Dunedin City Council

LTES LONG-TERM LANDSLIDE MONITORING

GREENACRES STREET EARTHFLOW

13 FEBRUARY 2025

CONFIDENTIAL

LTES LONG-TERM LANDSLIDE MONITORING
GREENACRES STREET LANDSLIDE

Dunedin City Council

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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 an Unmanned Aerial Vehicle (UAV) survey of the Greenacres Street 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 preliminary 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 16 October 2024. The inspection was limited to a site walkover within the ORC's defined landslide boundaries, and an UAV survey. The site inspection was completed following heavy rainfall experienced in Dunedin on 4 October 2024 (160 mm in 24 hrs), 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 Greenacres Street Landslide.

2 SITE DESCRIPTION

The Greenacres Street Earthflow ('the site') is located on the Otago Peninsula, approximately 8 km east of the Dunedin CBD. The earthflow is oriented on the northern facing slope of the Eastern Otago Peninsula. The landslide is situated in a semi-rural area surrounded by farmland on hillsides.

The site, represented in Figure 1, is ~700 m in length and with a headscarp ~200 m in width. The site is located within the "definite" landslide probability (pink) as assigned by the Otago Regional Council's natural hazards database[1]. The wider area identified in the yellow ("likely" landslide) represents an area of mass movement that surrounds the Greenacres Street Earthflow.

