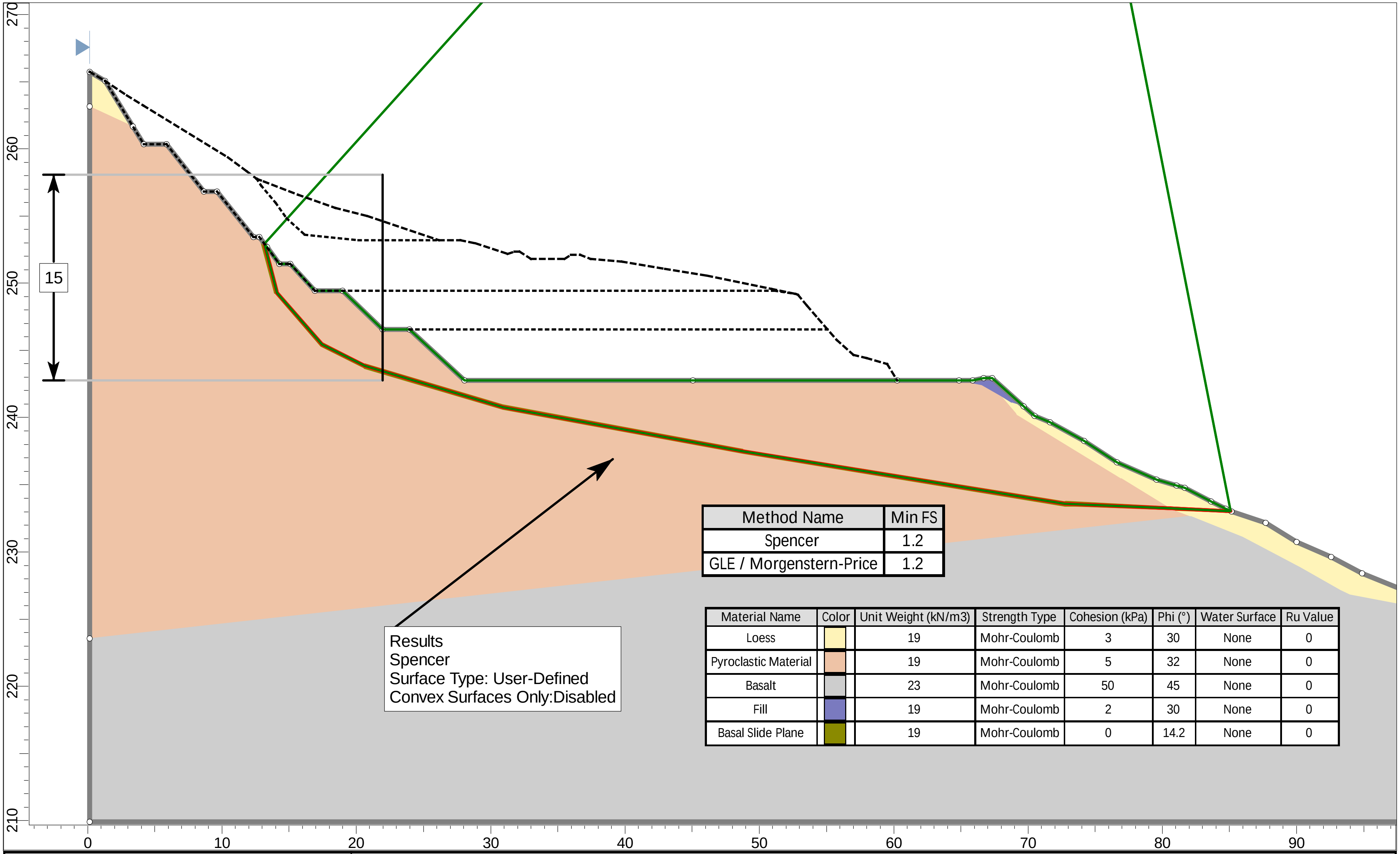
Material Name	Color	Unit Weight (kN/m3)	Strength Type	Cohesion (kPa)	Phi (°)	Water Surface	Ru Value
Loess	🟨	19	Mohr-Coulomb	3	30	None	0
Pyroclastic Material	🟧	19	Mohr-Coulomb	5	32	None	0
Basalt	⬜	23	Mohr-Coulomb	50	45	None	0
Fill	🟪	19	Mohr-Coulomb	2	30	None	0
Basal Slide Plane	🟫	19	Mohr-Coulomb	0	14.2	None	0

ENGEO

SLIDEINTERPRET 9.036

Project	28912.000.001 Lighthouse Road Landslide - Slope Stability

Section	1	*Scenario*	Modified Slope 12 m Cut
Drawn By	ID / DD	*Reviewed By*	JC
Date	07 August 2025	*Scale*	1:400



Results
Spencer
Surface Type: User-Defined
Convex Surfaces Only:Disabled

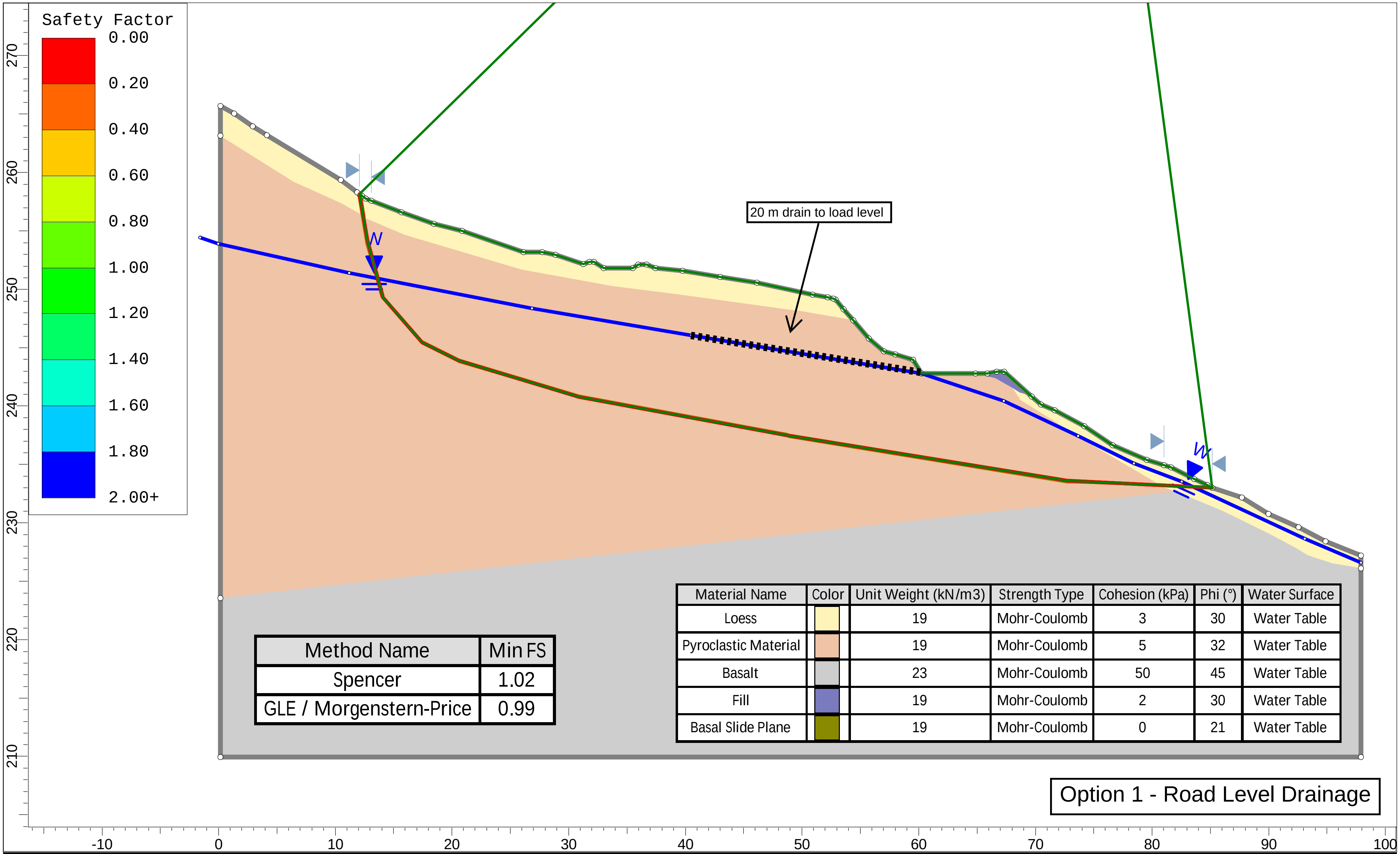
Method Name	Min FS
Spencer	1.2
GLE / Morgenstern-Price	1.2

Material Name	Color	Unit Weight (kN/m3)	Strength Type	Cohesion (kPa)	Phi (°)	Water Surface	Ru Value
Loess	🟨	19	Mohr-Coulomb	3	30	None	0
Pyroclastic Material	🟧	19	Mohr-Coulomb	5	32	None	0
Basalt	⬜	23	Mohr-Coulomb	50	45	None	0
Fill	🟪	19	Mohr-Coulomb	2	30	None	0
Basal Slide Plane	🟫	19	Mohr-Coulomb	0	14.2	None	0

ENGEO

SLIDEINTERPRET 9.036

Project	28912.000.001 Lighthouse Road Landslide - Slope Stability		
Section	1	*Scenario*	Modified Slope 15 m Cut
Drawn By	ID / DD	*Reviewed By*	JC
Date	07 August 2025	*Scale*	1:400



