

# Waitakere Coastal Communities Landslide Risk Assessment

**Overall Report - Muriwai** 

Auckland Council
15 May 2024

→ The Power of Commitment



Project name		Waitakere Coastal Communities Landslide Risk Assessment							
Document title		Waitakere Coastal Communities Landslide Risk Assessment   Overall Report - Muriwai							
Project number		12612462							
File name	9	12612462_Overa	ll Report_FINALF	Rev2.docx					
Status	Revision	Author	Reviewer		Approved for issue				
Code			Name	Signature	Name	Signature	Date		
S4	0	Matt Howard	Don Macfarlane	Delapoter	Matt Howard	Moward	03/11/2023		
S4	1	Matt Howard	Don Macfarlane	Dringolen	Matt Howard	Moward Moward Roy Prarson	30/04/2024		
S4	2	Matt Howard	Don Macfarlane	Delugolen	Matt Howard	Roy Prarson	15/05/2024		
[Status code]									
[Status code]									

#### **GHD Limited**

Contact: Matt Howard, Technical Director - Engineering Geologist | GHD

27 Napier Street, GHD Centre Level 3

Freemans Bay, Auckland 1010, New Zealand

T +64 9 370 8000 | F +64 9 370 8001 | E aklmail@ghd.com | ghd.com

#### © GHD 2024

This document is and shall remain the property of GHD. The document may only be used for the purpose for which it was commissioned and in accordance with the Terms of Engagement for the commission. Unauthorised use of this document in any form whatsoever is prohibited.

# **Contents**

1.	Introduc	tion	1
		Purpose of this report	1
		Background	1
	1.3	Scope	2
	1.4	Report structure and revision version	3
2.	Assessn	nent work stages	4
	2.1	Engineering geological report (Appendix B)	4
	2.2	Slope stability assessment (Appendix C)	5
	2.3	RAMMS debris flow analysis (Appendix D)	5
	2.4	Landslide risk assessment (Appendix E)	5
	2.5	Geotechnical investigations report (Appendix F)	6
3.	Limitatio	ons	8
Table Table		Summary of accompanying Muriwai landslide risk assessment reports Project A3-size figures in plan view	3 11
Appe Appe Appe	endic endix A endix B endix C	Figures Engineering Geological Report Slope Stability Report	
Appe	ndix D ndix E ndix F	RAMMS Debris Flow Analysis Landslide Risk Assessment Geotechnical Investigations Report	

### 1. Introduction

#### 1.1 Purpose of this report

GHD has been engaged by Auckland Council (AC)¹ to carry out Quantitative Landslide Risk Assessments (QRA) as well as to provide associated landslide risk management advice and geotechnical investigations in the Muriwai area ('the study area'). The purpose of this assessment is to carry out a Quantitative Landslide Risk Assessment (QRA) for the Muriwai area ('the study area'). The QRA is to estimate the risk of Loss of Life to individuals at these properties. The outcome of the QRA will be used to inform subsequent property risk categorisation and building placard designation review by AC. This report version is the final issue. It has taken into account any information provided by the landowner either through the Auckland Council feedback portal or through Auckland Council Recovery Office communication channels.

The purpose of this 'overall report' is to combine and summarise the various GHD geotechnical assessments for Muriwai in a single document. The focus of the report is on the large-scale hazard from the 80 m-high escarpment to the east of Muriwai township that experienced damaging landslides from the escarpment in February 2023 (see Figure 1). Our study includes elements that support a risk assessment that provides a quantified loss-of-life risk from landslides to occupants of dwellings.

This report contains appended reports, which should be read in conjunction with it.

#### 1.2 Background

Two significant rainfall events affected the Waitakere area in late January and early February 2023, resulting from the impacts of ex-tropical cyclones Hale and Gabrielle, respectively.

The Cyclone Gabrielle weather event of 14 February 2023 resulted in widespread catastrophic flooding and slope instability in the settlement of Muriwai where several debris avalanches (which included rocks and trees) occurred, some of which turned into saturated debris flows as they travelled downslope. These flows resulted in damage to buildings and infrastructure. Two fatalities occurred due to impact of landslides on private dwellings. This tragic event was similar to a 1965 storm event that also claimed two lives.

Following the recent event, rapid building assessment of residential properties was undertaken in Muriwai, with some houses having access by owners restricted (a yellow placard – e.g. access in daylight hours only) and some for which no access was permitted (a red placard). Dwellings that retained unrestricted access were white placarded.

<sup>&</sup>lt;sup>1</sup> As part of contract CW198379, Master Services Agreement CCCS: CW74240 dated 7/09/2019, subsequent work item 'Waitakere Coastal Communities Landslide Risk Assessment', dated 26/04/2023

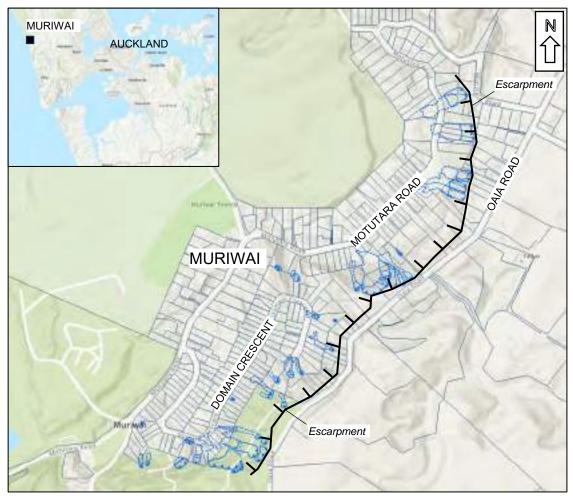


Figure 1 Muriwai location showing the February 2023 landslides mapped by GHD (blue lines)

## 1.3 Scope

AC would like to understand the risk-to-life of large-scale<sup>2,3</sup> slope instability in the settlement of Muriwai to inform possible future dwelling hazard designations, including the revision of building placards issued in February 2023. Landslides from the main escarpment to the east of Muriwai that were associated with Cyclone Gabrielle have demonstrated that some dwellings are exposed to an unacceptably high landslide risk. AC may designate these properties as being unsuitable for habitation. The approach to inform such decisions must be robust and defensible. The scope for this study is as follows:

- Establish a ground surface GIS model using data provided by AC.
- Conduct an engineering geological assessment of the area to understand the physical contributary factors that led to recent large-scale landslides and that may provide insight into future events.
- Conduct a ground borehole investigation of Muriwai to understand the geological materials in the area. This includes laboratory testing of recovered soil and rock to characterise their geotechnical properties.
- Simulate the slope stability of the main escarpment using a Limit Equilibrium slope stability analysis to quantify the failure conditions and to provide indications of two potential remedial measures.
- Undertake a simulation of the potential for future debris flow from the escarpment using RAMMS computer software. The focus for this is to identify which dwellings could be affected by potentially damaging, lifethreatening debris flows.

<sup>&</sup>lt;sup>2</sup> In this report 'large scale' landslide hazards refers to landslides originating from the main escarpment that typically have a volume of more than about 50 m³ with the potential to cause total or partial collapse of a dwelling.

<sup>&</sup>lt;sup>3</sup> Some limited, site-specific assessments by GHD have been appended to this report (see Appendix E-2, E-3, E-4) that do assess the risk to specific properties. This reflects an evolution in the scope of GHD's service as requested by Auckland Council.

- Quantify the risk to life of residents from potential future debris flows using data from the above items, in particular the RAMMS output.

AC requested that this study be limited to the assessment of the effect from 'large scale' landslide hazards originating from the main escarpment located to the south-east of Muriwai because the initial placard assessment was largely aimed at mitigating risks associated with these landslide hazards. Consequently, this report does not consider smaller, more localised landslide hazards that could originate (or may have already initiated) from other areas in Muriwai such as within the footprint of individual residential properties. Separate site-specific risk assessments have been undertaken by GHD for several individual properties at AC's request to further clarify risk outcomes within the area-wide study. The results of these are not included in this report.

This report has been prepared by GHD for Auckland Council and may only be used and relied on by Auckland Council for the purpose agreed between GHD and Auckland Council as set out in section 1.1 of this report.

GHD otherwise disclaims responsibility to any person other than Auckland Council arising in connection with this report. GHD also excludes implied warranties and conditions, to the extent legally permissible.

#### 1.4 Report structure and revision version

The appended reports and figures provide the detail and calculations of our study. This overall report provides a framework to combine this information and summarises the contents of each report. A draft version of this report was submitted to AC on 24 August 2023 and they used it to inform their provisional Risk Categorisation<sup>4</sup> assignment. The report and Risk Categorisation was released to the public shortly after.

A final (Revision 0) report was an updated version of the draft report that included completed geotechnical investigation and materials testing that was ongoing at the time of the draft release. The report also partially responded to comments from AC's technical peer review committee and from community feedback.

This report (Revision 1) is a further update that is considered to be complete, with no further additions intended. It addresses all outstanding comments from AC's technical peer review committee and community feedback. In most cases the structure of the appended reports is unchanged, but their content is supplemented with more detail, including some additional figures (e.g. figures A127-A129).

Excluded from this report is consideration of the risk relating to dwellings located along the crest of the main escarpment (i.e. the west side of Oaia Road) that could be undermined by the regression of the escarpment edge during future landslide events. Commentary on escarpment edge regression is to be included in a separate, future study.

A list of report sections is presented in Table 1. A3 plans referred to in this report are presented in Appendix A.

Table 1 Summary of accompanying Muriwai landslide risk assessment reports

Report Section	Description
Overall Report	Waitakere Coastal Communities Landslide Risk Assessment (Muriwai) Overall Report (this report)
Appendix A	Figures
Appendix B	Engineering Geological Report
Appendix C	Slope Stability Assessment
Appendix D	RAMMS debris flow analysis
Appendix E	Landslide Risk Assessment
Appendix F	Geotechnical Investigations Report

<sup>&</sup>lt;sup>4</sup> For an explanation of Risk Categories, see Property risk categories (aucklandcouncil.govt.nz)

# 2. Assessment work stages

This section summarises the project work stages and outlines the main conclusions.

#### 2.1 Engineering geological report (Appendix B)

The purpose of the engineering geological report was to assemble existing data and combine it with observations and anecdotal evidence from the community to inform a model for the area that provides the context for the observed landslides and helps to assess the nature of and triggers for future occurrences. This appendix report has been substantially updated from the draft version.

The following conclusions were reached in the engineering geological assessment of the Muriwai landslide hazard:

- 1. The recent (2023) and historical (1965) landslides that have affected the Muriwai community were high-velocity debris flows originating on the escarpment that extends up to 80 m above the township.
- 2. The model proposed for the recent (2023) and historical (1965) landslides that damaged the Muriwai community is that of saturated and shallow translational slips that quickly become high-velocity debris flows, entraining significant volumes of unconsolidated sand and vegetation.
- The formation of these landslides can be directly attributed to the saturation of surficial soil (colluvium and weathered rock) in the Awhitu Sand Formation which, upon losing its binding iron-cement, develops a shallow shear surface.
- 4. This process is probably influenced by a combination of surface water infiltration and subsurface pore pressure increases from perched aquifers and associated springs. However, as no groundwater or overland flow data is available from during the events, reliance is placed on anecdotal accounts which do not provide a clear picture.
- From the data available, including continuous groundwater monitoring established after the 2023 event, it is inferred that surface water flow and infiltration/saturation of shallow soils has had the greater effect on the onset of landslides.
- 6. The speed, composition, and volume of the debris generated make these debris flows highly destructive to dwellings and property located within the run-out area. As a result, tragically, multiple fatalities were experienced in both the 1965 and 2023 events.
- 7. The debris flows follow local catchment valleys which often coalesce multiple landslides into confined areas. Consequently, the location and degree of damage to residential properties is variable along Domain Crescent and Motutara Road.
- 8. Deep-seated landslides resulting from large (i.e. ARI 100 year) rain events within the study area (escarpment) and geology (Awhitu Formation) sand, are not considered likely. Although evidence that may be plausibly attributed to larger historical landslides has been observed, the relative magnitude of these features compared with the 2023 event suggests much larger, less frequent environmental conditions would be required to instigate failure (most likely a very large earthquake). Such conditions and resultant hazards have not been considered for this assessment.
- 9. Six geomorphological landslide 'zones' have been defined based on the surface topography, 2023 landslide characteristics and general geomorphology of the study area. These differentiate areas according to their susceptibility to large-scale landslides (i.e. having a volume of more than approximately 50 m³). Zones 2, 3 and 4 contain the Muriwai escarpment and have higher potential for future, large landslides.
- 10. The life risk to residents for each zone is considered separately in the risk assessment (Appendix E). Interactive community sessions held in September 2023 in Muriwai provided clarification to residents by GHD and AC following the release of the draft version of this report and associated appended reports. We received a large response from the community after the release of the draft report, with additional observations and suggested amendments to the anecdotal information presented below.

#### 2.2 Slope stability assessment (Appendix C)

The purpose of this report was to present a slope stability and back analysis assessment of one of the large, failed slopes at the escarpment to the east of Muriwai township. The objective of the analyses was to estimate rock or soil strength parameters that could be used to inform conceptual remediation options to demonstrate the likely effectiveness of engineering measures that could be required to stabilise the escarpment.

Slope stability analyses were carried out using Slope W version 2021.3 (a GeoStudio Package). As part of the back analyses and feasibility assessments, we examined non-circular, shallow, deep circular and irregular user-defined slip surfaces.

A two-dimensional Limit Equilibrium Analysis was carried out to estimate material parameters applicable to the failed zone. The analysis also assessed the influence of changing pore pressure levels. The seismic performance of the slopes was also assessed, considering factors such as design life, site soil class, peak ground acceleration, and compliance with the NZ Building Code. Based on this, we considered two engineering options that would provide long-term stability to the escarpment: widespread soil nails and benching of the slope. These highlighted the high cost of slope remediation on this scale.

### 2.3 RAMMS debris flow analysis (Appendix D)

The purpose of this assessment was to present the results of a RAMMS computer-simulated three-dimensional debris flow assessment undertaken to provide guidance on the potential effects of future events on dwellings in Muriwai. In addition, a sensitivity analysis of input parameters is presented. The analysis focus is on the large-scale hazard from the 80 m-high escarpment to the east of Muriwai township that experienced damaging landslides in February 2023. The results from the analysis provide an important part of the GHD loss of life risk study (see Appendix E) that will support decision-making by AC on the long-term suitability of sites and dwellings for occupancy.

The RAMMS debris flow analysis used simulated landslides from source areas similar to those of the damaging February 2023 Cyclone Gabrielle, and from potential, future sources. Geomorphological Zone 5 landslides as described in Appendix B were used to calibrate specific parameters for RAMMS analysis due to the relatively short debris flow runout distance when compared to other zones.

We conclude the following:

- 1. A quantitative comparison of the actual landslide runout areas with that determined from RAMMS simulation indicates a reasonable fit.
- 2. The predicted outcome of the simulation is that over 40 originally red-placarded dwellings could be subjected to impact by escarpment landslide debris that is greater than 0.5 m thick as shown on Figures A206 and A209. This has been assessed by GHD's risk assessment in Appendix E as having the potential to cause fatalities, especially if large trees are mobilised by the landslide.
- 3. Yellow placarded properties are largely beyond the extent of the escarpment landslide debris that is greater than 0.5 m thick.
- 4. The RAMMS predicted runout extent of damaging debris (i.e. more than 0.5 m maximum thickness) is in broad agreement with the 'F-angle' empirical landslide hazard prediction work undertaken by AC to allocate the original emergency property placards.

#### 2.4 Landslide risk assessment (Appendix E)

The purpose of this assessment was to present the results of a Quantitative Landslide Risk Assessment (QRA) carried out to estimate<sup>5</sup> the risk of loss of life posed by large-scale landslides to individuals in dwellings at Muriwai.

<sup>&</sup>lt;sup>5</sup> QRA is a systematic method that integrates knowledge and uncertainty to identify and quantify risks. In a QRA the life risk is determined by a calculation but the result is called an estimate because of the inherent uncertainty.

It was carried out in general accordance with the Australian Geomechanics Society Practice Note Guidelines for Landslide Risk Management, commonly known as AGS (2007c). A "risk to property" assessment has not been undertaken.

Occupants of dwellings that have been assessed to be in the path of landslide runout were considered as the elements at risk for this assessment. The risks posed to individuals in the 'open', such as people outside houses or situated on other public property such as roads, are not considered in this report. The 'tolerable' level of loss-of-life risk in AGS (2007c) is 10<sup>-4</sup> per annum, which is the same as 1 in 10,000 fatalities pa.

The assessment considers the risk within the six geomorphological landslide 'zones' that have been introduced in Appendix B. The risk assessment relied on the outputs of the RAMMS modelling in Appendix D as the basis for determining areas of the site that could be affected by landsliding.

Where RAMMS predicts debris flow of greater than 0.5 m depth, the greatest present estimated risk to life (climate change not considered) is as follows:

- For Zone 1 the risk is 'tolerable'.
- For Zone 2 the risk is 'not tolerable'.
- For Zone 3 the risk is 'not tolerable'.
- For Zone 4 the risk is 'not tolerable'.
- For Zone 5 the risk is 'not tolerable'.
- For Zone 6 the risk is 'tolerable'.

The risks are judged 'acceptable' or 'tolerable' where the depth of the debris flow is less than 0.5 m.

#### 2.5 Geotechnical investigations report (Appendix F)

The purpose of this report is to present data from a geotechnical borehole investigation and groundwater monitoring programme that was conducted as part of the landslide study. This report is a factual account of the work undertaken, the materials that were encountered and their geotechnical characterisation from laboratory testing. These results are used to inform the engineering geological characterisation in Appendix B.

Work undertaken was as follows:

#### **Boreholes**

- Nine cored boreholes advanced to a depth of between 11 m and 80 m below ground level (bgl) at locations at the top and below the escarpment, with the following distribution:
  - Three approximately 80 m deep boreholes at Oaia Road, east of (above) the Muriwai escarpment
  - Three boreholes below the Muriwai escarpment on Domain Crescent (two to approximately 11 m bgl and one to approximately 41 m bgl)
  - Three boreholes below the Muriwai escarpment on Motutara Road (two to approximately 11 m bgl and one to approximately 41 m bgl)
- Log the recovered material using NZGS (2005) guidelines
- Conduct Standard Penetration Tests (SPTs) at 1.5 m intervals
- Record data in AGS4 format and upload borehole logs to the New Zealand Geotechnical Database

#### Groundwater monitoring

- Install standpipe piezometer screens in some of the boreholes
- Measure initial water levels during drilling and following screen installation
- Supervise installation of water level data recorders and AC monitoring-compatible telemetry hardware to allow ongoing data collection (by AC)

#### Laboratory testing

Testing of recovered soils and rocks including:

- Atterberg Limit testing
- Particle size distribution (wet sieve) tests
- Unconfined Compressive Strength tests
- Pinhole and Crumb dispersibility

This report may be updated in the future to include ongoing data.

#### 3. Limitations

This report has been prepared by GHD Limited (GHD) for Auckland Council and may only be used and relied on by Auckland Council for the purpose agreed between GHD and Auckland Council as set out in Section 1 of this report.

GHD otherwise disclaims responsibility to any person other than Auckland Council arising in connection with this report. GHD also excludes implied warranties and conditions, to the extent legally permissible.

The services undertaken by GHD in connection with preparing this report were limited to those specifically detailed in the report and are subject to the scope limitations set out in the report.

The opinions, conclusions and any recommendations in this report are based on conditions encountered and information reviewed at the date of preparation of the report. GHD has no responsibility or obligation to update this report to account for events or changes occurring subsequent to the date that the report was prepared.

The opinions, conclusions and any recommendations in this report are based on assumptions made by GHD described in this report (refer Section 1 of this report). GHD disclaims liability arising from any of the assumptions being incorrect.

An understanding of the geotechnical site conditions depends on the integration of many pieces of information, some regional, some site specific, some structure specific and some experienced based. Hence this report should not be altered, amended, abbreviated, or issued in part in any way without prior written approval by GHD. GHD does not accept liability in connection with the issuing of an unapproved or modified version of this report.

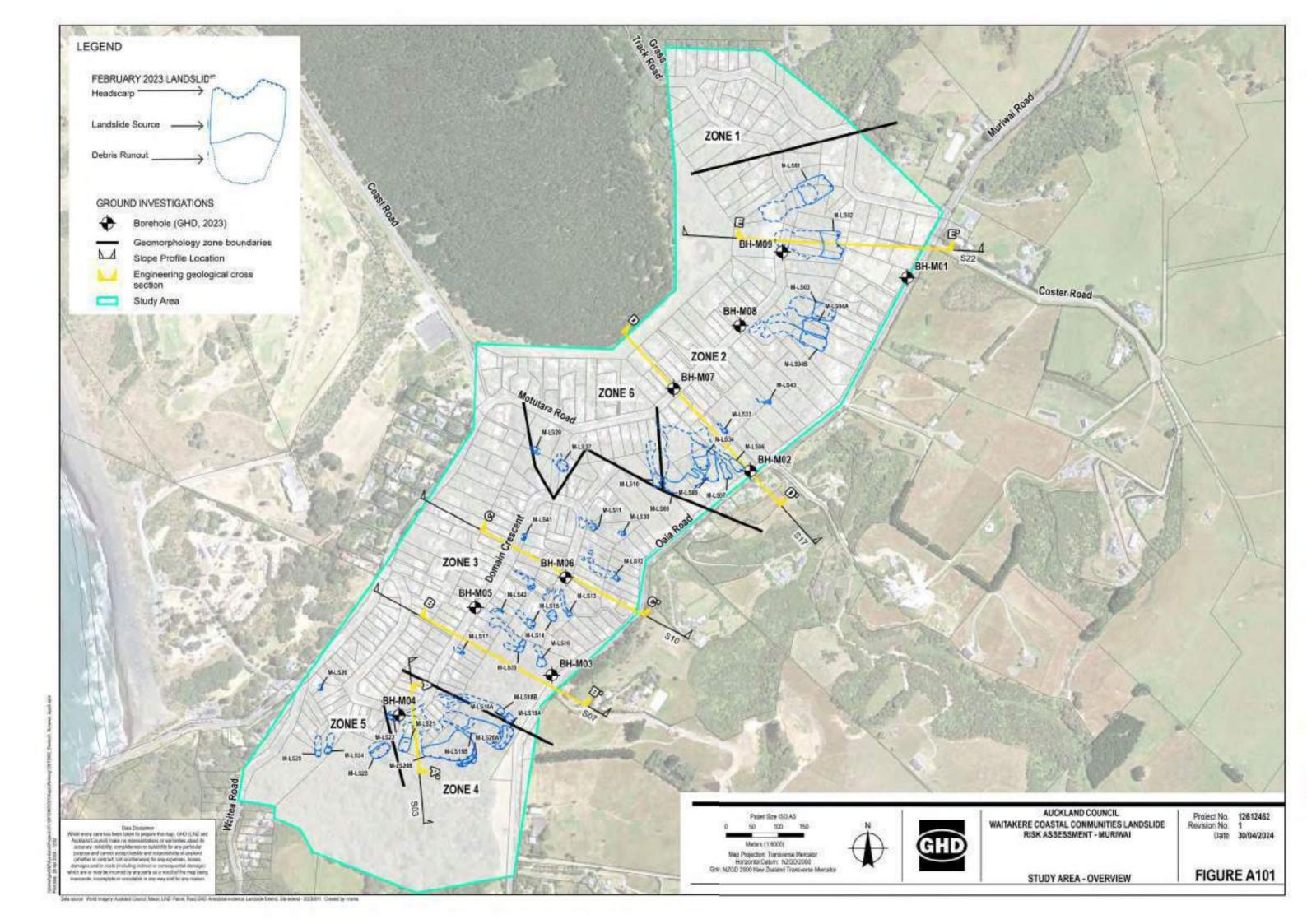
Verification of the geotechnical assumptions and/or model is an integral part of the design process - investigation, construction verification, and performance monitoring. If the revealed ground or groundwater conditions vary from those assumed or described in this report the matter should be referred back to GHD.

# Appendices

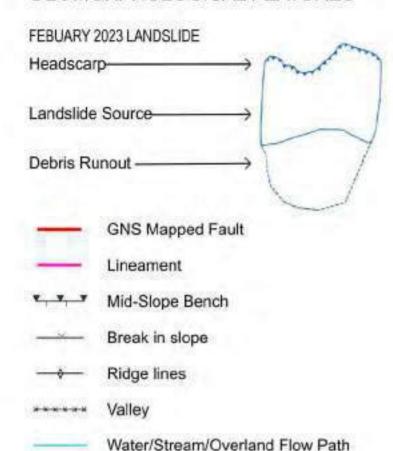
# Appendix A Figures

Table 2 Project A3-size figures

Figure No.	Description					
GENERAL SITE LAYOUT						
A101	OVERVIEW					
ENGINEERING	ENGINEERING GEOLOGICAL PLANS					
A111	LEGEND					
A112	OVERVIEW					
A113 -A116	CLOSE-UP PLANS					
CROSS SECTION	CROSS SECTIONS					
A120	CROSS SECTION A-A'					
A121	CROSS SECTION B-B'					
A122	CROSS SECTION C-C'					
A123	CROSS SECTION D-D'					
A124	CROSS SECTION E-E'					
GEOMORPHO	DLOGICAL LANDSLIDE ZONES					
A125	SLOPE RELIEF AND PROFILE COMPARISON PLAN					
ELEVATION M	IODEL COMPARISON					
A126	ELEVATION COMPARISON BETWEEN 2016 AND 2023 LIDAR TOPOGRAPHIC SURVEYS					
SLIP MECHANIS	SLIP MECHANISM MODEL					
A127	2023 CYCLONE GABRIELLE LANDSLIDE MECHANISM MODEL, MURIWAI					
A128	2023 CYCLONE GABRIELLE LANDSLIDE MECHANISM MODEL - PHOTO MARK-UP					
RAMMS DEBRIS FLOW SIMULATION PLANS						
A201	MAXIMUM DEBRIS HEIGHT EXTENTS FOR BEST CASE, PREDICTED AND WORST CASE SCENARIOS - (GREATER THAN 0.01 M DEEP) - OVERVIEW					
A202	PREDICTED MAXIMUM DEBRIS HEIGHT (GREATER THAN 0.01 M DEEP) - OVERVIEW					
A203 - A205	PREDICTED MAXIMUM DEBRIS HEIGHT (GREATER THAN 0.01 M DEEP) - CLOSE-UP					
A206	MAXIMUM DEBRIS HEIGHT EXTENTS (GREATER THAN 0.5 M DEEP) - OVERVIEW					
A207 - A209	MAXIMUM DEBRIS HEIGHT EXTENTS (GREATER THAN 0.5 M DEEP) - CLOSE-UP					



#### GEOMORPHOLOGICAL FEATURES



Reservoir

Mapped Spring

### **GEOLOGICAL UNITS**



<sup>\*</sup> Not visible at ground surface - refer to cross sections (A120 - A124)

#### **MISCELLANEOUS**



Borehole (GHD, 2023)



Indicative Strike and Dip of the Nihotupu Formation



Engineering geological cross section



Slope Profile Location



Contour (10m)



Contour (5m)



Contour (1m)



Geomorphology zone boundaries



Edwin Mitchelson Face Log



Edwin Mitchelson track



Historic landslide (1965)

#### ANECDOTAL EVIDENCE



Depression



Drain



Landslide



Retaining Wall





Anecdotal Spring



Stream

Data Disclame:

While every care two loves loters in proper that may, cold () (Fig. and

Auction Council make an exponentation or writinities about the

accuracy involving, completeness or involving to any protection

purpose and control, among tablely and responsibility of any fund

you and on a control, and a otherwise) for any regiments, losers, damages, additor coeds (including indexed or consequential damage). Not are or may be incurred by any party as a result of the imapidads.

Page See ISUAN

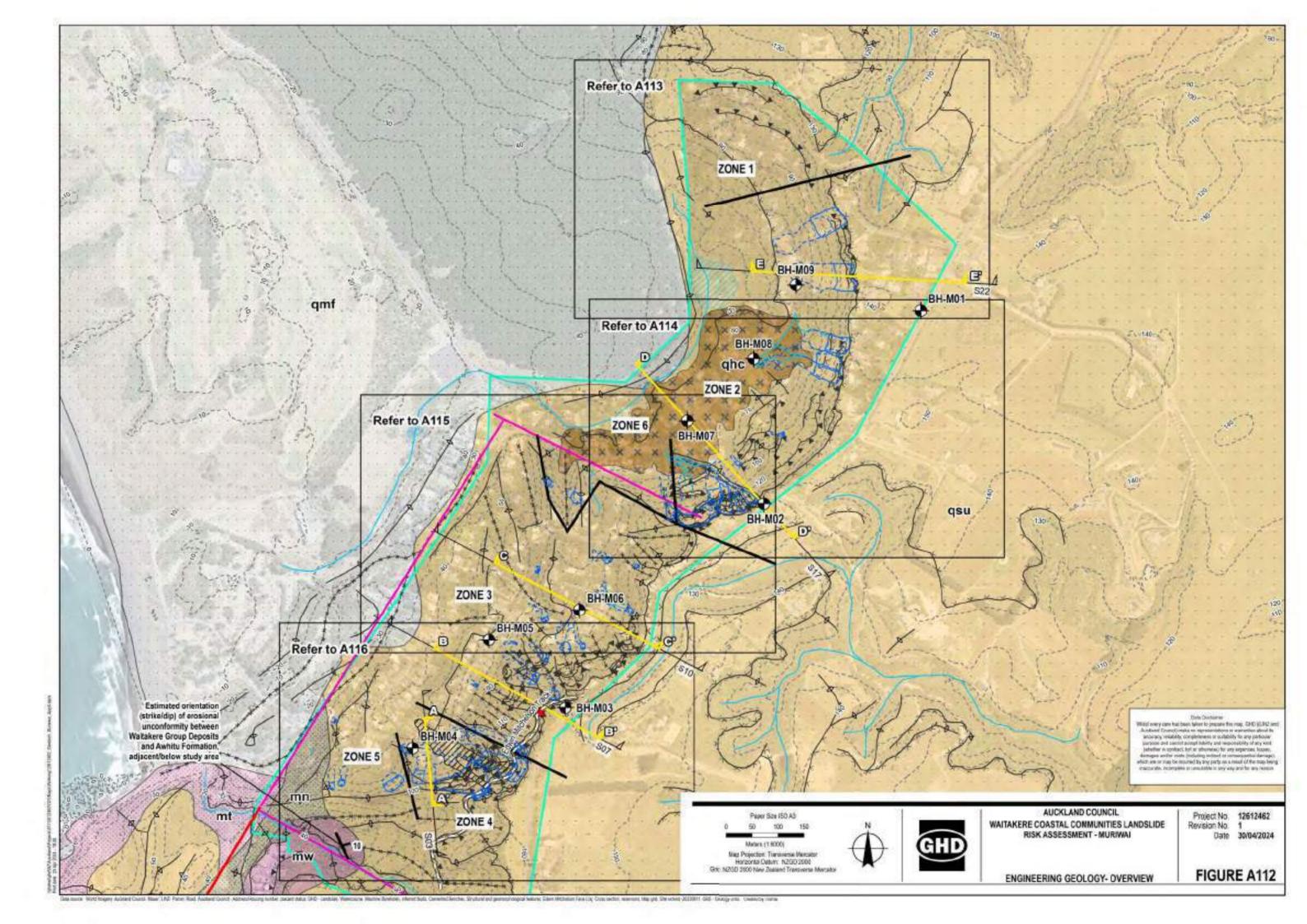


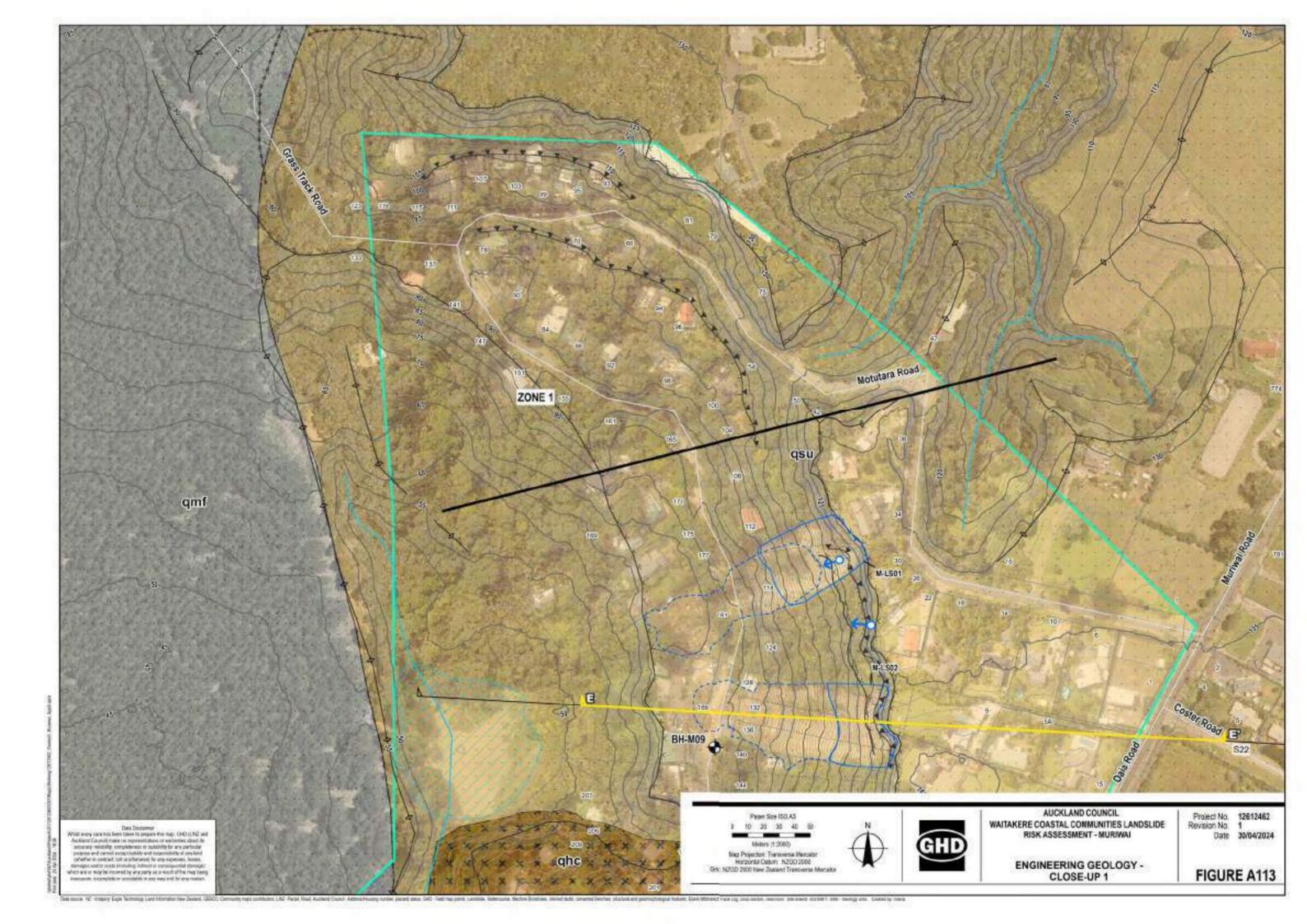
AUCKLAND COUNCIL WAITAKERE COASTAL COMMUNITIES LANDSLIDE RISK ASSESSMENT - MURIWAI