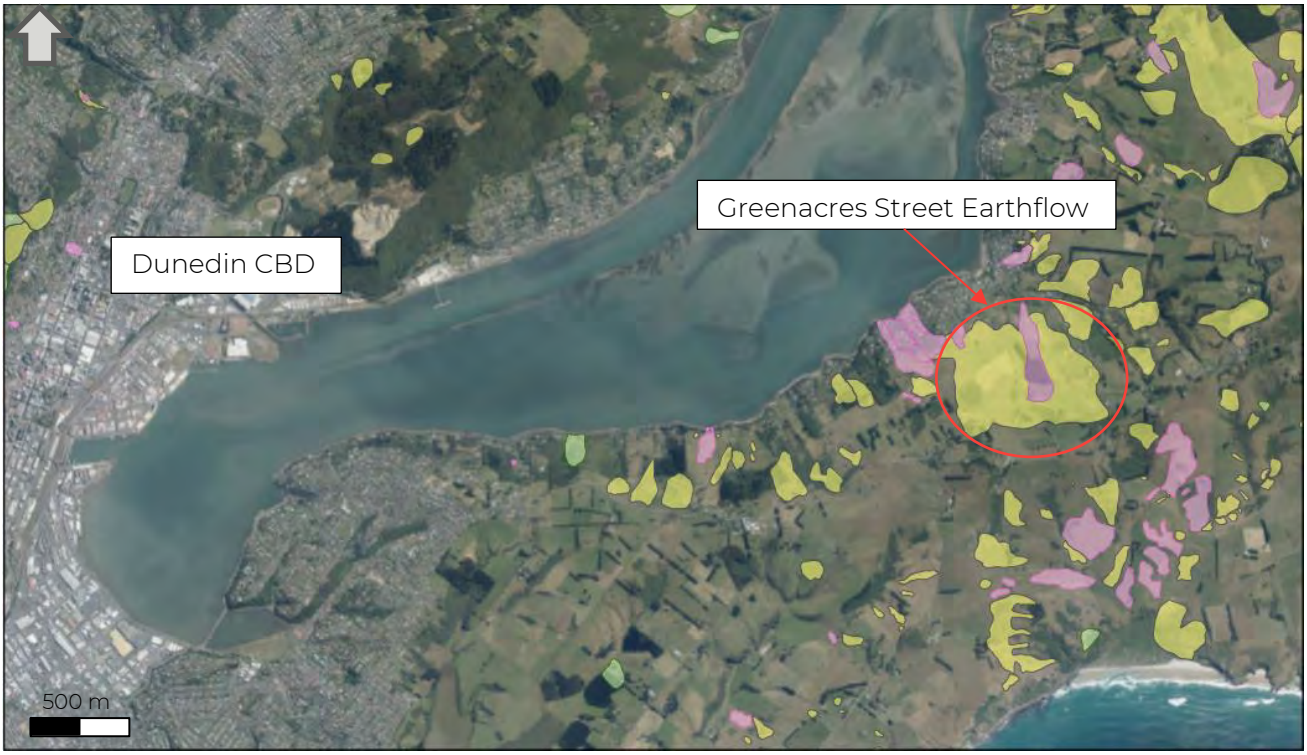

Figure 1: Location of the Greenacres Street Earthflow on the Otago Peninsula, with reference to Dunedin City CBD. Pink = 'definite' landslide, yellow = 'likely' landslide.

[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. Dunedin CBD is located on the Miocene aged Dunedin Volcanic Group[2].

3.2 LOCAL GEOLOGY

Based on the published Geology Map (1:250,000 Map)[3] (refer Figure 2) the headscarp and upper half of the Earthflow is predominately within the Dunedin Volcanic Group (DVG) first main phase extrusives, characterised as "Extensive flows of olivine basalt, plagioclase basalt, basanite, kaiwekite and trachyandesite". The southwestern section of the headscarp is within the DVG second main phase extrusives, described as "Extensive flows of trachybasalt, olivine dolerite, basalt, phonolite". The lower section of the landslide, nearest to Greenacres Street, is indicated as being in the DVG first main phase pyroclastics and characterised as "Vent-filling breccia and agglomerate".

The DVG has 3 main phases of intermittent eruptions, uncomformably interspersed with periods of erosional and depositional events. The Otago Peninsula forms the southeastern limb of the flanks of the Dunedin Volcano, which erupted intermittently between 10 – 16 Million Years (Ma). Uncomformably overlying the volcanics are thin layers of Quaternary-aged Loess (wind-blown silt-deposits).

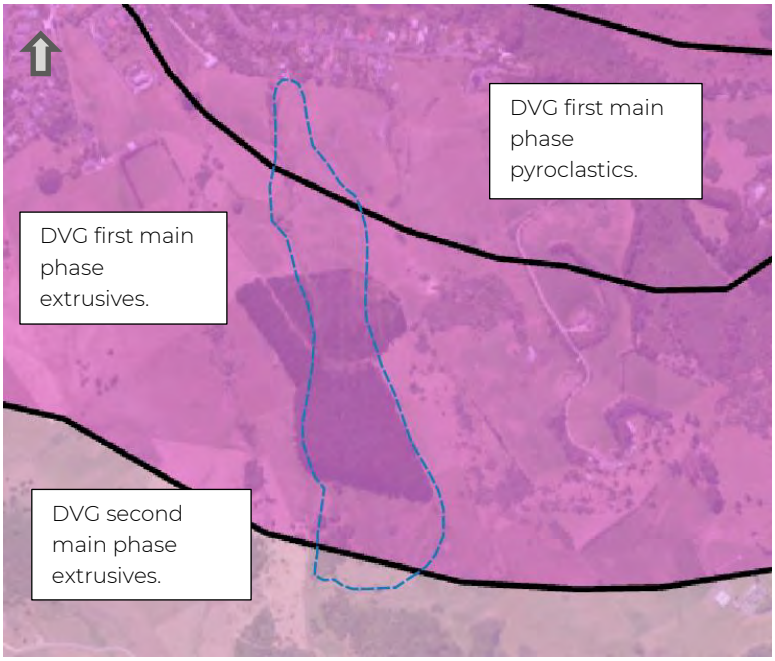

Figure 2: Published geologic map of the Greenacres Street Earthflow (Courtesy of GNS Science Geology Webmap)

[2] Geology 2.0.0

[3] Geology 2.0.0

3.3 GROUNDWATER ON THE PENINSULA

The Otago Peninsula is an aquitard, characterised by its non-porous low-permeability rock or sediment layer that slows groundwater transmission, meaning groundwater is capped between the volcanics and the overlying soils. Numerous watercourses and saturated areas converge at gullies directed by the hummocked and gullied terrains. Free-running water was found in gullies across the site, and multiple areas have been piped to help direct the flow of groundwater.