Method Name	Min FS
Spencer	1.02
GLE / Morgenstern-Price	0.99

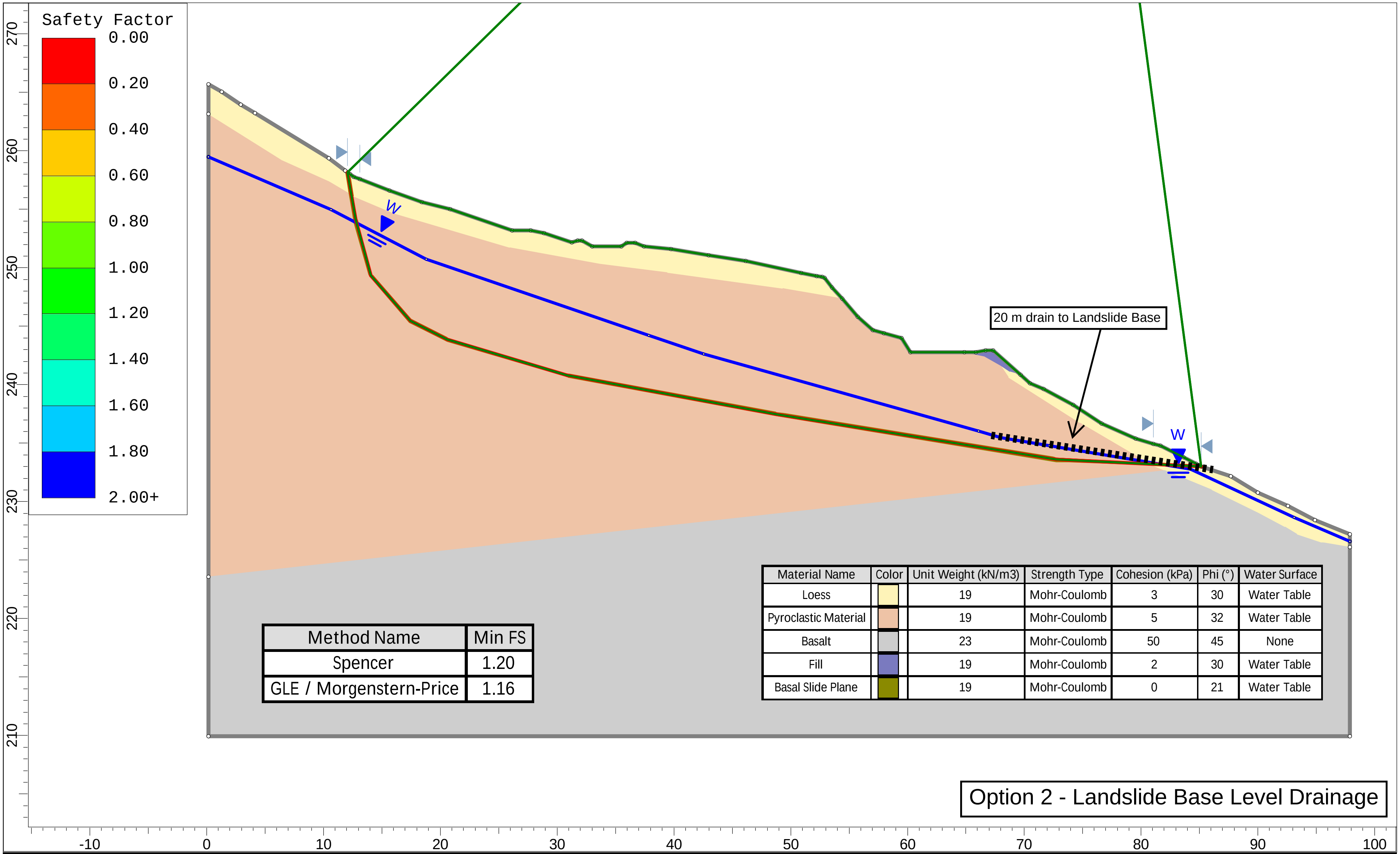
Material Name	Color	Unit Weight (kN/m3)	Strength Type	Cohesion (kPa)	Phi (°)	Water Surface
Loess	🟨	19	Mohr-Coulomb	3	30	Water Table
Pyroclastic Material	🟧	19	Mohr-Coulomb	5	32	Water Table
Basalt	⬜	23	Mohr-Coulomb	50	45	Water Table
Fill	🟪	19	Mohr-Coulomb	2	30	Water Table
Basal Slide Plane	🟫	19	Mohr-Coulomb	0	21	Water Table

Option 1 - Road Level Drainage

ENGEO

Project	Lighthouse Road Landslide Dewatering
Group	Maximum Groundwater Drawdown
Scenario	20 m Drain to Road Level
Drawn By	ID
Company	CCC
Date	9/06/2025, 1:39:09 PM
File Name	Lighthouse Road_DD.slmd

SLIDEINTERPRET 9.037



Method Name	Min FS
Spencer	1.20
GLE / Morgenstern-Price	1.16

Material Name	Color	Unit Weight (kN/m3)	Strength Type	Cohesion (kPa)	Phi (°)	Water Surface
Loess	🟨	19	Mohr-Coulomb	3	30	Water Table
Pyroclastic Material	🟧	19	Mohr-Coulomb	5	32	Water Table
Basalt	⬜	23	Mohr-Coulomb	50	45	None
Fill	🟪	19	Mohr-Coulomb	2	30	Water Table
Basal Slide Plane	🟩	19	Mohr-Coulomb	0	21	Water Table

Option 2 - Landslide Base Level Drainage

ENGEO

SLIDEINTERPRET 9.037

Project	Lighthouse Road Landslide Dewatering
Group	Maximum Groundwater Drawdown
Scenario	20 m Drain to Landslide Base
Drawn By	
Company	
Date	9/06/2025, 1:39:09 PM
File Name	Lighthouse Road_DD.slmd

APPENDIX 11:

Landslide Risk Table (CCC Risk Assessment)

Historical natural hazards causing fatalities in NZ Based on AGS 2007 F-N Curve generated by CoPilot (AI)

Fatalities (N)	Landslides (F)	Earthquakes (F)	Tsunamis (F)	Acceptable Risk (F) (Hong Kong)		Intolerable Risk (F) (Hong Kong)	
1	0.1	0.2	0.05	0.00001		0.001	
10	0.01	0.05	0.02	0.000001		0.0001	
50	0.002	0.01	0.005	0.0000002		0.00002	
100	0.001	0.005	0.002	0.0000001		0.00001	
500		0.001		0.00000002		0.000002	
1000			0.0005	0.00000001		0.000001	

2011 EQ Port Hills Data (GNS 2012-057, Table 44)

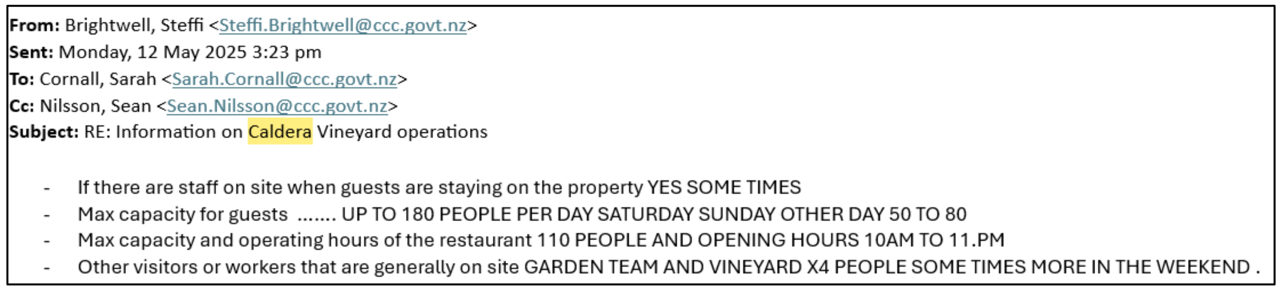
Fatalities (N)	Landslides (f)	Landslides (F)	
1	0.17	0.1948	
6	0.016	0.0248	(2) & night (10) estimates
10	0.008	0.0088	day only
39	0.0008	0.0008	

Norway Landslide Tsunami Fatalities

Fatalities (N)	Trigger Event (f)	Trigger Event (F)
32	0.0037	0.0343
40	0.0112	0.0306
61	0.0083	0.0193
74	0.0110	0.0110

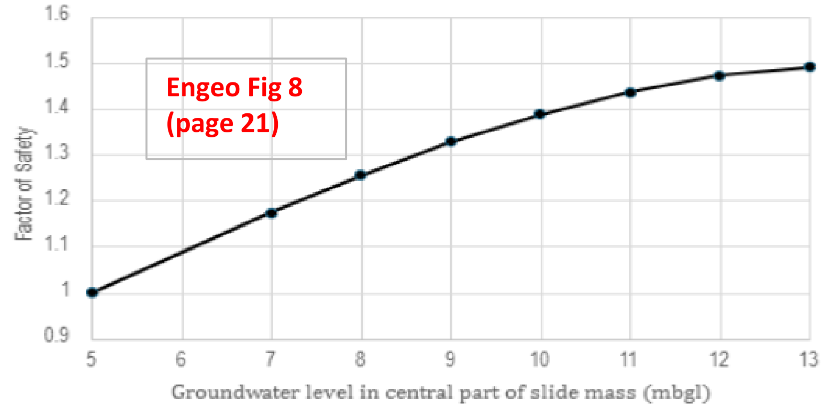
Lighthouse Rd Debris Flow (theoretical)

Scenario	Exposed Pop	Exp Fatalities	Number of Years (e.g. 100)	Reduced Risk (Management)	Comment	plus Dewatering (FoS >1.2)
			100	0.05		0.1
1	100				**Event** booking: 100+ guests/staff (assume once per weekend)	
2	20				**Casual** Restaurant plus staff (assume typical mid-week)	
3	6				essential **Staff** only => winery staff plus garden team	
4	8				Lighthouse Rd - est max exposed population = 2 cars x 4 persons/car	
5	5				Primary Evac zone Residential	
6	50				Secondary Evac zone Residential (Total Population)	



From: Brightwell, Steffi <Steffi.Brightwell@ccc.govt.nz>
Sent: Monday, 12 May 2025 3:23 pm
To: Cornall, Sarah <Sarah.Cornall@ccc.govt.nz>
Cc: Nilsson, Sean <Sean.Nilsson@ccc.govt.nz>
Subject: RE: Information on Caldera Vineyard operations

- If there are staff on site when guests are staying on the property YES SOME TIMES
- Max capacity for guests .... UP TO 180 PEOPLE PER DAY SATURDAY SUNDAY OTHER DAY 50 TO 80
- Max capacity and operating hours of the restaurant 110 PEOPLE AND OPENING HOURS 10AM TO 11.PM
- Other visitors or workers that are generally on site GARDEN TEAM AND VINEYARD X4 PEOPLE SOME TIMES MORE IN THE WEEKEND .