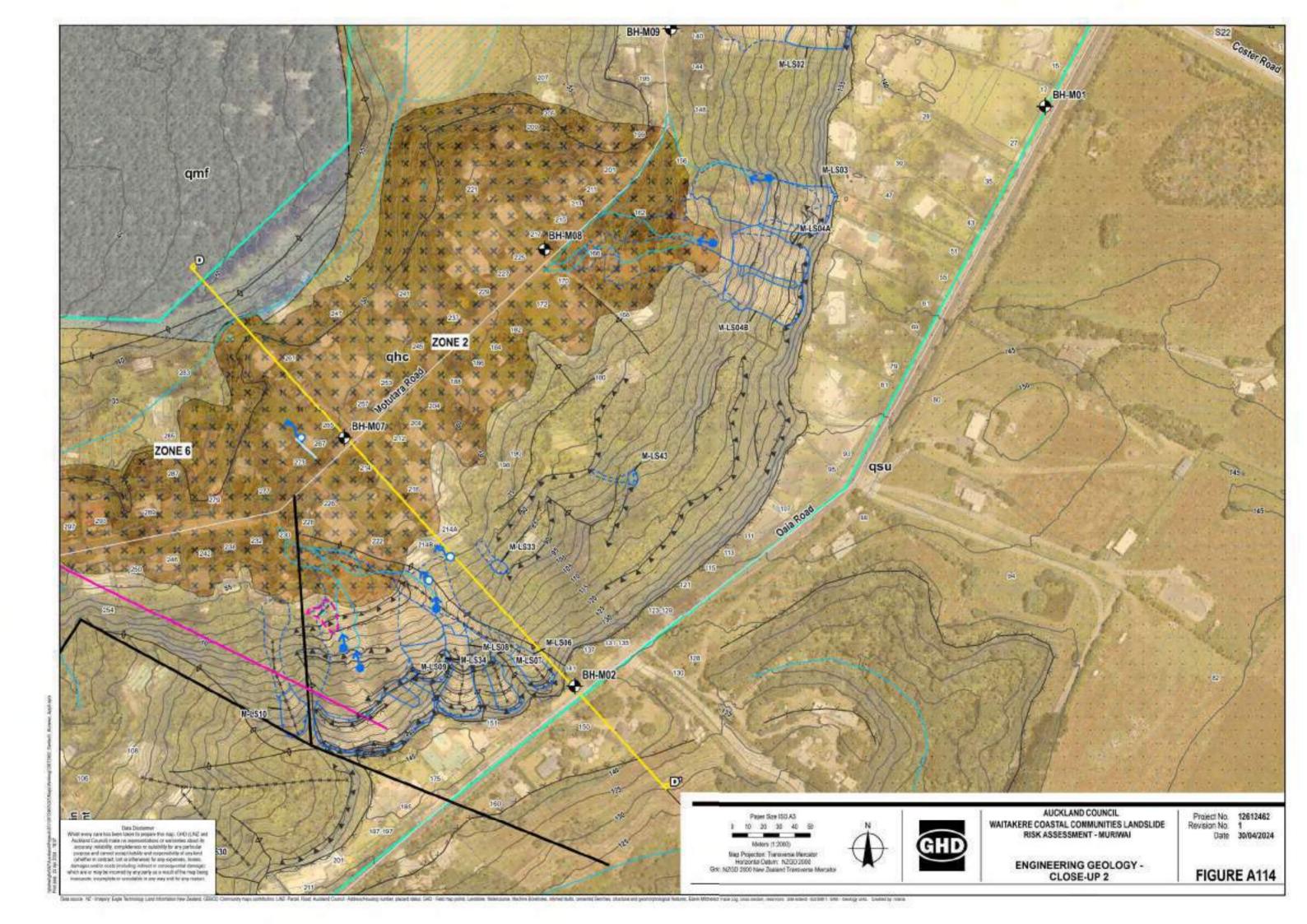
Project No. 12612462 Revision No. 30/04/2024 Date

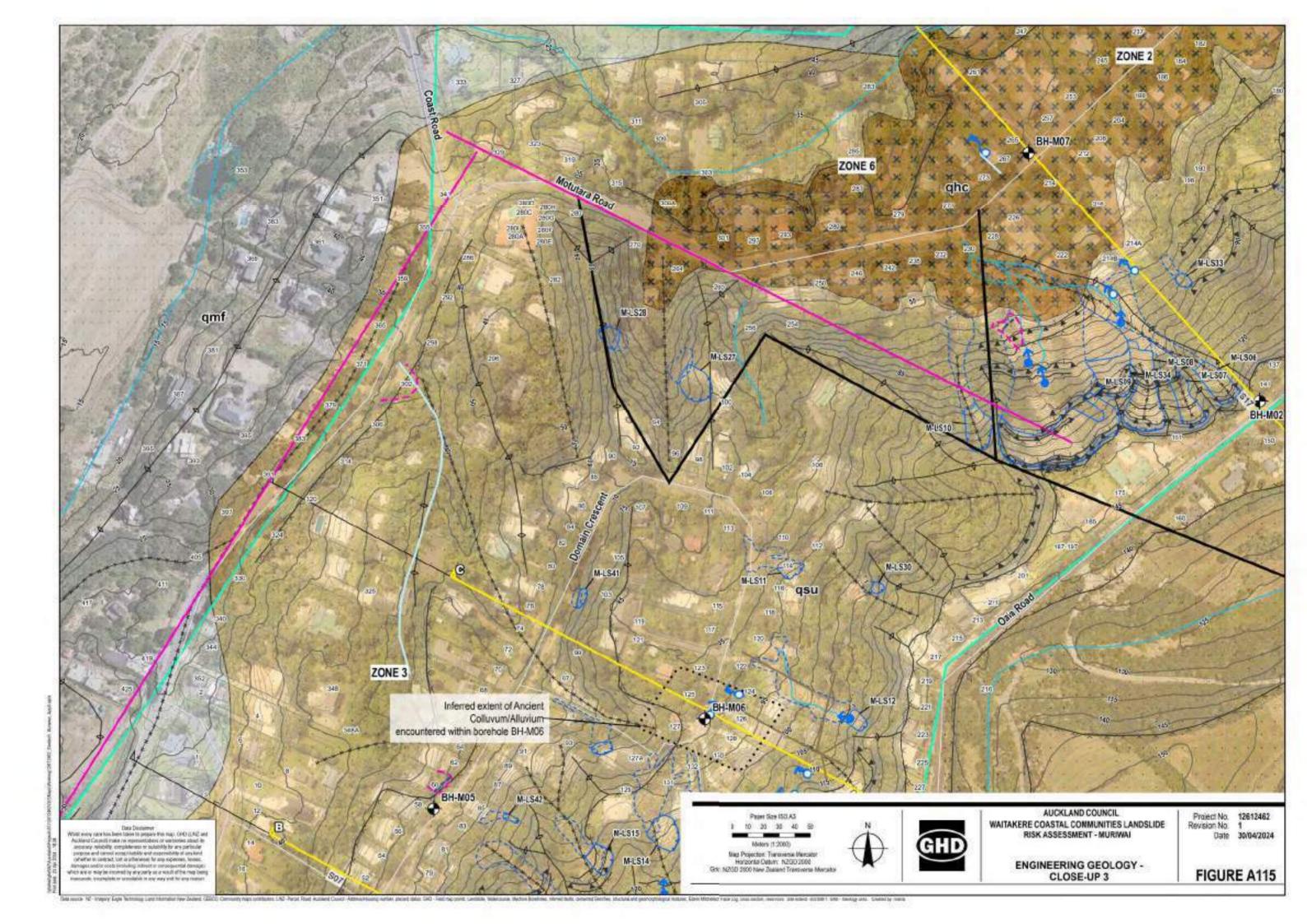
**ENGINEERING GEOLOGY - LEGEND** 

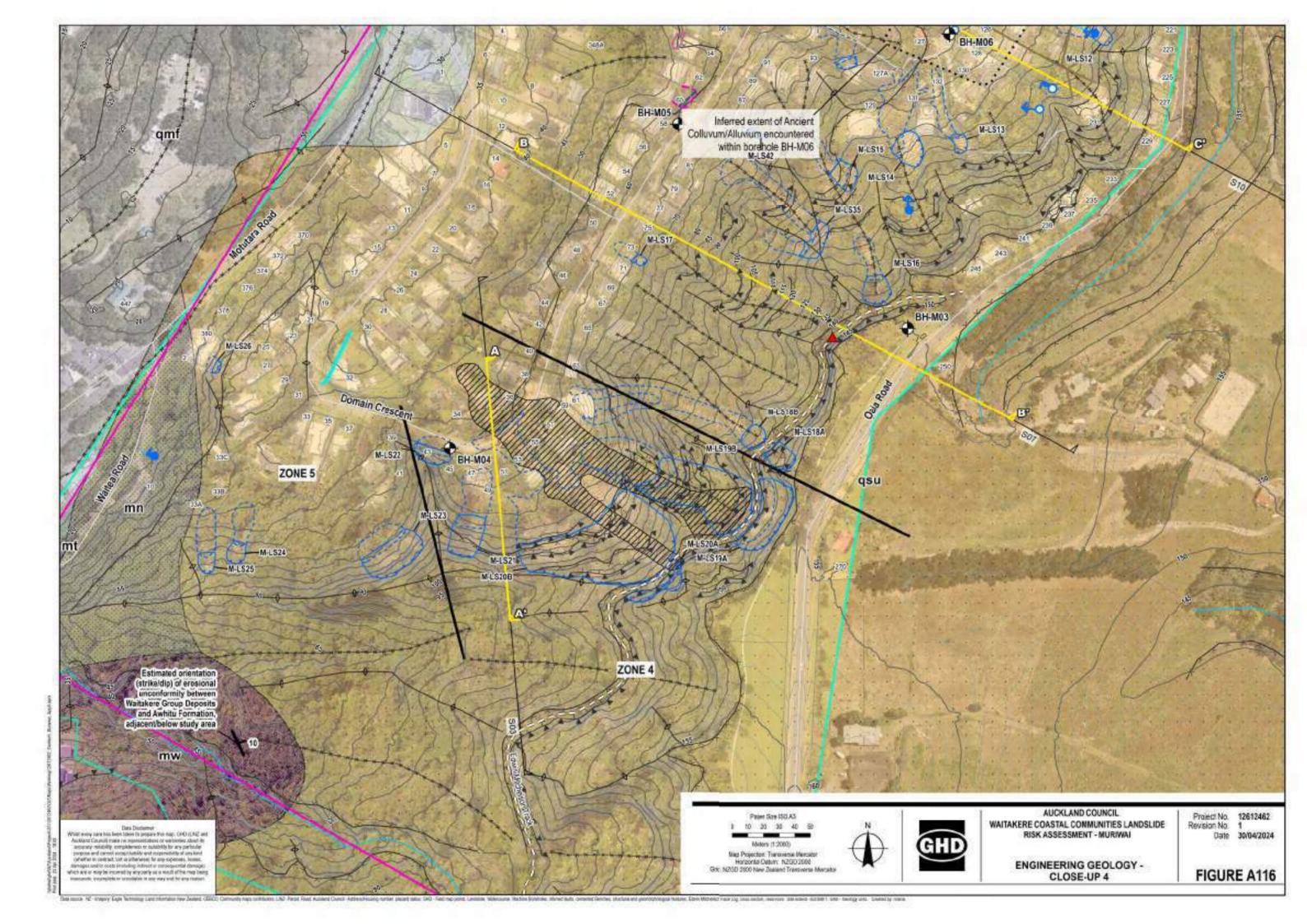
FIGURE A111

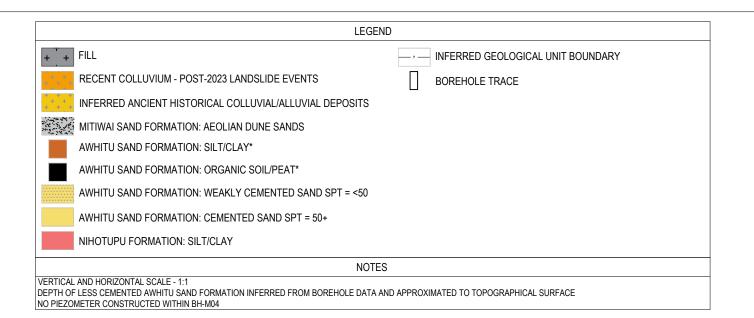


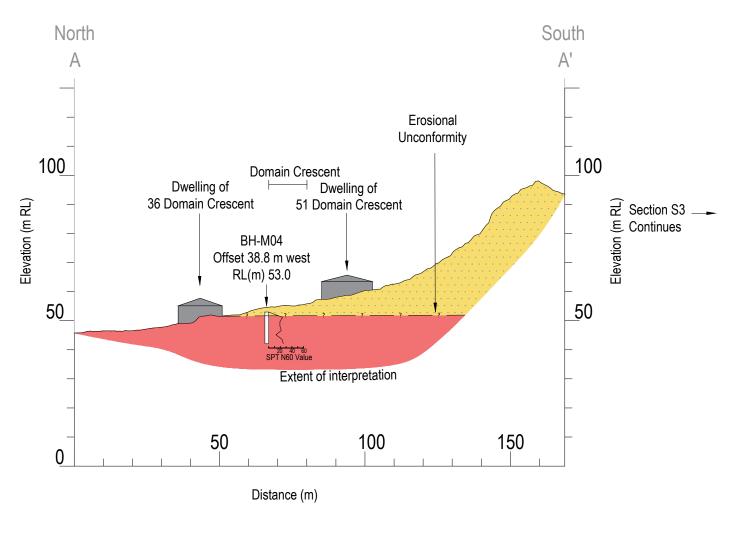
















Client AUCKLAND COUNCIL

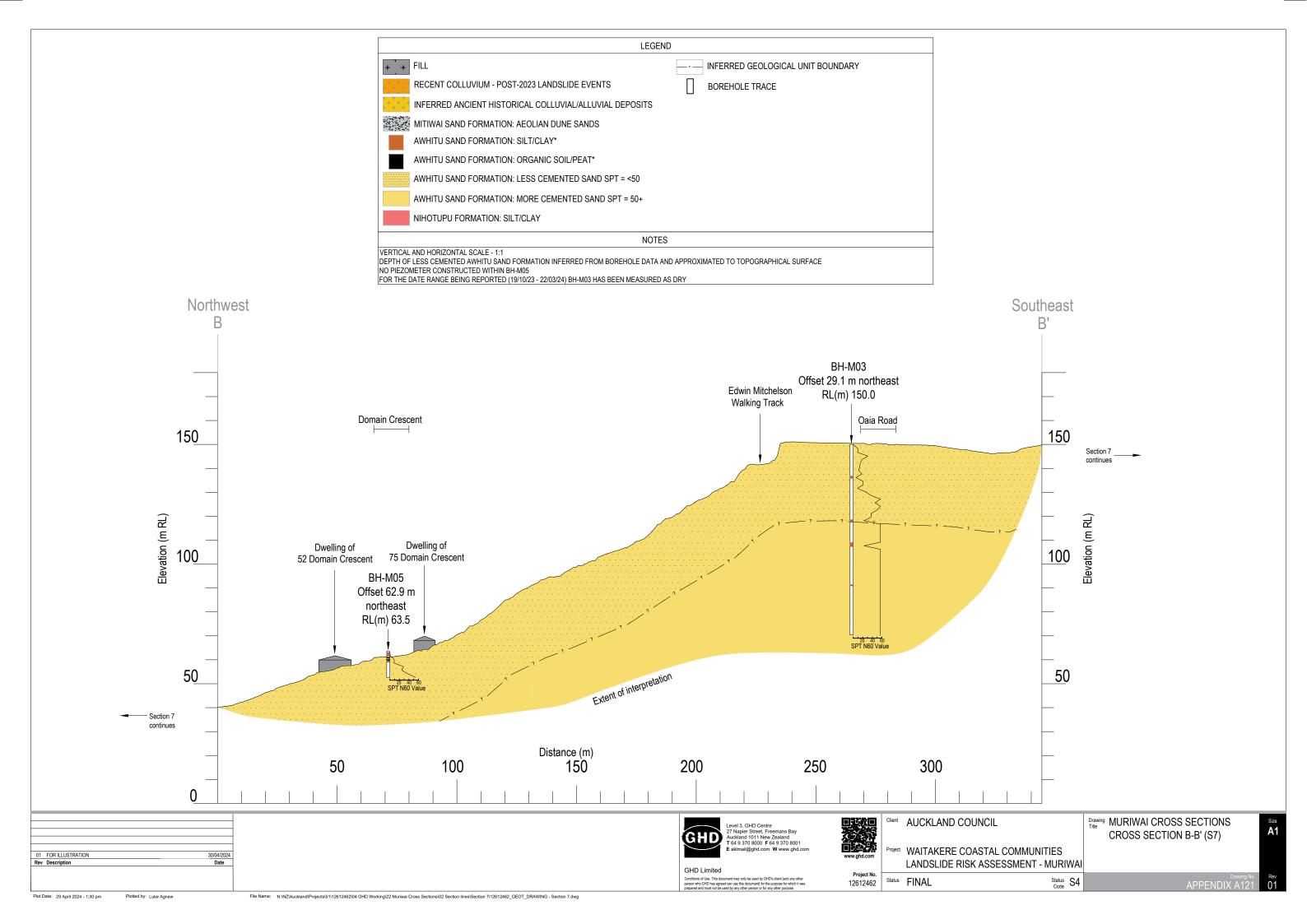
Status FINAL

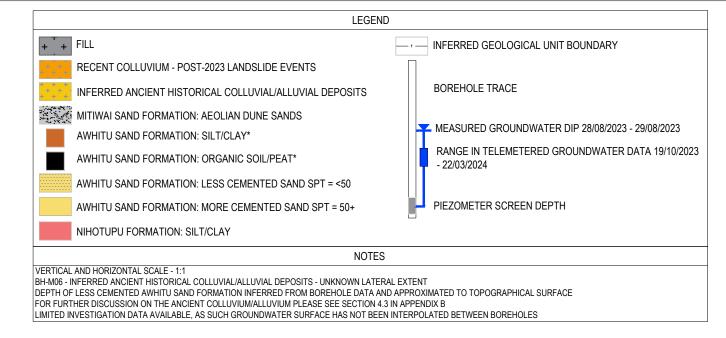
roject WAITAKERE COASTAL COMMUNITIES LANDSLIDE RISK ASSESSMENT - MURIWAI

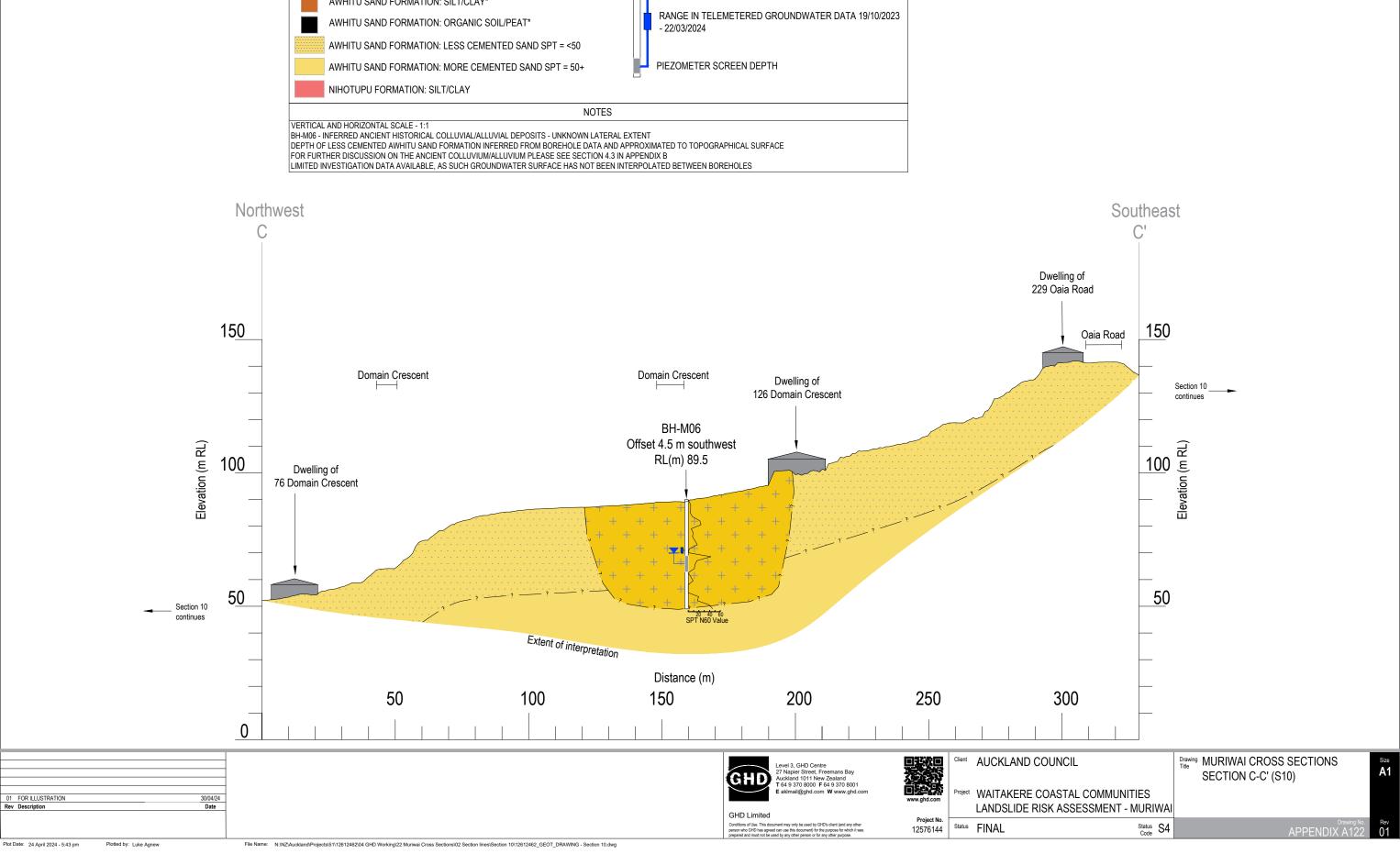
Drawing MURIWAI CROSS SECTIONS CROSS SECTION A-A' (S3)

