Dunedin City Council

LTES LONG-TERM LANDSLIDE MONITORING

PUKETERAKI LANDSLIDE

13 FEBRUARY 2025

CONFIDENTIAL

LTES LONG-TERM LANDSLIDE MONITORING
PUKETERAKI LANDSLIDE

Dunedin City Council

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	NAME	DATE	SIGNATURE
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1 INTRODUCTION

WSP New Zealand Limited (WSP) was engaged by Dunedin City Council (DCC) to undertake a geological site walkover and UAV survey of the Puketeraki Landslide as part of the LTES Long-term Landslide Monitoring project. The scope of services is presented in the WSP Offer of Service dated 3 September 2024, and are summarised below;

- Conduct a site walkover to identify any geological features or notable observations
- Undertake a UAV survey and create an aerial image to aid in feature mapping
- Compile site observations and UAV information into a site-specific report with a high-level interpretation of the geologic setting

The inspection was undertaken by Caitlin Hall (Engineering Geologist) and David Moffat (Surveyor) on 22 October 2024. The inspection was limited to a site walkover within the ORC's defined landslide boundaries, and an Unmanned Aerial Vehicle (UAV) survey. The site inspection was completed following heavy rainfall experienced in Dunedin on 4 October 2024 (160 mm in 24hrs), prior to this, Dunedin had experienced normal rainfall conditions.

This report summarises the inspection observations, presents an interpretation on the mode of failure, ground condition observations, and provides a qualitative risk assessment of the Puketeraki Landslide.

2 SITE DESCRIPTION

The Puketeraki Landslide ('the site') is located near Karitane, approximately 25 km north of Dunedin. The site is in a rural area surrounded by farmland and hillsides, with the Main South Line located at the toe of the landslide. The approximate extent of the landslide is annotated on Figure 1.

The landslide is ~1.5 km in length and is ~800 m wide within the "definite" landslide probability (pink) as assigned by the Otago Regional Council's natural hazards database[1].