Engeo Fig 8 (page 21)

Winery Scenarios (for each category - Event, Casual, Staff)

Scenario Name	Ann Prob (f)	P of N or more (F)	Exposed Pop	Exp Fatalities (N)	Fatalities per 100 yrs (N_{100})	Risk Man (95%) Ann Prob (f)	Risk w/ EW comp (FoS >1.2)	Description
E1	0.00950	0.01018	2	0.05	5	0.000509	0.000051	Rockfall during Event
E2	0.00047	0.00068	100	0.2	20	0.000034	0.000003	Likely Debris Flow during Event
E3	0.00016	0.00020	100	1	100	0.000010	0.000001	Max Credible Debris Flow during Event
E4	0.00005	0.00005	100	14	1400	0.000002	0.000000	Very Large Debris Flow during Event
C1	0.04749	0.05088	2	0.01	1	0.002544	0.000254	Rockfall during Casual Restaurant Operation

C2	0.00237	0.00340	20	0.04	4	0.000170	0.000017	Likely Debris Flow during Casual Restaurant Operation
C3	0.00078	0.00102	20	0.2	20	0.000051	0.000005	Max Credible Debris Flow Casual Restaurant Operation
C4	0.00024	0.00024	20	2.8	280	0.000012	0.000001	Very Large Debris Flow Casual Restaurant Operation
S1	0.06667	0.07143	2	0.003	0.3	0.003572	0.000357	Rockfall during Staff Operations only (no guests)
S2	0.00333	0.00477	6	0.012	1.2	0.000238	0.000024	Likely Debris Flow during Staff Operations only (no guests)
S3	0.00110	0.00143	6	0.06	6	0.000072	0.000007	Max Credible Debris Flow Staff Operations only (no guests)
S4	0.00033	0.00033	6	0.84	84	0.000017	0.000002	Very Large Debris Flow Staff Operations only (no guests)

Residential Scenarios

Scenario Name	Ann Prob (f)	P of N or more (F)	Exposed Pop	Exp Fatalities (N)	Fatalities per 100 yrs (N_{100})	Risk Man (95%) Ann Prob (f)	Risk w/ EW comp (FoS >1.2)	Description
R1-43	0.00167	0.00185	1	0.0025		0.000092	0.000009	Rockfall #43 Lighthouse Road
R2-43	0.00010	0.00018	5	0.025		0.000009	0.000001	Likely Debris Flow #43 Lighthouse Road
R3-43	0.00003	0.00008	5	0.08		0.000004	0.000000	Max Credible Debris Flow #43 Lighthouse Road
R4-43	0.00004	0.00004	5	0.5		0.000002	0.000000	Very Large Debris Flow #43 Lighthouse Road
R1-SZ	0.00083	0.00135	50	0.005		0.000067	0.000007	Rockfall Secondary Evacuation Zone
R2-SZ	0.00021	0.00051	50	0.025		0.000026	0.000003	Likely Debris Flow Secondary Evacuation Zone
R3-SZ	0.00014	0.00030	50	0.08		0.000015	0.000002	Max Credible Debris Flow Secondary Evacuation Zone
R4-SZ	0.00017	0.00017	50	0.5		0.000008	0.000001	Very Large Debris Flow Secondary Evacuation Zone
R1-41	0.00833	0.01548	2	0.1		0.000774	0.000077	Rockfall #41 Lighthouse Road
R2-41	0.00500	0.00715	5	1.25		0.000358	0.000036	Likely Debris Flow #41 Lighthouse Road
R3-41	0.00165	0.00215	5	3.2		0.000108	0.000011	Max Credible Debris Flow #41 Lighthouse Road
R4-41	0.00050	0.00050	5	5		0.000025	0.000003	Very Large Debris Flow #41 Lighthouse Road

Road Scenarios

Scenario Name	Ann Prob (f)	P of N or more (F)	Exposed Pop	Exp Fatalities (N)	Fatalities per 100 yrs (N_{100})	Risk Man (95%) Ann Prob (f)	Risk w/ EW comp (FoS >1.2)	Description
R1-43	0.000500	0.000536	2	0.005		0.000027	0.000003	Rockfall on LH Road
R2-43	0.000025	0.000036	8	0.16		0.000002	0.000000	Likely Debris Flow LH Road
R3-43	0.000008	0.000011	8	0.8		0.000001	0.000000	Max Credible Debris Flow LH Road
R4-43	0.000003	0.000003	8	3.6		0.000000	0.000000	Very Large Debris Flow LH Road

Individual Risk

			Risk Man (95%) Ann Prob (f)	Risk w/ EW comp (FoS >1.2)	
IR-43	0.000047	1	0.0000023	0.0000002	Individual Risk at 43 Lighthouse Rd (resident)
IR-12	0.000002	1	0.0000001	0.0000000	Individual Risk at 12 Lighthouse Rd (resident)
Caldera-V	0.000001	1	0.0000000	0.0000000	Individual Risk to visitor at Caldera Winery
Caldera-W	0.000108	1	0.0000054	0.0000005	Individual Risk to worker at Caldera Winery
Road User (2 trips/day)	0.000004	1	0.0000002	0.0000000	Individual Risk to person driving on LH Rd
Road User (8 trips/day)	0.000015	1	0.0000007	0.0000001	Individual Risk to person driving on LH Rd
IR-41 (bldg platform)	0.003223	1	0.0001611	0.0000161	Individual Risk at 43 Lighthouse Rd (resident)

Notes about results:

(Without any mitigation)

- all individual risks (AIFR) are considerd tolerable or acceptable, except for an individual living at 41 LH Road (Barrie's building site) would be exposed to **Unacceptable** level of risk,

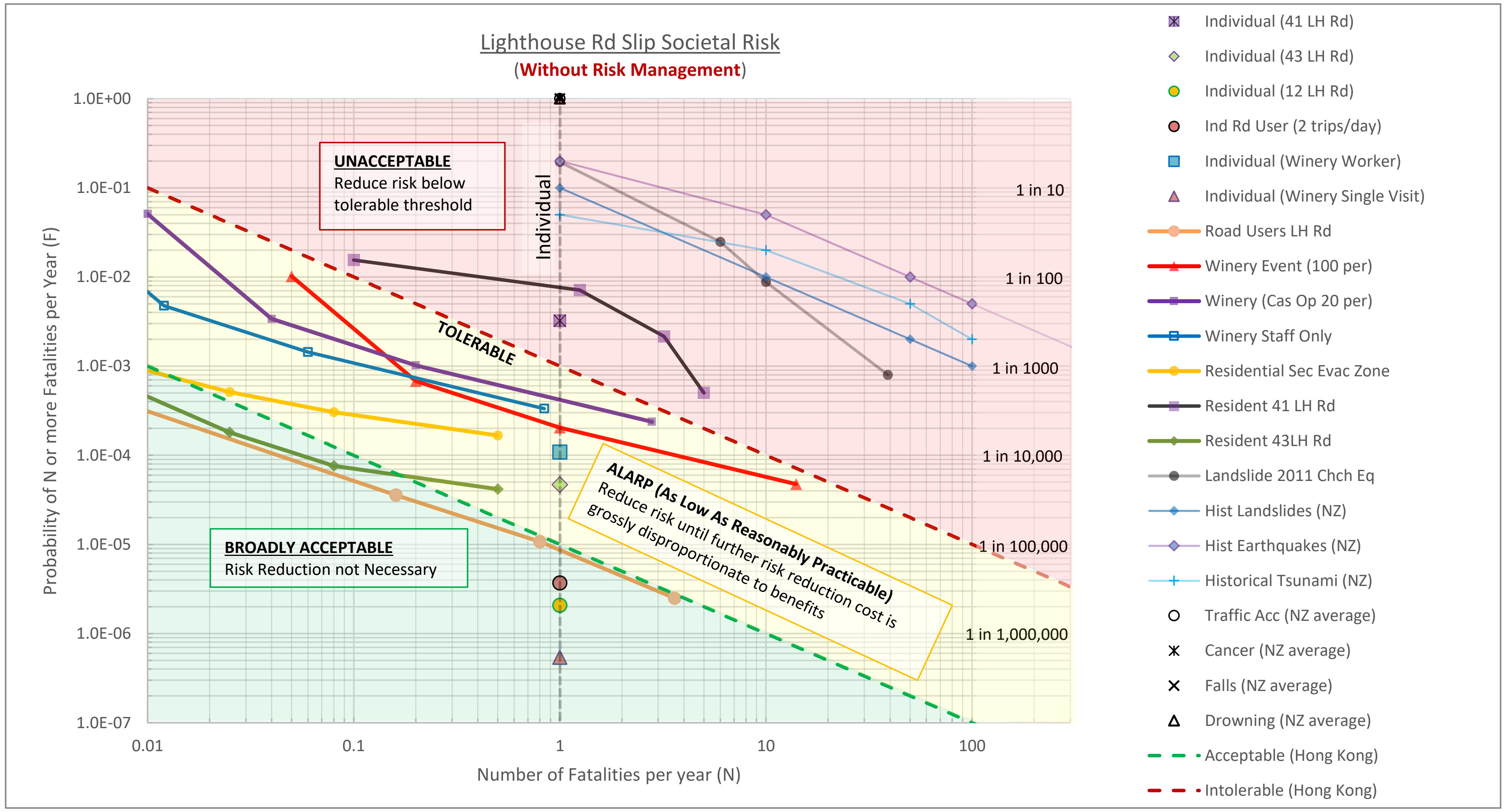
- the next highest individual risk would be to a winery worker (assumed on site 200 days/year) = **1.1×10^{-4}** - this is about the same as the criteria generally accepted for life safety risk due to rockfall in the Port Hills, and is broadly similar to the AIFR associated with driving in New Zealand.