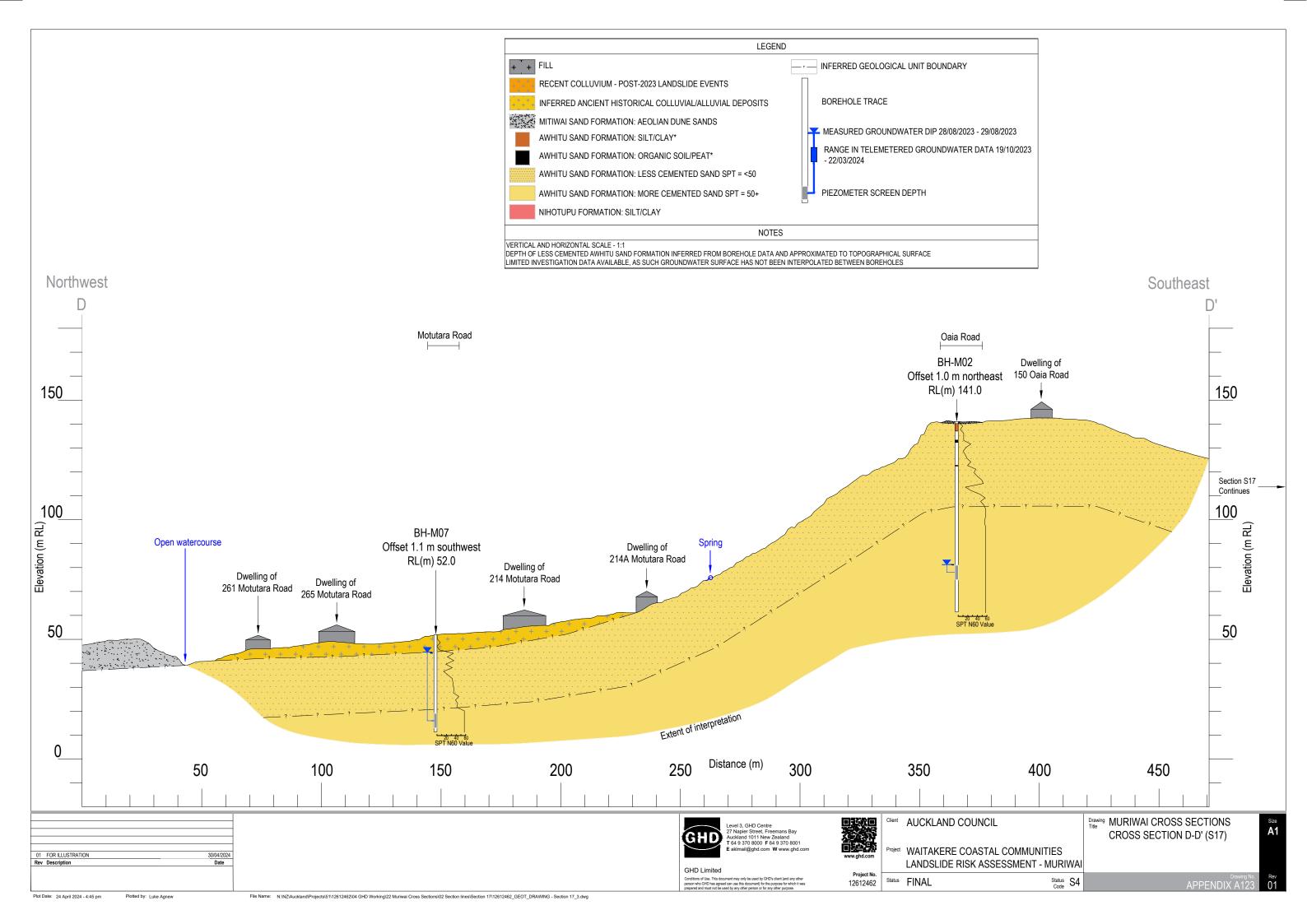
Status S4

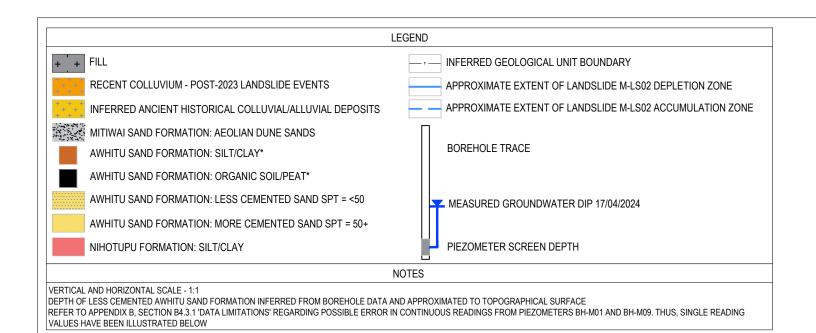
Size A1

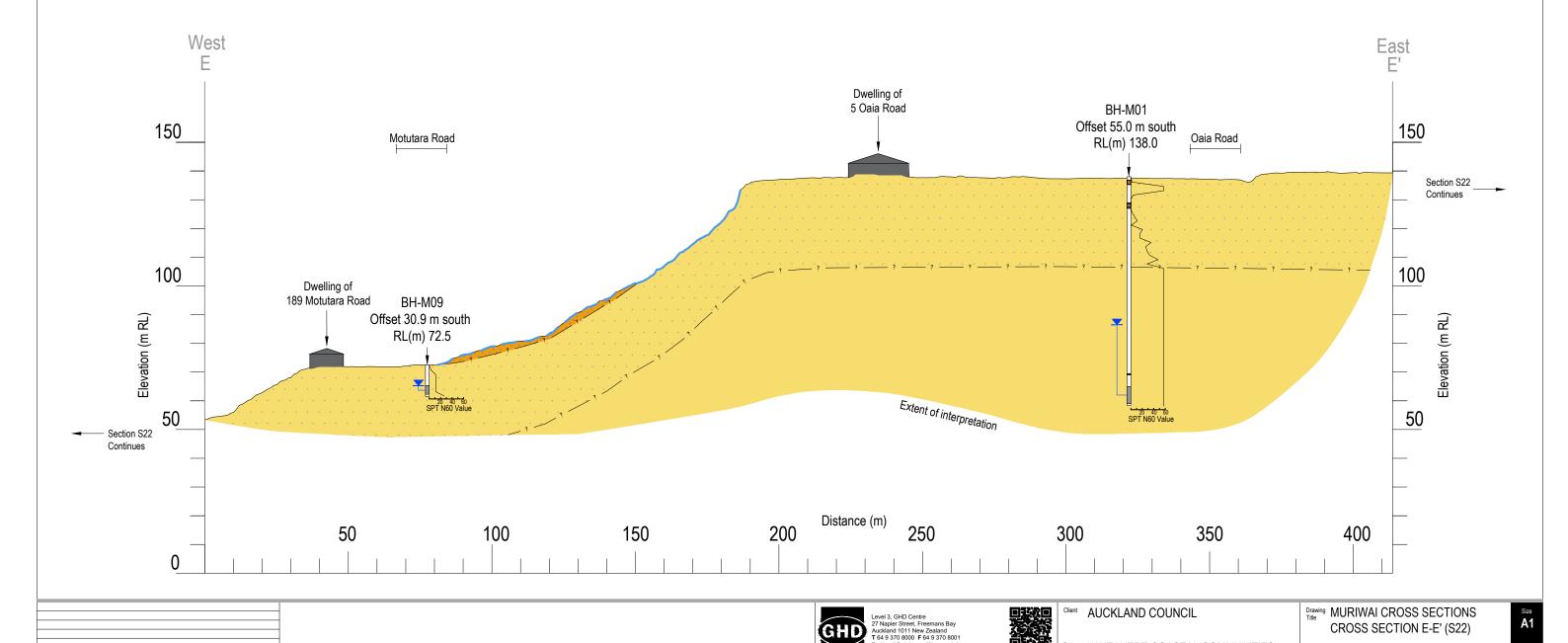












GHD Limited

oject WAITAKERE COASTAL COMMUNITIES

Project No. 12612462

Status FINAL

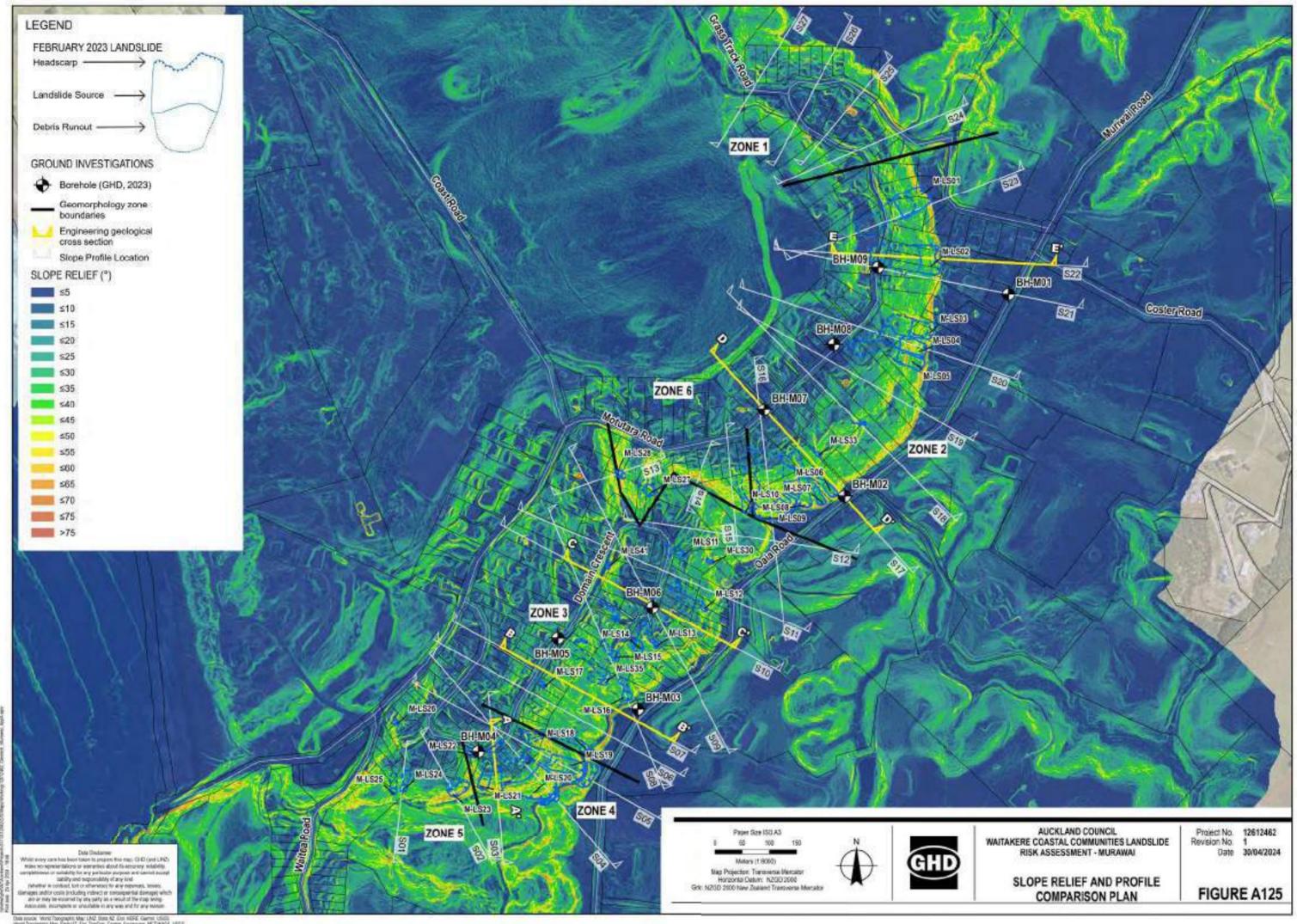
LANDSLIDE RISK ASSESSMENT - MURIWAI

Status S4

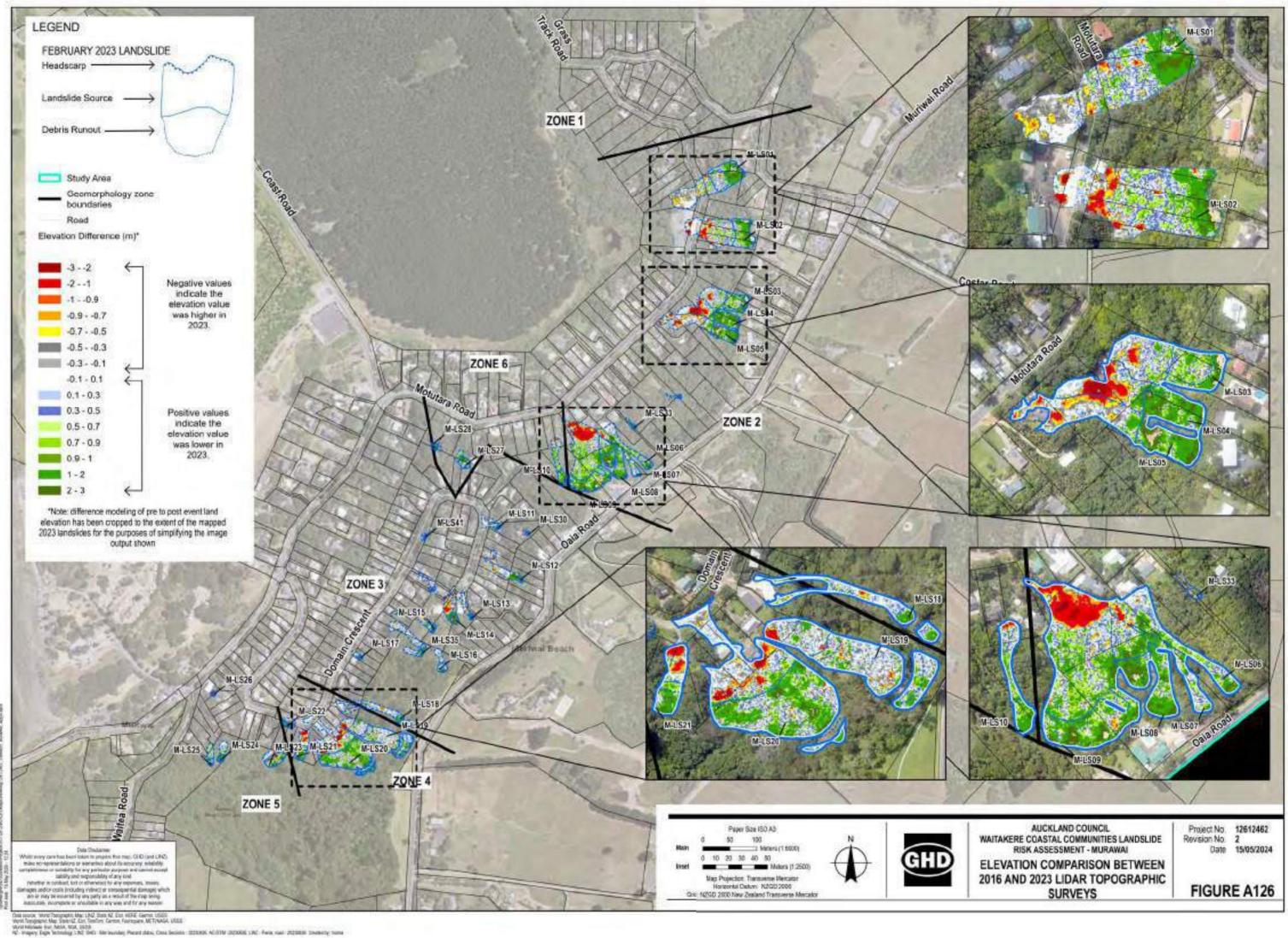
APPENDIX A1

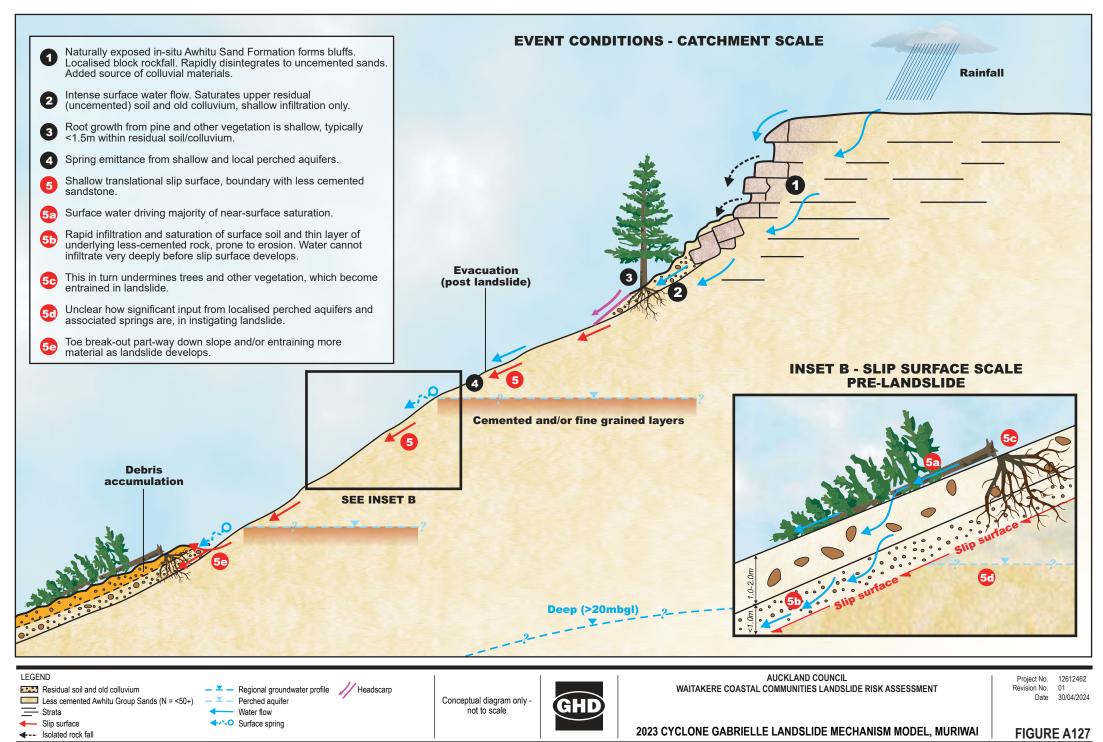
30/04/24 Date

01 FOR ILLUSTRATION
Rev Description



MATERIANA FOR MAIN, NO. 1923 NE Propry Egy Technolog I NE SHE Sandary Parent Main, Clean Section 122000, ACCITE 000005 CAC Parts, care 202000 Technolog I com-