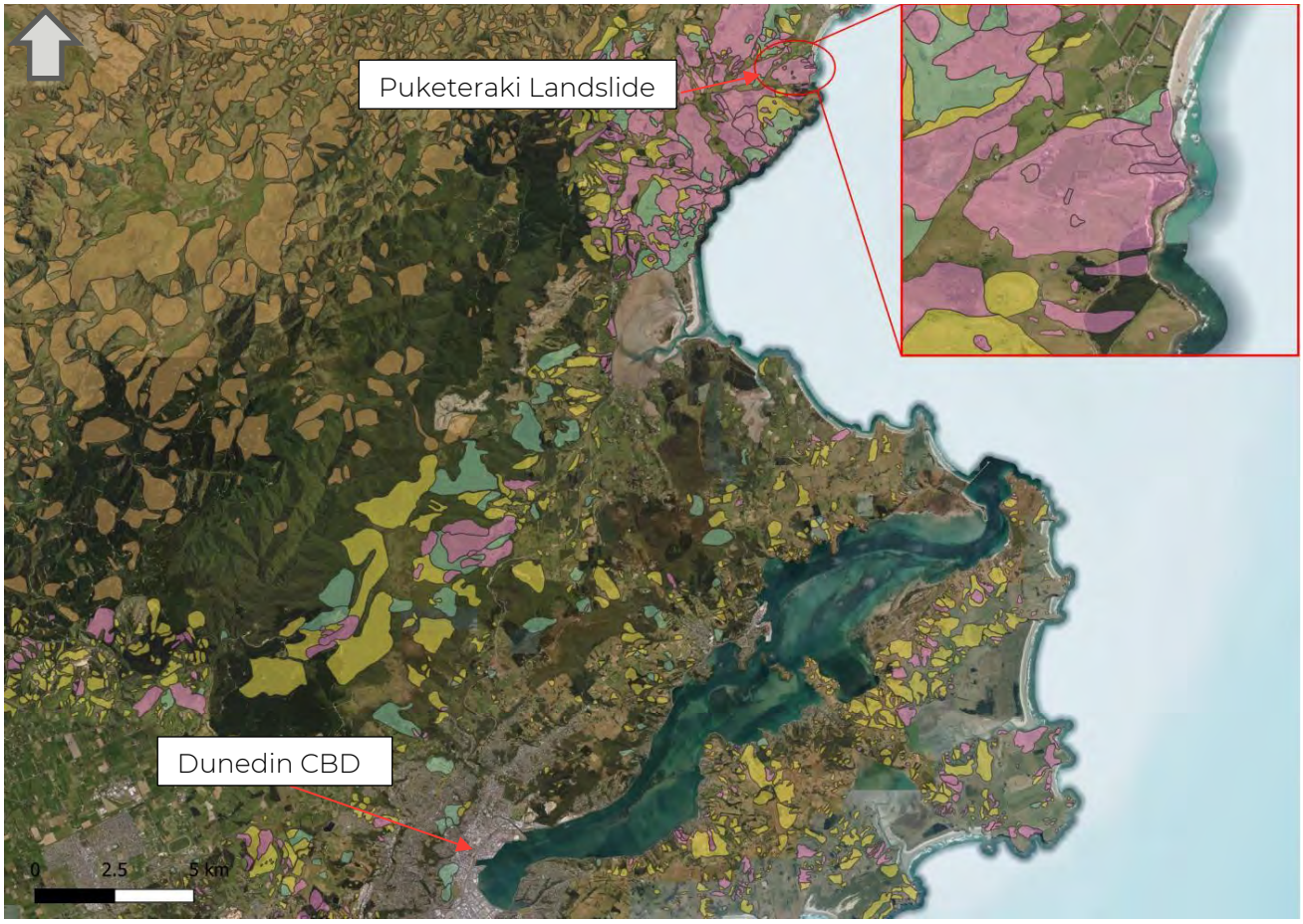

Figure 1 : Location of the Puketeraki Landslide, with reference to Dunedin City.

[1] Otago Natural Hazards Portal

3 GEOLOGY

3.1 REGIONAL GEOLOGY

The geology of the Otago Region comprises a complex arrangement of Mesozoic schist basement and Miocene shield volcanism, with erosional surfaces and quaternary sedimentary deposits interspersed. Puketeraki Landslide is located in the North Otago Sedimentary Sequence, with a thin layer of Quaternary-aged Loess blanketing the region[2].

3.2 LOCAL GEOLOGY

Based on the published Geology Map (1:250,000 Map) [3] (Figure 2) indicates the landslide is largely located in Undifferentiated Otakou Group sandstone, which is comprised of "Blue-grey siltstone sandstone and carbonaceous mudstone in shallowing-up sequence (north of Waihemo Fault Zone); outer shelf sandstone and impure limestone further south". A small northern section of the landslide boundaries falls within the Undifferentiated Onekara Group Early Paleocene to Eocene