- F-N pairs (societal risk) for winery operations and those living within the secondary evacuation zone are within the **Tolerable** (ALARP) region, indicating that the risk is probably acceptable in the short-term, but should be reduced as much as reasonably practicable over the longer-term,

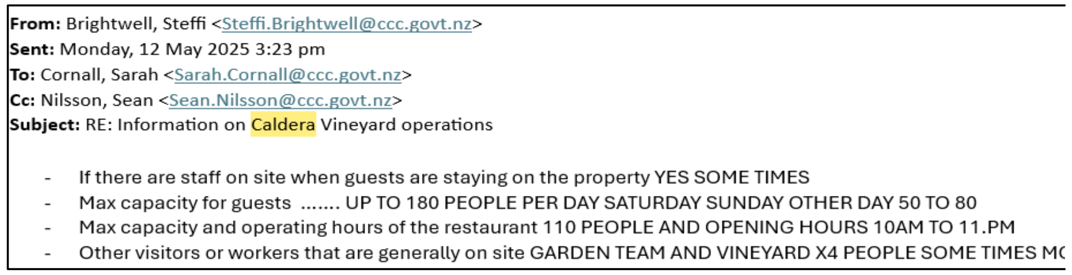
- The theoretical societal risk for residents living at the current building platform on Barries property (#41 Lighthouse Rd) is considered within the **Unacceptable** region, indicating that it is not safe for people to live there without implementing some mitigation and/or ongoing risk management,

- The societal risk for general road users (Lighthouse Rd at and below the slip area) and residents within the secondary evacuation zone are typically within the **Acceptable** region - no further action is required to mitigate these risks.

-



Caldera Winery - Inputs



From: Brightwell, Steffi <Steffi.Brightwell@ccc.govt.nz>
Sent: Monday, 12 May 2025 3:23 pm
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- Max capacity and operating hours of the restaurant 110 PEOPLE AND OPENING HOURS 10AM TO 11.PM
- Other visitors or workers that are generally on site GARDEN TEAM AND VINEYARD X4 PEOPLE SOME TIMES MC

Input Values for Risk Assessment
For the **Individual** most at risk
Assumes a visitor or employee who is subjected to debris flow or rockfall without any prior warning
Hazard from the "active" landslide area is considered only
Assumes person most at risk is fully exposed (not protected by barriers, etc)

Probabilities of Occurrence for Various Events (assumes no mitigation)

		Population Exposed?	
	$P_{(H)}$	**100**	Occurrence Interval
Likely Debris Flow (~1,000 m^3)	0.0100	0	occurs about once per 100 years
Maximum Credible Debris Flow (3,000 m^3)	0.0033	0	~1 per 300 years (unlikley)
Very Large Debris Flow (3,000-10,000 m^3)	0.0010	20	~1 per 1000 years (very unlikely)
Other (isolated Rockfall or small landslide)	0.2000	1	~1 per 5 years (uncertain)

Spatial and Temporal Exposure for Various Slope Hazards

Likely Debris Flow (~1,000 m3)	inundation depth 0-0.5m			
Average exposure time (per visit)		3.00	hours	estimated average exposure time
Temporal spatial probability $P_{(T:S)}$		3.42E-04		probability that a person will be in the path of debris flow
Probability of spatial impact $P_{(S:H)}$		0.01		Modelling shows event does not reach building
Maximum Credible Debris Flow (3,000 m3)	inundation depth 0.5-1m			
Average exposure time (per visit)		3.00	hours	estimated average exposure time
Temporal spatial probability $P_{(T:S)}$		3.42E-04		probability that a person will be in the path of debris flow
Probability of spatial impact $P_{(S:H)}$		0.02		Modelling shows event does not reach building
Very Large Debris Flow (3,000-10,000 m3)	inundation depth 1-2m			
Average exposure time (per visit)		3.00	hours	estimated average exposure time
Temporal spatial probability $P_{(T:S)}$		3.42E-04		probability that a person will be in the path of debris flow
Probability of spatial impact $P_{(S:H)}$		0.20		Event would need to be directed towards winery to reach area
Isolated Rockfall	no inundation, impact only			
Average exposure time (per visit)		5.00	minutes	estimated average exposure time
Temporal spatial probability $P_{(T:S)}$		9.51E-06		probability that a person will be in the path of rockfall
Probability of spatial impact $P_{(S:H)}$		0.50		building may provide some protection, etc

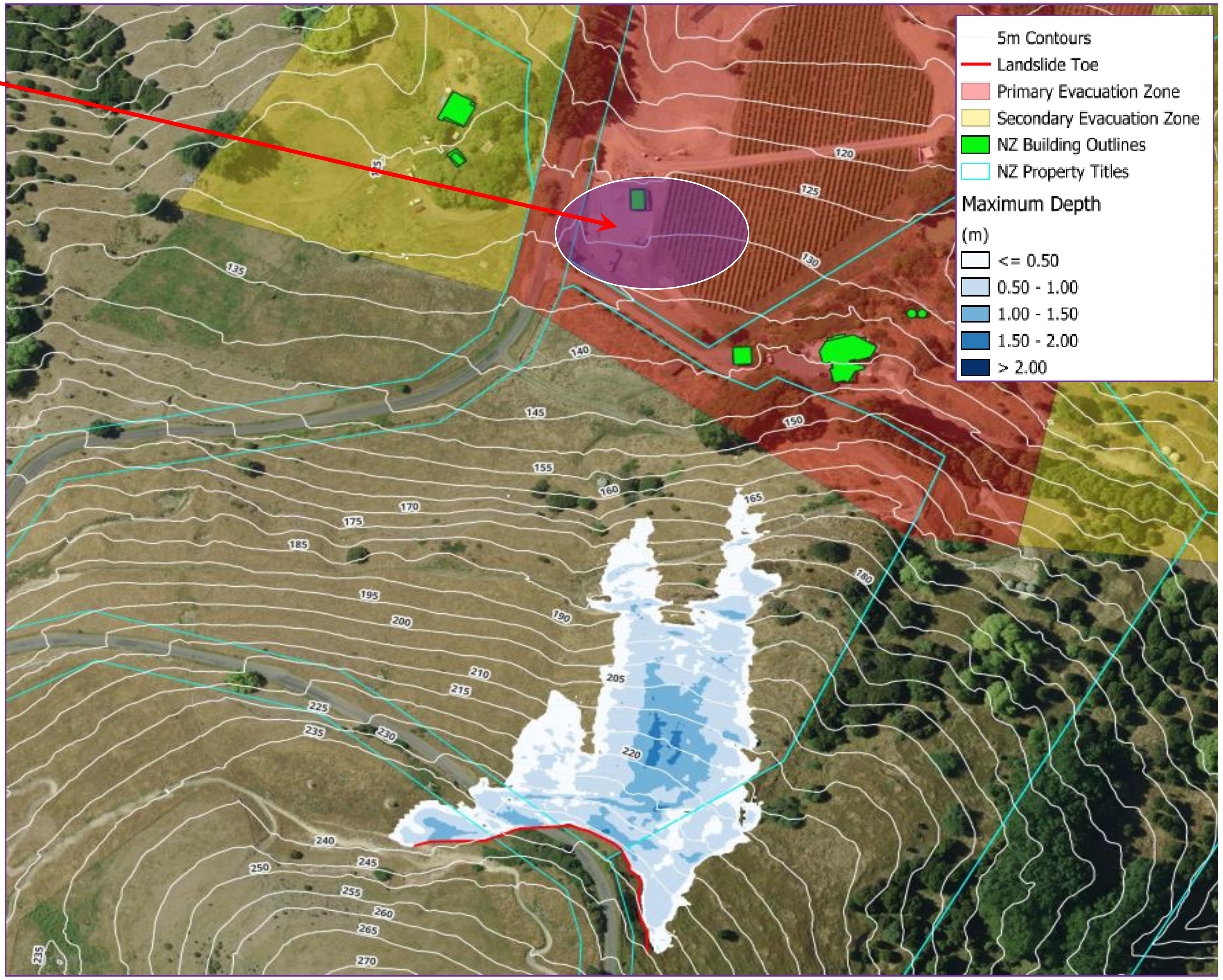
Vulnerability of Individuals Impacted by Various Slope Hazards

Likely Debris Flow (~1,000 m3)	$V_{(D:T)}$	vulnerability depends on depth and velocity of flow
probability of loss of life or serious injury given impact $V_{(D:T)}$	0.20	Not buried, high chance of survival
Maximum Credible Debris Flow (3,000 m3)		
probability of loss of life or serious injury given impact $V_{(D:T)}$	0.50	Not buried but serious injury/death possible
Very Large Debris Flow (3,000-10,000 m3)		
probability of loss of life or serious injury given impact $V_{(D:T)}$	0.70	death is possible/likley but debris may be slow moving, or be directed by obstacles before reaching buildings
Other (isolated Rockfall or small landslide)		
probability of loss of life or serious injury given impact $V_{(D:T)}$	0.50	rock energy dissapates beyond toe of slope

Caldera Winery - Calculations

Risk Tables for Debris Flow & Rockfall Events

From Engeo Worst-case Debris Flow Model (3,000m3)



Likely Debris Flow (~1,000 m3)

	Value	***Basis***
$P_{(H)}$	0.010	occurs about once per 100 years
$P_{(S:H)}$	0.01	probability of spatial impact
$P_{(T:S)}$	3.42E-04	probability that a person will be in the path of debris flow
$V_{(D:T)}$	0.20	vulnerability of a person if struck
$R_{(LOL)}$	6.8E-09	Risk to visitor (individual most at risk)

Maximum Credible Debris Flow (3,000 m3)

	Value	***Basis***
$P_{(H)}$	0.003	occurs about once per 300 years
$P_{(S:H)}$	0.02	probability of spatial impact
$P_{(T:S)}$	3.42E-04	probability that a person will be in the path of debris flow
$V_{(D:T)}$	0.50	vulnerability of a person if struck
$R_{(LOL)}$	1.1E-08	Risk to visitor (individual most at risk)

Very Large Debris Flow (3,000-10,000 m3)

	Value	***Basis***
$P_{(H)}$	0.001	occurs about once per 1000 years
$P_{(S:H)}$	0.20	probability of spatial impact
$P_{(T:S)}$	3.42E-04	probability that a person will be in the path of debris flow
$V_{(D:T)}$	0.70	vulnerability of a person if struck
$R_{(LOL)}$	4.8E-08	Risk to visitor (individual most at risk)

Other (isolated Rockfall or small landslide)

	Value	***Basis***
$P_{(H)}$	0.20	occurs about once per 5 years
$P_{(S:H)}$	0.50	probability of spatial impact
$P_{(T:S)}$	9.51E-06	probability that a person will be in the path of rockfall/landslide
$V_{(D:T)}$	0.50	vulnerability of a person if struck
$R_{(LOL)}$	4.8E-07	Risk to visitor (individual most at risk)