00 FOR ILLUSTRATION
Rev Description

LA NB 30/04/2 Checked Approved Date

GHD Limited

Conditions of Use. This document may only be used by GHD's client (and any other

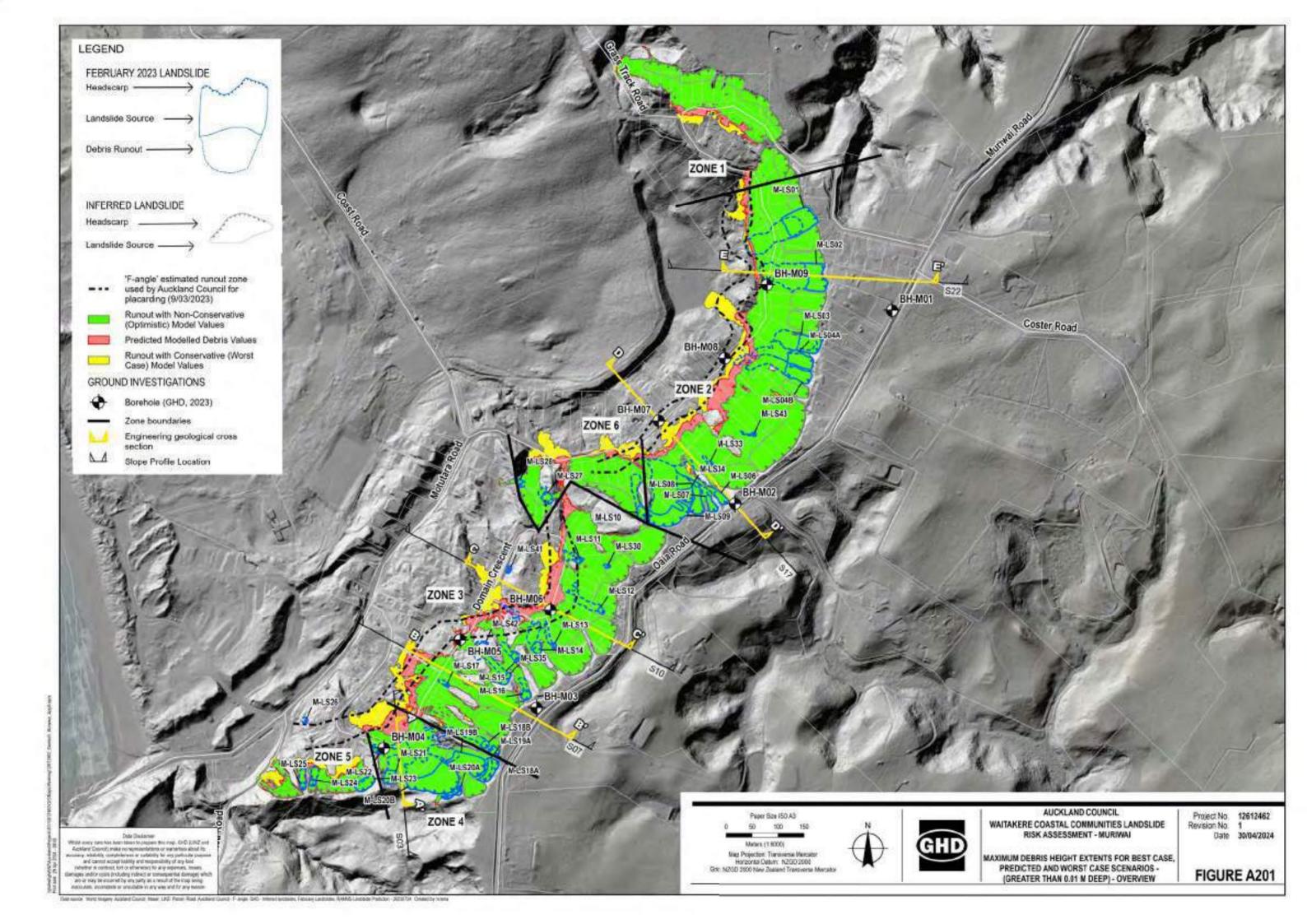
nd www.ghd.com

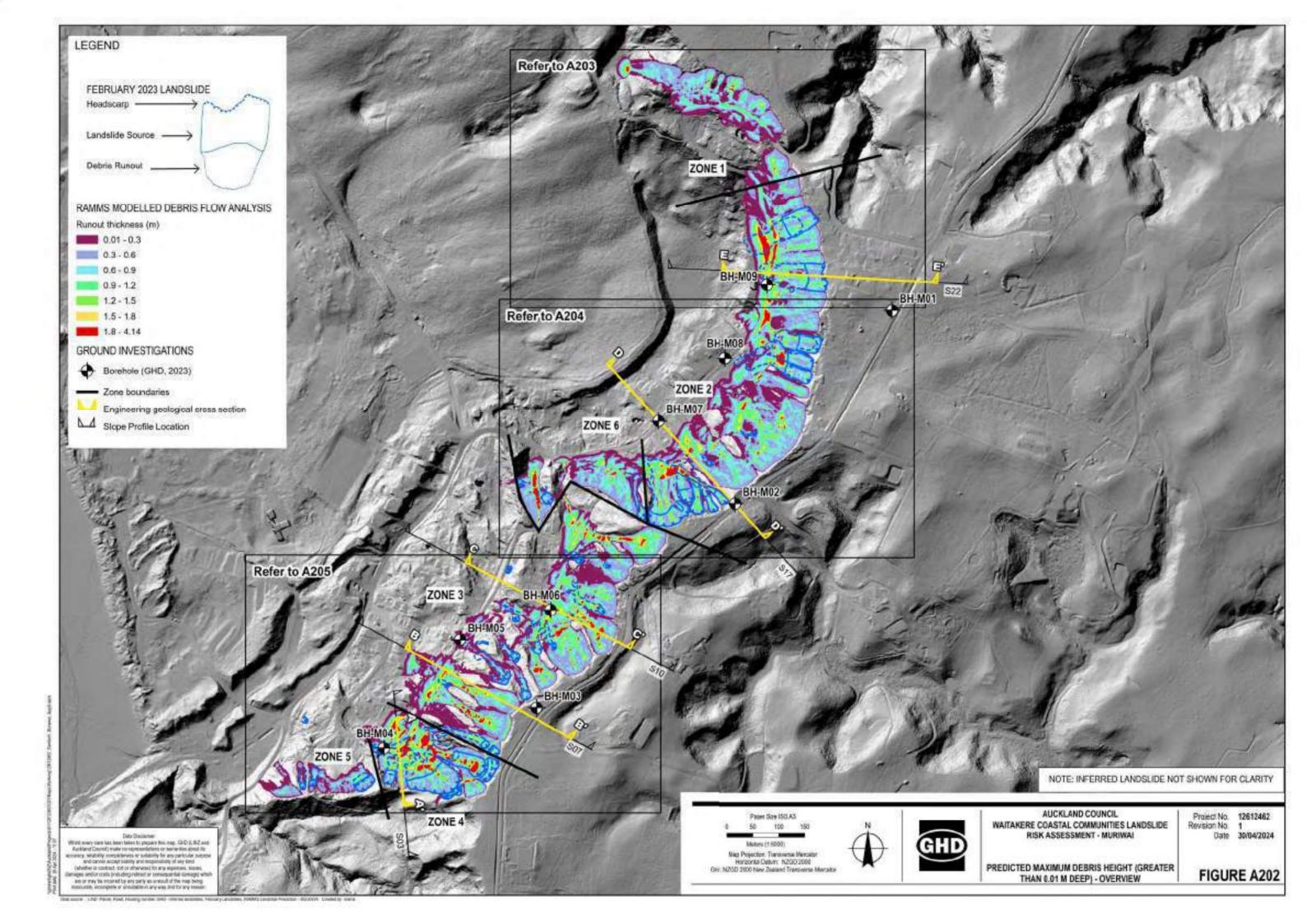
Project WAITAKERE COSTAL COMMUNITIES LANDSLIDE RISK ASSESSMENT - MURIWAI

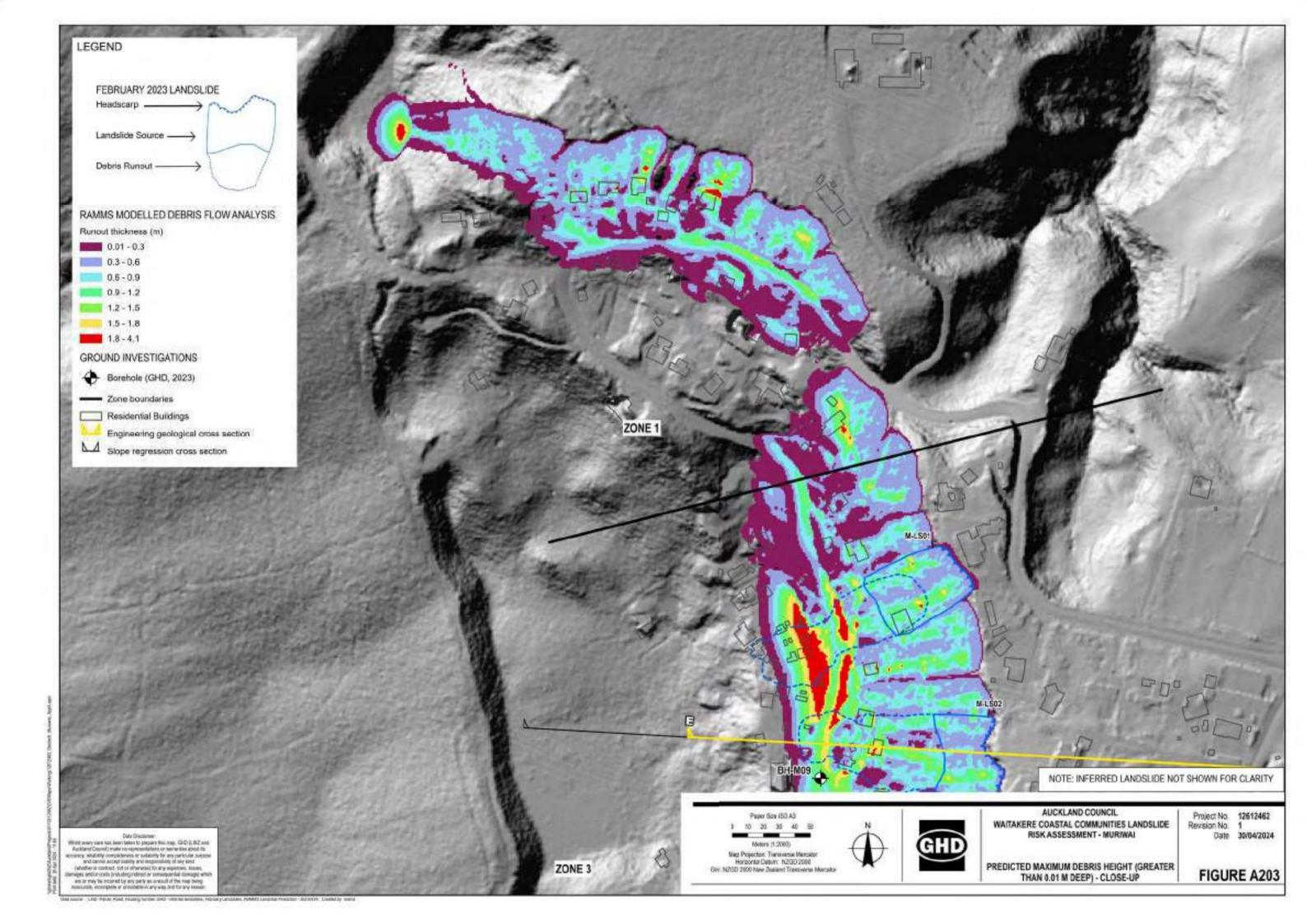
FOR ILLUSTRATION Status S4

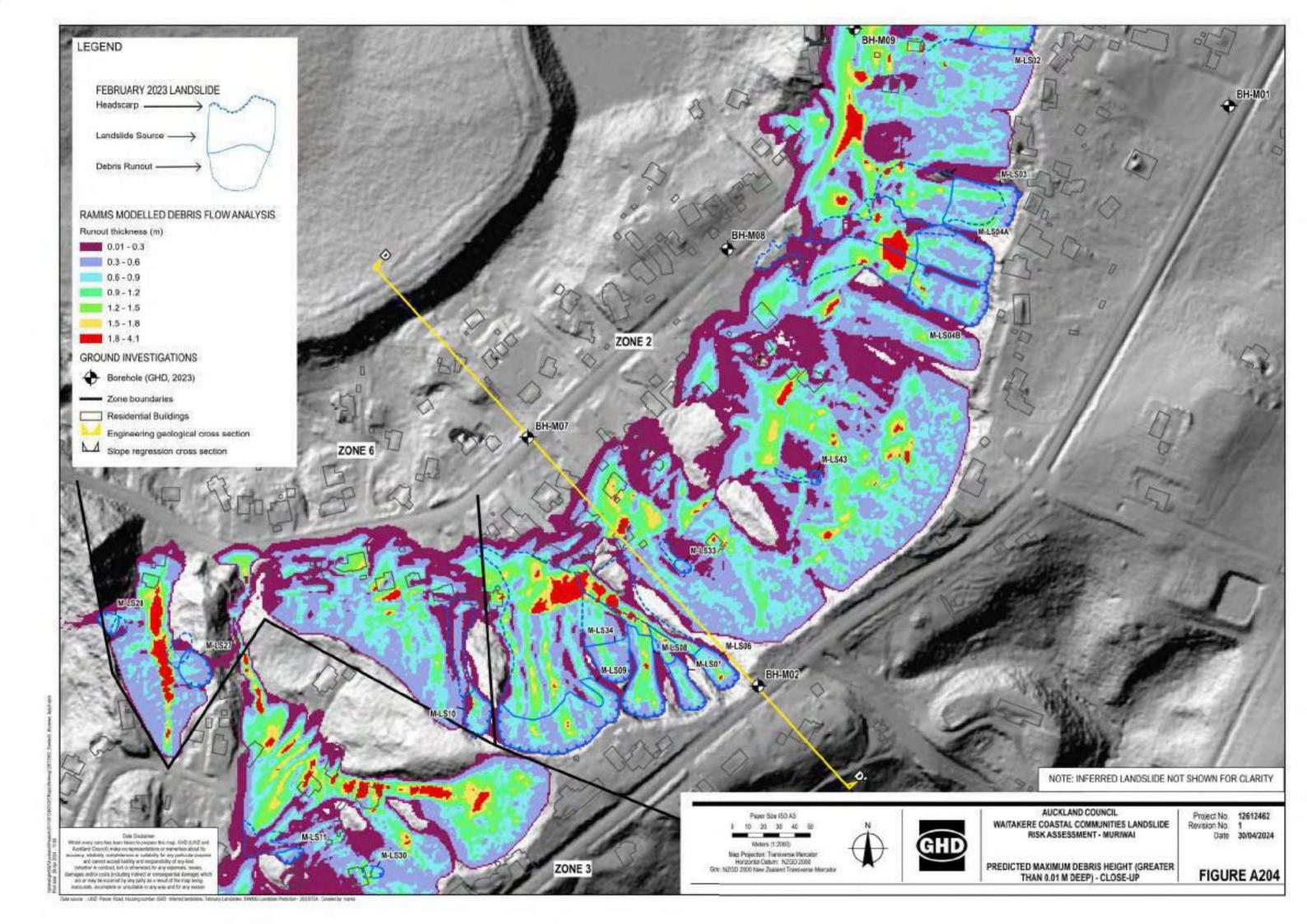
2023 CYCLONE GABRIELLE LANDSLIDE MECHANISM MODEL, MURIWAI - PHOTO MARK-UP

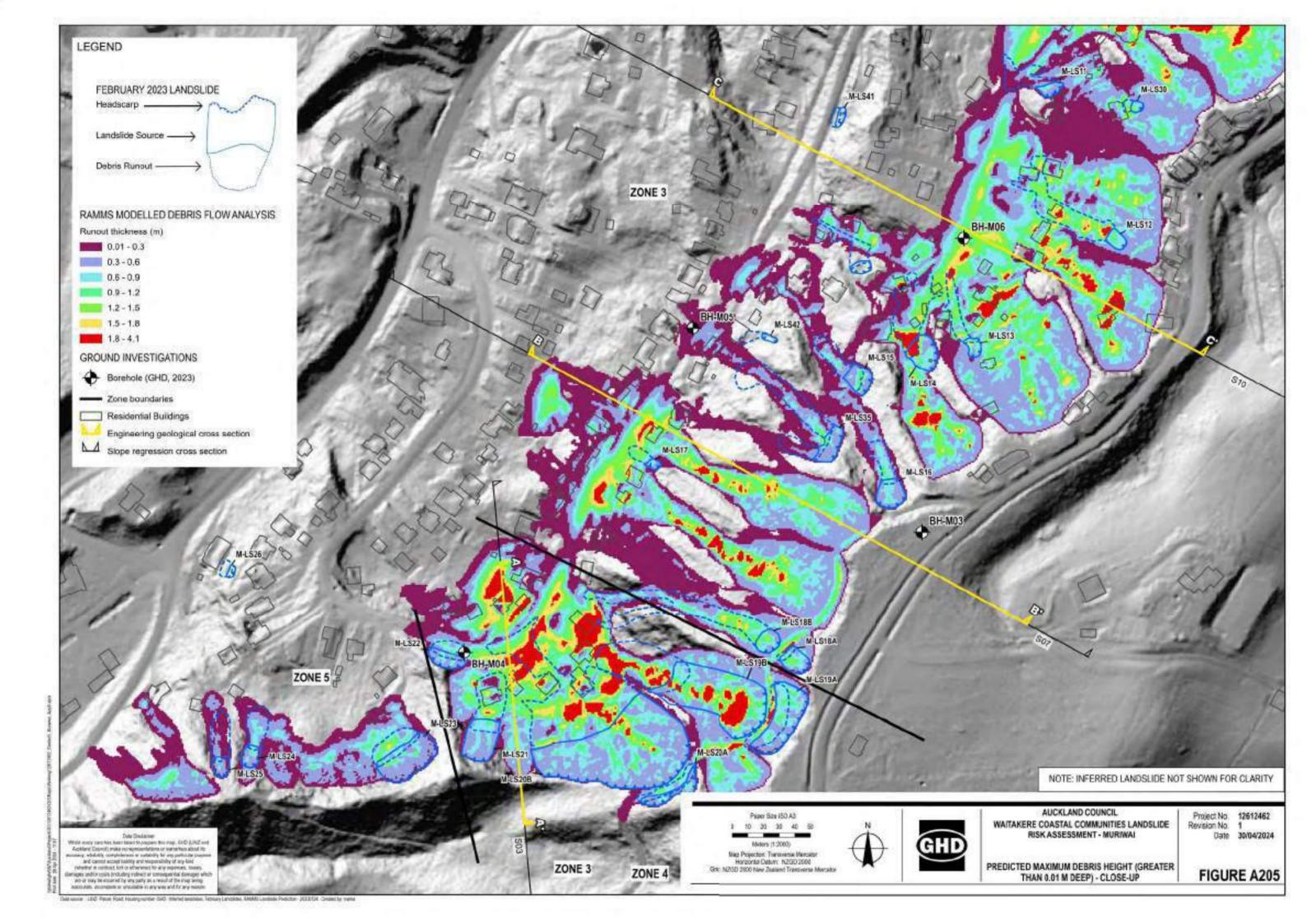
Drawing No.
APPENDIX A128

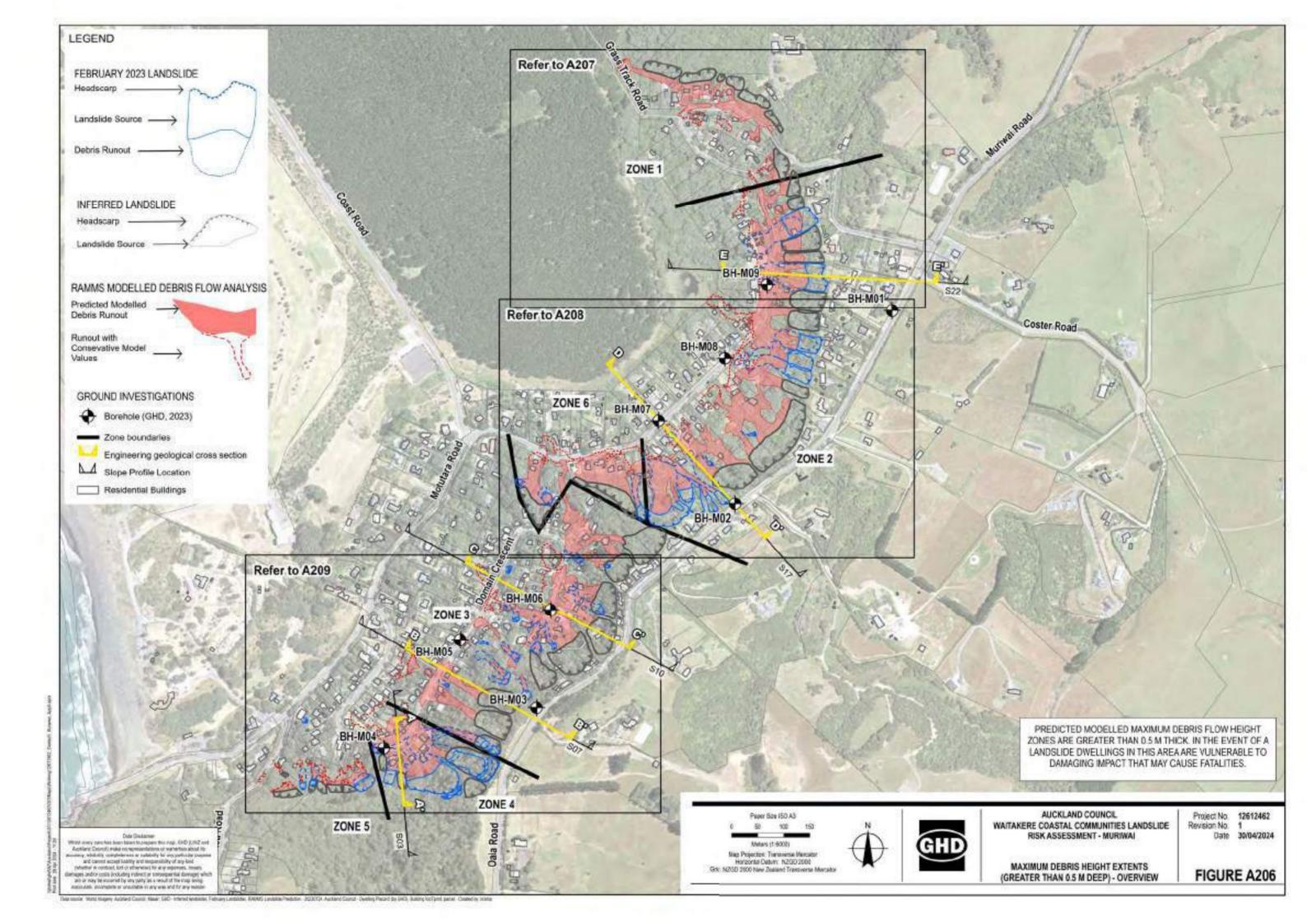


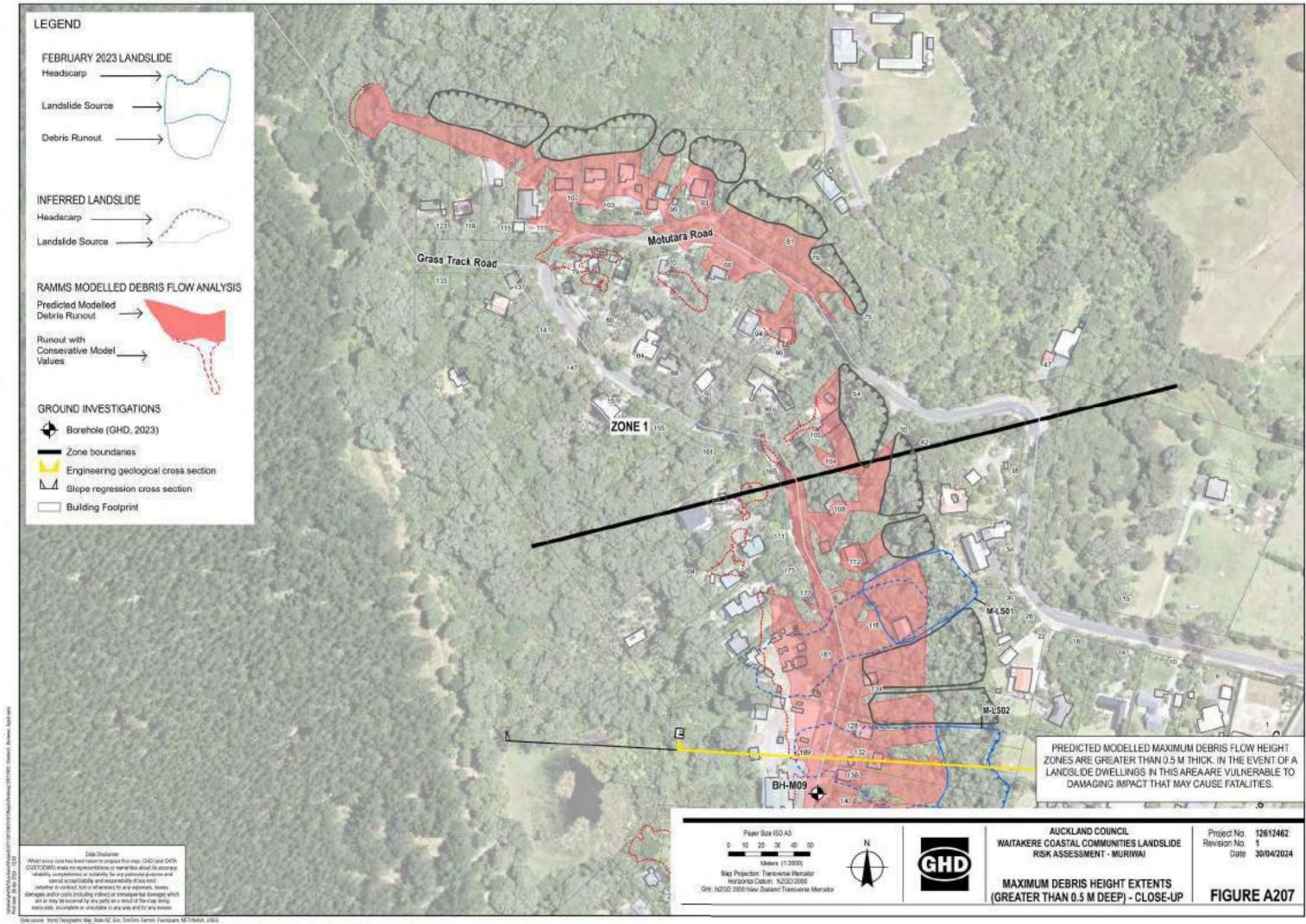


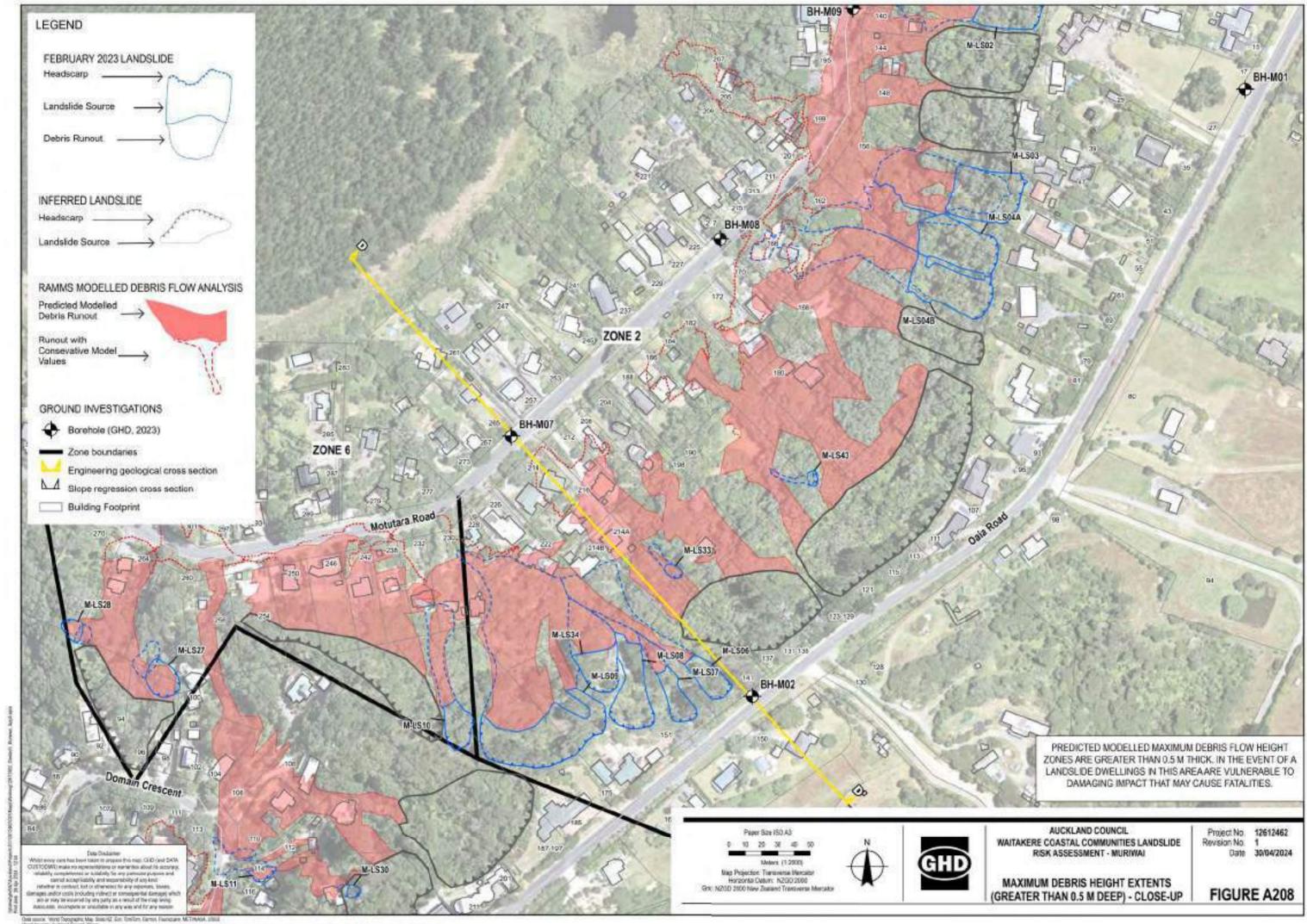


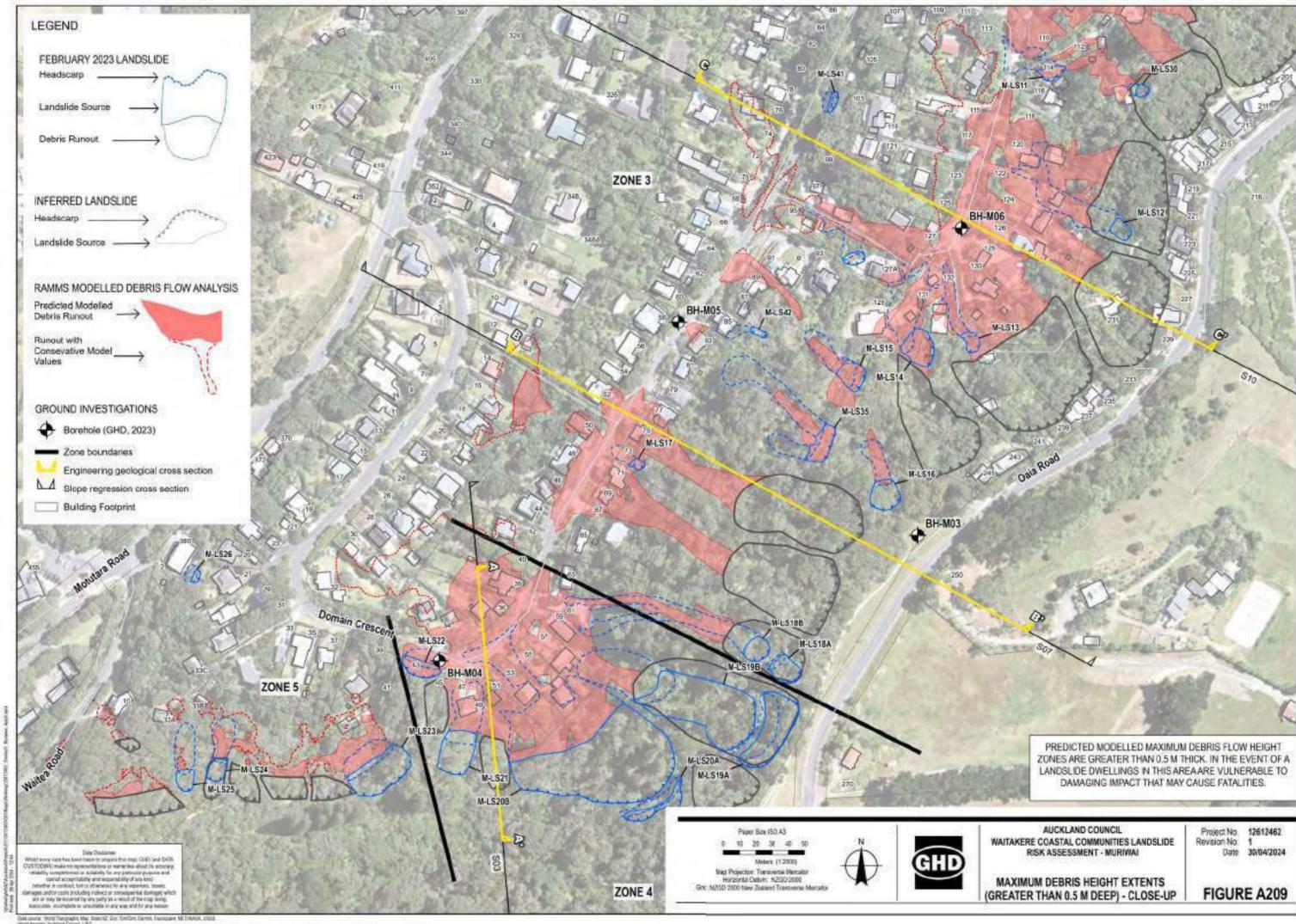












# Appendix B

**Engineering Geological Report** 



# Waitakere Coastal Communities Landslide Risk Assessment

Appendix B – Muriwai Engineering Geological Report

Auckland Council
15 May 2024

→ The Power of Commitment



Project name		Waitakere Coastal Communities Landslide Risk Assessment					
Document title		Waitakere Coastal Communities Landslide Risk Assessment   Appendix B – Muriwai Engineering Geological Report					
Project number		12612462					
File name	:	12612462_App	endix B_Rev2.docx				
Status	Revision	Author	Reviewer		Approved for	issue	
Code			Name	Signature	Name	Signature	Date
S4	0	Nick Burke	Don Macfarlane	Dragadan	Roy Pearson	loy Prarson	3/11/2023
S4	1	Nick Burke	Don Macfarlane	Dolafarlan	Roy Pearson	Roy Pearson	30/04/2024
S4	2	Nick Burke	Don Macfarlane	Dragadan	Roy Pearson	Roy Prarson	15/05/2024
[Status code]							
[Status code]							

#### **GHD Limited**

Contact: Matt Howard, Technical Director - Engineering Geologist | GHD

27 Napier Street, GHD Centre Level 3

Freemans Bay, Auckland 1010, New Zealand

T +64 9 370 8000 | F +64 9 370 8001 | E aklmail@ghd.com | ghd.com

#### © GHD 2024

This document is and shall remain the property of GHD. The document may only be used for the purpose for which it was commissioned and in accordance with the Terms of Engagement for the commission. Unauthorised use of this document in any form whatsoever is prohibited.

# **Contents**

B1.	Introdu	uction	1
	B1.1	Background	1
	B1.2	Purpose of this report	1
	B1.3	Scope	1
	B1.4	Report Structure	2
B2.	Method	dology	4
	B2.1	Data review	4
		B2.1.1 Topographic data	4
		B2.1.2 Anecdotal community feedback	4
		B2.1.3 Historical literature review	4
	B2.2	2023 – 2024 field investigations	6
		B2.2.1 Geological field observations and measurements B2.2.2 Subsurface geological investigations	6
D2	C4dv.	5 5	-
B3.	B3.1	area description	7
	B3.1	Nature and extent of the study area	7
	D3.2	Study area geology B3.2.1 Stratigraphy	3
		3.2.1.1 Mitiwai Sand	8
		3.2.1.2 Awhitu Sand	3
		3.2.1.3 Waitakere Group	3
	B3.3	B3.2.2 History and structure Surface characteristics	10
	D3.3	B3.3.1 Surface features	10
		B3.3.2 Surface water catchments	10
	B3.4	Historical land-use change	11
	B3.5	1965 Landslide event	12
	B3.6	Overview of February 2023 landslides	13
B4.	Engine	eering geological interpretation	15
	B4.1	Geological units	15
	B4.2	Geomorphology	15
	B4.3	Groundwater	21
		B4.3.1 Data	21
		B4.3.2 Groundwater interpretation	24
	B4.4	Surface water	24
	B4.5	Ground model of study area	25
		B4.5.1 Distribution of geological units	25
		B4.5.2 Material properties, Awhitu Sand	25
		B4.5.3 Groundwater B4.5.4 Surficial deposits	25 25
	B4.6	Conceptual landslide model	26
	∪4.0	B4.6.1 Mechanism and controls	26
		B4.6.2 Uncertainties	27

B5.	Chara	cterisatio	n of lands	lide hazard	28
	B5.1	Morpho	logy		28
		B5.1.1	Definition of	of landslide type(s)	28
		B5.1.2	•	d size characteristics	28
		B5.1.3	Distribution	n	28
		B5.1.4	Debris		29
		B5.1.5		of occurrence	32
	B5.2	•		e runout assessment	32
		B5.2.1	Backgroun		32
		B5.2.2 B5.2.3	F-angle as	d Fell (2002) empirical method	34 35
DC	1			· , , .	
B6.			rd assessi		38
	B6.1			dslide source areas	38
	B6.2		-	-seated landslides within Awhitu Formation	38
	B6.3		. •	l landslide zones	39
		B6.3.1		and overview of zones	39
		B6.3.2	2one cnara 6.3.2.1	acterisation Zone 1	41 41
			6.3.2.2	Zone 2	42
			6.3.2.3	Zone 3	43
			6.3.2.4	Zone 4	44
			6.3.2.5 6.3.2.6	Zone 5 Zone 6	45 46
D.7	Canal		0.3.2.0	Zone o	
B7.		usions			48
B8.	Limita	tions			49
B9.	Refere	ences			50
Tal	ala in	dov			
ıaı	ole in	uex			
Tabl	e B1	Sum	mary of ac	companying Muriwai landslide risk assessment reports	2
Tabl	e B2	List	of maps an	d images in Appendix A that are associated with this report.	3
Tabl	e B3	Sum	mary of red	ceived data	5
Tabl	e B4	Stud	y area geo	logical stratigraphy	ç
Tabl	e B5	Land	d use chang	ge early 1900s - present day	11
Tabl	e B6			ological units	16
Tabl	e B7	Sum	mary of gro	oundwater data reviewed and observations	21
Tabl	e B8	Sum	marised di	mensional values (size and shape) of 2023 landslides	28
Tabl	e B9	Sum	mary of F-a	angle assessment	36
Tabl	e B10	Sum	mary of pre	edicted travel distance angles	37
Tabl	e B11		mary of slo le colours)	ppe angle and height for zone profiles (zones coloured to match	40

# Figure index

Figure B1	Muriwai location showing the February 2023 landslides mapped by GHD (blue lines)	7
Figure B2	Excerpt from Hayward, B.W 1983: Sheet Q11, Waitakere. Geological Map if New Zealand 1:50,000. NZGS.	8
Figure B3	Water catchments in Muriwai. Solid blue lines are individual catchments and thin blue dashed lines are nominal surface water flow paths. Defined by GHD using LINZ topographic data.	10
Figure B4	Early 1900s (unspecified), approximate location of present-day Edwin Michelson Track/Oaia Road, looking due North over Muriwai Beach. Source: Supplied by Auckland Council, 2023, Edwin Mitchelson House	12
Figure B5	Mapped extent of 1965 Landslides (after Wright 1966)	13
Figure B6	View from Domain Crescent of 1965 landslides and destroyed dwellings (after Wright 1966)	13
Figure B7	Entrained vegetation and sand/silt comprising the overall 'colluvial debris', GHD 2023. Debris resulting from Landslides M-LS07,08,09.	14
Figure B8	Example of significant destruction of dwelling, associated with landslide debris runout, GHD 2023. Debris resulting from Landslides M-LS12.	14
Figure B9	Example of engineering geological unit '2023 Recent Colluvium'. Medium grained sand, unconsolidated, spread out thinly across existing surfaces.	17
Figure B10	'Fill Deposits' soil recovered in BH - M02: 0.0 – 1.5 mbgl	17
Figure B11	'Ancient Colluvial/Alluvial' soils recovered from BH-M07: 3.65 – 5.34 mbgl	17
Figure B12	Example of in-situ 'blocks' of cross-bedded Awhitu Formation within Ancient Colluvial/Alluvial soils, from BH-M06: 36.45 – 38.2 mbgl	18
Figure B13	Outcrop of Awhitu Sand Formation - Less Cemented Sands, cross bedding evident (left). Exposed within 2023 landslide, Domain Crescent.	18
Figure B14	Example of Awhitu Formation Less Cemented Sands, weakly consolidated material from BH – M02, 11.6 – 14.7 mbgl	18
Figure B15	Face log of Awhitu Formation Less Cemented Sands preserving rock fabric and structure, Edwin Mitchelson Track cut slope. Refer Figure A116 for specific location (marked).	19
Figure B16	Outcrop of Awhitu Formation – Less Cemented Sands, layer of finer grained material (silt, clay). Approximate thickness ~1.0m.	20
Figure B17	Example of layer of peat/organic soil within Awhitu Formation Less Cemented and Cemented Sandstones, from BH-M02, between 7.95 – 8.75 m bgl.	20
Figure B18	Example of Awhitu Formation Cemented very weak Sandstone, oxidised, from BH – M02 36.65 – 37.5 mbgl	20
Figure B19	Example of Nihotupu Formation Residual Silt and Clay, from BH – M04 3.95 – 5.90 mbgl	21
Figure B20	Groundwater seepage above highly oxidised (limonite) layer within Awhitu Formation 'less cemented' sand	22
Figure B21	Groundwater spring emitting above silt/clay bed within Awhitu Formation 'less cemented' sand.	23
Figure B22	Historical well location plan with water level, where known (measured between 2004 and 2007). Supplied by Auckland Council.	23

Figure B23	Example of lateral extent of near horizontal silt/clay beds within Awhitu Group, indicated by dashed line. Domain Crescent, M-LS20B for reference. Gentle dip due north – northeast.	26
Figure B24	Typical features of single landslides areas.	30
Figure B25	Typical features of single landslides areas.  Typical features of larger, merged landslide areas.	31
Figure B26	Fahrböschung angle definition after Heim (1932).	33
•		33
Figure B27	Definition of downslope angle below source area $\alpha_2$ for slides on steep natural slopes (Hunter & Fell (2002))	33
Figure B28	Height / Length ratio vs volume plot for all Muriwai landslides on the main escarpment	34
Figure B29	H/L versus tangent of the downslope angle $\alpha_2$ plot for Muriwai data together with Hunter & Fell (2002) relationships for rapid slides on steep natural slopes in dilative soils.	35
Figure B30	Potential landslide failure zones have been identified by GHD based on having similar geomorphology (ground shape) and geology to February 2023 landslide source areas. The above example shows a potential landslide source zone (grey outline) that has similar bowl-shaped characteristics to recently failed blue areas. Yellow lines indicate expected debris flow path. Background surface model has a 'hill shade' applied to highlight the geomorphology. Location is below the escarpment and west of Oaia Road.	38
Figure B31	Deep seated landslide (earthflow) within Awhitu Sand Formation, underlying contact with Waitakere Formation daylighting in toe area (cliffs). Background surface model has a 'hill shade' applied to highlight the geomorphology.	39
Figure B32	Slope profile comparison of 27 cross sections in Zones 1 to 6 (see Figure A137). Profiles are mostly viewed in a north-looking direction and have been centred on the crest of each slope (in most cases this is the top of the escarpment).	40
Figure B33	Number of February 2023 landslides per zone	41
Figure B34	Number and size of February 2023 landslides shown per zone	41
Figure B35	Location of the Zone 1 / Zone 2 boundary. North is to the top of the page.	42
Figure B36	Slope profile comparison of Zone 1 surface cross sections (see Figure A137 for location of sections)	42
Figure B37	Slope profile comparison of Zone 2 surface cross sections (see Figure A137 for location of sections)	43
Figure B38	Location of the Zone 3 / Zone 4 boundary. North is to the top of the page.	43
Figure B39	Slope profile comparison of Zone 3 surface cross sections (see Figure A137 for location of sections)	44
Figure B40	Location of the Zone 4 / Zone 5 boundary. North is to the top of the page.	45
Figure B41	Slope profile comparison of Zone 4 surface cross sections (see Figure A137 for location of sections)	45
Figure B42	Slope profile comparison of Zone 5 surface cross sections (see Figure A137 for location of sections)	46
Figure B43	Location of the Zone 2 / Zone 3 / Zone 6 boundary. North is to the top of the page.	47
Figure B44	Slope profile comparison of Zone 6 surface cross sections (see Figure A125 for location of sections)	47

# **Appendices**

Appendix B-1 Historical air photograph record

Appendix B-2 Summary of anecdotal evidence

Appendix B-3 Summary of reviewed literature

Appendix B-4 Database of observed 2023 landslides

Appendix B-5 Survey data used for GHD analysis and plans

# **B1.** Introduction

#### B1.1 **Background**

Two significant rainfall events affected the Waitakere area in late January and early February, resulting from the impacts of ex-tropical cyclones Hale and Gabrielle, respectively.

The Cyclone Gabrielle weather event of 14 February 2023 resulted in widespread catastrophic flooding and slope instability in the settlement of Muriwai where several debris avalanches (which included rocks and trees) occurred, some of which developed into saturated debris flows that resulted in damage to buildings and infrastructure. Two fatalities occurred due to impact of landslides on private dwellings. This tragic event was similar to a 1965 storm event that also claimed two lives.

Following the event, rapid building assessment of residential properties was undertaken in Muriwai, with some houses having access by owners restricted (a yellow placard - e.g., access in daylight hours only) and some for which no access was permitted (a red placard).

#### **B1.2** Purpose of this report

GHD was engaged by Auckland Council (AC)1 to carry out landslide risk assessments and to provide associated landslide risk management advice and geotechnical investigations in the Waitakere area, specifically for the residential areas of Muriwai, Piha and Karekare.

The purpose of this report is to present an engineering geological assessment of the Muriwai area to explain the context in which the damaging landslides of February 2023 occurred. This report is informed by remotely acquired topography data, historical information, community observations, geological mapping, subsurface geotechnical investigations and materials testing.

This report is an appendix to the overall GHD landslide risk report and should be read in conjunction with it, as well as the other associated appendices. The overall report contains additional information and synthesises the results of other appended assessments carried out by GHD (refer to Section B1.4).

#### **B1.3** Scope

The agreed scope for this engineering geology assessment was as follows:

- Assemble GIS database information relating to topography, land use, geology and geohazards from publicly available sources, and that provided by AC. This has been used as a basis for presenting our findings.
- Undertake desktop and ground-based engineering geological mapping of the Muriwai settlement, focussing on characterisation of recent landslides and associated geological landforms.
- Present classification and indexing of recent large landslides within the Muriwai settlement.
- Present a summary of anecdotal evidence gathered from local community members that relates to geohazards, such as previous observations of ground instability or surface water flows.
- Review publicly available literature associated with Muriwai geology and landslide hazard.
- Provide an interpretation of the geology and geomorphology of Muriwai to understand possible future landslide distribution, characteristics and triggering mechanism(s).

Geotechnical ground investigations took place at the same time as the work described above and are presented in Appendix F.

Under Contract CW198379, Master Services Agreement CCCS: CW74240 dated 7/09/2019

The focus of this study is limited to the assessment of the effects from 'large scale' landslide<sup>2</sup> hazards originating from the main escarpment located to the south-east of Muriwai because this is where damaging, fatality-causing landslides have historically originated. Smaller, more localised landslide hazards (on the scale of less than a property section wide or long) are not considered as they rarely lead to loss-of-life. The combination of numerous, small landslides would be considered if it were to result in a damaging debris flow.

Excluded from this report is consideration of the hazard relating to dwellings located along the crest of the main escarpment (i.e. the west side of Oaia Road) that could be undermined by regression of the escarpment during future landslide events. This is to be included in a separate future study.

This report: has been prepared by GHD for Auckland Council and may only be used and relied on by Auckland Council for the purpose agreed between GHD and Auckland Council as set out in Section 1.2 of this report.

GHD otherwise disclaims responsibility to any person other than Auckland Council arising in connection with this report. GHD also excludes implied warranties and conditions, to the extent legally permissible.

#### **Report Structure B1.4**

This report accompanies and informs numerous other assessments associated with the Muriwai landslides. A list of companion reports is presented in Table B1. A3 plans referred to in this report are listed in Table B2 and relevant additional images and data are presented in Appendices B-1, B-2, B-3 and B-4.

Summary of accompanying Muriwai landslide risk assessment reports Table B1

Report Section	Description
Overall Report	Waitakere Coastal Communities Landslide Risk Assessment (Muriwai)
Appendix A	Figures
Appendix B	Engineering Geological Report (this report)
Appendix C	Slope Stability Assessment
Appendix D	RAMMS Debris Flow Analysis
Appendix E	Landslide Risk Assessment
Appendix F	Geotechnical Investigations Report

<sup>&</sup>lt;sup>2</sup> In this report 'large scale' landslide hazards refers to landslides originating from the main escarpment that typically have a volume of more than about 50 m<sup>3</sup> with the potential to cause total or partial collapse of a dwelling.

Table B2 List of maps and images in Appendix A that are associated with this report.

Figure No.	Description				
GENERAL SITE	GENERAL SITE LAYOUT				
A101	STUDY AREA - OVERVIEW				
ENGINEERING	GEOLOGICAL PLANS				
A111	LEGEND				
A112	OVERVIEW				
A113 -A116	CLOSE-UP PLANS 1 - 4				
CROSS SECTIO	NS .				
A120	CROSS SECTION A-A'				
A121	CROSS SECTION B-B'				
A122	CROSS SECTION C-C'				
A123	CROSS SECTION D-D'				
A124	CROSS SECTION E-E'				
GEOMORPHO	LOGICAL LANDSLIDE ZONES				
A125	SLOPE RELIEF AND PROFILE COMPARISON PLAN				
ELEVATION M	ODEL COMPARISON				
A126	ELEVATION COMPARISON BETWEEN 2016 AND 2023 LIDAR TOPOGRAPHIC SURVEYS				
SLIP MECHANI	SLIP MECHANISM MODEL				
A127	2023 CYCLONE GABRIELLE LANDSLIDE MECHANISM MODEL - MURIWAI				
A128	2023 CYCLONE GABRIELLE LANDSLIDE MECHANISM MODEL - PHOTO MARK-UP				

#### **B2.** Methodology

#### **B2.1** Data review

GHD received and sourced a variety pre-existing data to support the landslide risk assessments carried out within this report and supporting Appendices (Refer Section B1.4). A summary of this data including how and where it has been applied is given in Table B3 and discussed further below.

# B2.1.1 Topographic data

Pre- and post-Cyclone Gabrielle topographic data from airborne LiDAR surveys were made available to GHD by AC and LINZ for this study for use in this report, the slope stability study (Appendix C) and RAMMS debris flow modelling (Appendix D). The spacing of data is 1 m, which is judged to be suitable for these purposes. We understand that the provided data had been processed to be 'bare earth', i.e. buildings and vegetation had been removed.

A comparison of pre- and post-Cyclone Gabrielle elevation data by GHD is presented in Figure A126 (see Appendix A). If the data were in spatial agreement, it is expected that areas that have not experienced any ground damage would have the same elevation. Landslides would exhibit a loss in elevation (i.e. a positive value in Figure A126) at the head of the feature and the debris flow runout would display a gain (i.e. a negative value in Figure A126). However, the comparison shows that, typically, areas in Muriwai not known to have experienced land damage exhibit a decrease in elevation post-Cyclone Gabrielle of up to 0.3 m and some localised undamaged areas of several square metres show a difference of more than 0.3 m. We therefore consider that data is accurate to ±0.3 m. We speculate that this may be due to one or more of the following reasons:

- The pre- and post-Cyclone Gabrielle datasets have been subject to different processing methods, particularly with respect to removal of vegetation.
- Different coverage areas and density of vegetation between 2016 and 2023.
- The 2023 landslides are typically unvegetated, allowing for accurate LiDAR.
- Erosion of the 2023 landslide surface between 14 February and 4 March 2023 (almost 3 weeks).

Further technical information regarding the data is described in Appendix B-5.

# B2.1.2 Anecdotal community feedback

Anecdotal evidence from the occupants of an area can be a useful source of information to supplement and/or confirm formal evidence. The community contains many people who have resided in Muriwai for decades and some are multi-generational residents. GHD Engineering Geologists met with members of the public at the Muriwai Surf Club for two separate sessions on 28 May 2023 and then again on 2 and 3 September 2023.

Anecdotal testimony of residents was taken, with maps being referred to for identification of feature locations. Residents who were unable to participate with the in-person interviews were given the opportunity to email any information of importance to Auckland Council, which was forwarded to GHD. Appendix B-2 gives a generalised summary of the information, with some data appearing on Appendix A Figures A101 and A111-A116. We have not reproduced all names and addresses of contributors but have presented the common themes.

The September sessions were to provide clarification to residents by GHD and AC following the release of the draft version of this report and associated appended reports. There was a large response from the community from the draft release of this report, with additional observations and suggested amendments to the presented anecdotal information. The community's assistance was helpful, appreciated and used to help improve the report.

#### B2.1.3 Historical literature review

A review of published documents that relate to the landslide hazard in Muriwai is presented in Appendix B-3. Several of these discuss the 1965 and 2023 fatality-causing landslides. Several large flood events in the 1920s and 1930s are reported but, notably, no other damaging landslide events are described.

Table B3 Summary of received data

Data type	Owner	Detail	Quality and limitation	Application
Topographical survey	LINZ, Auckland Council (Appendix B-5 for details)	<ul> <li>2016 LiDAR elevation model at 1 m point spacing from AC (pre-Cyclone Gabrielle)</li> <li>2016-2018 LiDAR elevation model at 1 m point spacing from LINZ (pre-Cyclone Gabrielle)</li> <li>2023 LiDAR elevation model at 1 m point spacing from AC (post-Cyclone Gabrielle)</li> </ul>	<ul> <li>The two datasets were converted into Digital Terrain Models to derive topographical surfaces and contours</li> <li>Figure A126 outlines a comparison between the two surfaces, showing the resolved volume difference. This indicates significant relative discrepancy, and potentially some distortion within each individual survey.</li> </ul>	<ul> <li>The two datasets were converted into Digital Terrain Models to derive topographical surfaces and contours</li> <li>The 2023 dataset has been used to inform GHD mapping in this report.</li> <li>Pre and post-Cyclone Gabrielle data has been used to inform GHD slope stability (Appendix C) and RAMMS debris flow modelling (Appendix D).</li> </ul>
Measured and estimated rainfall	Auckland Council (measured) and Met Service (estimated)	<ul> <li>Measured data from tipping bucket gauge 'TP-08'</li> <li>Quantitative Precipitation Estimate (QPE) from Met Service</li> </ul>	<ul> <li>Tipping bucket gauge TP-08 was damaged from flooding associated with the event and therefore did not provide continuous data over the course of the cyclone.</li> <li>The QPE was generated from rainfall estimated off Met Services rain radar and used to derive rainfall accumulation and peak values. There is inherent uncertainty with this data given it is a quantitative derivative.</li> </ul>	<ul> <li>Assessment of recurrence values assigned to the risk assessment (Appendix D).</li> <li>General reference throughout this report and in comparison, with measured groundwater data (Appendix F)</li> </ul>
Public bore records	Auckland Council legacy Consent Data	<ul> <li>Historical public bore records surrounding study area general vicinity</li> <li>Records depth of bore, depth of measured groundwater level below ground level and date</li> </ul>	- Unverified data, quality unknown	- General reference to support groundwater assessment (Section B4.3)
Historical aerial imagery	Aerial Photography: LINZ/ LGGA Satellite Imagery: Google	<ul> <li>Non continuous record since 1940, varying image scale</li> <li>1940 - 1975: Aerial photography</li> <li>2004 - 2023: Satellite imagery</li> </ul>	- None-specific	<ul> <li>Illustrating past development and land use change across the study area and supporting discussions around overall geological characterisation pf he site.</li> <li>Compiled in Appendix B-1 with relevant features marked.</li> </ul>
Private property file data	Auckland Council	Design and construction details of dwelling foundations and general property earthworks and stormwater/wastewater control	- Quality is variable dependant on completeness of data.	Generally referred to in this report (Appendix B) to support understanding of any impact or otherwise from surface water drainage

# **B2.2** 2023 – 2024 field investigations

# B2.2.1 Geological field observations and measurements

Desktop and field-based mapping by GHD in 2023 and early 2024 collected discrete geological observational data over the whole study area. The mapping focused on definition of the extent and characterisation of the landslides. Associated engineering geological features such as springs and outcrops were also recorded. The data has been used to support the overall ground model interpretation and landslide characterisation and is reflected in Appendix A, Drawings A111 – 116, A120 – A127.

Landslides identified through the mapping process were catalogued in a register with common measurements included. This is attached as Appendix B-4.

The objective of the mapping was to:

- Confirm the location and extent of the February 2023 landslides.
- Record the observed exposed geology and geomorphological features.
- Inspect and assess pre-identified areas of geological interest (i.e. Edwin Mitchelson Track, geological outcrops, areas associated with anecdotal evidence).

The methodology included both desktop and field-based mapping:

- 1. Initial desktop mapping via QGIS and ArcMaps; identification and indexing of landslides using post-event topographical and photographic surveys; mapping of observable landforms and correlation with mapped geology.
  - a. Initial site-based field mapping to ground truth the extent and nature of landslides (including their engineering geological properties), mapped geology extent and nature; assess geomorphological features and some man-made features (e.g. Edwin Mitchelson Track). This involved use of analogue (paper base maps) and digital techniques (ArcGIS FieldMaps) to collate GPS-tagged photographs and site notes;
- 2. Refinement and updating of final maps on desktop QGIS software following site-based data collection.
- 3. Further field mapping and updating of maps to include assessment of tension cracking adjacent to the escarpment crest (Oaia Road).

Site based mapping was carried out over the following dates:

- 24-26 May 2023: General mapping and classification of landslides, surficial geology and landforms surrounding escarpment
- 7 August 2023: Exploration for identification of tension cracking behind the escarpment crest.
- 30 Jan-15 Feb 2024: Further measurements of slope profile along escarpment crest.

# B2.2.2 Subsurface geological investigations

Subsurface geotechnical investigations comprising nine rotary cored boreholes up to 80 metres deep, in-situ measurements, and installation of groundwater monitoring within constructed piezometer wells, were completed between 29<sup>th</sup> June and 17 August 2023. This was supported by a subsequent sampling and laboratory testing programme.

The investigations were intended to help develop an understanding of the ground conditions and groundwater regime in the vicinity of the site with particular emphasis on the material behind and below the escarpment. The data collected, including a detailed account of methodology of acquisition, calibration records and any reported error, is given in Appendix F (Geotechnical Investigations Report – Muriwai). The locations of the boreholes are shown on Figure A101 (Appendix A). Continuous telemetered groundwater monitoring of piezometers in six boreholes (BH-M01, M02, M03, M06, M07, M09) commenced from 19 October 2023.

# **B3.** Study area description

# **B3.1** Nature and extent of the study area

Muriwai is situated on the west coast of Auckland at the north-western terminus of the Waitakere Ranges (see Figure B1 and Figure A101 (Appendix A). The site is defined by a near-continuous 1.5 km-long escarpment that is aligned to northeast – southwest. The escarpment face extends 80m vertically and is over 100 m above sea level at its crest. The town of Muriwai is built above and below it, including some properties directly at its base, and other directly on its crest. The landslides that have impacted Muriwai properties are predominantly located within this feature.

The crest of the escarpment is irregular along its length – some areas are inset further than others (Figure B1). Domain Crescent and Motutara Road are located within two larger inset areas and provide access to properties at the base of the escarpment. Oaia Road runs parallel to and setback from the crest and provides access to properties above the escarpment. Muriwai Beach, which comprises a long open coastline extending beyond the study area to the north, is accessed several hundred meters west of the escarpment, from which it is separated by sand dunes.

Current land use within and surrounding the site includes residential, isolated light commercial, recreational public land (beach frontage, regional park, and sand dunes), and private land (forestry and golf course).