3.4 TOPOGRAPHY AND SLOPE ANGLE

The primary driver of landsliding on the Otago Peninsula is the slope angle and topography of the slope, driven by gravity. The modification of natural run-off and drainage paths have the potential to affect the slope stability of an area, which is evident in the hillsides of the peninsula.

For Greenacres Street Earthflow, the topography is gentle, farmland which has remained unchanged for a number of years and the slope angle (derived from UAV data) is ~22 degrees to horizontal. The wider area exhibits a general topography comprising of slopes at estimated angles of 20 – 30 degrees to horizontal.

3.5 ACTIVE FAULTS

No known active faults are located within 20 km of the site. The Titri Fault lies ~20 km west of the site. Given the distances of the 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

During the October 2024 heavy rainfall event, surface water from the surrounding slopes and runoff from Highcliff Road, activated a debris flow that could be seen in the area to the west of the identified Greenacres Earthflow. This debris flow led to the inundation of Greenacres Street during the October 2024 rainfall event.

Inspection observations were limited to a site walkover and UAV survey. The observed underlying geology was that of a thin layer of topsoil (100 mm) underlain by highly weathered DVG.

A portion of a pine plantation located in the middle of the Greenacres Earthflow was harvested during 2018. At the time of the inspection, this area had become a swampy environment, with water actively flowing downstream. A groundwater spring was also identified in this area.

Areas where drainage measures have been implemented were still extremely saturated underfoot, and there had been areas of block sliding. The surveyor onsite noted the ground was significantly saturated than previous visits to the site. A number of areas had groundwater seepage and ponding above ground level. Water also caused ballooning of the ground surface. Areas of ponding and water flow paths were observed whilst onsite, and majority of the grass underfoot was saturated.

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

4.1 PRELIMINARY MAPPING

Landslide hazard 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.

The close proximity of residential dwellings to the toe of the landslide are the main drivers of the mapping, to inform the risk assessment below.

4.2 SLOPE FAILURE MECHANISM AND EXTENT

The movement appears to be an earthflow, with mass behaving like a liquid and gravity being the main driver of the land movement. 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 land movement.

5 RISK ASSESSMENT

Based on the findings of the visual site assessment, the earthflow appears to be active, and the future behaviours of the earthflow are difficult to constrain, largely due to the area of the site and the complexity of the region. It is with this basis, that the following risk assessment has be prepared. It is important to note that this risk assessment is limited to the boundaries of the Greenacres Street "Definite" Earthflow as per the scope of this project. The assessment produced below is qualitative only and is primarily 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 under normal and extreme operating conditions has an 'Unlikely' likelihood of occurrence

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

- The full collapse (full failure) event under normal operating conditions has a 'Rare' likelihood of occurrence
- The full collapse (full failure) under extreme operating conditions has an 'Unlikely' likelihood of occurrence

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}	$5x10^{-3}$	100 years	200 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}	$5x10^{-5}$	10,000 years	20,000 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 'Medium' 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%	100% 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 summarised in Table 4 below.