Total Cumulative Risk (AIFR)

5.4E-07	Cumulative Risk to Individual most at risk (single 4-hour trip per annum)
7.9E-04	Annual Risk to person living on site (365 days per year)
1.1E-04	Annual Risk to most exposed Individual (e.g. a worker, assuming 200 visits/year)

Annual Aggregate Risk Depending on Visitor Numbers (persons per day)

	Winery Guests per event (assume one event per weekend = 52 events/year)
1.4E-04	5

#43 Lighthouse Rd - Inputs

Input Values for Risk Assessment
For the **Individual** most at risk
Assumes a person on their propety who is subjected to debris flow or rockfall without any prior warning
Hazard from the "active" landslide area is considered only
Assumes person most at risk is fully exposed (not protected by barriers, etc)
Note that the house is not exposed to the hazard, but the garage/driveway are

Probabilities of Occurrence for Various Events (assumes no mitigation)

	$P_{(H)}$	Occurrence Interval
Likely Debris Flow (~1,000 m^3)	0.0100	occurs about once per 100 years
Maximum Credible Debris Flow (3,000 m^3)	0.0033	~1 per 300 years (unlikley)
Very Large Debris Flow (5,000-10,000 m^3)	0.0010	~1 per 1000 years (very unlikely)
Other (isolated Rockfall or small landslide)	0.2000	~1 per 5 years (uncertain)

Spatial and Temporal Exposure for Various Slope Hazards

Likely Debris Flow (~1,000 m3)	inundation unlikely			
Average daily exposure time (resident)		0.25	hours	estimated average exposure time
Temporal spatial probability $P_{(T:S)}$		1.04E-02		probability that a person will be in the path of debris flow
Probability of spatial impact $P_{(S:H)}$		0.01		Modelling shows event does not reach site
Maximum Credible Debris Flow (3,000 m3)	inundation unlikely			
Average daily exposure time (resident)		0.25	hours	estimated average exposure time
Temporal spatial probability $P_{(T:S)}$		1.04E-02		probability that a person will be in the path of debris flow
Probability of spatial impact $P_{(S:H)}$		0.02		Modelling shows event does not reach site
Very Large Debris Flow (5,000-10,000 m3)	inundation unlikely			
Average daily exposure time (resident)		1.00	hours	estimated average exposure time
Temporal spatial probability $P_{(T:S)}$		4.17E-02		probability that a person will be in the path of debris flow
Probability of spatial impact $P_{(S:H)}$		0.10		Even if event occurs, would need to be exceptional to reach area
Other (isolated Rockfall or small landslide)	no inundation, impact only			
Average daily exposure time (resident)		0.20	hours	estimated average exposure time
Temporal spatial probability $P_{(T:S)}$		8.33E-03		probability that a person will be in the path of a single rockfall
Probability of spatial impact $P_{(S:H)}$		0.05		Prob of impacting person is small. Buildings may provide some pr

Vulnerability of Individuals Impacted by Various Slope Hazards

	$V_{(D:T)}$	
Likely Debris Flow (~1,000 m3)		vulnerability depends on depth and velocity of flow
probability of loss of life or serious injury given impact $V_{(D:T)}$	0.50	even chance of survival
Maximum Credible Debris Flow (3,000 m3)		
probability of loss of life or serious injury given impact $V_{(D:T)}$	0.80	low chance of survival
Very Large Debris Flow (5,000-10,000 m3)		
probability of loss of life or serious injury given impact $V_{(D:T)}$	1.00	death is almost certain
Other (isolated Rockfall or small landslide)		
probability of loss of life or serious injury given impact $V_{(D:T)}$	0.50	rock energy/velocity disapates quickly at toe of slope

#43 Lighthouse Rd - Calculations

Risk Tables for Debris Flow & Rockfall Events

Likely Debris Flow (~1,000 m3)

	Value	*Basis*
$P_{(H)}$	0.010	occurs about once per 100 years
$P_{(S:H)}$	0.01	probability of spatial impact
$P_{(T:S)}$	1.04E-02	probability that a person will be in the path of debris flow
$V_{(D:T)}$	0.50	vulnerability of a person if struck
$R_{(LOL)}$	5.2E-07	Risk to resident (individual most at risk)

Maximum Credible Debris Flow (3,000 m3)

	Value	*Basis*
$P_{(H)}$	0.003	occurs about once per 300 years
$P_{(S:H)}$	0.02	probability of spatial impact
$P_{(T:S)}$	1.04E-02	probability that a person will be in the path of debris flow
$V_{(D:T)}$	0.80	vulnerability of a person if struck
$R_{(LOL)}$	5.5E-07	Risk to resident (individual most at risk)

Very Large Debris Flow (3,000-10,000 m3)

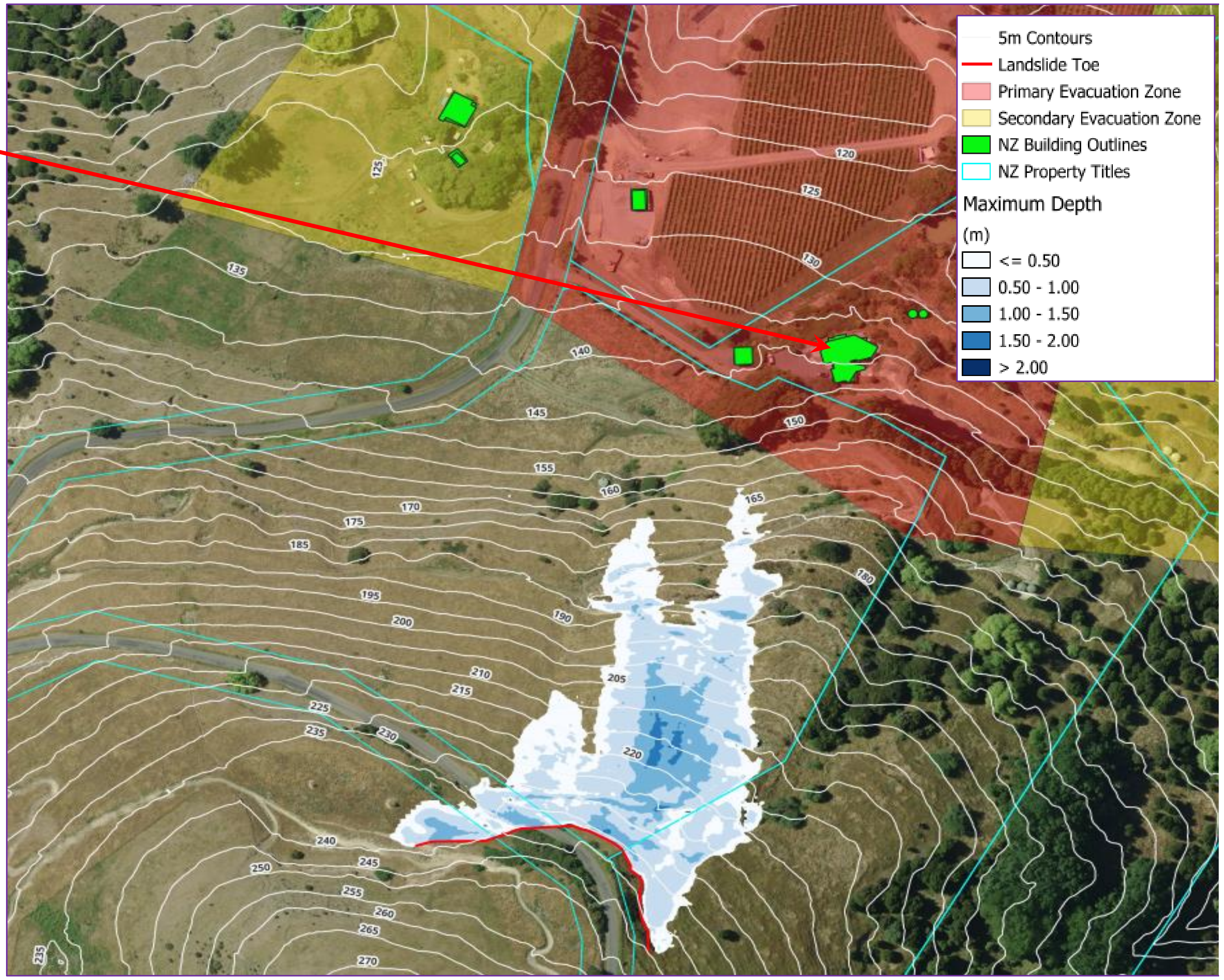
	Value	*Basis*
$P_{(H)}$	0.001	occurs about once per 1000 years
$P_{(S:H)}$	0.10	probability of spatial impact
$P_{(T:S)}$	4.17E-02	probability that a person will be in the path of debris flow
$V_{(D:T)}$	1.00	vulnerability of a person if struck
$R_{(LOL)}$	4.2E-06	Risk to resident (individual most at risk)

Other (isolated Rockfall or small landslide)

	Value	*Basis*
$P_{(H)}$	0.200	occurs about once per 5 years
$P_{(S:H)}$	0.05	probability of spatial impact
$P_{(T:S)}$	8.33E-03	probability that a person will be in the path of rockfall/landslide
$V_{(D:T)}$	0.50	vulnerability of a person if struck
$R_{(LOL)}$	4.2E-05	Risk to resident (individual most at risk)

Total Cumulative Risk (AIFR)

4.7E-05	Cumulative Risk to Resident (no mitigation)
4.7E-06	with 90% reduction due to risk management
2.3E-06	with 95% reduction due to risk management



#41 Lighthouse Rd - Inputs (Existing Building Platform)

Input Values for Risk Assessment
For the **Individual** most at risk
Assumes a person on their propety who is subjected to debris flow or rockfall without any prior warning
Hazard from the "active" landslide area is considered only
Assumes person most at risk is fully exposed (not protected by barriers, etc)

Probabilities of Occurrence for Various Events (assumes no mitigation)

	$P_{(H)}$	Occurrence Interval
Likely Debris Flow (~1,000 m^3)	0.0100	occurs about once per 100 years
Maximum Credible Debris Flow (3,000 m^3)	0.0033	~1 per 300 years (unlikley)
Very Large Debris Flow (5,000-10,000 m^3)	0.0010	~1 per 1000 years (very unlikely)
Other (isolated Rockfall or small landslide)	0.2000	~1 per 5 years (uncertain)