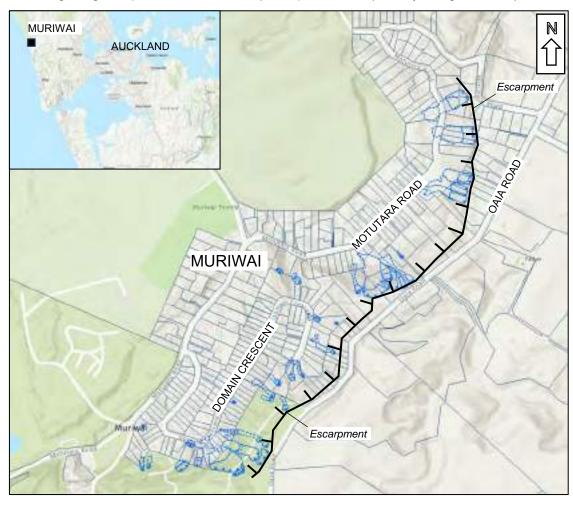


Figure B1 Muriwai location showing the February 2023 landslides mapped by GHD (blue lines)

# **B3.2** Study area geology

# B3.2.1 Stratigraphy

Figure B2 shows the geological setting of the study area. Most of the site is locally underlain by Awhitu Sand Formation. The stratigraphy in the study area is summarised below and in Table B4.



Figure B2 Excerpt from Hayward, B.W 1983: Sheet Q11, Waitakere. Geological Map if New Zealand 1:50,000. NZGS.

#### 3.2.1.1 Mitiwai Sand

'Modern beach and drifting sand, and fixed dune sand', Hayward, (1983). The sand black and minerally rich (iron and titanium). In relation to the study area, these sands make up the dune systems northwest of its boundary and impacted dwellings from the landslides.

#### 3.2.1.2 Awhitu Sand

'Coarse sand, clayey, often limonitised (iron cemented), with minor tuff, lignite and siltstone', Hayward (1983). The limonite imparts some strength, making the material weak to extremely weak sandstone, when unweathered. The material weathers to a sandy soil at the surface. The country that Awhitu Sands underlies is typically rolling flat terrain except for where the escarpment is located which is comprised of this material. The sandstone varies from a massive to a bedded structure and is cross bedded at roughly metre scale.

#### 3.2.1.3 Waitakere Group

Three formations of the Waitakere Group volcanic/volcaniclastic deposits uncomfortably underly the Awhitu Sands, in the proximity of the study area. Nihotipu, Waiatarua and Tirikohua Formations underlie the Awhitu sands and outcrop at the surface south of Domain Crescent on Waitea Road.

- Nihotupu Formation: volcaniclastic sandstone, thinly bedded at shallow angles, often with discrete layers
  of course angular volcanic conglomerate. Outcrops south of the study area. Deposited concurrently and
  interlain with Waiatarua Formation.
- Waiatarua Formation: submarine basalt flows and pillow lavas. Columnar jointing common. Locally weathers to clay near the surface.
- Tirikohua Formation: volcaniclastic sandstone, bedded at shallow angles. Generally comprising finer grained material than Nihotupu Formation.

Table B4 Study area geological stratigraphy

GNS Group	GNS Formation	GNS symbol	Geological age (absolute)
Kaihu Group	Mitiwai Sand, fixed dunes (qmf)	qm + qmf	Holocene, <10 Kya
	Awhitu Sand (qs)	qs	Pleistocene, <2 Mya
	Regional und	onformity	
Waitakere Group	Tirikoha Formation (mt)	— mt	Late Miocene, ~ 5 Mya
	Waiatarua Formation (mw)	mw	Miocene, ~23 – 5 Mya
	Nihotupu Formation (mn)	. mn	Miocene, ~23 – 5 Mya

Note: Stratigraphy as per Hayward, (1983), GNS 1:50,000 Map, Sheet Q11 Waitakere

# B3.2.2 History and structure

From the late Miocene to Pleistocene, the geological history of the study area is broadly summarised as being subject to repeating cycle of deposition, erosion, uplift and further down-wearing of the Waitakere Group volcanic deposits (Hayward, 1979). From the Pleistocene onwards, the Awhitu Sand Formation has been deposited unconformably on-top of an erosional surface of the Waitakere Group (Nihotupu and Waiatura Formations at the study area) and as a result experienced similar uplift and down-wearing cycles. The uplift occurred on a series of faults that primarily strike Northeast and have formed 'blocks' of land that are upthrown and downthrown relative to each other (Hayward, 1976). This process has also resulted in shallow (10-15°) dip to the northeast along the unconformity, within the 'Maori Bay Block', as mapped immediately south of the study area (Figure B2).

Tirikohua Formation locally outcrops in the coastal cliff line southwest of the study area and is bounded by a fault that is mapped to continue to the northeast before losing its surface exposure at the southern extent of the study area (i.e. at Domain Crescent). It is unclear whether this fault continues to the northeast along the base of the escarpment.

### **B3.3** Surface characteristics

#### B3.3.1 Surface features

The top of the escarpment has a prominent scalloped nature, as shown in Figure B1, and combined with the presence of the irregular (hummocky) benches occupied by Motutara Road and Domain Crescent below the escarpment suggests that study area may have been subject to large-scale land sliding in the past. The mapping and drilling described in Section B2.2 were undertaken partly to investigate this possibility.

#### B3.3.2 Surface water catchments

There are approximately ten small catchments within the vicinity of the Muriwai escarpment and there are numerous surface water flow paths within these (see Figure B3). The surface water west of the escarpment flows to the west and the surface water at Oaia Road and surrounding properties flows to the northeast.

GHD (2023¹) assessed the stormwater discharge from 35 properties between Oaia Road and the escarpment edge and demonstrated that the discharge from private properties drains towards Oaia Road and that the public stormwater system on Oaia Road is adequately sized and conveys flows away from the escarpment.

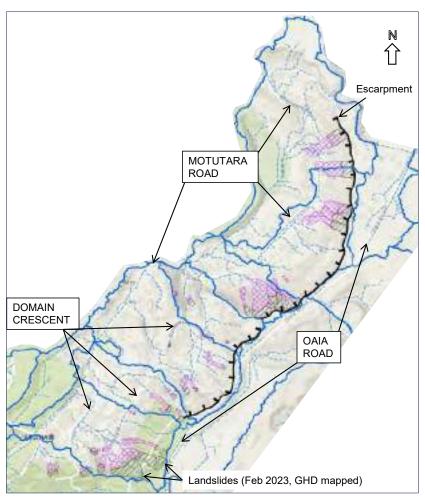


Figure B3 Water catchments in Muriwai. Solid blue lines are individual catchments and thin blue dashed lines are nominal surface water flow paths. Defined by GHD using LINZ topographic data.

# **B3.4** Historical land-use change

Appendix B-1 presents available historical aerial photographs and satellite imagery of the Muriwai area from 1940 through to 2023. A summary of the known land use and vegetation change since the early 1900s is given in Table B5.

Table B5 Land use change from early 1900s to the present day

Time period	Commentary				
Early 1900s	<ul> <li>Refer to Figure B4 (view north from Edwin Mitchelson house)</li> <li>Residential development began in the early 1900s with isolated dwellings accessed by Oaia Road and Edwin Mitchelson Track</li> <li>Coastal/dune systems along Muriwai beach undeveloped and possibly lower in elevation</li> </ul>				
1940	<ul> <li>Motutara Road constructed, associated with more residential development and several community buildings near beach.</li> <li>Escarpment is covered in low density scrub and medium sized vegetation. Some areas below escarpment have been recently cleared. Coastal sand dunes are unvegetated.</li> <li>Exposed soil/rock noted near the crest and off leading ridgelines.</li> <li>Surrounding countryside mainly cleared and predominantly agricultural land use.</li> </ul>				
1950 – 1975	<ul> <li>Domain Crescent, Waitea Road constructed, later followed by Coast Road (1975), associated with continual residential and commercial infill in these areas. Many sections still bare or utility structures only.</li> <li>Muriwai Golf course constructed and local earthworks / contouring of land apparent.</li> <li>Stormwater reservoir to the west of Motutara Road now constructed.</li> <li>Pine plantation established northwest of Motutara Road, cleared and regrown.</li> </ul>				
1975 – present day	<ul> <li>Continual infilling of residential development both below and above escarpment</li> <li>Wilding pine and native vegetation gradually increasing across escarpment to present day density.</li> </ul>				



Figure B4 Early 1900s (unspecified), approximate location of present-day Edwin Michelson Track/Oaia Road, looking due North over Muriwai Beach. Source: Supplied by Auckland Council, 2023, Edwin Mitchelson House

#### B3.5 1965 Landslide event

Two parallel landslides occurred on Domain Crescent on 27 and 28 August 1965, destroying two dwellings and killing two people. These landslides followed two days of unusually heavy rain, with a nearby gauge recording 95 mm on August 25 to 26, plus 45 mm in the 12 hours preceding the landslide that occurred on 27 August 1965 (Hayward, 1965). Elsewhere between 190 mm (Manukau Heads) and 220 mm (Whenuapai) was recorded over the 3-day period. The two landslides were reported as fast-travelling mud slides by witnesses. Many additional smaller landslides occurred over the wider area for several days after the rain event (Wright, 1996). The headscarp of the two larger landslides was located directly below Edwin Michelson Track. Various reports at the time suggested they were triggered by excessive surface water being diverted off the track resulting from blocked table drains (Hayward, 2022). Wright (1966) observed that for days after the events water seeped out of the Awhitu Sand about midway up the landslide paths. Hayward (2022) concluded that the landslides were likely triggered by a combination of the surface water flows and the groundwater springs.

The two separate debris paths coalesced near the bottom of the escarpment and flowed across Domain Crescent (Figure B5 and Figure B6). Both the destroyed dwellings were located on the uphill side of the road and were translated with the debris flow.

Five dwellings have since been constructed at the site of the 1965 landslides. A series of new landslides occurred at the same location resulting from the 2023 ex-tropical cyclones.



Figure B5 Mapped extent of 1965 Landslides (after Wright 1966)



Figure B6 View from Domain Crescent of 1965 landslides and destroyed dwellings (after Wright 1966)

# **B3.6 Overview of February 2023 landslides**

The February 2023 landslides occurred along the Muriwai Escarpment within Awhitu Formation sand and silt, above the Domain Cresent and Motutara Road benches, and from several leading ridgelines between. The locations of all recorded landslides are given in Figure A101 (see Appendix A). Examples of the damage associated with the runout are given in Figure B7 and Figure B8. Key details of the event are summarised as:

- Most landslides originated near the crest of the escarpment on the evening of the 14<sup>th</sup> February 2023
  (peak rainfall intensity), travelling down the face and terminating at or close to the base. Most landslides
  were greater than 50 m³ of material released and often entrained large amounts of vegetation, including
  trees.
- The material was saturated and flowed at significant speed, giving little to no warning.
- Significant damage and destruction (including complete collapse) of impacted residential structures occurred, contributing to two fatalities. In addition:
  - Some properties above the landslides (accessed from Oaia Road) were partially undermined from the loss of material.

- Various damage to non-residential structures also occurred (commercial buildings; AC property; walking tracks)
- On-going erosion after the event resulted in the repeated blocking of public table drains in road corridors.
- Many new groundwater springs were observed to be emitting constant flow after the event.



Figure B7 Entrained vegetation and sand/silt comprising the overall 'colluvial debris', GHD 2023. Debris resulting from Landslides M-LS07,08,09.



Figure B8 Example of significant destruction of dwelling, associated with landslide debris runout, GHD 2023. Debris resulting from Landslides M-LS12.

# **B4.** Engineering geological interpretation

This section of the report explains the development of the engineering geological model of the site area from analysis of the available geological, geomorphological, groundwater and surface water data.

# **B4.1** Geological units

Engineering geological units were developed from the GNS mapped geology (Table B4) and the site investigation data (Appendix F) to support the ground interpretation and landslide assessments of the study area. The information is presented as follows:

- Table B6 summarises the geological unit characteristics and defining features.
- Illustrations of examples of the units as recovered in borehole core and/or observed in outcrop are given in photo figures below the table.
- Interpretation of the <u>surface</u> distribution of the units is given on the Engineering Geological Maps (Appendix A, Figures A111 – A116).
- Interpretation of the <u>sub-surface</u> distribution of the units is given in the Engineering Geological Cross Sections (Appendix A, Figures A120 124).

# **B4.2 Geomorphology**

The study area has been divided geomorphologically into six landslide 'zones' based on the surface topography, February 2023 landslide characteristics and general geomorphology. The purpose of this is to differentiate areas according to their susceptibility of large-scale landsliding. The geomorphological zones are shown on the attached engineering geological maps (Appendix A, Figures A111 – A116) and the basis for the zoning and the zone characteristics are described in Section B6.3.

Table B6 Engineering geological units

GNS Formation	Engineering geological unit	General description / comments	In-situ strength characterises	Occurrence across study area	Example photo figures
N/A	Recent Colluvium (2023)	<ul> <li>Orange to pale yellow, uncemented and unconsolidated sand, varying level of silt intermixed. Usually entrained with surficial vegetation debris and topsoil.</li> <li>Still consolidated/cemented blocks near source (headscarp) which are partially broken down</li> <li>No discernible structure or internal fabric</li> <li>Easily eroded / dispersed by surface water</li> <li>Sourced from Less Cemented Sand unit</li> </ul>	<ul> <li>No measurable strength</li> <li>Inferred as very loose, with friction angle of less than 10°.</li> </ul>	Within mapped landslide, usually collected at the base of the escarpment along Domain Crescent and Motutara Road. Some material still preserved on escarpment face.	-Figure B7 -Figure B8 -Figure B9
	Fill Deposits	<ul> <li>Orange, brown clayey silt, mixed with topsoil</li> <li>Less than 1 m thick where encountered</li> </ul>	- Single shear vane value > 100 kPa	Encountered locally within single borehole (BH-M02) however inferred to be present across study area in discrete and small volumes (<50 m³) to support residential, building platforms, localised road fill	-Figure B10
	Ancient Colluvial & Alluvial Deposits	<ul> <li>Chaotic' texture with irregular shaped clasts of silty and clayey material</li> <li>Varying degrees of organic material</li> <li>Often significant (more than 1 m) inclusions of 'intact' Awhitu formation sand, cross bedded</li> <li>Sharp and irregular boundaries between varying textures/types of material</li> <li>Within BH-M06, potentially contains alluvial materials as well as colluvial sourced material</li> </ul>	- Variable, generally characterised by: - SPT 'N' value 0 to <20	Encountered to varying depths within boreholes: - BH-M05, BH-M07, BH-M08, up to 7.5mbgl BH-M06, up to 38 mbgl  Lateral extent between boreholes poorly constrained.	-Figure B11 -Figure B12
Awhitu Sand Formation (qs)	AS: Less Cemented Sands  Includes discrete layers of: - ASf: Organic Soil / Peat - ASf: Silt/ Clay	<ul> <li>Variable coloured and weathered, generally orange, light yellow, or cream white at surface, and orange to grey below surface</li> <li>Uniformly graded medium to coarse sand</li> <li>Some cement (evident by in-situ density) although often recovered as unconsolidated and dilated in core</li> <li>Discrete layers of limonitic material</li> <li>Crossbedding common at a sub-metre scale with laminated layers 0.1 m thick, with no visible preferred orientation.</li> <li>Bedded to massive, beds 1-2 m thick separated by thinner (&lt;1.0 m) layers of finer grained material. In outcrop, beds display near horizontal, slight northward dip. Non-continuous.</li> <li>Jointing vertical and tight, develops moderately sized blocks &lt;1m3 near crest Escarpment</li> <li>Occasional occurrences of thin layers/lenses (&lt;1.0 m thick) of finer grained silt, and peat</li> <li>Prone to erosion ('dispersibility') and possible tunnel gully erosion based on the results of Pinhole and crumb testing results (Appendix F, Section F4.5). Note – no direct evidence of tunnel gully erosion has been observed during GHD site investigations, or within previously documented studies.</li> </ul>	<ul> <li>SPT 'N' value 0 – 20, generally unchanging with depth, some variability with more cemented sand layers.</li> <li>UCS &lt;1 MPa</li> <li>Peat and silt/clay layers unmeasured, inferred:         <ul> <li>SPT 'N' value = &lt;10</li> <li>Vane Shar strength =</li> </ul> </li> </ul>	<ul> <li>Surficial deposit over majority of study area, exposed within the slip face of most recent landslides.</li> <li>Generally encountered to 20-30 m bgl before transitioning into cemented sands/candstone (below)</li> <li>Bedding and crossbedding observed in outcrop in many landslide source areas</li> <li>Layers of silt and clay observed in outcrop and often extending up to 100 m laterally at surface, 1.0 m thick</li> <li>Peat layers rarely encountered and not traceable laterally.</li> </ul>	-Figure B13 (cross bedding  -Figure B14 (less cemented sand)  -Figure B15 (interbedded sand and silt layers)  -Figure B16 (silt/clay layer)  -Figure B17 (peat/organic soil)
	AS: Cemented Sand / Very weak Sandstone  Includes discrete layers of: - ASf: Organic Soil / Peat - ASf: Silt/ Clay	<ul> <li>Generally dark orange,</li> <li>Variably weathered (slightly to moderate), extremely weak to weak, iron cemented Sandstone. Massive to bedded.</li> <li>Presence of more cement than the overlying less cemented material is inferred to be responsible for the increase in in-situ strength.</li> <li>Uniform (coarse) grained sand clasts</li> <li>Similar but better preserved fabric as overlying less cemented material:         <ul> <li>Cross bedding &lt;1m scale, horizontally bedded (interbedded with finer grained material)</li> <li>Irregular occurrences of limonite layers</li> </ul> </li> </ul>	- SPT 'N' Value = 50+ - UCS >1 MPa, to >2 MPa	Not encountered in outcrop / at surface, generally 20-30 m and deeper below local ground level	Figure B18
Nihotupu Formation (mn)	N: Residual Silty Clay	<ul> <li>Dark red and brown, very stiff clayey silt and gravelly silt.</li> <li>Irregular limonite staining</li> <li>Relic rock texture visible</li> </ul>	<ul><li>Vane shear strength = &gt;100 kPa</li><li>SPT 'N' Value = 17-22</li></ul>	Encountered south of study area at surface, in outcrop (Awatere Road).  Within study area, encountered in BH-M04 from surface (below road fill).	Figure B19

<u>Note:</u> Mitiwai Sand Formation is referred to in Section B2.2.1.1 and included within Appendix A figures for general reference, where indicated by Hayward (1983) mapping. It has not been assessed from an engineering geological perspective as it is not encountered within the study area at the surface / sub-surface. It is not considered relevant to the observed landslides that have occurred on the escarpment face.



Figure B9 Example of engineering geological unit '2023 Recent Colluvium'. Medium grained sand, unconsolidated, spread out thinly across existing surfaces.



Figure B10 'Fill Deposits' soil recovered in BH - M02: 0.0-1.5 mbgl



Figure B11 'Ancient Colluvial/Alluvial' soils recovered from BH-M07: 3.65-5.34 mbgl



Figure B12 Example of in-situ 'blocks' of cross-bedded Awhitu Formation within Ancient Colluvial/Alluvial soils, from BH-M06: 36.45-38.2 mbgl



Figure B13 Outcrop of Awhitu Sand Formation - Less Cemented Sands, cross bedding evident (left). Exposed within 2023 landslide, Domain Crescent.



Figure B14 Example of Awhitu Formation Less Cemented Sands, weakly consolidated material from BH-M02, 11.6-14.7 mbgl

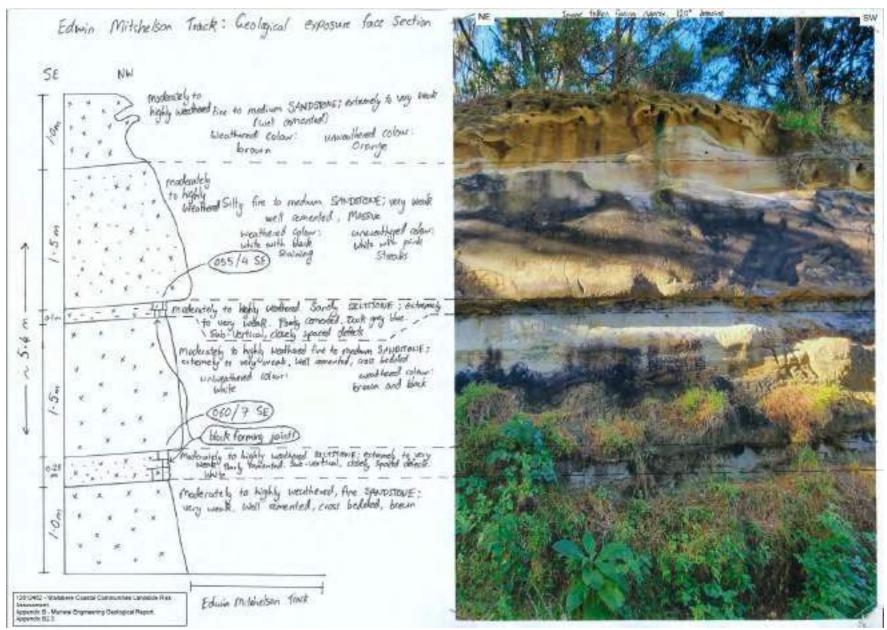


Figure B15 Face log of Awhitu Formation Less Cemented Sands preserving rock fabric and structure, Edwin Mitchelson Track cut slope. Refer Figure A116 for specific location (marked).



Figure B16 Outcrop of Awhitu Formation – Less Cemented Sands, layer of finer grained material (silt, clay). Approximate thickness 1 m.



Figure B17 Example of layer of peat/organic soil within Awhitu Formation Less Cemented and Cemented Sandstones, from BH-M02, between 7.95 8.75 m bgl.



Figure B18 Example of Awhitu Formation Cemented very weak Sandstone, oxidised, from BH-M02 36.65-37.5 mbgl



Figure B19 Example of Nihotupu Formation Residual Silt and Clay, from BH-M04 3.95-5.90 mbgl

# **B4.3** Groundwater

# B4.3.1 Data

Table B7 summarises the available groundwater data and our assessment of this data.

Table B7 Summary of groundwater data reviewed and observations

Data	Comment	Example / reference
Surface seeps/springs	Springs have been observed and mapped across the escarpment (Figure A112-116). Where the source of seepage was observed directly it was commonly located above finer grained silt/clay beds and more oxidised/cemented layers (limonite).	Figure B20 Figure B21
Variable head permeability testing	Hydraulic conductivity values measured within BH-M01, M02, M06 and M07 (E-08 to E-09) are considered typical for the material that their respective screens are constructed within (massive sandstone, M01, M02, M07) and silt/clay soil (M06).	Appendix F, Table F6
On-going groundwater level monitoring	Continuous groundwater level monitoring established in six piezometers since 19 October 2023 (BH-M01, M02, M03, M06, M07, M09).  Refer discussion below, assumed error within BH-M01 and M09  BH-M03 has been dry since shortly after installation.  Generally little to no connection observed between recorded rainfall and groundwater level, except for:  BH-M06: positive correlation when peak daily rainfall exceeds approximately 12 mm/day. Fluctuation in groundwater level relatively short, generally +/- 2 mbgl for 1-2 days following peak rainfall.  BH-M07: weak correlation when peak daily rainfall exceeds approximately 15mm/day, corresponding groundwater level fluctuation of less than 0.5 m, with very gradual return to baseline level (2-3 weeks).  Generally stable / unchanging monthly average values, no seasonal variation observed.	Appendix F5 (groundwater vs rainfall graphs)

Data		Example / reference
Electronic dip- tape measurements	measurements, considered insignificant to trend observed in telemetry.	Appendix F, Table F5
records –	3 bores installed surrounding the project area.  #21261 and #22794 record significantly deeper groundwater levels (120- 129 mRL than adjacent GHD piezometer BH-M01 (approximately 80 m vertical RL difference). GWL at BH-M03 is unclear given well is dry.  Recorded geology at screen suggests bore is socketed into underlying Waitakere Group deposits.	Figure B22

#### **Data limitations**

- Piezometer BH-M01 data is considered invalid (erroneous) given both the 'erratic' nature of day to day changes in recorded groundwater level and the two significant sudden changes of approximately +/- 8 m vertically over 24 hr time periods that are uncorrelated to measured rainfall. The telemetry unit and data have been inspected for any obvious physical or recording errors/damage, however none were revealed.
- Piezometer BH0M09 data is considered as potentially invalid given the recorded groundwater level is physically unchanged over the recorded interval expect for one brief (<24 hr) change in late November before returning to the constant reading approximately 7.6 mbgl.



Figure B20 Groundwater seepage above highly oxidised (limonite) layer within Awhitu Formation 'less cemented' sand



Figure B21 Groundwater spring emitting above silt/clay bed within Awhitu Formation 'less cemented' sand.

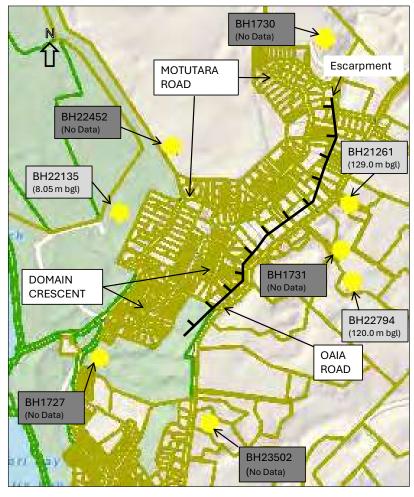


Figure B22 Historical well location plan with water level, where known (measured between 2004 and 2007). Supplied by AC.

# B4.3.2 Groundwater interpretation

From the subsurface and surface groundwater data/observations, it is inferred that:

- A 'regional' groundwater table is located within Awhitu Formation sands, at or above the unconformity with underlying Waitakere Group Deposits, which are expected to represent a significant change (decrease) in relative permeability.
  - Historical data (Figure B22) suggests Waitakere Group may have been encountered east of the escarpment, at an RL approximately 30-40 m below its base elevation. The unconformity was not encountered below the study area other than at the southern end, in BH-M04.
  - It is unlikely that this regional groundwater table has any influence on the groundwater recorded in the study area.
  - All piezometers installed by GHD are located within overlying Awhitu Group deposits and record perched groundwater levels at significantly higher elevations.
- The Awhitu Formation sands contain a series of perched aquifers, some of which daylight as springs within the escarpment and that have variable (often none to minimal) connection to surface rainwater input.
  - They are bounded by discontinuous, relatively lower permeability layers/beds of silt/clay and limonite within the Awhitu Formation sands. The continuity of the aquifers is therefore a function of these layers/beds.

The relationship between the local groundwater level and pressure in the perched aquifers during peak or long duration rain events (such as Cyclone Gabrielle) is uncertain given there is no continuous subsurface data to date across an event of this magnitude. It is judged that the vertical and horizontal flow of groundwater within the Awhitu Formation sands is highly variable across spatial and temporal domains. Individual perched aquifers may be influenced by surface rainfall infiltration. It is also possible that, following the 2023 landslides, shallow perched aquifers have been destroyed or modified because of loss of overlying soils. This is partly supported by anecdotal observations of changes at springs from residents.

# **B4.4** Surface water

The escarpment is a significant barrier to the direction that surface water flows across the study area. Rainwater collects and flows due east above/behind the escarpment and due west within or below the escarpment.

Within the escarpment, flow paths are further controlled and concentrated by the smaller catchments defined by confining ridgelines and spurs, generally at right angles to the slope. These are summarised in Figure B3 for the study area.

The built environment of the local area, both above and below the escarpment, has resulted in the addition of impermeable land cover (hardstands/driveways, houses) and diversion of three waters (stormwater and septic water lines from residential property and stormwater drainage within public and private roads). The potential for any of these built structures to influence the natural surface water flow paths was assessed by reviewing AC supplied information for thirty-five properties located on Oaia and Motutara Road, as well as the stormwater catchment system within Oaia Road (GHD 2023 'Desktop Assessment Report'; GHD 2023 'Oaia Road and Edwin Mitchelson track Investigation Report'). It was concluded that:

- None of the private property stormwater / wastewater discharge was directed toward the observed landslides or damaged by them, except for 225 Oaia Road
- The existing stormwater catchment system on Oaia Road is adequately sized and draining away from (east of) the escarpment crest
- The table drains along Edwin Mitchelson track have been blocked by landslide debris.

Thus, GHD do not consider there to be any evidence for instigation or worsening of any observed 2023 landslides from built structures, from the available data reviewed.

# B4.5 Ground model of study area

# B4.5.1 Distribution of geological units

The surface morphology of the study area is the result of it being uplifted and tilted to the north-east unconformity of the underlying Waitakere Group deposits (Section B3.2.2). Nihotupu and Waiatarua Formations outcrop directly south of the study area (see Figure A114), but dip below the surface to the northeast and were not encountered at surface or at depth (beyond the location of BH-M04). Awhitu Sand Formation has been deposited and uplifted on top of this contact, thus sharing similar structural orientation, evident from silt/clay beds in outcrop (see Figure B23).

Previous studies (Hayward, 2022; Wright 1966) have suggested Waitakere Group deposits were located directly at the base of the escarpment however GHD's 2023 ground investigations and mapping do not provide evidence for this. The unconformity is illustrated on cross-section A-A' (see Figure A120).

# B4.5.2 Material properties, Awhitu Sand

The in-situ strength profile of the Awhitu Sand formation increases with depth, observed from increasing SPT 'N' values within boreholes. This is interpreted to be the result of increasing quantities of iron cement within the sand and leaching associated with the development of an in-situ weathering profile from the surface. Engineering geological cross-sections (see Figures A120-124) illustrate this with the inferred boundary between less cemented and more cemented sands/sandstones. Significant uncertainty in spatial constraint of this zone is expected, given the lack of subsurface data points available.

Recently exposed sands (landslide slip surfaces) often retain near-vertical bluffs and rock mass fabric (block jointing and bedding, Figure B15); however, it is easily disrupted when physically agitated or when water is passed through it, as observed by sections of shallow core having disaggregated upon recovery. This is not observed with core at depth.

Silt/clay rich beds and thinner lenses are encountered randomly at depth with poorly defined lateral connection. They are not interpreted to be continuous over the study area however are observed to extend at least 100 m laterally approximately (Figure B23). These layers are often associated with areas of flatter slope profile, illustrated as 'mid-slope benches' on Figures A112-116. Organic layers are less common and only observed as <1.0m layers/lenses within borehole core (Figure B17).

#### B4.5.3 Groundwater

There is likely a deep regional water table (probably draining to sea level) well below the escarpment. The silt/clay beds within the Awhitu Sand influence groundwater movement and result in localised perched aquifers some of which are directly affected by rainfall (Section B4.3).

# B4.5.4 Surficial deposits

Ancient deposits of colluvium (and potentially intermixed alluvium) are present at the base of the escarpment along sections of Domain Crescent and Motutara Road (Figure B11 and Figure B12; Table B6). An interpretation of their spatial extent, based on where the material was recovered within boreholes, is given in Figures A114,115,112 and 123. It is acknowledged that there is uncertainty with the extent of this material given the limited data points.

A graphical interpretation has not been given surrounding BH-M06 (Figure A122) due to the unknown lateral extent of the deep pocket of material encountered there (to at least 38 mbgl). Two interpretations are considered plausible:

- It represents a localised paleo-gully' formed from a different sea level than present and has since been infilled by colluvial, alluvial and possible marine sources over time.
- It is a remnant of debris from a much larger ancient landslide that may encompass the northern area of Domain Crescent and explain the local higher elevation and irregular topography, possibly extending south of BH-M05.

The uncertainties associated with the nature and distribution of this material are not directly relevant to the scope of this assessment as it is not involved in any landslides associated with Cyclone Gabrielle. For this reason, it has not been considered further.



Figure B23 Example of lateral extent of near horizontal silt/clay beds within Awhitu Group, indicated by dashed line. Domain Crescent, M-LS20B for reference. Gentle dip due north – northeast.

# **B4.6** Conceptual landslide model

#### B4.6.1 Mechanism and controls

The mechanism proposed for the shallow translational landslides that transition to high velocity debris flows is illustrated in Figures A127 and A128 and summarised as:

- Intense and prolonged rainfall delivers significant volumes of surface water into the valleys of the
  catchments along the escarpment slope. The water is sourced from overflow along the crest as well as
  directly intercepted by the catchment. An unknown (but possibly not insignificant) amount of groundwater
  saturates discrete areas of the slope from surface springs emitting from local perched aquifers within the
  Awhitu Formation.
- A relatively thin surficial layer of less cemented sands and historical colluvium rapidly becomes saturated through infiltration by surface runoff and groundwater. The surficial sandy soil layer weakens from rapid loss of cement.
- At a certain point (within minutes or hours depending on rainfall and runoff intensity) the weight and pore pressure within the already weakened layer cannot be sustained and a planar shear surface develops at the base of this zone (typically less than 1.5 m deep). This process may be accelerated by the innate erosive/dispersive nature of the Awhitu Formation. The slip surface often undermines shallow rooted vegetation and larger pine trees that were previously providing a degree of structural support to the surface soil but now become entrained.
- The high-water content of the surficial materials causes them to lose internal strength and flow downslope rapidly as a debris flow.

- Finer grained silt and clay layers within the Awhitu Formation that have a higher degree of cohesion may experience preferentially less infiltration and be less impacted by cementation loss, and in turn resist shear surfaces developing. This may cause the surface to 'break out' over the top and flow over otherwise in-situ soil and vegetation that then becomes entrained and transported downslope.
- Additions of relatively intact, less cemented sandstone blocks from isolated rockfalls on the upper escarpment are also released, inferred to be the result of pore pressure developing between near-surface joints and bedding layers, and carried downslope within the debris flow.

The mechanism proposed is supported by observational data across the study area, from the 1965 and recent 2023 events. Deeper seated landslides that may develop along circular slip surfaces (for example) have not been observed during either the 1965 or 2023 events within the escarpment study area and Awhitu Formation Sands geology. Deep seated rotational landslides from water driven events are therefore not considered possible at this site. This does not necessarily preclude the possibility of deep-seated earthquake-induced landslides on a larger scale than those caused by Cyclone Gabrielle, however the observation and assessment of these are outside of the scope of this assessment.