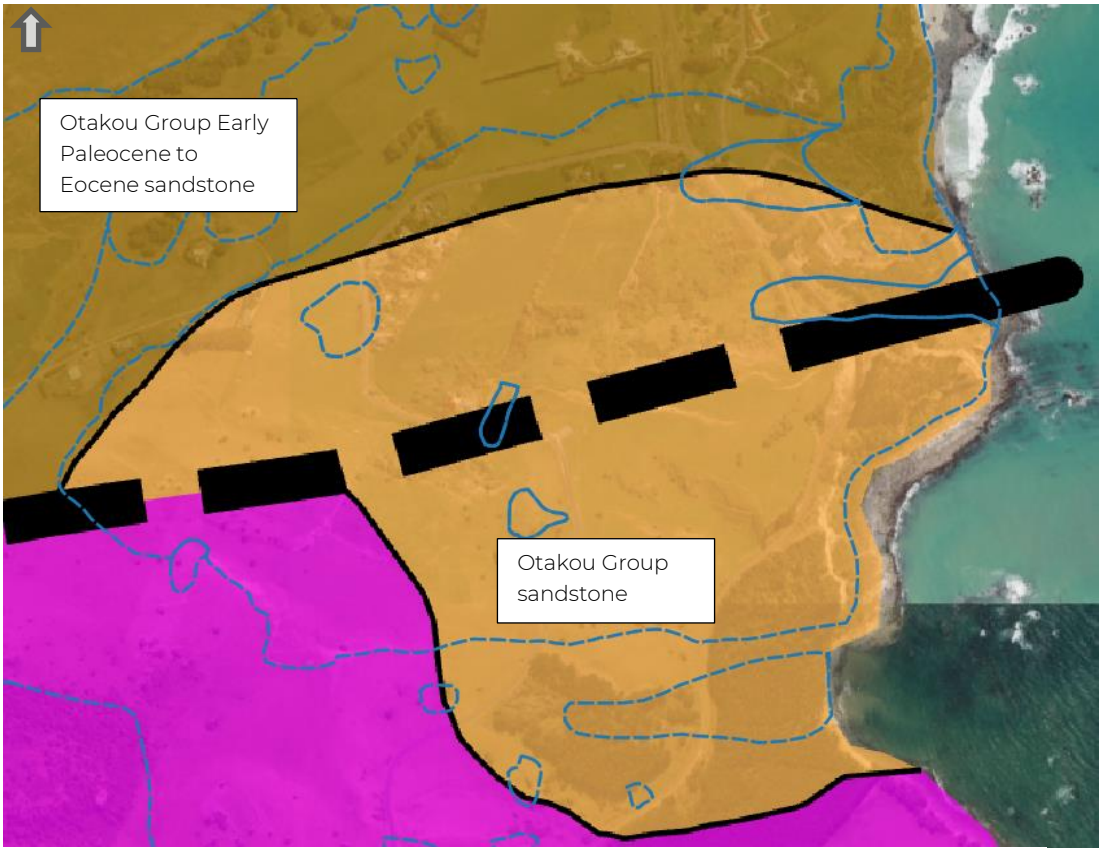

Figure 2: Geology as indicated by GNS with the outline of definite landslides in blue dashed lines. The thick black line indicates an inferred fault trace

[2] Geology 2.0.0

[3] Geology 2.0.0

sandstone, comprised of “Quartzose and glauconitic sandstone, siltstone, shell beds and limestone”.

3.3 TOPOGRAPHY AND SLOPE ANGLE

For Puketeraki Landslide, the topography is a mix of gentle and steeply sloping farmland which has remained unchanged for several years. The average slope angle of this farmland (derived from UAV data) is ~28 degrees to horizontal. The surrounding area exhibits a general topography comprising of slopes at estimated angles of 20 – 40 degrees to horizontal. A semi-vertical cut face at the toe of the landslide allows for a continuous railway line.

3.4 ACTIVE FAULTS

No active faults are noted within 50 km of the site. The GNS Geology Web Map indicates a potential fault trace that passes through the site, however there is no information regarding this fault expression Figure 2. Given the distances of active faults from the site, the risk of associated ground movements at the site in the event of a rupture is considered to be ‘low’.

4 INSPECTION OBSERVATIONS

After the recent heavy rainfall in October 2024, the majority of the site's ground conditions remained saturated at the time of the site visit. Inspection observations were limited to a site walkover and UAV survey. Two distinct geological units were observed whilst onsite, one being vent breccia isolated at the top of conical hills and the remainder of the surrounding area was largely bioclastic limestone.

Isolated areas of past movement were evident, in the form of circular slumps and displacement of lithological units.

Tension cracks were noted across the site, and specifically across Coast Road, where there was obvious displacement and slumping of the road (Refer photograph 10 Appendix B). It is obvious that the road has required multiple surface patches in the past and there was an approximate 200 mm difference in the elevation of the road at the time of the inspection.

The saturated ground conditions observed on site included an area of ponding of groundwater and surface water since the Otago heavy rainfall event. Anecdotal evidence from the landowners indicates that one of the two ponds on the site has appeared in 2024, and there is potential evidence for a few more underground expressions of groundwater to the west of the current ponds (Refer Appendix A)

A difference in topography was noted in the middle of the site, where large vertical deformation had occurred. A height difference of approximately 2-3 m between blocks was noted along the trace of the inferred fault. Furthermore, the deformation extended approximately 3 m below the ground level.

A preliminary engineering geological map of the identified geological site features in included in Appendix A, with a photographic log in Appendix B.

4.1 PRELIMINARY MAPPING

Landslide mapping can aid the decision around avoidance, prevention or mitigation of the existing and future landslide hazards. Notable observations have been compiled into a preliminary map provided in Appendix A and used to inform the risk assessment for this report. An outline of the risk assessment methodology is discussed in Section 5.

4.2 SLOPE FAILURE MECHANISM AND EXTENT

The primary driver of landsliding is the slope angle and topography of the slope, driven by gravity. The modification of the landslide toe for railway developments (tunnel and trunk line) has the possibility to destabilise the slope above.

The movement appears to be a complex slide (mass moves along a roughly planar surface to a shallow depth (surficial material and upper bedrock). However, the exact mechanism was unable to be constrained with the limited observations made onsite and the large extent of the area encompassed by this landslide.

5 RISK ASSESSMENT

Based off the findings of the site assessment, the landslide is active with several of the survey marks having moved >200 mm in the previous 12 months. This movement, along with the large site area, and the complexity of the region, makes the future behaviour of the landslide difficult to constrain. It is with this basis, that the following risk assessment been derived. It is important to note that this risk assessment is limited to the boundaries of the Puketeraki "Definite" Landslide as per the scope of this project. The assessment produced below is qualitative only and mainly reliant on published information, site observations and cumulative survey results.