Spatial and Temporal Exposure for Various Slope Hazards

Likely Debris Flow (~1,000 m3)	inundation unlikely			
Average daily exposure time (resident)		12.00	hours	estimated average exposure time
Temporal spatial probability $P_{(T:S)}$		5.00E-01		probability that a person will be in the path of debris flow
Probability of spatial impact $P_{(S:H)}$		0.50		Modelling shows event does not reach site
Maximum Credible Debris Flow (3,000 m3)	inundation unlikely			
Average daily exposure time (resident)		12.00	hours	estimated average exposure time
Temporal spatial probability $P_{(T:S)}$		5.00E-01		probability that a person will be in the path of debris flow
Probability of spatial impact $P_{(S:H)}$		0.80		Modelling shows event does not reach site
Very Large Debris Flow (5,000-10,000 m3)	inundation unlikely			
Average daily exposure time (resident)		12.00	hours	estimated average exposure time
Temporal spatial probability $P_{(T:S)}$		5.00E-01		probability that a person will be in the path of debris flow
Probability of spatial impact $P_{(S:H)}$		1.00		Even if event occurs, would need to be exceptional to reach area
Other (isolated Rockfall or small landslide)	no inundation, impact only			
Average daily exposure time (resident)		1.00	hours	estimated average exposure time
Temporal spatial probability $P_{(T:S)}$		4.17E-02		probability that a person will be in the path of a single rockfall
Probability of spatial impact $P_{(S:H)}$		0.10		Prob of impacting person is small. Buildings may provide some pr

Vulnerability of Individuals Impacted by Various Slope Hazards

Likely Debris Flow (~1,000 m3)	$V_{(D:T)}$	vulnerability depends on depth and velocity of flow
probability of loss of life or serious injury given impact $V_{(D:T)}$	0.50	even chance of survival
Maximum Credible Debris Flow (3,000 m3)		
probability of loss of life or serious injury given impact $V_{(D:T)}$	0.80	low chance of survival
Very Large Debris Flow (5,000-10,000 m3)		
probability of loss of life or serious injury given impact $V_{(D:T)}$	1.00	death is almost certain
Other (isolated Rockfall or small landslide)		
probability of loss of life or serious injury given impact $V_{(D:T)}$	0.50	rock energy/velocity disapates quickly at toe of slope

#41 Lighthouse Rd - Calculations

Risk Tables for Debris Flow & Rockfall Events

Likely Debris Flow (~1,000 m3)

	Value	***Basis***
$P_{(H)}$	0.010	occurs about once per 100 years
$P_{(S:H)}$	0.50	probability of spatial impact
$P_{(T:S)}$	5.00E-01	probability that a person will be in the path of debris flow
$V_{(D:T)}$	0.50	vulnerability of a person if struck
$R_{(LOL)}$	1.3E-03	Risk to resident (individual most at risk)

Maximum Credible Debris Flow (3,000 m3)

	Value	***Basis***
$P_{(H)}$	0.003	occurs about once per 300 years
$P_{(S:H)}$	0.80	probability of spatial impact
$P_{(T:S)}$	5.00E-01	probability that a person will be in the path of debris flow
$V_{(D:T)}$	0.80	vulnerability of a person if struck
$R_{(LOL)}$	1.1E-03	Risk to resident (individual most at risk)

Very Large Debris Flow (3,000-10,000 m3)

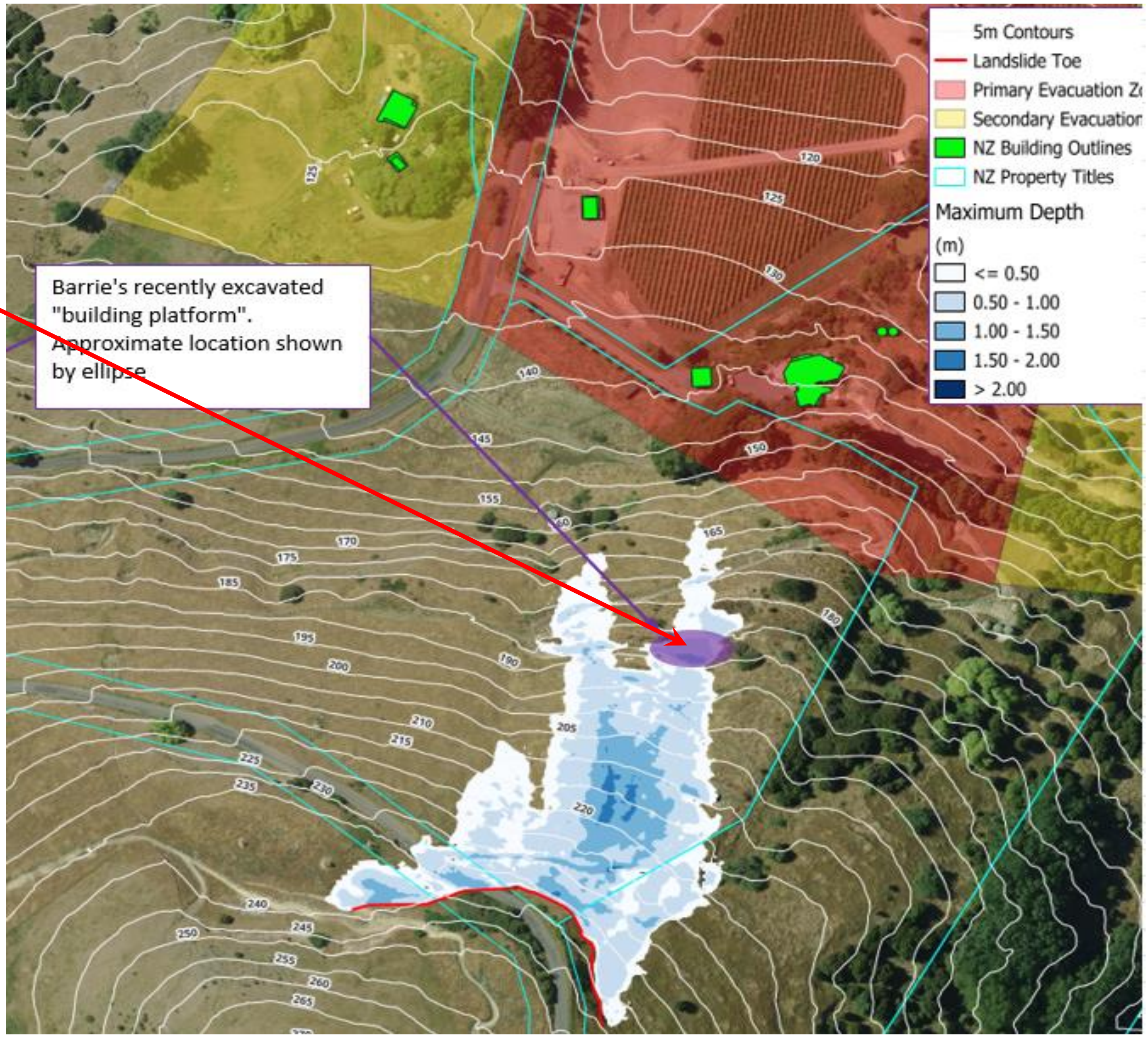
	Value	***Basis***
$P_{(H)}$	0.001	occurs about once per 1000 years
$P_{(S:H)}$	1.00	probability of spatial impact
$P_{(T:S)}$	5.00E-01	probability that a person will be in the path of debris flow
$V_{(D:T)}$	1.00	vulnerability of a person if struck
$R_{(LOL)}$	5.0E-04	Risk to resident (individual most at risk)

Other (isolated Rockfall or small landslide)

	Value	***Basis***
$P_{(H)}$	0.200	occurs about once per 5 years
$P_{(S:H)}$	0.10	probability of spatial impact
$P_{(T:S)}$	4.17E-02	probability that a person will be in the path of rockfall/landslide
$V_{(D:T)}$	0.50	vulnerability of a person if struck
$R_{(LOL)}$	4.2E-04	Risk to resident (individual most at risk)

Total Cumulative Risk (AIFR)

3.2E-03	Cumulative Risk to Resident (no mitigation)
3.2E-04	with 90% reduction due to risk management
1.6E-04	with 95% reduction due to risk management


Barrie's recently excavated "building platform". Approximate location shown by ellipse

#12 Lighthouse Rd - Inputs

Input Values for Risk Assessment
For the **Individual** most at risk
Assumes a person on their propety who is subjected to debris flow or rockfall without any prior warning
Hazard from the "active" landslide area is considered only
Assumes person most at risk is fully exposed (not protected by barriers, etc)

Probabilities of Occurrence for Various Events (assumes no mitigation)

	$P_{(H)}$	Occurrence Interval
Likely Debris Flow (~1,000 m^3)	0.0100	occurs about once per 100 years
Maximum Credible Debris Flow (3,000 m^3)	0.0033	~1 per 300 years (unlikley)
Very Large Debris Flow (5,000-10,000 m^3)	0.0010	~1 per 1000 years (very unlikely)
Other (isolated Rockfall or small landslide)	0.2000	~1 per 5 years (uncertain)

Spatial and Temporal Exposure for Various Slope Hazards

Likely Debris Flow (~1,000 m3)	probably won't reach property			
Average daily exposure time (resident)		0.50	hours	estimated average exposure time
Temporal spatial probability $P_{(T:S)}$		2.08E-02		probability that a person will be in the path of debris flow
Probability of spatial impact $P_{(S:H)}$		0.001		Modelling shows does not reach area
Maximum Credible Debris Flow (3,000 m3)	inundation depth 0-0.5m			
Average daily exposure time (resident)		1.00	hours	estimated average exposure time
Temporal spatial probability $P_{(T:S)}$		4.17E-02		probability that a person will be in the path of debris flow
Probability of spatial impact $P_{(S:H)}$		0.002		Modelling shows does not reach area
Very Large Debris Flow (5,000-10,000 m3)	inundation depth 0.5-1m			
Average daily exposure time (resident)		4.00	hours	estimated average exposure time
Temporal spatial probability $P_{(T:S)}$		1.67E-01		probability that a person will be in the path of debris flow
Probability of spatial impact $P_{(S:H)}$		0.010		Exceptional event only
Other (isolated Rockfall or small landslide)	does not reach			
Average daily exposure time (resident)		0.10	hours	estimated average exposure time
Temporal spatial probability $P_{(T:S)}$		4.17E-03		probability that a person will be in the path of rockfall
Probability of spatial impact $P_{(S:H)}$		0.001		Unlikley to reach this shadow angle