#### B4.6.2 Uncertainties of landslide mechanism

Identified uncertainty or unknown processes and factors associated with the proposed mechanism of landslide development are:

- Relative influence of surface vs groundwater in slip development: Others (Wright, 1966; Hayward, 2022) have stated that groundwater fluctuations and spring emittance played a significant role within the 1965 landslides and by deduction this inference could be extended to the 2023 events. The especially wet summer season of 2023-2024 may have contributed to overall wetter soils and a relatively higher groundwater table. We do not disagree with this. However, without a continuous monitoring record of groundwater levels and rainfall prior to and during the landslide events, it is not possible to determine their relative proportional impact. Anecdotal commentary associated with springs along the face is difficult to rely on given the time of the event (night) and already significant volumes of surface/sheet flow that would affect the reliability of observations. We suggest that surface water (rainfall and runoff) during the event had the predominant impact based on the groundwater data collected to date which indicates only minor fluctuations following subsequent rain events.
- Landslide reactivation and retreat 'lifecycle' across escarpment: Recently failed areas now expose fresher more intact material within the slip face and are therefore less likely to generate future large landslides compared with neighbouring catchments which did not recently experience them and thus have a greater layer of weaker surficial material. It is possible that other factors would still have greater influence of the location and frequency of landslide occurrence, for example: size of confining catchment, slope angle, density of springs. The recurrence of significant landslide activity in 2023 at the same location as the two large landslides of 1965 must also be considered. Without sufficient record of multiple large events like this, preferential retreat/erosion cycles in one section of escarpment vs another is plausible, but unknown.
- Removal of native fauna and/or replacement with exotics: Accompanying the development of the Muriwai community native vegetation has been removed and replaced by exotic species (mainly pine trees). The latter are particularly prominent along the crest of the escarpment as wildling pines, which were commonly observed to be entrained within slip debris and in some cases increased the hazard of the landslides given their destructive force on built structures. It is not clear whether the addition of pine trees on the slope increased the probability of landslide development, but it is considered possible given they are significantly heavier than most surrounding native vegetation and are prone to windfall due to their shallow root systems.

# **B5.** Characterisation of landslide hazard

# **B5.1 Morphology**

Refer to Appendix B-4 which catalogues the main features of all landslides mapped in 2023. Dimensional values of the landslides are given in Table B8. Estimated volumes and (run-out) lengths are also reproduced in Table B9.

We have used the following terminology, which is in broad accordance with that of Hungr et al (2014).

# B5.1.1 Definition of landslide type(s)

The landslides mapped on the Muriwai escarpment are *shallow translational slide movements* within Less Cemented Awhitu Formation sands. Once mobilised, they develop into *high-speed debris flows* down steep slopes (approximately more than 45° typical) until arresting at or near the base where they either encounter flatter topography or an existing dwelling, or both.

 There are often instances of rockfall that releases from near-vertical bluffs formed by some of the larger landslides main scarp (headscarp), resulting from apparent near-surface rock mass jointing within the Awhitu Formation material that creates blocks of less than 1m3 volume.

### B5.1.2 Shape and size characteristics

- Usually have a relatively large run-out length compared with the width at the main scarp, consistent with typical debris flows. Less common, smaller landslides of less than 50 m³ recorded with runouts of similar values to their widths. Figure B24 and Figure B25 show typical examples of the shape and size of single landslides, and merged larger landslide areas, respectively.
- The landslides expose less cemented Awhitu Formation sands with silt and clay beds, along the sliding surface (Figure B23). The height of observed main scarps and corresponding depth of slip surface relative to the pre-existing ground profile was observed during field mapping to be between 0.5 m and 1.5 m.
- Tension cracks above the crest of the escarpment and headscarps of the larger landslides were not generally observed in field mapping. Some evidence of these was observed in several properties along Oaia Road, however it is unclear if these were present before the event. In these instances, the observed cracking is close to the escarpment crest and thus may represent local relaxation and toppling of the material at the crest.
- Figure A126 shows that within the larger slides the average depth of the depletion zone (above the slip surface) is quite variable. Similarly, the zone of accumulation varies in thickness. Note the limitations with the data to develop Figure A126 is described in Appendix B-5.

Table B8 Summarised dimensional values (size and shape) of 2023 landslides

Summarised values for 2023 landslides	Main headscarp width (m)	Debris runout (m)
Average	22	48
Maximum	96	137
Minimum	4	8
Standard deviation (1)	19	36

#### **B5.1.3** Distribution

- Most landslides originate (and form their main headscarp) near the crest of the escarpment and travel slightly beyond its base, with the largest slides traversing the full length (distance) to Motutara Road. Smaller slips originate within the escarpment or the main spurs from it.

- There are four distinct areas along the escarpment where landslide activity was more concentrated and debris fields merged. These are illustrated in Figure A126.

#### B5.1.4 Debris

- The debris is a mixture of residual soil and Less Cemented Awhitu Formation sand, silt, and clay, with 'blocks' of less cemented sandstone, entrained surficial vegetation and debris from impacted dwellings.
- The volume of debris accumulated at the base of the slopes tends to be a function of the confining catchment, with some debris fields being the merging of many separate depletion zones and in some cases originating from areas with merged head scarps (see Figure B25). The risk associated with this merging is addressed in Appendix D.
- The fluid nature of the debris flow means its travel path is strongly governed by the encompassing catchment / topography. This creates inconsistency in the spread of damage to the built environment at the base of the escarpment slopes.
- Field-based observations of inflicted damage suggest that debris travel velocities were 'very rapid to extremely rapid' (3 m/min to greater than 5 m/s; in accordance with Cruden & Varnes, 1996, 'Figure 3-17' and 'Table 3-5'). Anecdotal evidence broadly agrees with these estimates.
- Silt and fines carried in solution during initial failure and deposition were re-mobilised periodically following later rain events.
- The cemented blocks from the isolated rockfalls typically disintegrated into the larger debris flow but occasionally reached the toe of the extent of the run out without being destroyed (e.g. landslides M-LS03, M-LS04, M-LS04a, see Figure A114)
- There is general uncertainty and expected error in the exact definition of the point of inflection between the depletion compared with the accumulation zones within each landslide given the colluvial debris are often observed to begin depositing part way up the landslide face in a thin veneer. This is difficult to map accurately.



Figure B24 Typical features of single landslides areas.



Figure B25 Typical features of larger, merged landslide areas.

# B5.1.5 Frequency of occurrence

The rainfall data presented by AC (Table B3 'Measured and estimated rainfall') indicates a peak rainfall total for Muriwai during the Cyclone Gabrielle event of 146.9 mm, occurring over 12-hour period. This total is >100-year event at a 12-hour duration. The data suggests that for the 12-hour duration rainfall the Annual Recurrence Interval (ARI) is >100 years and may be in the order of 250 years. However, we understand that the calculation above the 100-year assessment becomes increasingly unreliable, primarily because of the relatively short statistical rainfall records available in New Zealand. For the other durations modelled, the rainfall was below the 100-year event.

For the risk assessment discussed in the Appendix E report we have assumed that the annual likelihood of a landslide event that is similar in magnitude to the February 2023 event is about 1 in 100 (i.e., 0.01). The assumption of 1 in 100 based on rainfall frequency is a simplifying and possibly conservative assumption that we consider reasonable. It does not consider other factors that could potentially affect stability (antecedent conditions, geology, groundwater conditions, slope height and angle, vegetation, surface water management- overland flow path, overflow from water storage tanks, effect of effluent disposal field) all of which vary between locations and are difficult to quantify.

Based on discussions with AC, we understand that no reliable storm ARI value is available for the 1965 landslide event due to the lack of data. Hayward (2022) states that the 1965 landslides followed 2 days of unusually heavy rain, with a nearby gauge recording 95 mm on August 25 to 26, plus 45 mm in the 12 hours preceding the landslides that occurred on 27 August 1965. However, the author goes on to mention that this is somewhat less than that recorded officially for the 3-day period at Whenuapai (220 mm) and Manukau Heads (190 mm). Review of publicly available NIWA rainfall data suggests the ARI for a day-day rainfall event of similar magnitude is less than 100mm. The 1965 landslide event affected a considerably smaller area of the Muriwai escarpment than the recent 2023 event, suggesting that the triggering rainfall event was smaller. Considering the uncertainties above, we have assumed that a rainfall event with an ARI of about 50 (assuming current climate conditions) could trigger a similar landslide event to that experienced in 1965.

As discussed above, the review of historical aerial photographs and available literature did not reveal evidence for any other landslide events besides the 1965 event. It is considered likely that small landslides (perhaps less than about 20 m³) could occur more frequently than an event similar in magnitude to the 1965 event. These events could easily go unnoticed (or become forgotten) should they occur in vegetated areas or not result in damage to dwellings.

When more data is available it is common practice to develop landslide size frequency models to present judgments and help predict the future size and frequency of landsliding (e.g. Moon et.al 2005, Hunter et al. 2022). Given that only two landslide-initiating events are known at the site, as well as the uncertainties with rainfall data, we do not believe this approach is practical for this site based on the available data at this time.

# **B5.2** Empirical landslide runout assessment

### B5.2.1 Background

Empirical methods have been used to further compare the landslide runout distances predicted using RAMMS (see Appendix D report) and the observed landslide runouts.

The "fahrböschung" angle (F-angle) assessment is a commonly used, long established rapid screening method for estimating landslide runout. Heim (1932) defined the "fahrböschung" angle as the tangent of the ratio of fall height (H) to horizontal runout distance (L) between the crest of the source zone and toe of the deposit as presented in Figure B26).

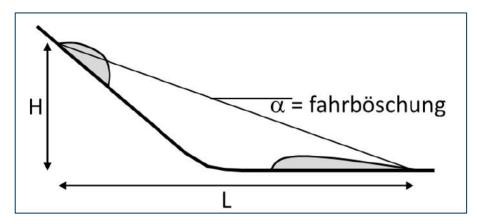


Figure B26 Fahrböschung angle definition after Heim (1932).

Other authors refer to the F-angle by different terms although the definition is the same. For example, Hunter and Fell (2002) adopt the term 'travel distance angle' (referred to by other workers as 'reach angle' or 'angle of reach'). There are many published empirical methods for estimating landslide travel distance (or travel distance angle). Many of these methods are based on slide volume as the main dependent variable (Heim 1932; Scheidegger 1973; Hsu 1975; Smith and Hungr 1992; Corominas 1996; Finlay et al 1999; amongst others). Other authors have proposed empirical expressions based on the inverse relationship between the tangent of the reach angle (H/L) and the landslide volume (i.e. Finlay et al 1999).

Hungr et al. (2005) reported that the volume dependence of the reach has been questioned by several authors for both large landslides (Hsü 1975, Smith and Hungr 1992) and small landslides (Hunter & Fell 2003) and other alternative explanations have been proposed. These works show that there is a lack of agreement among researchers, and opposite conclusions have been derived from these simple relations. Consequently, Hungr et al. (2005) recommends that the use of the F- angle to determine travel distance is made with care.

Finlay et al.'s (1999) data was a mixture of good and modest quality information which is reflected in the large scatter of the predicted travel distances. Hungr et al. (2005) states that Hunter & Fell (2002, 2003) revised this work using more selective good quality data and their recommendations are to be preferred. Hunter & Fell (2002) found that the downslope angle below the source area, provides a useful method for prediction of the travel distance angle for "rapid" slides in natural slopes (Figure B27).

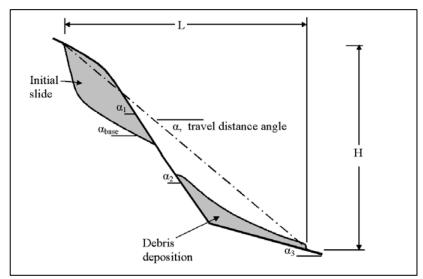


Figure B27 Definition of downslope angle below source area α2 for slides on steep natural slopes (Hunter & Fell (2002))

### B5.2.2 F-angle assessment

Following the February 2023 landslide event AC carried out an area-wide 'F-angle' assessment (documented in an internal Auckland Council memo dated 9/03/2023, document ID: AKLCGEO-1790012875-1831). The purpose of this assessment was to inform decision making about managed temporary access (to enable residents to retrieve property, or insurance assessors to assess losses) and amend placard designations. The assessment was not intended for use in long-term decision making or planning.

The AC study used approximately 15 cross sections through landslides to calculate F-angles. The results ranged from 22° to 25°. This range of angles was projected downwards from the crest of the cliff scarps to predict the possible travel distance of future landslides.

As part of this study, GHD carried out an independent F-angle assessment, using new mapping and the LiDAR data captured on 18 February 2023, of 32 landslides located across the escarpment. A summary of the assessment is presented in Table B9. Volumes were estimated from the mapped area of the depletion zone of each landslide, multiplied by the approximated averaged depth; the latter value is given for each landslide in Appendix B-4.

Some of the calculated F-angles should be considered with caution because landslide flows at some locations were affected by built structures such as driveways and houses. Furthermore, in some instances a number of different landslides coalesced and it was not possible to determine where individual landslides stopped.

The assessment revealed a wide range in F-angles ranging from about 16° to 42°. The range is likely attributable to the effects of local topography, degree of channelisation and potentially obstacles such as vegetation and built structures. This review of F-angles at Muriwai suggests that while it is a useful rapid screening method for landslide runout prediction, the range in the data makes it difficult for this method to be used in isolation.

We have also compared the relationship between landslide volume and runout distance by presenting the data on a H / L vs volume plot (Figure B28). As is apparent from the plot, there is a broad scatter of data with a poor correlation between the H / L ratio and landslide volume. Runout estimation methods based on a volume relationship such as Finlay et al (1999) therefore do not appear to be useful in the case of Muriwai. This is consistent with commentary in the literature by Hungr et al. (2005).

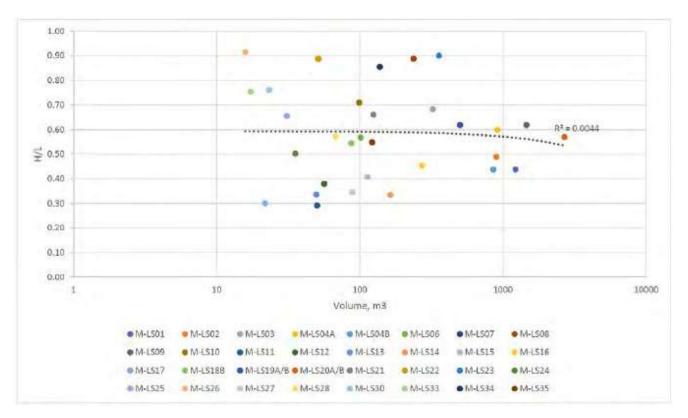


Figure B28 Height / Length ratio vs volume plot for all Muriwai landslides on the main escarpment

# B5.2.3 Hunter and Fell (2002) empirical method

Using the Hunter & Fell (2002) method for "rapid" landslides the travel distance angle of the failed slide mass is calculated from assessment of the failure mechanics of the initial slide (whether contractile or dilative on shearing), the type of slope, slide volume, geometry of the slope at and below the slide source area, and the degree of confinement of the travel path of the landslide. Given the predominantly sandy composition of the Muriwai debris flows it is assessed that the material will dilate following the initial failure.

The Muriwai landslide data is presented on a H / L ratio vs tangent of the downslope angle plot according to the Hunter & Fell (2002) method (Figure B29). This also includes data for the 1965 landslide. Regression lines have also been established based on the degree of confinement. The regression line for a 'partially confined' travel path was found to be very similar to the Hunter & Fell (2002) regression line for a 'partially confined' travel path.

Table B10 presents the predicted travel distance angles for a range of slope angles using this method.

Comparison of the method with the known F-angles calculated for several of the February 2023 Muriwai landslides typically found agreement within a few degrees.

The predicted travel distances using the Muriwai relationship are very similar to the Hunter & Fell (2002) method, albeit usually at the higher end of the travel distance angle range. Based on the results of this exercise there is a good correlation between landslide runout and the downslope angle for the landsliding at Muriwai, meaning that landslide runout will vary across the escarpment depending on the local geomorphology. The close similarity between the Hunter & Fell (2002) predictive method and the Muriwai relationship probably suggests that while some variability is to be expected, future landslides are unlikely to travel appreciably further than the observed February 2023 runout distances.

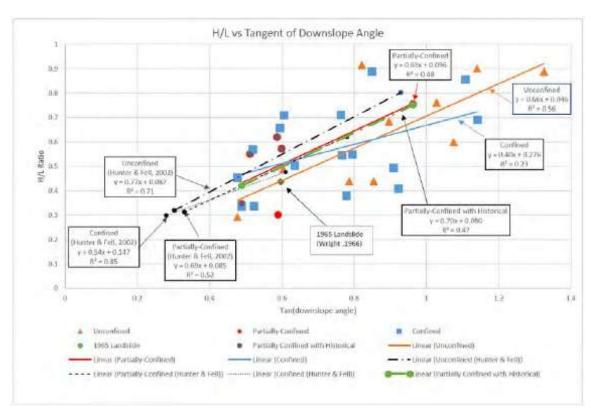


Figure B29 H/L versus tangent of the downslope angle  $\alpha_2$  plot for Muriwai data together with Hunter & Fell (2002) relationships for rapid slides on steep natural slopes in dilative soils.

Table B9 Summary of F-angle assessment

Landslide ID	Length (m)	Height (m)	Downslope Angle (α2)	F-Angle	Estimated Landslide volume (m³)	Comments	
M-LS01	142.8	62.6	38	24	1222		
M-LS02	133.6	65.396	31	26	899		
M-LS03	89.1	60.9	42	34	324		
M-LS04A	108	64.7	47	31	914		
M-LS04B	147.8	64.7	41	24	855	Length measured from landslide centreline due to channelised landslide flow	
M-LS06	113.4	64.4	27	30	101		
M-LS07	59.5	42.2	31	35	99	Difficult to determine toe of slide due to coalescence of adjacent debris flows	
M-LS08	69.2	61.5	40	42	237	Difficult to determine toe of slide due to coalescence of adjacent debris flows	
M-LS09	131.4	81.4	30	32	1457		
M-LS10	88.7	63	37	35	99		
M-LS11	44.2	12.9	25	16	50	Slide originated on lower escarpment slope. Length measured from landslide centreline due to channelised landslide flow	
M-LS12	84.3	32.02	38	21	56		
M-LS13	57.7	19.4	28	19	50	Flow appears to have been channelised along driveway - runout may be misleading	
M-LS14	66.4	22.2	26	18	164	Length measured from landslide centreline due to channelised landslide flow	
M-LS15	48.1	19.6	43	22	113		
M-LS16	44.3	20.1	26	24	272		
M-LS17	23.6	7.1	31	17	22	Small, localised landslide on lower escarpment slope	
M-LS18B	131.7	71.7	37	29	87	Length measured from landslide centreline due to channelised landslide flow	
M-LS19B	116	63.8	27	29	500		
M-LS20B	139.1	68.6	42	26	2692		
M-LS21	57.3	39.6	49	35	124		

Landslide ID	Length (m)	Height (m)	Downslope Angle (α2)	F-Angle	Estimated Landslide volume (m³)	Comments	
M-LS22	17.9	15.9	53	42	51		
M-LS23	30.3	27.3	49	42	357		
M-LS24	39.2	19.7	32	27	35		
M-LS25	41.6	27.3	31	33	31		
M-LS26	9.4	8.6	39	42	16	Small, localised landslide on lower escarpment slope	
M-LS27	35.8	12.4	26	19	89	Small, localised landslide originating on ridgeline - lower escarpment slope	
M-LS28	20.8	11.9	31	30	68		
M-LS30	13.4	10.2	46	37	23		
M-LS33	26.9	20.3	44	37	17	Small, localised landslide on lower escarpment slope	
M-LS34	63.7	54.5	48	41	138	Difficult to determine toe of slide due to coalescence of adjacent debris flows	
M-LS35	81.8	44.9	39	29	122		

Table B10 Summary of predicted travel distance angles

Downslope Angle (°)	Predicted Travel Distance Angle (°) (Hunter and Fell (2002) empirical method)*	Predicted Travel Distance Angle (°) – Muriwai Regression Data	
20	19	19	
25	22	23	
30	25 - 26	26	
35	28 - 30	30	
40	31 - 34	34	
45	34 - 38	38	
50	38 - 42	43	
55	43 - 47	47	
60	47 - 52	52	

<sup>\*</sup>Confined and partly confined travel pat

# **B6.** Landslide hazard assessment

# **B6.1** Inferred future landslide source areas

The distribution of potential landslides is an important consideration for the assessment of future debris flow risks (see Appendix D for rationale and reference to figures that show inferred potential landslide sources). Appendix E quantifies the relative risk of damaging landslides for each zone.

Potential landslide failure zones have been identified based on having similar geomorphology (ground shape) and geology to February 2023 landslide source areas. For example, the bowl-shaped head-scarp shape of recent landslides observed at the crest of the escarpment is similar to the shape of the escarpment where failures did not occur in 2023 (Figure B30) but have almost certainly occurred at some time in the past. Hence, we infer that the whole of the escarpment has similar landslide susceptibility due to the likely similar conditions of geology and possibly groundwater. We have assumed that future landslides on the escarpment have the potential to fail with similar damaging effects as the February 2023 landslides. Inferred landslides were used as RAMMS debris flow source areas to model potential future landslide hazard areas (see the Appendix D RAMMS analysis report).

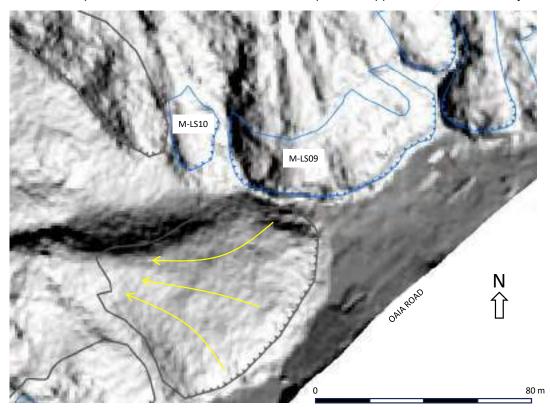


Figure B30 Potential landslide failure zones have been identified by GHD based on having similar geomorphology (ground shape) and geology to February 2023 landslide source areas. The above example shows a potential landslide source zone (grey outline) that has similar bowl-shaped characteristics to recently failed blue areas. Yellow lines indicate expected debris flow path. Background surface model has a 'hill shade' applied to highlight the geomorphology. Location is below the escarpment and west of Oaia Road.

# B6.2 Potential for deep-seated landslides within Awhitu Formation

Two instances of deep-seated landslide activity are observed or inferred within Awhitu Formation sand surrounding the study area. These features are located outside of and within the study area, respectively. The mode and cause of failure are not considered to be related to the trigger event associated with the 2023 landslides resulting from Cyclone Gabrielle.

- A deep-seated translational landslide is present within the Awhitu Formation, south of the study area, immediately south of Waitea Road (Figure B31). Its geomorphology is suggestive of an earth flow. The toe region of the landslide appears to be un-buttressed and eroding into the ocean over a large cliff line. The outcropping Nihotupu Formation at the toe of the slope is inferred to control the depth of slip by acting as a relatively impermeable barrier to groundwater flow. This underlying unconformity is the same feature interpreted to dip below the study site from the southern end of Domain Crescent (Section B4.5).
- The possibility for a large, 'ancient' landslide identified from surface geomorphology and subsurface core recovered in BH-M06 was raised in Section B4.5 and. A feature of this scale would likely be complex in its mode and mechanism of failure and, as implied from BH-M06, the principal slip surface may extend several tens of meters below ground.

These modes of landslide failure are not considered applicable to the study area and the debris flow hazard off the escarpment at Muriwai township.

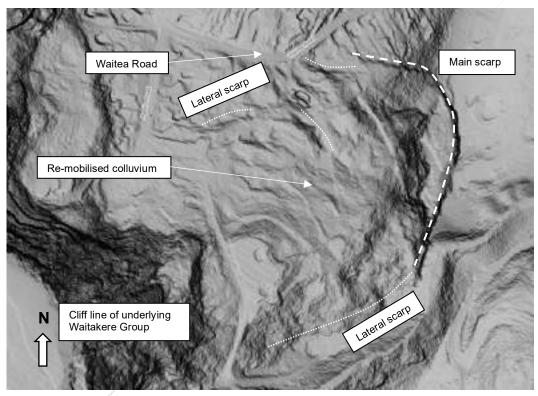


Figure B31 Deep seated landslide (earthflow) within Awhitu Sand Formation, underlying contact with Waitakere Formation daylighting in toe area (cliffs). Background surface model has a 'hill shade' applied to highlight the geomorphology.

# **B6.3** Geomorphological landslide zones

#### B6.3.1 Definition and overview of zones

The study area has been divided into six geomorphological 'zones' based on the surface topography, February 2023 landslide characteristics and general geomorphology. The purpose of this is to differentiate areas according to their susceptibility to large-scale<sup>3</sup> landslides. The life risk to residents for each zone is considered separately in the risk assessment (see overall report Appendix E).

To help define the zones, we applied a colour scale to a plan of Muriwai (Figure A125 in Appendix A) to highlight the topographic variation and show areas that are steeper than others. Cross sections were then used to generate slope profiles, mostly normal to the Muriwai escarpment, but in some cases below the escarpment, and the profiles were overlain to identify similarities and differences.

<sup>&</sup>lt;sup>3</sup> In this report 'large scale' landslide hazards refers to landslides originating from the main escarpment that typically have a volume of more than about 50 m<sup>3</sup> with the potential to cause total or partial collapse of a dwelling.

The slope angle and approximate height of the steeper section of the profile is shown for each zone in Table B11. This estimate is subjective and is an approximation only, however, it is a sound basis for differentiating between zones.

Table B11 Summary of slope angle and height for zone profiles (zones coloured to match profile colours)

Zone	Average Angle	Minimum Angle	Maximum Angle	Approximate vertical height to nearest 10 m	
1	30	26	31	20	
2	33	30	41	70	
3	25	23	30	60	
4	44		5	0	
5	38	NOT APPLICABLE DUE TO VARIABLE SLOPE PROFILE SHAPES	30		
6	39	3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3	20		

Figure B32 shows the slope profiles, coloured according to zone to allow comparison. The common point of reference for the profiles is the top of the slope (i.e. the top of the escarpment).

Similarly, comparison of the number of landslides and the distribution of these according to zone highlights the spatial variability of these (see Figure B33 and Figure B34).

The following sections describe the landslide and topographic characteristics of each zone referring to these data.

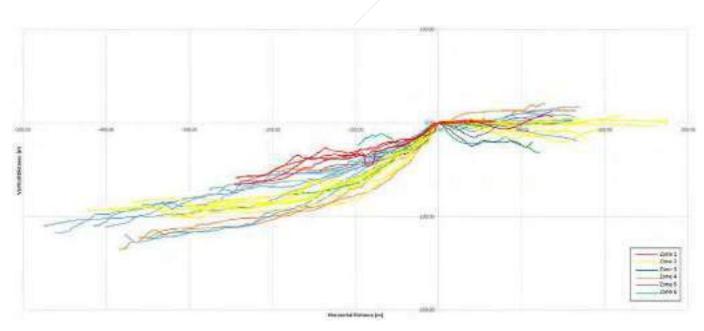


Figure B32 Slope profile comparison of 27 cross sections in Zones 1 to 6 (see Figure A137). Profiles are mostly viewed in a north-looking direction and have been centred on the crest of each slope (in most cases this is the top of the escarpment).

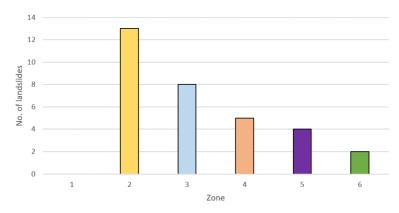


Figure B33 Number of February 2023 landslides per zone

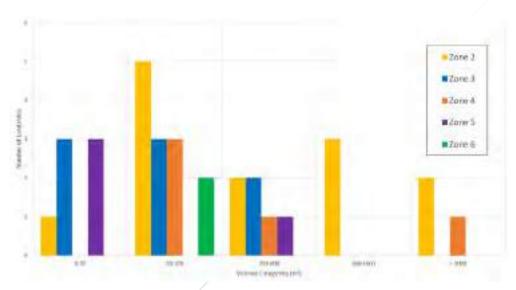


Figure B34 Number and size of February 2023 landslides shown per zone

#### B6.3.2 Zone characterisation

#### 6.3.2.1 Zone 1

Zone 1 is located at the northern end of Motutara Road north of, and including, 42 and 104 Motutara Road (see Figure B35). The features of Zone 1 are as follows:

- The steepest part of the slope at the top of Motutara Road is approximately 30°, which is relatively flat (see Figure B36).
- The vertical height of the slope at this steepness is approximately 20 m, which is one of the lowest on the escarpment.
- No large landslides occurred in this area in the February 2023 storm event.
- The general slope-facing direction is towards the southwest, which may not directly face the direction of origin for sub-tropical cyclone storm events.

When considering the potential for future landslides, we have considered that Zone 1 may have favourable conditions (low susceptibility) partly due to the location of Motutara Road at the upper part of the slope (i.e. in the vicinity of 42 Motutara Road), which may act to intercept and redirect surface flows from further up the slope, and partly due to its aspect. In addition, anecdotal evidence from community interaction is that the surface water conditions during the February 2023 storm were not notably extreme, with no observed concentrated flow.



Figure B35 Location of the Zone 1 / Zone 2 boundary. North is to the top of the page.

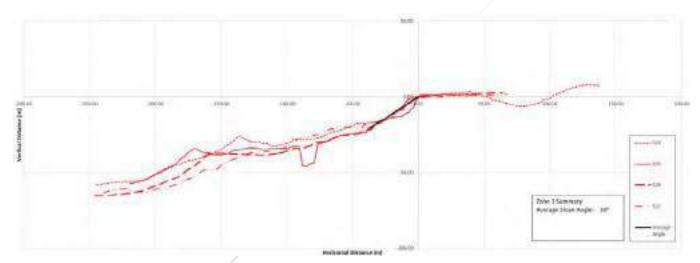


Figure B36 Slope profile comparison of Zone 1 surface cross sections (see Figure A137 for location of sections)

#### 6.3.2.2 Zone 2

Zone 2 is the largest zone and is above Motutara Road. It is defined in the north by, and including, 38 and 108 Motutara Road (see Figure B35) while the southern limit of Zone 2 is bounded by, and includes, 228 and 230 Motutara Road (see Figure B43). The features of Zone 2 are as follows:

- The average slope angle is 33° but is locally much steeper (see Figure B37).
- The vertical height of the slope is greater than 70 m on average, which is the highest of all zones.
- Thirteen large landslides occurred in Zone 2 in the February 2023 storm, with two having a volume greater than 500 m<sup>3</sup>. The landslides are commonly broader relative to other zones (e.g. Zone 3).
- The general slope-facing direction is to the west, which is expected to be towards future sub-tropical cyclone storm events.
- The shape of the escarpment tends to be mostly gently and continuously curving. Elsewhere on the escarpment, for example in Zone 3, there are many distinctive, tightly curved headscarp features.

The above observations align well with this area having the potential for multiple, highly damaging landslides, as was the case in the February 2023 event.

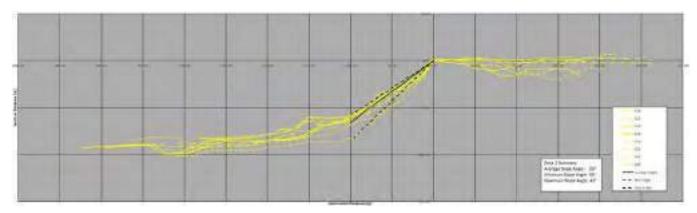


Figure B37 Slope profile comparison of Zone 2 surface cross sections (see Figure A137 for location of sections)

#### 6.3.2.3 Zone 3

Zone 3 is located at the Muriwai escarpment above Domain Crescent, being defined to the north by properties on the northern side of Domain Crescent (see Figure B43) and to the south by 63 Domain Crescent (see Figure B38). The features of Zone 3 are as follows:

- The slope is approximately 25° on average, which is relatively flat (see Figure B39).
- The vertical height of the slope at this steepness is approximately 60 m, which is relatively high.
- Eight large landslides occurred in February 2023, all with a volume of less than 600 m<sup>3</sup>.
- The general slope-facing direction is to the west, which is potentially towards future sub-tropical cyclone storm events.
- The escarpment has many distinctive, tightly curved headscarps in marked contrast with Zone 2. Debris flows are typically more channelised in this zone.

The observations above indicate a regime with potential for large, destructive landslides.



Figure B38 Location of the Zone 3 / Zone 4 boundary. North is to the top of the page.

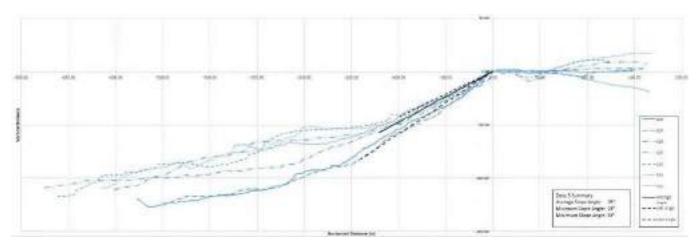


Figure B39 Slope profile comparison of Zone 3 surface cross sections (see Figure A137 for location of sections)

#### 6.3.2.4 Zone 4

Zone 4 is located at the southern end of Domain Crescent between 47 and 61 Domain Crescent (see Figure B40 and Figure B38, respectively). The features of Zone 4 are as follows:

- The average slope angle is 44°, which is relatively steep (see Figure B41).
- The vertical height of the slope at this steepness is approximately 50 m, which is less than in Zones 2 and 3.
- Five large landslides occurred in February 2023, with one over 1000 m<sup>3</sup> in volume. Note that Zone 4 is smaller than other, similar zones and so the number of landslides may give a false impression of the exposure of dwellings at the slope base.
- This is the location of the large 1965 landslide (see Section B3.3.2).
- The general slope-facing direction is to the west, which is expected to be towards future sub-tropical cyclone storm events.
- The escarpment has many distinctive, tightly curved headscarps.

The observations above indicate a regime with a demonstrated potential for large, destructive landslides on a similar scale to Zone 2.