5.1 QUALITATIVE RISK ASSESSMENT

A qualitative risk assessment has been undertaken to determine the risk of landslide instability to the safety of road users and farmland. The assessment considers factors such as soil conditions, geological features, historical ground movements, downstream developments and nearby hazards.

This assessment is based on a qualitative methodology guided by AGS 2007 Guidelines for Landslide Risk Management[4] and provides a framework for evaluating risks through observable features.

The risks have also been assessed under both the 'normal operating conditions' and 'extreme conditions'. The extreme conditions are considered to be as follows:

- A heavy rainfall event, typically defined by the Otago Regional Council (ORC) as rainfall exceeding 40 mm in a 24-hour period or 60 mm in a 48-hour period.
- A seismic event of sufficient intensity (typically considered to be an Ultimate Limit State (ULS) shaking event in Dunedin).

Additionally, partial failure and full failure scenarios of the landslide are considered to be as follows:

- A partial collapse refers to a situation where only a portion of the landslide mass moves or fails (i.e. localised failures).
- A full collapse involves the complete failure of the landslide mass, resulting in a more significant movement of material.

5.1.1 LIKELIHOOD

The assessment involves the assessment of likelihood, which considers geomorphological features, historical movement and observable features indicative of ground movement.

We estimate the likelihood of the scenarios as follows:

- The partial collapse (localised failure) event has an 'Unlikely' to 'Possible' likelihood of occurrence under 'Normal' and 'Extreme' operating conditions respectively.

[4] Australian Geomechnics Volume 42 No 1 March 2007 "Practice Note Guidelines for Landslide Risk Management 2007"

- The full collapse (complete failure) event has an 'Unlikely' to 'Possible' likelihood of occurrence under 'Normal' and 'Extreme' operating conditions respectively.

Table 1: Risk likelihood categories from AGS 2007. Red dashed line represents partial collapse scenario, and red highlighted represents full collapse scenario

QUALITATIVE MEASURES OF LIKELIHOOD

Approximate Annual Probability		Implied Indicative Landslide Recurrence Interval		Description	Descriptor	Level
Indicative Value	Notional Boundary					
10^{-1}	$5x10^{-2}$	10 years	20 years	The event is expected to occur over the design life.	ALMOST CERTAIN	A
10^{-2}		100 years		The event will probably occur under adverse conditions over the design life.	LIKELY	B
10^{-3}	$5x10^{-4}$	1000 years	2000 years	The event could occur under adverse conditions over the design life.	POSSIBLE	C
10^{-4}		10,000 years		The event might occur under very adverse circumstances over the design life.	UNLIKELY	D
10^{-5}	$5x10^{-6}$	100,000 years	200,000 years	The event is conceivable but only under exceptional circumstances over the design life.	RARE	E
10^{-6}		1,000,000 years		The event is inconceivable or fanciful over the design life.	BARELY CREDIBLE	F

5.1.2 CONSEQUENCE

When assessing consequences, consideration for potential impacts to infrastructure and road users are considered. We estimate the consequences categories for the scenarios as follows;

- The partial collapse scenario may have 'Minor' damage
- The full collapse scenario may have 'Medium' to 'Major' damage

Table 2: Risk consequence categories from AGS 2007. Red dashed line represents partial collapse scenario, and red highlighted represents full collapse scenario

QUALITATIVE MEASURES OF CONSEQUENCES TO PROPERTY

Approximate Cost of Damage		Description	Descriptor	Level
Indicative Value	Notional Boundary			
200%		Structure(s) completely destroyed and/or large scale damage requiring major engineering works for stabilisation. Could cause at least one adjacent property major consequence damage.	CATASTROPHIC	1
60%	40%	Extensive damage to most of structure, and/or extending beyond site boundaries requiring significant stabilisation works. Could cause at least one adjacent property medium consequence damage.	MAJOR	2
20%		Moderate damage to some of structure, and/or significant part of site requiring large stabilisation works. Could cause at least one adjacent property minor consequence damage.	MEDIUM	3
5%	1%	Limited damage to part of structure, and/or part of site requiring some reinstatement stabilisation works.	MINOR	4
0.5%		Little damage. (Note for high probability event (Almost Certain), this category may be subdivided at a notional boundary of 0.1%. See Risk Matrix.)	INSIGNIFICANT	5

5.1.3 RISK

For the purpose of this assessment, we have only considered risk to the health and safety of the following:

1) Inundation or potential loss of function for Greenacres Street, impacting on driver safety and travel delays.
2) Damage to farmland or dwellings in the downstream vicinity of the landslide.