Vulnerability of Individuals Impacted by Various Slope Hazards

	$V_{(D:T)}$	vulnerability depends on depth and velocity of flow
Likely Debris Flow (~1,000 m3)		
probability of loss of life or serious injury given impact $V_{(D:T)}$	0.50	even chance of survival
Maximum Credible Debris Flow (3,000 m3)		
probability of loss of life or serious injury given impact $V_{(D:T)}$	0.80	low chance of survival
Very Large Debris Flow (5,000-10,000 m3)		
probability of loss of life or serious injury given impact $V_{(D:T)}$	1.00	death is almost certain
Other (isolated Rockfall or small landslide)		
probability of loss of life or serious injury given impact $V_{(D:T)}$	0.10	Rock is unlikely to have much energy even if it is able to reac

Risk Reduction Factor

#12 Lighthouse Rd - Calculations

Risk Tables for Debris Flow & Rockfall Events

Likely Debris Flow (~1,000 m3)

	Value	***Basis***
$P_{(H)}$	0.01	occurs about once per 100 years
$P_{(S:H)}$	0.00	probability of spatial impact
$P_{(T:S)}$	2.08E-02	probability that a person will be in the path of debris flow
$V_{(D:T)}$	0.50	vulnerability of a person if struck
$R_{(LOL)}$	1.0E-07	Risk to resident (individual most at risk)

Maximum Credible Debris Flow (3,000 m3)

	Value	***Basis***
$P_{(H)}$	0.00	occurs about once per 10 years
$P_{(S:H)}$	0.00	probability of spatial impact
$P_{(T:S)}$	4.17E-02	probability that a person will be in the path of debris flow
$V_{(D:T)}$	0.80	vulnerability of a person if struck
$R_{(LOL)}$	2.2E-07	Risk to resident (individual most at risk)

Very Large Debris Flow (3,000-10,000 m3)

	Value	***Basis***
$P_{(H)}$	0.00	occurs about once per 100 years
$P_{(S:H)}$	0.01	probability of spatial impact
$P_{(T:S)}$	1.67E-01	probability that a person will be in the path of debris flow
$V_{(D:T)}$	1.00	vulnerability of a person if struck
$R_{(LOL)}$	1.7E-06	Risk to resident (individual most at risk)

Other (isolated Rockfall or small landslide)

	Value	***Basis***
$P_{(H)}$	0.20	occurs about once per 5 years
$P_{(S:H)}$	0.00	probability of spatial impact
$P_{(T:S)}$	4.17E-03	probability that a person will be in the path of rockfall/landslide
$V_{(D:T)}$	0.10	vulnerability of a person if struck
$R_{(LOL)}$	8.3E-08	Risk to resident (individual most at risk)

Total Cumulative Risk (AIFR)

2.1E-06	Cumulative Risk to Resident (no mitigation)
2.1E-07	with 90% reduction due to risk management
1.0E-07	with 95% reduction due to risk management
1.0E-04	Aggregate risk assuming 50 persons exposed (no mitigation)

Road User (Lighthouse Rd) Inputs

Input Values for Risk Assessment
For the **Individual** most at risk
Assumes a person driving on the road below the landslilde is subjected to debris flow or rockfall without any prior warning
Hazard from the "active" landslide area is considered only
Assumes person most at risk is within a vehicle

Total distance on road exposed to hazard (from Onuku Rd intersection)	**1.2**
Average speed (km/hr)	**40**
Driving Time (hours)	**0.030**

Probabilities of Occurrence for Various Events (assumes no mitigation)

	$P_{(H)}$	Occurrence Interval
Likely Debris Flow (~1,000 m^3)	0.0100	occurs about once per 100 years
Maximum Credible Debris Flow (3,000 m^3)	0.0033	~1 per 300 years (unlikley)
Very Large Debris Flow (5,000-10,000 m^3)	0.0010	~1 per 1000 years (very unlikely)
Other (isolated Rockfall or small landslide)	0.2000	~1 per 5 years (uncertain)

Spatial and Temporal Exposure for Various Slope Hazards

Likely Debris Flow (~1,000 m^3)	probably won't reach road			
Average daily exposure time (2 trips/day)		0.06	hours	estimated average exposure time
Temporal spatial probability $P_{(T:S)}$		2.50E-03		probability that a person in vehicle will be in the path of debris
Probability of spatial impact $P_{(S:H)}$		0.10		only affects part of the road, may be able to avoid debris/drop
Maximum Credible Debris Flow (3,000 m^3)	probably won't reach road			
Average daily exposure time (2 trips/day)		0.06	hours	estimated average exposure time
Temporal spatial probability $P_{(T:S)}$		2.50E-03		probability that a person in vehicle will be in the path of debris
Probability of spatial impact $P_{(S:H)}$		0.20		only affects part of the road, may be able to avoid debris/drop
Very Large Debris Flow (5,000-10,000 m^3)	inundation depth 0.5-1m			
Average daily exposure time (2 trips/day)		0.06	hours	estimated average exposure time
Temporal spatial probability $P_{(T:S)}$		2.50E-03		probability that a person in vehicle will be in the path of debris
Probability of spatial impact $P_{(S:H)}$		0.50		Even very large event will not inundate full road
Other (isolated Rockfall or small landslide)	does not reach			
Average daily exposure time (2 trips/day)		0.06	hours	estimated average exposure time
Temporal spatial probability $P_{(T:S)}$		2.50E-03		probability that a person in vehicle will be in the path of rockfa
Probability of spatial impact $P_{(S:H)}$		0.01		Single rockfall could roll down road ~100m

Vulnerability of Individuals Impacted by Various Slope Hazards

Likely Debris Flow (~1,000 m3)	$V_{(D:T)}$	vulnerability depends on velocity and type of accident (car hit
probability of loss of life or serious injury given impact $V_{(D:T)}$	0.20	Vehicle may partially protect from debris flow and/or drop out
Maximum Credible Debris Flow (3,000 m3)		
probability of loss of life or serious injury given impact $V_{(D:T)}$	0.50	Vehicle may partially protect from debris flow and/or drop out
Very Large Debris Flow (5,000-10,000 m3)		
probability of loss of life or serious injury given impact $V_{(D:T)}$	0.90	Even very large event will not inundate full road
Other (isolated Rockfall or small landslide)		
probability of loss of life or serious injury given impact $V_{(D:T)}$	0.30	From AGS2007 Practice Note Guidelines, Appendix F

Road User (Lighthouse Rd) Risk Calcs

Risk Tables for Debris Flow & Rockfall Events

Likely Debris Flow (~1,000 m3)

	Value	*Basis*
$P_{(H)}$	0.01	occurs about once per 100 years
$P_{(S:H)}$	0.10	probability of spatial impact
$P_{(T:S)}$	2.50E-03	probability that a person will be in the path of debris flow
$V_{(D:T)}$	0.20	vulnerability of a person if struck
$R_{(LOL)}$	5.0E-07	Risk to resident (individual most at risk)

Maximum Credible Debris Flow (3,000 m3)

	Value	*Basis*
$P_{(H)}$	0.00	occurs about once per 10 years
$P_{(S:H)}$	0.20	probability of spatial impact
$P_{(T:S)}$	2.50E-03	probability that a person will be in the path of debris flow
$V_{(D:T)}$	0.50	vulnerability of a person if struck
$R_{(LOL)}$	8.3E-07	Risk to resident (individual most at risk)

Very Large Debris Flow (3,000-10,000 m3)

	Value	*Basis*
$P_{(H)}$	0.00	occurs about once per 100 years
$P_{(S:H)}$	0.50	probability of spatial impact
$P_{(T:S)}$	2.50E-03	probability that a person will be in the path of debris flow
$V_{(D:T)}$	0.90	vulnerability of a person if struck
$R_{(LOL)}$	1.1E-06	Risk to resident (individual most at risk)

Other (isolated Rockfall or small landslide)

	Value	*Basis*
$P_{(H)}$	0.20	occurs about once per 5 years
$P_{(S:H)}$	0.01	probability of spatial impact
$P_{(T:S)}$	2.50E-03	probability that a person will be in the path of rockfall/landslide
$V_{(D:T)}$	0.30	vulnerability of a person if struck
$R_{(LOL)}$	1.3E-06	Risk to resident (individual most at risk)

Total Cumulative Risk (AIFR)

3.7E-06	Individual Risk for 2 x Road Trips per day
3.7E-07	with 90% reduction due to risk management
1.9E-07	with 95% reduction due to risk management
1.9E-04	Aggregate risk assuming 50 persons exposed (no mitigation)