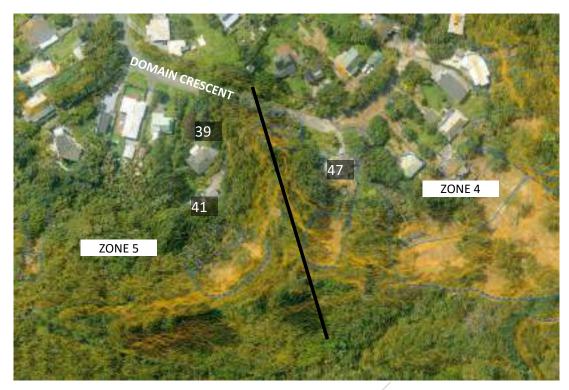


Figure B40 Location of the Zone 4 / Zone 5 boundary. North is to the top of the page.

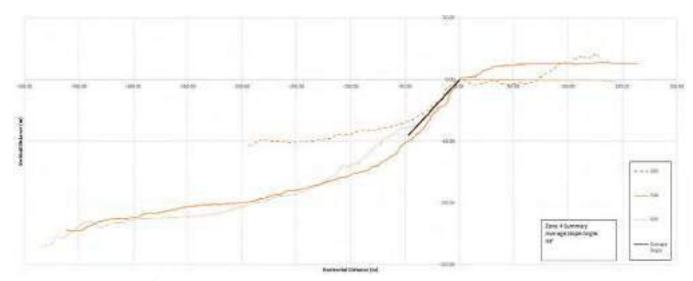


Figure B41 Slope profile comparison of Zone 4 surface cross sections (see Figure A137 for location of sections)

#### 6.3.2.5 Zone 5

Zone 5 is the southernmost zone between Domain Crescent and Waitea Road. The boundary of Zone 5 is to the east of 39 and 41 Domain Crescent (see Figure B40). The features of Zone 5 are as follows:

- The slope is approximately 38°, which is derived from only two cross sections (see Figure B42).
- The slope facing Domain Crescent is one side of a ridge, meaning that the catchment for surface water or groundwater recharge is limited compared with escarpment zones. This may mean that Zone 5 is less susceptible to landslides.
- Four landslides occurred in the February 2023 storm, most of which were less than 50 m³; none impacted dwellings.
- The general slope-facing direction is towards the northwest, which may be the direction of origin for future sub-tropical cyclone storm events.

When considering the potential for future landslides, we suggest that Zone 5 may have favourable conditions due to the topography, which does not encourage storage of groundwater behind the slope, and the limited potential for surface runoff to saturate the slope.

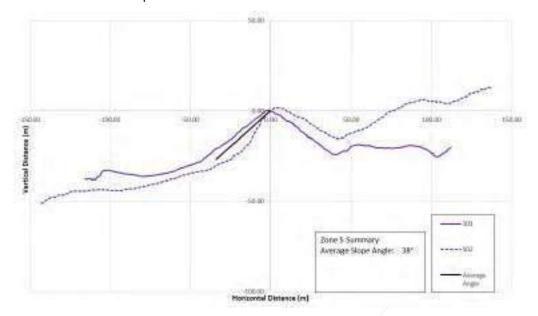


Figure B42 Slope profile comparison of Zone 5 surface cross sections (see Figure A137 for location of sections)

#### 6.3.2.6 Zone 6

Zone 6 is located between Zone 3 and 2. It includes 264 Motutara Road to the west through to 232 Motutara Road to the east (see Figure B43). This zone is away from the Muriwai escarpment but is locally steeper than surrounding land. The features of Zone 6 are as follows:

- The average steepness of the three cut profiles is about 39°, although the variability of the profiles is noted (see Figure B44).
- The vertical height is approximately 20 m, which is relatively low.
- Two landslides in the range of 50 to 150 m<sup>3</sup> were recorded following the February 2023 storm event.
- The general slope-facing direction is towards the north.

When considering the potential for future landslides, we consider that Zone 6 may have favourable conditions due to the topography, which does not encourage storage of groundwater behind the slope, the low slope height, and limited potential for surface runoff/saturation.

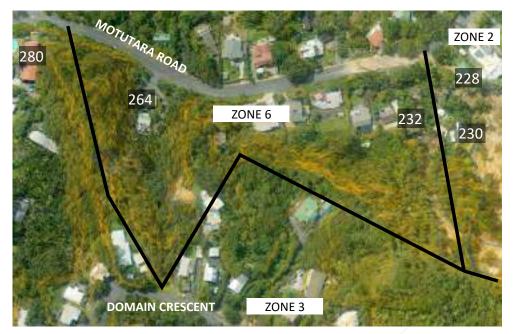


Figure B43 Location of the Zone 2 / Zone 3 / Zone 6 boundary. North is to the top of the page.

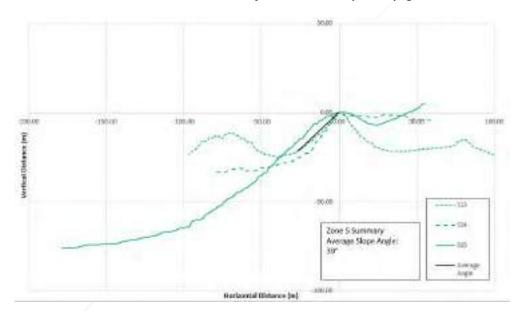


Figure B44 Slope profile comparison of Zone 6 surface cross sections (see Figure A125 for location of sections)

# **B7.** Conclusions

The following conclusions are made in relation to the engineering geological assessment of the Muriwai landslide hazard:

- 1. The recent (2023) and historical (1965) landslides that have affected the Muriwai community were high-velocity debris flows originating on the escarpment that extends up to 80 m above the township.
- 2. The model proposed for the recent (2023) and historical (1965) landslides that damaged the Muriwai community is that of saturated and shallow translational slips that quickly become high-velocity debris flows, entraining significant volumes of unconsolidated sand and vegetation.
- The formation of these landslides can be directly attributed to the saturation of surficial soil (colluvium and weathered rock) in the Awhitu Sand Formation which, upon losing its binding iron-cement, develops a shallow shear surface.
- 4. This process is probably influenced by a combination of surface water infiltration and subsurface pore pressure increases from perched aquifers and associated springs. However, as no groundwater or overland flow data is available from during the events, reliance is placed on anecdotal accounts which do not provide a clear picture.
- From the data available, including continuous groundwater monitoring established after the 2023 event, it is inferred that surface water flow and infiltration/saturation of shallow soils has had the greater effect on the onset of landslides.
- 6. The speed, composition, and volume of the debris generated make these debris flows highly destructive to dwellings and property located within the run-out area. As a result, tragically, multiple fatalities were experienced in both the 1965 and 2023 events.
- The debris flows follow local catchment valleys which often coalesce multiple landslides into confined areas.
   Consequently, the location and degree of damage to residential properties is variable along Domain Crescent and Motutara Road.
- 8. Deep-seated landslides resulting from large (i.e. ARI 100 year) rain events within the study area (escarpment) and geology (Awhitu Formation) sand, are not considered likely. Although evidence that may be plausibly attributed to larger historical landslides has been observed, the relative magnitude of these features compared with the 2023 event suggests much larger, less frequent environmental conditions would be required to instigate failure (most likely a very large earthquake). Such conditions and resultant hazards have not been considered for this assessment.
- 9. Six geomorphological landslide 'zones' have been defined based on the surface topography, 2023 landslide characteristics and general geomorphology of the study area. These differentiate areas according to their susceptibility to large-scale landslides (i.e. having a volume of more than approximately 50 m³). Zones 2, 3 and 4 contain the Muriwai escarpment and have higher potential for future, large landslides.
- 10. The life risk to residents for each zone is considered separately in the risk assessment (Appendix E).

# **B8.** Limitations

This report has been prepared by GHD Limited (GHD) for Auckland Council and may only be used and relied on by Auckland Council for the purpose agreed between GHD and Auckland Council as set out in Section 1 of this report.

GHD otherwise disclaims responsibility to any person other than Auckland Council arising in connection with this report. GHD also excludes implied warranties and conditions, to the extent legally permissible.

The services undertaken by GHD in connection with preparing this report were limited to those specifically detailed in the report and are subject to the scope limitations set out in the report.

The opinions and conclusions and any recommendations in this report are based on conditions encountered and information reviewed at the date of preparation of the report. GHD has no responsibility or obligation to update this report to account for events or changes occurring subsequent to the date that the report was prepared.

The opinions, conclusions and any recommendations in this report are based on information obtained from, and testing undertaken at or in connection with, specific sample points. Site and ground conditions inferred at other parts of the site may be different from the site conditions found at the specific sample points.

The opinions, conclusions and any recommendations in this report are based on assumptions made by GHD described in this report (refer Section 1 of this report). GHD disclaims liability arising from any of the assumptions being incorrect.

GHD does not accept responsibility arising from, or in connection with, varied conditions and any change in conditions. GHD is also not responsible for updating this report if the conditions change.

An understanding of the geotechnical site conditions depends on the integration of many pieces of information, some regional, some site specific, some structure specific and some experienced based. Hence this report should not be altered, amended, abbreviated, or issued in part in any way without prior written approval by GHD. GHD does not accept liability in connection with the issuing of an unapproved or modified version of this report.

Verification of the geotechnical assumptions and/or model is an integral part of the design process - investigation, construction verification, and performance monitoring. If the revealed ground or groundwater conditions vary from those assumed or described in this report the matter should be referred back to GHD.

# **B9.** References

#### **Technical Literature**

Auckland Council (2023). 'Guidelines on the use of AGS (2007) for landslide risk assessment in Auckland following the 2023 flooding and cyclone'. Memorandum dated 20 September 2023.

- B. W Hayward (1976): 'Lower Miocene geology and sedimentary history of the Muriwai-Te Waharoa coastline, North Auckland, New Zealand'; New Zealand Journal of Geology and Geophysics, Volume 19, No. 5
- B. W Hayward (1979): 'Ancient Undersea Volcanoes: A guide to the geological formations at Muriwai, west Auckland"; Geological Society of New Zealand Guidebook No. 3'
- B. W Hayward (2022). The tragic 1965 Muriwai Landslide. Geocene 28: 2-5
- Corominas, J. (1996). The angle of reach as a mobility index for small and large landslides. Canadian Geotechnical Journal, Vol 33, pp. 260-271.
- D. J.: 'Slope movement types and processes. In Special Report 176: Landslides: Analysis and . Varnes, 1978Control'; TRB National Research Council Washington.
- D.M. Cruden & D. J. Varnes (1996): 'Landslide Types and Processes'; Transportation Research Board, U.S. National Academy of Sciences, Special Report, 247: 36-75
- Fell R., Ho K.K.S., Lacasse S., Leroi E. (2005). A framework for landslide risk assessment and management. In: Hungr O, Fell R, Couture R, Eberhardt E (eds) Landslide risk management. Taylor & Francis, London, pp 533–541
- Finlay P.J.; Mostyn G.R. and Fell R. (1999). Landslides: Prediction of travel distance and guidelines for vulnerability of persons. Proceedings of the 8th Australia New Zealand Conference on Geomechanics, (Vitharana and Colman eds.) Hobart, Australian Geomechanics Society, pp. 105-113.
- GHD (2023¹). Muriwai Resilience Assessment Stormwater; Private Property Desktop Assessment Report. For Auckland Council. 15 December 2023.
- GHD (2023²). Muriwai Resilience Assessment Stormwater; Oaia Road and Edwin Mitchelson Track Investigation Report. For Auckland Council. 18 December 2023.
- Heim, A. (1932). Landslides and human lives (Bergstruz and Menchen leben). Translated by N. Skermer. BiTech Publishers, Vancouver, B.C., 195 p
- Hsu, K.J. (1975). Catastrophic debris streams (sturzstroms) generated by rockfalls. Geological Society of America Bulletin, Vol 86, pp. 129-140.
- Hungr, O., Leroueil, S. and Picarelli, L. (2014). The Varnes Classification of Landslide Types, an Update. Landslides (2014) 11:167–194
- Hungr. O.; Corominas, J. and Eberhardt, E. (2005). Estimating landslide motion mechanisms, travel distance and velocity. In Landslide Risk Management Editors. O. Hungr, R. Fell, R. Couture and E. Eberhardt. Taylor and Francis, London. 99-128.
- Hunter, G. & Fell, R. (2003). Travel distance angle for rapid landslides in constructed and natural soil slopes. Canadian Geotechnical Journal 40(6): 1123-1141.
- Hunter. A., Flentje, F. and Moon. A. (2022). Bulli Pass Landslide Risk Management Part 1. Australian Geomechanics, Vol 57, No3.
- Hunter. G., & Fell. R. (2002). Estimation of Travel Distance for Landslides in Soil Slopes. Australian Geomechanics, Vol 37, No2.
- J. C. Schofield, 1975: 'Sea-level fluctuations cause periodic, post-glacial progradation, South Kaipara Barrier, North Island, New Zealand'; New Zealand Journal of Geology and Geophysics, Volume 18, No. 2
- L. W. Wright, 1966: 'The Muriwai Debris-Avalanche: Some Aspects of Its form and Genesis'; New Zealand Geographer

Moon A.T., Wilson R.A. and Flentje P.N. (2005). Developing and using landslide size frequency models. In: Hungr O, Fell R, Couture R and Eberhardt, E (eds) Landslide Risk Management, CRC Press, pp 681-690.

P.R. Goldsmith & E.H Smith, 1984: "Tunnelling soils in South Auckland, New Zealand"; Fourth Australia – New Zealand Conference on geomechanics, Perth, 14-18 May 1984

Rodney District Council, 2005: "Muriwai Community Plan"; Strategy and Policy

Scheidegger, A.E. (1973) On the prediction of the reach and velocity of catastrophic landslides. Rock Mechanics, Vol 5, pp. 231-236.

Smith, D. and Hungr, O. (1992) Failure behaviour of large rockslides – Report to the Geological Survey of Canada and BC Hydro and Power Authority. Report No. 16-11-6, Thurber Engineering Ltd.

#### **Public Articles**

Interest New Zealand. Brooke, 21 Feb 2023, from <u>Learning the lessons from landslides | interest.co.nz</u>
Paper Past New Zealand. 1965. <u>Papers Past | Newspapers | Press | 2 September 1965 | Mopping Up After Slips (natlib.govt.nz)</u> PRESS, VOLUME CIV, ISSUE 30845, 2 SEPTEMBER 1965, PAGE 3

Stuff New Zealand. 15 Aug 2013, from Old memories revisited | Stuff.co.nz

Auckland Star. 20 June 1934. Papers Past | Newspapers | Auckland Star | 20 June 1934 | THE DELUGE. (natlib.govt.nz) AUCKLAND STAR, VOLUME LXV, ISSUE 144, 20 JUNE 1934, PAGE 9

Manawatu Standard. 27 Dec 1926. Papers Past | Newspapers | Manawatu Standard | 27 December 1926 | FLOODS IN THE NORTH. (natlib.govt.nz) MANAWATU STANDARD, VOLUME XLVII, ISSUE 24, 27 DECEMBER 1926, PAGE 8

Evening Star. 27 Dec 1926. Papers Past | Newspapers | Evening Star | 27 December 1926 | RECORD FLOOD (natlib.govt.nz) EVENING STAR, ISSUE 19441, 27 DECEMBER 1926, PAGE 7

Wairarapa Daily Times. 1926. <u>Papers Past | Newspapers | Wairarapa Daily Times | 28 December 1926 | UNSEASONABLE WEATHER. (natlib.govt.nz)</u> WAIRARAPA DAILY TIMES, 28 DECEMBER 1926, PAGE 5

Southland Times. 28 Dec 1926. Papers Past | Newspapers | Southland Times | 28 December 1926 | AUCKLAND'S RAIN (natlib.govt.nz) SOUTHLAND TIMES, ISSUE 20063, 28 DECEMBER 1926, PAGE 7

Christchurch Star. 27 Dec 1926. Papers Past | Newspapers | Star (Christchurch) | 27 December 1926 | The Worst Floods For Fifty Years Do Damage In... (natlib.govt.nz) STAR (CHRISTCHURCH), ISSUE 18039, 27 DECEMBER 1926, PAGE 7

Evening Post, 28 Dec 1922. Papers Past | Newspapers | Evening Post | 28 December 1922 | HEAVY FLOODS (natlib.govt.nz) EVENING POST, VOLUME CIV, ISSUE 154, 28 DECEMBER 1922, PAGE 7

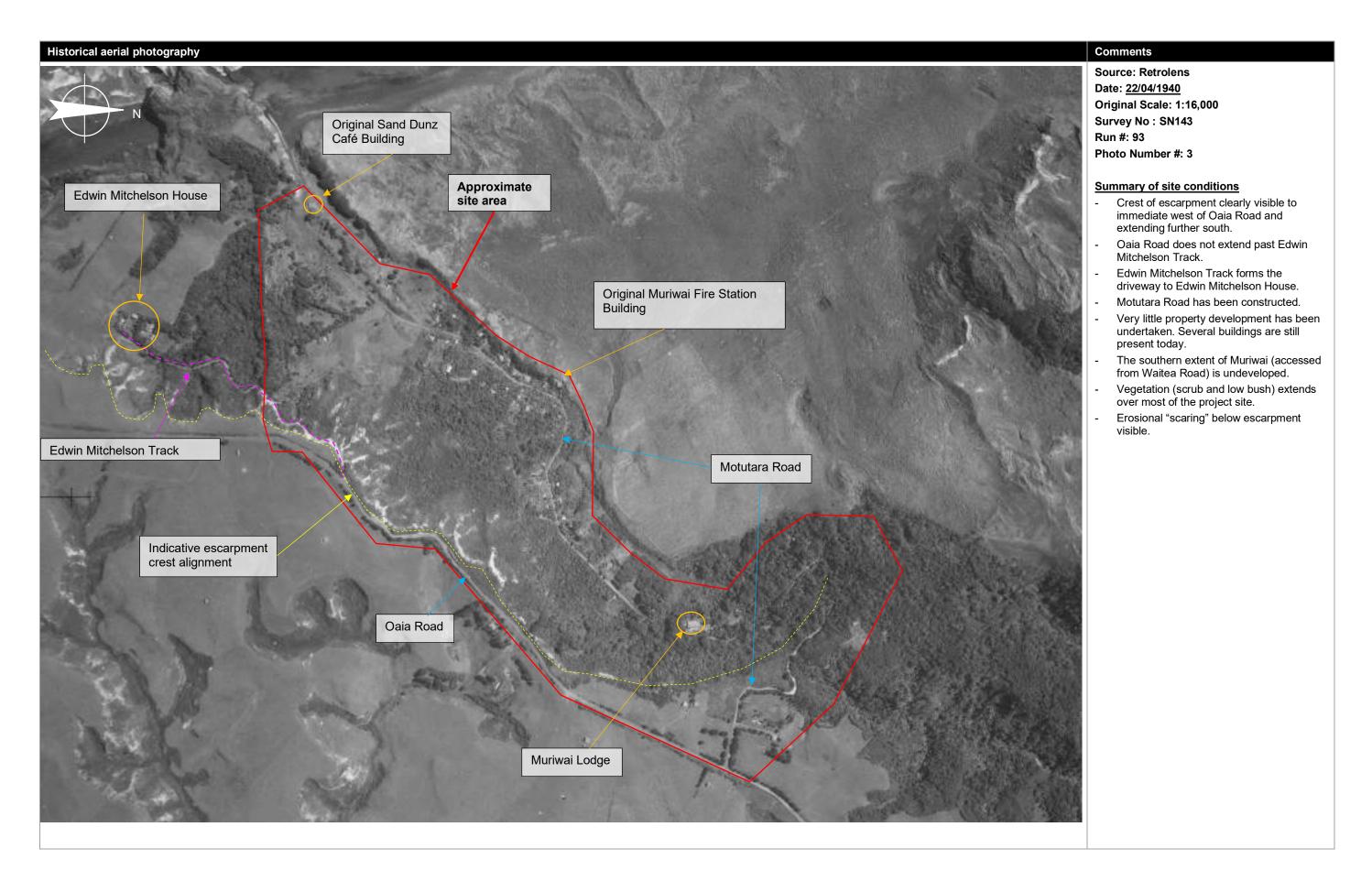
Manawatu Times. 29 Dec 1922. Papers Past | Newspapers | Manawatu Times | 29 December 1922 | HEAVY FLOODS. (natlib.govt.nz) MANAWATU TIMES, VOLUME XLVI, ISSUE 2536, 29 DECEMBER 1922, PAGE 5

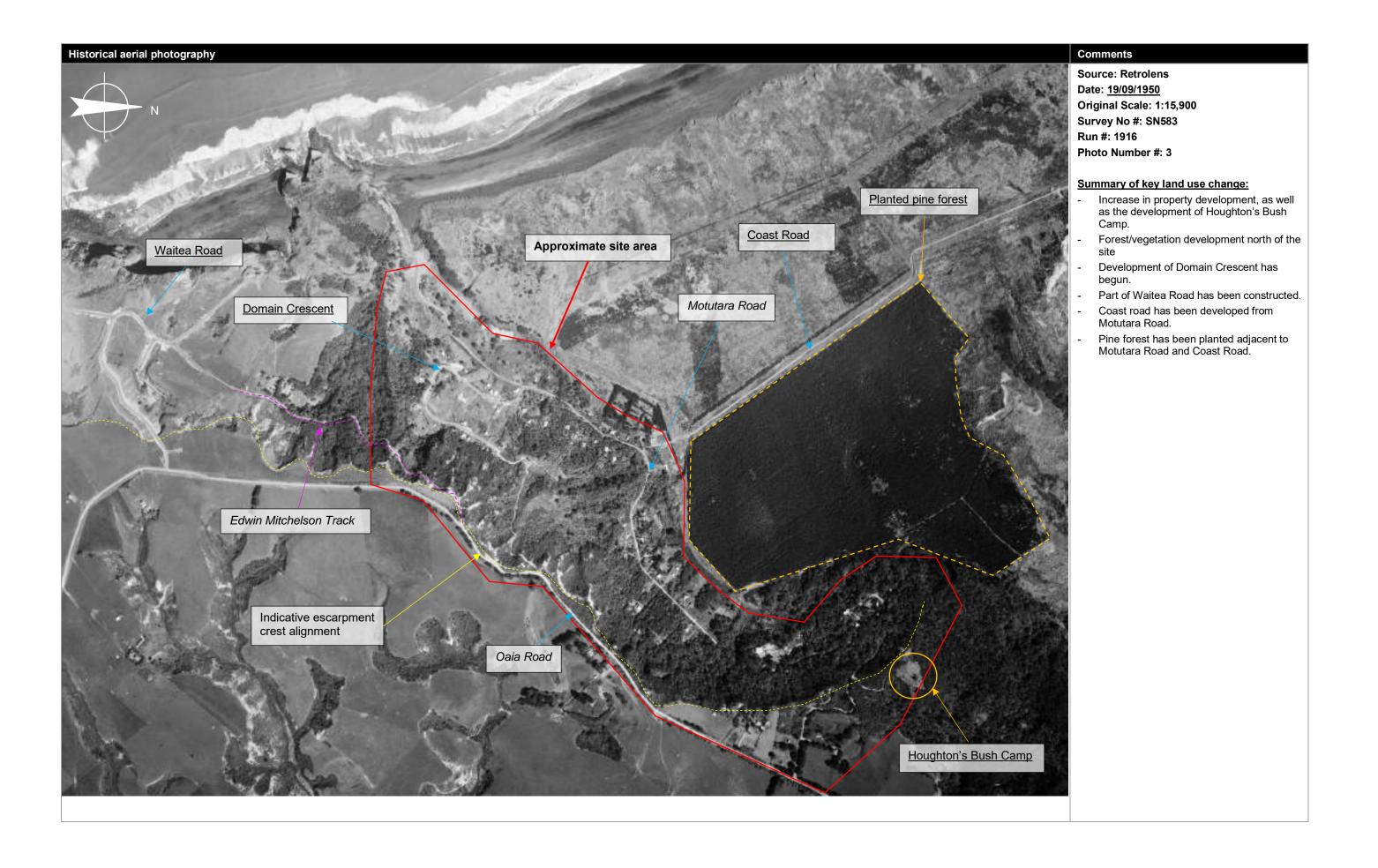
# Appendices

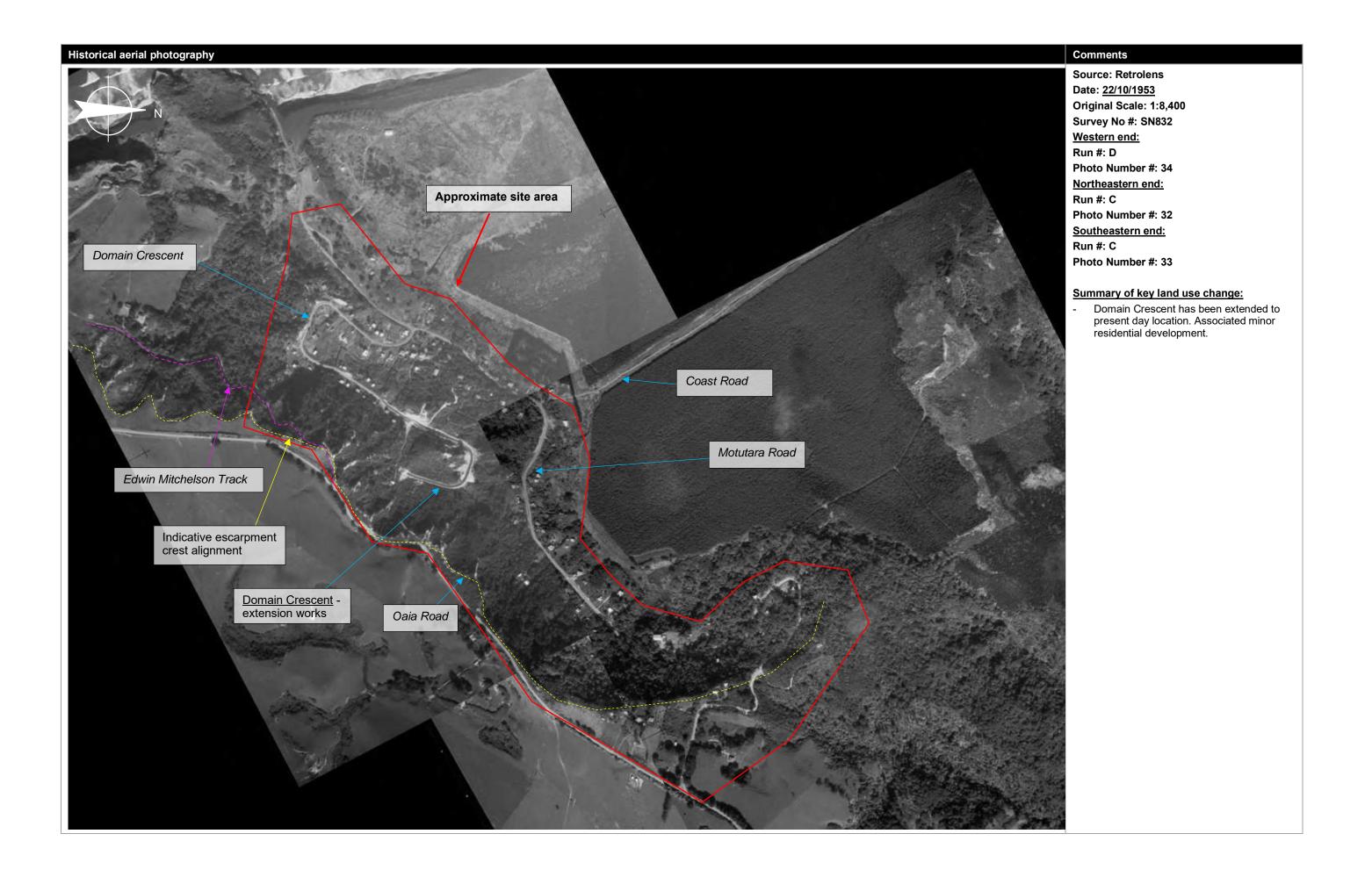
# Appendix B-1

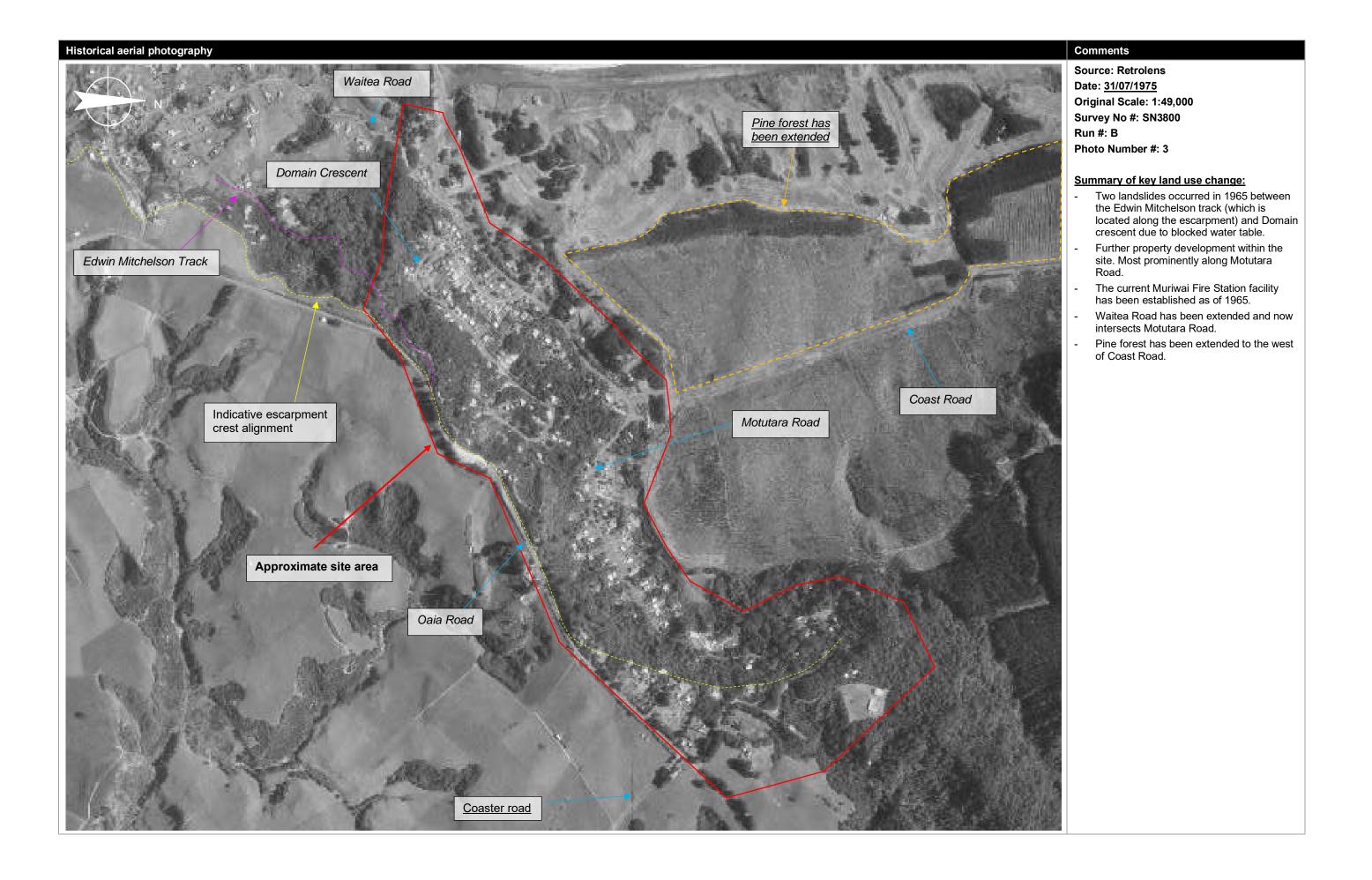
Historical air photograph record

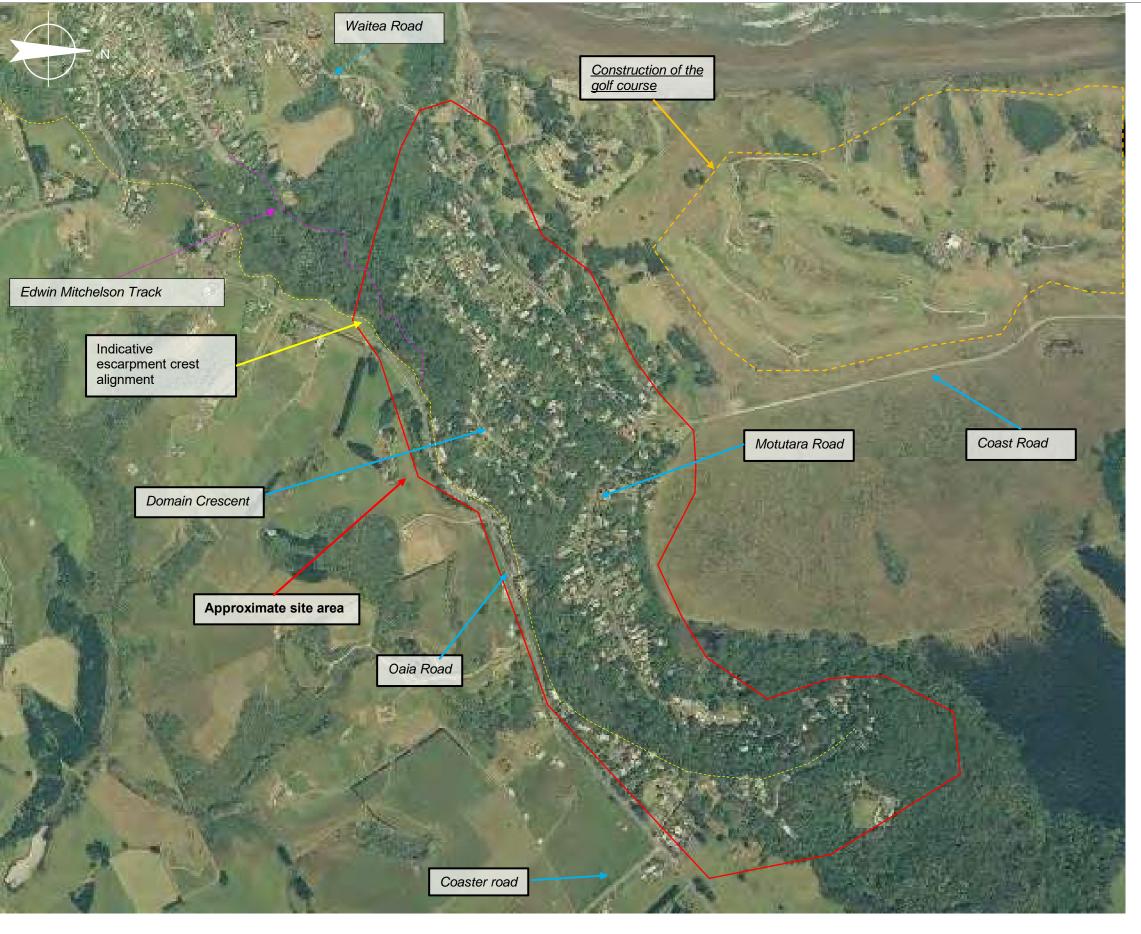












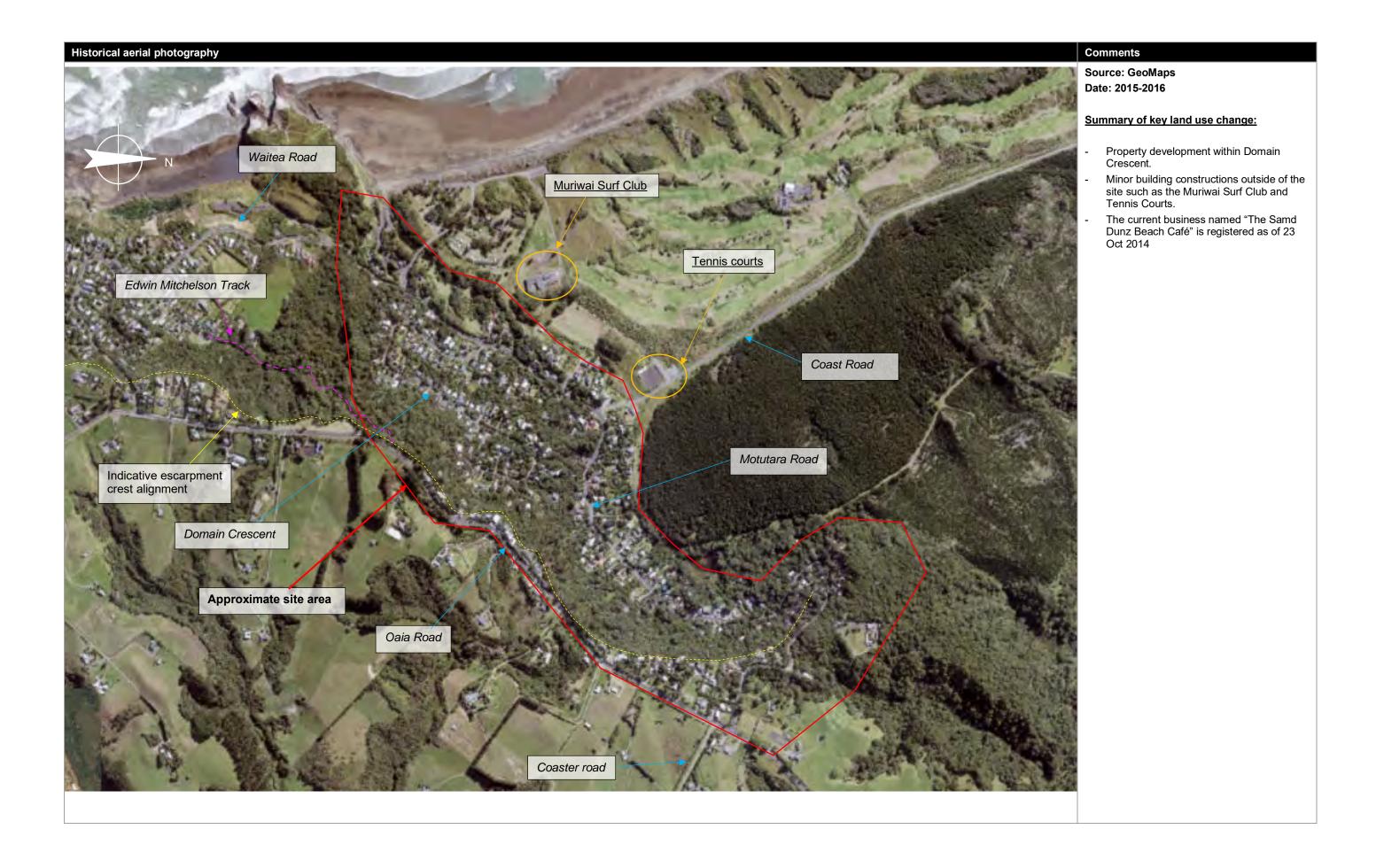
Source: Retrolens
Date: 02/01/2004
Original Scale: 1:49,000
Survey No #: SN3800

Run #: B

Photo Number #: 3

#### Summary of key land use change:

- The pine forest, west of Coast Road has been removed and the golf course has been constructed.
- Increased density of residential housing.