The resulting level of risk to property at the site is presented in Table 3 and is summarised as follows:

Table 3: Property risk matrix from AGS 2007. Red dashed line represents partial collapse scenario, and red highlighted represents full collapse scenario

QUALITATIVE RISK ANALYSIS MATRIX – LEVEL OF RISK TO PROPERTY

LIKELIHOOD		CONSEQUENCES TO PROPERTY (With Indicative Approximate Cost of Damage)				
	Indicative Value of Approximate Annual Probability	1: CATASTROPHIC 200%	2: MAJOR 60%	3: MEDIUM 20%	4: MINOR 5%	5: INSIGNIFICANT 0.5%
A – ALMOST CERTAIN	10^{-1}	VH	VH	VH	H	M or L (5)
B - LIKELY	10^{-2}	VH	VH	H	M	L
C - POSSIBLE	10^{-3}	VH	H	M	M	VL
D - UNLIKELY	10^{-4}	H	M	L	L	VL
E - RARE	10^{-5}	M	L	L	VL	VL
F - BARELY CREDIBLE	10^{-6}	L	VL	VL	VL	VL

RISK LEVEL IMPLICATIONS

Risk Level		Example Implications (7)
VH	VERY HIGH RISK	Unacceptable without treatment. Extensive detailed investigation and research, planning and implementation of treatment options essential to reduce risk to Low; may be too expensive and not practical. Work likely to cost more than value of the property.
H	HIGH RISK	Unacceptable without treatment. Detailed investigation, planning and implementation of treatment options required to reduce risk to Low. Work would cost a substantial sum in relation to the value of the property.
M	MODERATE RISK	May be tolerated in certain circumstances (subject to regulator's approval) but requires investigation, planning and implementation of treatment options to reduce the risk to Low. Treatment options to reduce to Low risk should be implemented as soon as practicable.
L	LOW RISK	Usually acceptable to regulators. Where treatment has been required to reduce the risk to this level, ongoing maintenance is required.
VL	VERY LOW RISK	Acceptable. Manage by normal slope maintenance procedures.

With the above considered, the risk assessment results are presented in Table 4 below.

Table 4: Risk assessment findings

Hazard	Likelihood	Consequence	Risk Level
Partial Failure – Normal Operating Conditions	Unlikely	Minor	Low
Full Failure – Normal Operating Conditions	Unlikely	Medium to major	Low to Moderate
Partial Failure – Extreme Conditions	Possible	Minor	Moderate
Full Failure – Extreme Conditions	Possible	Medium to major	Moderate to High

6 CONCLUSIONS AND RECOMMENDATIONS

- The Puketeraki Landslide is a large landslide that in the event of failure has the potential to affect rail services as well as farmland and scenic road access
- The landslide appears to be active with several of the survey marks having moved >200 mm in the previous 12 months
- There is active localised landsliding across the larger landslide area, and areas that are likely to have been affected by minor faulting
- Groundwater ponding and release of ground stress overtime are evident across the site

Considering the risk posed by the Puketeraki Landslide the following is recommended:

- Continue with scheduled monitoring every 12 months, unless there is a significant rainfall or seismic event.
- A site-specific report every two years including more detailed field mapping.
- Due to the medium to major consequences associated with full failure under normal conditions, the installation of a remote landslide monitoring system, such as GNSS sensor monitoring, should be considered.

7 LIMITATIONS

This report ('Report') has been prepared by WSP exclusively for Dunedin City Council ('Client') in relation to the landslide monitoring at selected sites in Dunedin (Landslide Monitoring Long-Term SoW DCC Reference 9662). The scope of this Report is to present the survey monitoring results and recommendations for future surveys for the site ('Purpose'). The findings in this Report are based on and subject to the assumptions specified in the Report. WSP accepts no liability whatsoever for any reliance on or use of this Report, in whole or in part, for any use or purpose other than the Purpose or any use or reliance on the Report by any third party.