3,000 m^3 is now considered to be the worst-case scenario for debris flow

Updated Aug2025 following BHs & lab testing

1,000m^3 Debris Flow

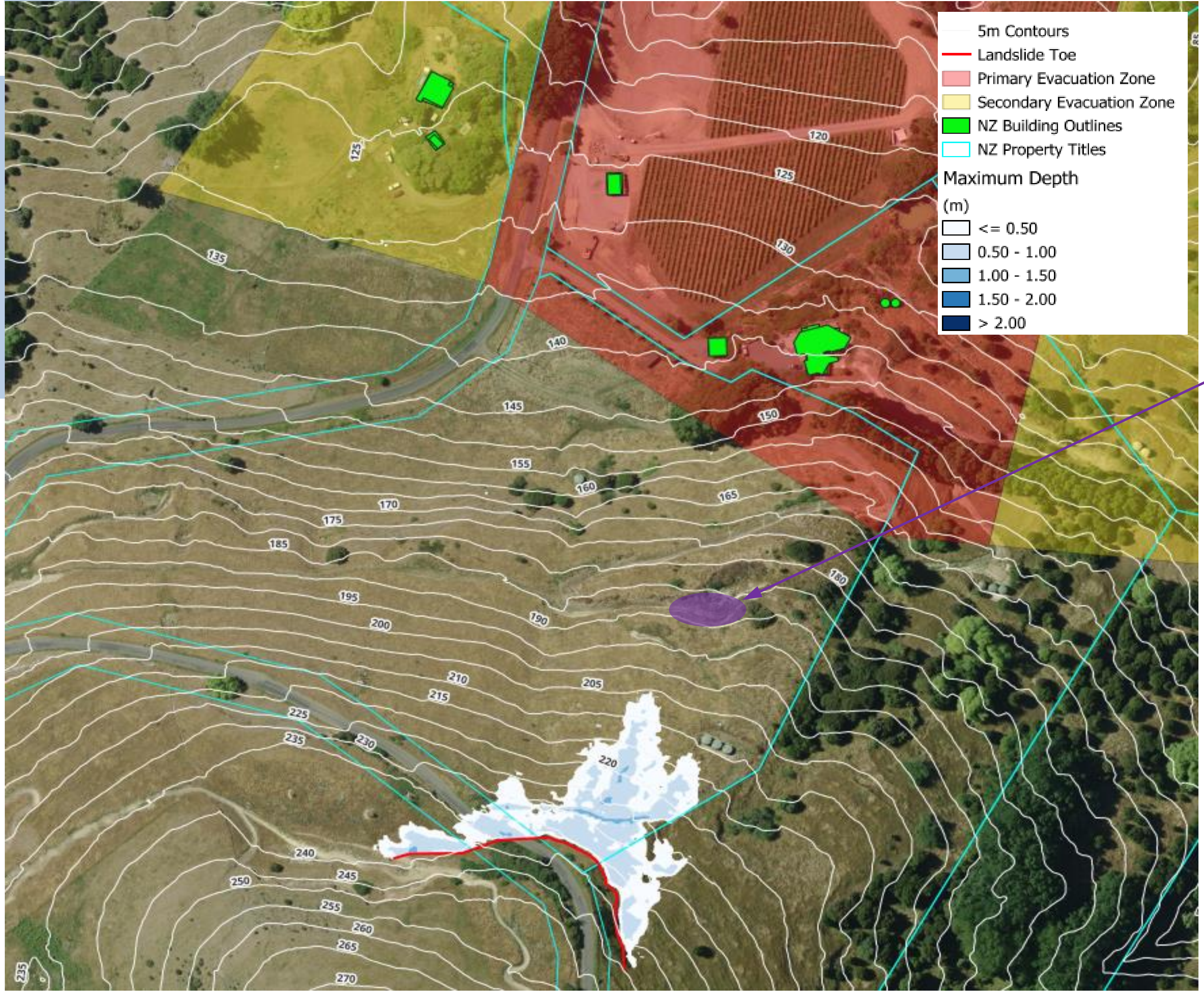
Most likely DF volume, in the event that the toe transforms into a rapidly moving DF.
No inundation of existing buildings/structures. Debris does not reach excavated building platform on #41 LH Road (Barrie's property).

3,000m^3 Debris Flow

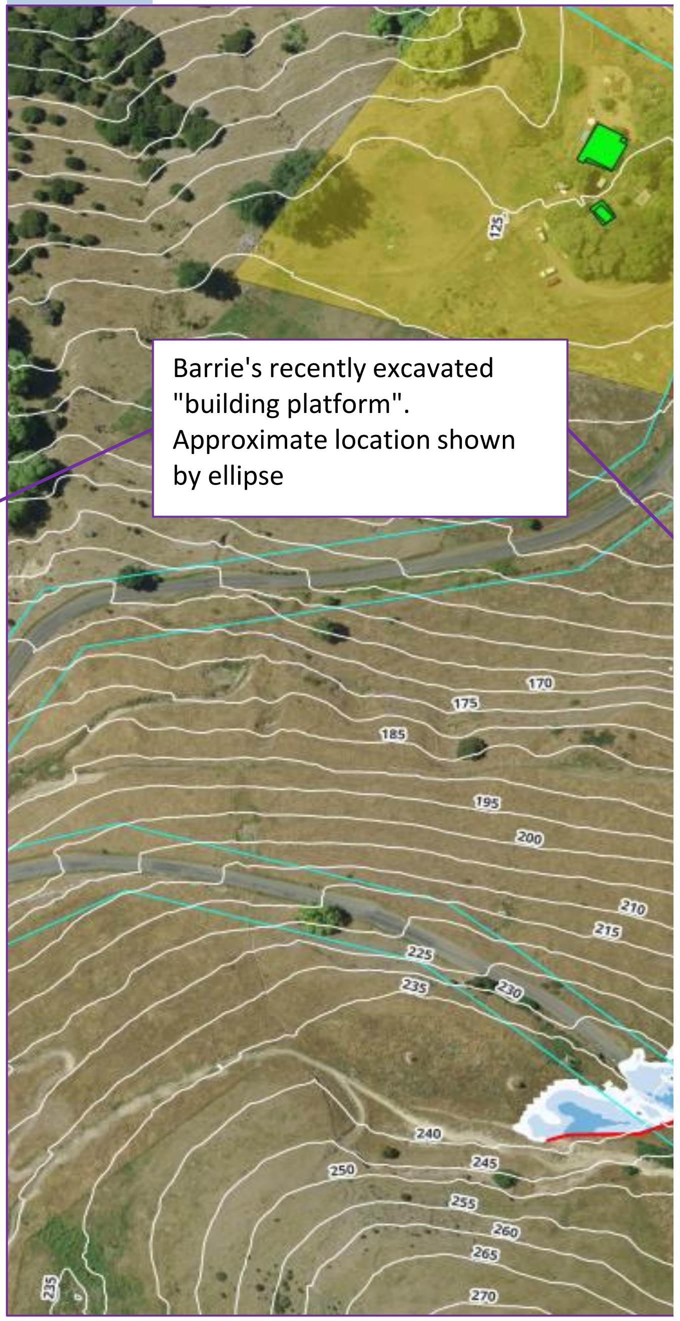
Largest credible event based on eng geological model.

No inundation of existing buildings/structures. Debris does reach excavated building platform on #41, but would have a maximum depth of around 1-1.5m at the back of the bench.

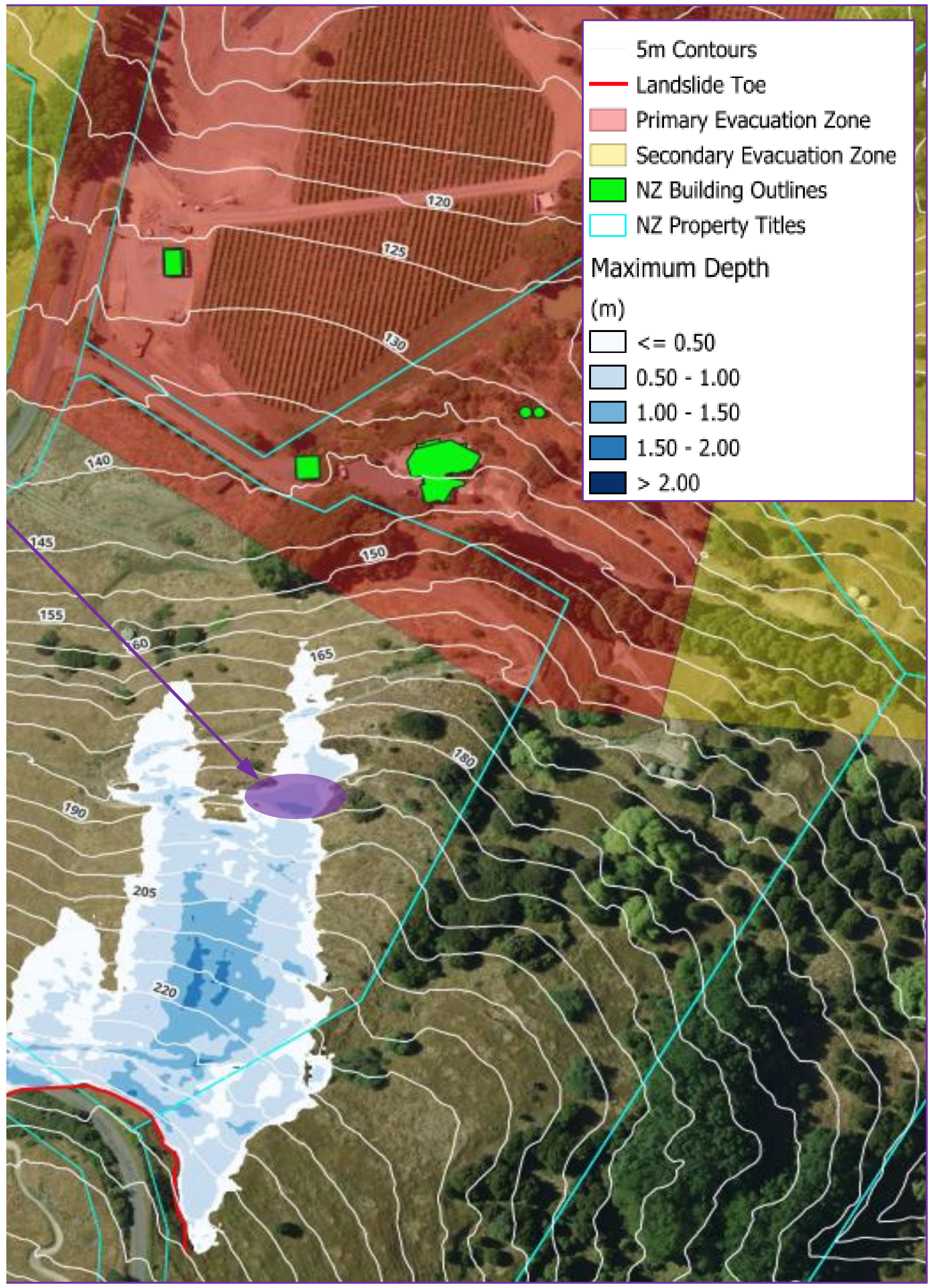
1,000m^3



3,000m^3



Barrie's recently excavated "building platform". Approximate location shown by ellipse


5m Contours
Landslide Toe
Primary Evacuation Zone
Secondary Evacuation Zone
NZ Building Outlines
NZ Property Titles
Maximum Depth
(m)
<= 0.50
0.50 - 1.00
1.00 - 1.50
1.50 - 2.00
> 2.00
120
125
130
140
145
150
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160
165
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190
205
220