Table 4: Risk assessment findings

Hazard	Likelihood	Consequence	Risk Level
Partial Collapse – Normal Operating Conditions	Unlikely	Medium	Low
Full Collapse – Normal Operating Conditions	Rare	Medium to major	Low
Partial Collapse – Extreme Conditions	Unlikely	Medium	Low
Full Collapse – Extreme Conditions	Unlikely	Medium to major	Low to Moderate

6 CONCLUSIONS AND RECOMMENDATIONS

- The Greenacres Street Earthflow is a significant earthflow that in the event of failure has the potential to affect the function for Greenacres Street as well as nearby farmland and dwellings
- The earthflow appears to be active with two of the survey marks having moved >1.5 m since monitoring began in 2015
- The behaviour of the land movement appears to be an earthflow, with mass behaving like a liquid and gravity being the main driver of this landslide
- Free-running water was found in gullies across the site and areas where drainage measures had been installed were still extremely saturated underfoot

Considering the risk posed by the Greenacres Street 'Earthflow' 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 with the debris flow to the west of the current earthflow boundaries to be added to future inspections
- Investigate options to control the direction and flow of surface water at Highcliff Road away from the area of the Greenacres Street Landslide

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

Greenacres Street

Earthflow within larger mass. Saturated underfoot, with ballooning of ground surface

Recent surficial landslide

Slow-slip movement / hummocky terrain

Exposed volcanic cutting

Earthflow

Rotated slump

Evidence of slow-slip movement

New water course established during October 2024 heavy rain. Caused debris flow to inundate Greenacres Street

Spring location (within younger pine plantation)

Headscarp extends beyond image extents

0 100 200 m

Legend

- Observed slump
- Landslide outline
- Observed watercourse
- Inferred watercourse
- Direction of movement

APPENDIX B

Photographic Log

PHOTOGRAPHIC LOG

Client Name	Site Location	Project No.
Dunedin City Council	Greenacres Street Earthflow	6-CD109.55

Photo No.	Date
1	16/10/2024

Description

View of the watercourse feature down the flanks of the earthflow (to the left of the image). Image taken facing north

Photo No.	Date
2	16/10/2024

Description

Looking up towards the headscarp, with the pine plantation and spring in the red circle. Image taken facing south

	PHOTOGRAPHIC LOG

Client Name	**Site Location**	**Project No.**
Dunedin City Council	Greenacres Street Earthflow	6-CD109.55

Photo No.	**Date**
3	16/10/2024

Description

Small landslide as a result of the October 2024 heavy rainfall event and evidence of slope stabilization (tree planting) in the valley. Image taken facing southeast

Photo No.	**Date**
4	16/10/2024

Description

View of blocks of earthflow. Image taken facing main body of earthflow and west

	PHOTOGRAPHIC LOG

Client Name	**Site Location**	**Project No.**
Dunedin City Council	Greenacres Street Earthflow	6-CD109.55

Photo No.	**Date**
5	16/10/2024

Description

Cut and fill exposure of volcanics overlain by a thin layer of loess, within the “Likely” certainty area of the mass movement. Image taken facing south

Photo No.	**Date**
6	16/10/2024

Description

Close up view of the cut and fill platform. Completely weathered pyroclastics overlain by topsoil

	PHOTOGRAPHIC LOG	
Client Name Dunedin City Council	**Site Location** Greenacres Street Earthflow	**Project No.** 6-CD109.55

Photo No.	Date
7	16/10/2024

Description

Outside of landslide boundary, cutting for farm track exposing shallow volcanics with thin overlying topsoil. Image taken facing south

Photo No.	Date
8	16/10/2024

Description

Close up of volcanics

	PHOTOGRAPHIC LOG

Client Name	**Site Location**	**Project No.**
Dunedin City Council	Greenacres Street Earthflow	6-CD109.55

Photo No.	**Date**
9	16/10/2024

Description

Hummocky terrain – saturated underfoot, looking up at pine plantation

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

Description

When applying pressure to the ground surface at this location, water extruded from the ground

	PHOTOGRAPHIC LOG	
Client Name Dunedin City Council	**Site Location** Greenacres Street Earthflow	**Project No.** 6-CD109.55

Photo No.	Date
11	16/10/2024

Description

Image of debris flow that recently activated during October floods

Photo No.	Date
12	16/10/2024

Description

Image of stabilization (tree planting) and a recent landslide caused by the heavy rainfall