In preparing this Report, WSP has relied upon data, surveys, analyses, designs, plans and other information ('Client Data') provided by or on behalf of the Client. Except as otherwise stated in this Report, WSP has not verified the accuracy or completeness of the Client Data. To the extent that the statements, opinions, facts, information, conclusions and/or recommendations in this Report are based in whole or part on the Client Data, those conclusions are contingent upon the accuracy and completeness of the Client Data. WSP will not be liable for any incorrect conclusions or findings in the Report should any Client Data be incorrect or have been concealed, withheld, misrepresented or otherwise not fully disclosed to WSP.

APPENDIX A

Preliminary Observations / UAV Map

N

Saturated ground conditions (potential expressions of groundwater?)

Pond levels have increased since October 2024 rainfall

New pond appeared since October 2024 rainfall

Slow-creep movement observed (stepped grass tracks)

Limestone and volcanic agglomerate outcrop

Slumping in road (refer photolog)

Coast Road

Natural watercourse

Approximately 2-3 m vertical difference (fissure?) between upper and lower block, that extends a further 3 m bgl. decreases eastward

Largest survey movement (~3.5 m) was in this middle block, seaward

Volcanic breccia / conical vent

Small slump that inundated part of the road during October floods

Dislocated block (arrow indicates direction of movement)

0 75 150 m

Legend

- Observed slump
- Inferred slump
- Observed watercourse
- Inferred watercourse
- Tension crack / fissure
- Direction of movement

APPENDIX B

Photographic Log

PHOTOGRAPHIC LOG

Client Name	Site Location	Project No.
Dunedin City Council	Puketeraki Landslide	6-CD109.55

Photo No.	Date
1	22/10/2024

Description

View of Puketeraki look out. Image taken facing northeast above Coast Road

Photo No.	Date
2	22/10/2024

Description

Small slump forming in farmland opposite Coast Road. Image taken facing north

	PHOTOGRAPHIC LOG

Client Name	**Site Location**	**Project No.**
Dunedin City Council	Puketeraki Landslide	6-CD109.55

Photo No.	**Date**
3	22/10/2024

Description

View of recent scarps and limestone/volcanic boulders (red circle). Image taken facing southwest

Photo No.	**Date**
4	22/10/2024

Description

Puketeraki Landslide main scarp identified in red circle. Rotational slide in foreground (ORC Landslide ID: 101416). Image taken facing south

	PHOTOGRAPHIC LOG	
Client Name Dunedin City Council	**Site Location** Puketeraki Landslide	**Project No.** 6-CD109.55

Photo No.	Date
5	22/10/2024

Description

Image of headscarp observed in Photo 4 above, in volcanic agglomerate.

Photo No.	Date
6	22/10/2024

Description

Tension cracks observed within the main block.

	PHOTOGRAPHIC LOG

Client Name	**Site Location**	**Project No.**
Dunedin City Council	Puketeraki Landslide	6-CD109.55

Photo No.	**Date**
7	22/10/2024

Description

Slump above Coast Road. Image taken facing northeast

Photo No.	**Date**
8	22/10/2024

Description

View of main scarp (background) off Puketeraki. Image taken facing southwest

	PHOTOGRAPHIC LOG

Client Name	**Site Location**	**Project No.**
Dunedin City Council	Puketeraki Landslide	6-CD109.55

Photo No.	**Date**
9	22/10/2024

Description

View of deformation of Coast Road

Photo No.	**Date**
10	22/10/2024

Description

Close up of tension cracks formed in Coast Road.

	PHOTOGRAPHIC LOG	
Client Name Dunedin City Council	**Site Location** Puketeraki Landslide	**Project No.** 6-CD109.55

Photo No.	Date
11	22/10/2024

Description

View of dislodged block, person in image is approx. 2 m in height. Image taken facing west

Photo No.	Date
12	22/10/2024

Description

Close up of fossiliferous limestone observed in image 11.

	PHOTOGRAPHIC LOG	
Client Name Dunedin City Council	**Site Location** Puketeraki Landslide	**Project No.** 6-CD109.55

Photo No.	**Date**
13	22/10/2024

Description

Block slumping and exposure of slope (lower end of field area)

Photo No.	**Date**
14	22/10/2024

Description

Juxtaposed volcanic agglomerate and limestone. Image taken above the Main South Train Line (left of image) and image taken facing southeast

	PHOTOGRAPHIC LOG	
Client Name Dunedin City Council	**Site Location** Puketeraki Landslide	**Project No.** 6-CD109.55

Photo No.	**Date**
15	22/10/2024

Description

Planar beds dipping seaward. Located on the other side of the KiwiRail Main South Line

Photo No.	**Date**
16	22/10/2024

Description

Recently activated landslide, currently outside of the boundaries of the Puketeraki Landslide mapped area.