# Appendix B-2

Summary of anecdotal evidence

Information relating to the vicinity of Domain Crescent:

- Noted that individual slopes have not experienced any slope failure or topsoil slips, including from people who have been residents since 1975.
- A small landslip occurred in 2000 on the east side of 60 Domain Crescent. A retaining wall was subsequently constructed in 2006 as part of a dwelling construction.
- The southern area of Domain Crescent below the escarpment (approximate house numbers 51 to 65) was swampy in 1981. In the same area above the dwellings, slope debris has been observed, as have downhill-leaning trees.
- Following February 2023, water seepage has been observed from areas not previously known to have seeped, e.g. in cracks in paved surfaces.
- Numerous seepage points have been noted at the uppermost, eastern end of Domain Crescent on the slope below the escarpment (approximate house numbers 124 to 131). An array of open drains has been installed, most recently in 2018 by Auckland Council. Swampy, saturated ground was noted in areas that subsequently failed in February 2023.
- Reference has been made to the Park Rangers asking local people to clear drains on public land below the escarpment in the 1970s and 1980s.
- Open drains frequently blocked by leaf litter. Some were flowing prior to Cyclone Gabrielle.

Information relating to the vicinity of the escarpment at Oaia Road and north Motutara Road:

- Small, localised landslip below escarpment at north Motutara Road following a 2021 storm.
- Numerous springs within the escarpment at north Motutara Road.
- Some reports of water reticulation pipework directed over the top of the escarpment from Oaia Road properties towards Muriwai. In addition, blockages of public stormwater sumps with vegetation has been observed.
- Tree-fall from was observed from February 2023 storm damage. Some downhill-leaning trees have been observed.

Information relating to the vicinity below the escarpment at Motutara Road.

- In January a small slip was observed on the road below 112 Motutara Road and one further uphill in the bush
- Mature trees that lean downslope have been observed. Some of these have been felled by homeowners.
- Swampy ground observed at toe of slope on the eastern site of Motutara Road. Some small-scale slips have also been observed in this area.
- Surface water flow east of Motutura Road has been observed with increasing volume from January and February 2023. In some cases these discharge from below buildings and have entrained sediment.
- A spring was observed on the western (downhill) side of Motutara Road.
- In the late 1990s, a stream was observed from Domain Crescent through to 302 Motutara Road. This was later remediated by Auckland Council. A slip was observed on the side of Motutara Road.
- Blocked open drains have been observed. Residents sometimes clear these.
- Stormwater infrastructure was observed to be overwhelmed by February 2023 stormwater flows.
- Localised flooding observed in frequent occurrence (i.e. relatively small) storm events.

We conclude the following from the anecdotal evidence:

- Below the escarpment there are numerous springs and saturated, swampy areas.
- Surface water control has been necessary with open drains for a long period of time. In some cases these have not been maintained, or have been overwhelmed by storm flows, particularly in early 2023.
- There have been numerous indications of shallow slope instability, such as leaning trees or small-scale slips.
- There are no anecdotal reports of large landslides having affected the area between 1965 and 2023, in addition to the published events.

## Appendix B-3

**Summary of reviewed literature** 

Source/subject	Summary of key points relevant to this assessment					
Wright (1966). Engineering geological review of 1965 Muriwai landslides.	- A severe storm in August 1965 resulted in approximately 200 mm of rain and, two large landslides above Domain Crescent that caused destruction of a house and two fatalities.					
	- Anecdotal evidence suggests the landslide moved as a high velocity, saturated debris flow. Discussion and field observations suggest initial movement of an intact block before near-instantons break down to a liquefied debris flow.					
	- The depth of the slip plane was estimated between approximately 0.5 m and 2.0 m.					
	- Face-seepage of groundwater was observed at mid-slope along the landslide (extending for several days after) and concentrated along bedding plane outcrops with siltstone-sandstone. These may have contributed to the landslide.					
Interest NZ (2023)	- 1965 landslide above Domain Crescent in Muriwai					
Landslides and law: Cyclone Gabrielle raises serious questions about where we've been allowed to build						
Press (1965)	- 1965 landslide above Domain Crescent					
Mopping up After slips						
Rodney District Council (2005). Muriwai future planning document dealing with a wide range of considerations including environmental hazard.	- Addresses the implications of the built environment having a negative impact on ske stability natural hazard at Muriwai: removal of stabilising vegetation to support residential growth; addition of low permeability surfaces that increases run off and erosion; lack of reticulated wastewater system, increases ground saturation through septic-systems.					
	- Recommended most of the area below the escarpment and on the escarpment be avoided for construction of residential dwellings without prior geotechnical assessment.					
	- Outlines that the township in its current location is vulnerable to slope stability hazard.					
	- Notes the history of road-side failure/ drop-outs on Domain Crescent					
	<ul> <li>Notes multiple areas of surface stormwater ponding, which are primarily concentrated at the immediate base of the escarpment slope, overlain with residential properties built off Domain Crescent and Motutara Road</li> </ul>					
Hayward (2022). Summary of 1965 landslip event with focus on two Domain Crescent slips and additional	- Draws additional focus to the mechanism of the 1965 landslide failure; concludes it likely the result of both groundwater surface springs from geological unconformity (per Wright, 1965) but in addition, direct surface saturation near the headscarp from surface flows over-topping the Edwin Mitchelson Track.					
commentary to Wright, 1966.	<ul> <li>Notes that Rodney District Council stated no further development in the area destroyed (surrounding 51-53 Domain Crecent); however, notes that in present day, this has not been adhered too with multiple new dwellings.</li> </ul>					
Auckland Council (2023). Summary of measured and inferred rainfall accumulation at Muriwai during Cyclone Gabrielle. Reference reproduced in Appendix E.	- Outlines that rainfall in Muriwai was measured via direct rain gauge (tipping bucket 'TP08') however this failed at 1am 14 February due to flooding damage. In addition to this record, a Quantitative Precipitation Estimate was taken, which estimates rainfall intensity and accumulation from rainfall radar data.					

	<ul> <li>Data indicates over 130 mm of rain fell at Muriwai over a 12-hour period from 13-14 February. In total, over 180 mm was estimated to accumulate over the Cyclone Gabrielle event.</li> <li>The recorded figures above exceed the 100-year event return period for a 12-hour duration.</li> <li>The total rainfall that had been recorded over January (including Cyclone Hale) was approximately seven times the normal accumulated amount for this month in this location (490 mm recorded, compared with 70 mm for normal).</li> </ul>
Stuff (2013) Old memories revisited	- 2013 landslide above Domain Crescent in Muriwai
Auckland Star (1934) The deluge. Many floods. Traffic delay.	<ul> <li>1934 flooding observed of the creek close to Muriwai beach causing a relief workers' camp to flood</li> </ul>
Manawatu Standard (1926) Floods in the North. A record rainfall in Waitakere Ranges. Campers in peril at Muriwai	- 1926 flooding observed in Muriwai. A few buildings were flooded and displaced at Motutara Domain. The road approach the beach was washed away, and the campground became untenable.
Evening Star (1926) Record flood. Auckland cloud bursts eight inches of rain in a day.	
Wairarapa Daily Times (1926) Unseasonable weather. Floods in the North.	
Southland Times (1926) Auckland's rain phenomenal fall. The worst for fifty years.	
Christchurch Star (1926) The worst floods for fifty years do damage in North.	
Evening Post (1922) Heavy floods. Auckland trippers caught. [10]	- 1922 flooding cut off traffic access to Muriwai.
Manawatu Times. 29 Dec 1922. Heavy floods. Auckland trippers caught. [11]	

## Appendix B-4

Database of observed 2023 landslides

Geomorphology		Landslide	Coordinat	tes (NZTM)		Landslide Di	mensional Data		General Landslide	
Zone	Landslide ID	Mechanism, Type	Easting (m)	Northing (m)	Approx. Main Scarp Width (m)	Approx. Average Depletion Zone Depth (m)	Approx. Debris Runnout Length (m)	Approx. Local Slope Angle (Degrees)	Information	Photographs
Zone 2	M-LS01	Translational, Debris flow	1728500.19	5924036.28	36	0.5	142	38	Large landslide has damaged or destroyed multiple structures on multiple properties. A patch of insitu trees is visible.	M-LSO1  M-LSO2
	M-LS02	Translational, Debris flow	1728523.55	5923935.03	52	0.5	127	31	Large landslide has damaged or destroyed multiple structures on multiple properties. Landslide debris comprises Awhitu Sand. Patch of Insitu palm trees present within the centre of the landslide	

Geomorphology		Landslide	Coordinat	es (NZTM)		Landslide Di	mensional Data		General Landslide	
Zone	Landslide ID	Mechanism, Type	Easting (m)	Northing (m)	Approx. Main Scarp Width (m)	Approx. Average Depletion Zone Depth (m)	Approx. Debris Runnout Length (m)	Approx. Local Slope Angle (Degrees)	Information	Photographs
Zone 2	M-LS03	Translational, Debris flow	1728528.85	5923806.37	33	0.25	91	42	Large landslide above Watercare's water treatment plant on Motutara Road	M-LISO3
ZONE Z	M-LS04A	Translational, Debris flow	1728515.77	5923775.84	26	0.75	116	47	Large landslide with strip of intacted trees down the middle. Spring daylighting near the base of escarpment	M-LISO4A

Geomorphology		Landslide	Coordinat	es (NZTM)		Landslide Dii	mensional Data		General Landslide	Photographs	
Zone	Landslide ID	Mechanism, Type	Easting (m)	Northing (m)	Approx. Main Scarp Width (m)	Approx. Average Depletion Zone Depth (m)	Approx. Debris Runnout Length (m)	Approx. Local Slope Angle (Degrees)	Information	Photographs	
	M-LS04B	Translational, Debris flow	1728510.78	5923749.67	27	0.75	151	41	Large landslide with strip of intacted trees down the middle. Spring daylighting near the base of escarpment	M-LSO4B	
Zone 2								M-LS05 do	pes not exist. Next landlside is	M-LS06	
	M-LS06	Translational, Debris flow	1728361.87	5923509.18	15	0.25	120	27	Three distinct landslides. Spring located towards the base of the slope. A darker confining layer is present below the spring.	M-LS06	

Geomorphology	Geomorphology Landslide ID Machanism  Coordinates (NZTM)  Landslide Dimensional Data  General Landslide  General Landslide									
Zone	Landslide ID	Mechanism, Type	Easting (m)	Northing (m)	Approx. Main Scarp Width (m)	Approx. Average Depletion Zone Depth (m)	Approx. Debris Runnout Length (m)	Approx. Local Slope Angle (Degrees)	Information	Photographs
Zone 2	M-LS07	Translational, Debris flow	1728341	5923497.96	16	0.25	10	31	Three distinct landslides. Spring located towards the base of the slope. A darker	M-LSO7
Zone 2	M-LS08	Translational, Debris flow	1728314.83	5923503.88	27	0.25	108	40	confining layer is present below the spring.	M-LSGR

Geomorphology		Landslide	Coordina	tes (NZTM)		Landslide Di	mensional Data		General Landslide	
Zone	Landslide ID	Mechanism, Type	Easting (m)	Northing (m)	Approx. Main Scarp Width (m)	Approx. Average Depletion Zone Depth (m)	Approx. Debris Runnout Length (m)	Approx. Local Slope Angle (Degrees)	Information	Photographs
	M-LS09	Translational, Debris flow	1728261.56	5923470.24	77	0.75	154	31	Large landslide with amalgamated debris flow at base. Debris comprises Awhitu Sand and vegetation. No observed spring feature, however water was observed on the face of a darker confining layer close to the invert of the base of the slope.	
Zone 2								M-LS31 and M-l	LS32 do not exist. Next landsli	ide is M-LS33
	M-LS33	Translational, Debris flow	1728339.44	5923575.22	8	0.25	26	44	Smaller landslide occurred within dense vegetation, located near the base of the escarpment	

Geomorphology		Landslide	Coordinat	tes (NZTM)		Landslide Di	mensional Data		General Landslide	
Zone	Landslide ID	Mechanism, Type	Easting (m)	Northing (m)	Approx. Main Scarp Width (m)	Approx. Average Depletion Zone Depth (m)	Approx. Debris Runnout Length (m)	Approx. Local Slope Angle (Degrees)	Information	Photographs
Zone 2	M-LS34	Translational, Debris flow	1728294.58	5923514.47	19	0.25	63	48	A separate landslide downslope of the main escarpment. Two confining ridgelines form the headscarp.	M-LS34
	M-LS43	Translational, Debris flow	1728425.33	5923631.56	9	1	30	35	Smaller landslide occurred within dense vegetation, located near the base of the escarpment	大型上型之际的数字 1 15 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5

Geomorphology		Landslide	Coordinate	es (NZTM)		Landslide Di	mensional Data		General Landslide	
Zone	Landslide ID	Mechanism, Type	Easting (m)	Northing (m)	Approx. Main Scarp Width (m)	Approx. Average Depletion Zone Depth (m)	Approx. Debris Runnout Length (m)	Approx. Local Slope Angle (Degrees)	Information	Photographs
7.0.0 2	M-LS11	Translational, Debris flow	1728087.884	5923389.317	15	0.5	47	25	Landslide has occurred within the cut slope above the driveway.	M-LS11
Zone 3	M-LS12	Translational, Debris flow	1728130.018	5923292.121	8	0.5	89	38	A confining layer is present towards the base of the depletion zone with a small spring located above it. The landslide is located on the mid-slope of the escarpment	

Geomorphology		Landslide	Coordinat	tes (NZTM)		Landslide Di	mensional Data		General Landslide		
Zone	Landslide ID	Mechanism, Type	Easting (m)	Northing (m)	Approx. Main Scarp Width (m)	Approx. Average Depletion Zone Depth (m)	Approx. Debris Runnout Length (m)	Approx. Local Slope Angle (Degrees)	Information	Photographs	
Zone 3	M-LS13	Translational, Debris flow	1728038.624	5923223.157	9	0.5	58	28	Cross bedded Awhitu Sand visible in head scarp. Seepage originating from cross bedding is visible. Dark bluish grey clayey material observed 2 m below head scarp.	M-LS13	
	M-LS14	Translational, Debris flow	1728006.382	5923218.951	20	0.5	71	26	Landslide has occurred along a dark bluish grey silty / clayey material. Thickness of this unit in this location is approx. 8 m.		

Geomorphology		Landslide	Coordinate	es (NZTM)		Landslide Di	mensional Data		General Landslide	
Zone	Landslide ID	Mechanism, Type	Easting (m)	Northing (m)	Approx. Main Scarp Width (m)	Approx. Average Depletion Zone Depth (m)	Approx. Debris Runnout Length (m)	Approx. Local Slope Angle (Degrees)	Information	Photographs
Zone 3	M-LS15	Translational, Debris flow	1727964.793	5923202.596	15	0.5	47	43	Landslide is located on the mid-slope of the escarpment to the south of the dwelling at 131 Domain Crescent.	
Zone 3	M-LS16	Translational, Debris flow	1727985.431	5923129.154	19	1	45	27	Intact culvert protruding from the headscarp. Landslide located downslope of the Edwin Mitchelson Track cut (underslip). Middle of slip has been scoured by culvert outlet	

Geomorphology		Landslide	Coordinat	tes (NZTM)		Landslide Di	mensional Data		General Landslide	
Zone	Landslide ID	Mechanism, Type	Easting (m)	Northing (m)	Approx. Main Scarp Width (m)	Approx. Average Depletion Zone Depth (m)	Approx. Debris Runnout Length (m)	Approx. Local Slope Angle (Degrees)	Information	Photographs
	M-LS17	Translational, Debris flow	1727833.251	5923147.612	6	0.5	23	31	Landslide located within the vacant lot. Slip face observes a blocky texture indicating possible block failure manifesting as a debris flow.	
Zone 3	M-LS18A	Translational, Debris flow	1727924.372	5923021.288	13	0.25	18	55	Landslide has occurred within the upslope cut of the Edwin Mitchelson track (overslip). Track remains mostly intact with some debris on the track.	MALS13

Geomorphology		Landslide	Coordinat	tes (NZTM)		Landslide Di	mensional Data		General Landslide	
Zone	Landslide ID	Mechanism, Type	Easting (m)	Northing (m)	Approx. Main Scarp Width (m)	Approx. Average Depletion Zone Depth (m)	Approx. Debris Runnout Length (m)	Approx. Local Slope Angle (Degrees)	Information	Photographs
	M-LS18B	Translational, Debris flow	1727906.46	5923033.905	38	0.5	132	37	Landslide has occurred as ar underslip below the Edwin Mitchelson Track. along walking track.	
Zone 3	M-LS30	Translational, Debris flow	1728143.531	5923377.985	7	0.5	14	46	Small headscarp located behind dwelling at 114 Domain Crescent. Debris locally arrested by house.	M-LS3D

Geomorphology		Landslide	Coordinates (NZTM)		Landslide Dir	nensional Data		General Landslide		
Zone	Landslide ID	Mechanism, Type	Easting (m) Northing (m)	Approx. Main Scarp Width (m)	Approx. Average Depletion Zone Depth (m)	Approx. Debris Runnout Length (m)	Approx. Local Slope Angle (Degrees)	Information	Photographs	
	M-LS35	Translational, Debris flow	1727947.192 5923160.384		0.5	81	39	Inaccessible by foot - mapping was caried out using aerial photography.	MALES SERVICE AND ADMINISTRATION OF THE PROPERTY OF THE PROPER	
Zone 3							M-LS36 to M-	LS40 do no exist. Next landlside	is M-LS41	
	M-LS41	Translational, Debris flow	1727953.227 5923371.054	14	1	8	55	Landslide has occurred as a overslip within the road cut o Domain Crescent.		

Geomorphology		Landslide	Coordinat	es (NZTM)		Landslide Di	mensional Data		General Landslide		
Zone	Landslide ID	Mechanism, Type	Easting (m)	Northing (m)	Approx. Main Scarp Width (m)	Approx. Average Depletion Zone Depth (m)	Approx. Debris Runnout Length (m)	Approx. Local Slope Angle (Degrees)	Information	Photographs	
Zone 3	M-LS42	Translational, Debris flow	1727907.628	5923229.037	4	1	25	40	A landslide has occurred behind and upslope of the dwelling. The landslide has occurred on the slopes toward the lower base of the escarpment.		
Zone 4	M-LS19A	Translational, Debris flow	1727917.791	5922983.788	49	0.5	25	55	Landslide has occurred within the upslope cut of the Edwin Mitchelson track (overslip). Track remains mostly intact with some debris on the track.		

Geomorphology		Landslide	Coordinat	es (NZTM)		Landslide Di	mensional Data		General Landslide	
Zone	Landslide ID	Mechanism, Type	Easting (m)	Northing (m)	Approx. Main Scarp Width (m)	Approx. Average Depletion Zone Depth (m)	Approx. Debris Runnout Length (m)	Approx. Local Slope Angle (Degrees)	Information	Photographs
Zono 4	M-LS19B	Translational, Debris flow	1727875.58	5922999.209	38	0.25	115	27	Landslide has occurred as ar underslip adjacent to the Edwin Mitchelson track cut. Seepage observed above limonite layers	
Zone 4	M-LS20A	Translational, Debris flow	1727848.788	5922938.305	46	0.5	13	55	Landslide has occurred within the upslope cut of the Edwin Mitchelson track (overslip). Track remains mostly intact with some debris on the track.	M-LS20

Geomorphology		Landslide	Coordinat	es (NZTM)		Landslide Di	mensional Data		General Landslide	
Zone	Landslide ID	Mechanism, Type	Easting (m)	Northing (m)	Approx. Main Scarp Width (m)	Approx. Average Depletion Zone Depth (m)	Approx. Debris Runnout Length (m)	Approx. Local Slope Angle (Degrees)	Information	Photographs
7000 4	M-LS208 Translational. Debris flow Translational. Debris flow 2012 692964.941 96 0.75 137 42 Landslide has occurred as an undersity adjacent to the	M-LS20								
Zone 4	M-LS21	Translational, Debris flow	1727721.219	5922970.237	18	0.25	57	40	Landslide has occured within the slopes behine the dwelling. Relatively shallow failure of residual soil with some of the underlying intac blocks of cemented sand. Approx. 1m thick. Debris very close to slope base, arrested by house on property 47. scarp exposes a 2 m thick bed of white siltys and, with slight NW dip.	M-LS21

Geomorphology		Landslide	Coordinat	es (NZTM)		Landslide Di	mensional Data		General Landslide	
Zone	Landslide ID	Mechanism, Type	Easting (m)	Northing (m)	Approx. Main Scarp Width (m)	Approx. Average Depletion Zone Depth (m)	Approx. Debris Runnout Length (m)	Approx. Local Slope Angle (Degrees)	Information	Photographs
Zone 4	M-LS22	Translational, Debris flow	1727698.555	5923022.184	23	0.25	17	53	Landslide has occurred as an overslip within the road cut for Domain Crescent. Relatively shallow <1m depth. Visible cross bedding in 10 cm horizons. finer grained/massive texture.	
Zone 5	M-LS23	Zone 4	1727675.035	5922958.321	40	0.5	30	49	Landslide has occurred within the slopes behind the dwelling. Headscarp is located along the confining local ridgeline	

Geomorphology		Landslide	Coordinat	tes (NZTM)		Landslide Di	mensional Data		General Landslide		
Zone	Landslide ID	Mechanism, Type	Easting (m)	Northing (m)	Approx. Main Scarp Width (m)	Approx. Average Depletion Zone Depth (m)	Approx. Debris Runnout Length (m)	Approx. Local Slope Angle (Degrees)	Information	Photographs	
Zone 5	M-LS24	Translational, Debris flow	1727573.789	5922959.879	12	0.25	39	32	Landslide within Awhitu Sand has displaced minimal soil and mostly comprises vegetation. Significant scour observed within the escarpment.		
	M-LS25	Translational, Debris flow	1727554.474	5922953.181	8	0.25	42	31	Landslide was not physically accessible, as such was mapped using aerial photography and lidar.	MALS25	

Geomorphology		Landslide	Coordinate	es (NZTM)		Landslide Di	mensional Data		General Landslide	
Zone	Landslide ID	Mechanism, Type	Easting (m)	Northing (m)	Approx. Main Scarp Width (m)	Approx. Average Depletion Zone Depth (m)	Approx. Debris Runnout Length (m)	Approx. Local Slope Angle (Degrees)	Information	Photographs
Zone 5	M-LS26	Translational, Debris flow	1727561.406	5923078.92	8	0.51	9	39		MES28
Zone 6	M-LS10	Translational, Debris flow	1728207.043	5923480.828	19	0.25	52	37	Groundwater seeping out of escarpment in multiple locations. Less cemented sand present for most of slip The landslide has manifested as a debris flow and impacted the dwelling at 23 & 230 Motutara Road	ip. ed

Geomorphology		Landslide	Coordinat	tes (NZTM)		Landslide Di	mensional Data		General Landslide	
Zone	Landslide ID	Mechanism, Type	Easting (m)	Northing (m)	Approx. Main Scarp Width (m)	Approx. Average Depletion Zone Depth (m)	Approx. Debris Runnout Length (m)	Approx. Local Slope Angle (Degrees)	Information	Photographs
Zone 6	M-LS27	Translational, Debris flow	1728026.436	5923507.502	19	0.25	35	26	White silty fine white sand exposed. An open watercourse is present at the base of the gully	
Zone 6	M-LS28	Translational, Debris flow	1727970.984	5923538.966	11	0.5	20		Landslide has occurred off a spur off the main escarpment	

## Appendix B-5

Survey data used for GHD analysis and plans

The survey data used by GHD for data presentation and modelling used the following datasets:

- 2016 LiDAR elevation model (Muriwai\_dtm\_2016)
  - Source: Auckland Council
  - Point cloud accuracy is vertical <= 0.10 m RMS and horizontal <= 0.30 m RMS</li>
- 2016-2018 LINZ DEM (Auckland North LiDAR 1 m DEM)
  - o Source: Auckland North LiDAR 1m DEM (2016-2018) | LINZ Data Service 4
  - Vertical Accuracy Specification is +/- 0.2m (95%), Horizontal Accuracy Specification is +/- 0.6m (95%).
- 2023 Muriwai elevation model (Muriwai dtm 20230304 calibrated internal).
  - o Source: Auckland Council
  - Metadata: <u>Specified Auckland Areas Post Cyclone LiDAR Point Cloud | Auckland Council</u>
     <u>Open Data (arcgis.com)</u><sup>5</sup>

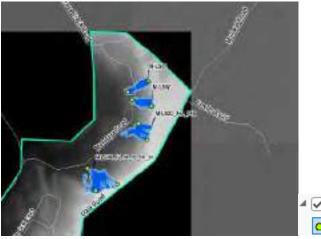
The 2023 Muriwai DTM does not state the vertical datum in the metadata. However, AC have advised the DEM was in NZVD2016 vertical datum.

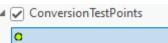
The 2016 elevation DTM did not have a vertical datum attributed, however the AAM metadata for the 2016-2017 Auckland Council LiDAR data collection mentioned that all products are supplied in Auckland 1946 vertical datum and point cloud products are also supplied in NZVD2016 vertical datum.

As the 2023 elevation data was stated as being in NZVD 2016 and the Auckland DEM from LINZ has metadata stating it to be in NZVD2016 the 2016 DEM from LINZ was selected for raster calculations.

A sample set of 9 points across the landslide areas was created to cross check for differences in elevation. It was noted across this sample set that the Muriwai\_dtm\_2016 was showing elevation values that were consistently 0.29 m (2 dp) greater than the elevation value off the LINZ DEM confirming that it was in Auckland 1946.

A further check of the 9 sample points by using the LINZ online converter (New Zealand Vertical Datum Conversions (Iinz.govt.nz)) to convert the Muriwai\_dtm\_2016 elevation values at those sample points to NZVD 2016 using the online converter and comparing them to the values in the LINZ DEM. The average difference was 0.001 (3 dp). This indicated that substituting the LINZ DEM in lieu of converting the Muriwai\_dtm\_2016 was not going to result in any elevation differences that was likely to affect our interpretations of raster calculations. Also noting this calculated average difference was much smaller than the vertical accuracies stated for the LINZ DEM (+/-0.2m) and Muriwai dtm 2016 (<=0.1 m).





<sup>&</sup>lt;sup>4</sup> Auckland North LiDAR 1m DEM (2016-2018) | LINZ Data Service

<sup>&</sup>lt;sup>5</sup> Specified Auckland Areas Post Cyclone LiDAR Point Cloud | Auckland Council Open Data (arcgis.com)



→ The Power of Commitment

# Appendix C Slope Stability Report

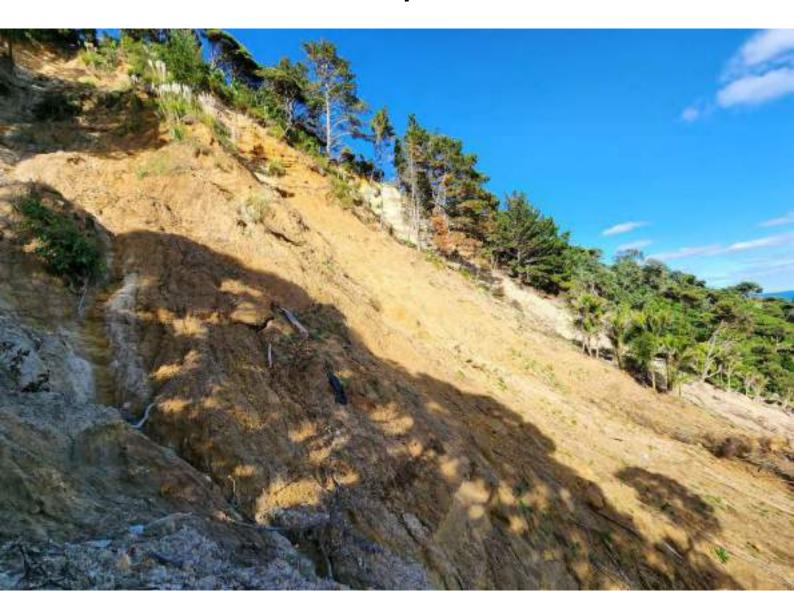


# Waitakere Coastal Communities Landslide Risk Assessment

Appendix C – Muriwai Slope Stability Assessment Report

Auckland Council 30 April 2024

→ The Power of Commitment



Project na	ame	AC Geo Panel - Wa	aitakere Coastal	Communities LHF	RA								
Documen	t title	Waitakere Coastal Communities Landslide Risk Assessment   Appendix C – Muriwai Slope Stability Assessment Report											
Project n	umber	12612462	12612462										
File name	;	12612462_Appendix C SlopeStability_FINALRev1.docx											
Status	Revision	Author	Reviewer		Approved for	issue							
Code			Name	Signature	Name	Signature	Date						
S4	0	T Khansari	D Macfarlane	Mujorten	Roy Pearson	Roy Prarson	30/04/2024						
[Status code]													
[Status code]													
[Status code]													
[Status code]													

#### **GHD Limited**

Contact: Matt Howard, Technical Director - Engineering Geologist | GHD

27 Napier Street, GHD Centre Level 3

Freemans Bay, Auckland 1010, New Zealand

T +64 9 370 8000 | F +64 9 370 8001 | E aklmail@ghd.com | ghd.com

#### © GHD 2024

This document is and shall remain the property of GHD. The document may only be used for the purpose for which it was commissioned and in accordance with the Terms of Engagement for the commission. Unauthorised use of this document in any form whatsoever is prohibited.

### **Contents**

C1.	Introd	uction	1
	C1.1	Purpose of this Report	1
	C1.2	Scope	2
C2.	Repor	t Structure	3
C3.	Geote	chnical Information	4
	C3.1	Representative Cross Section	4
	C3.2	Ground Model	5
C4.	Analys	sis	7
	C4.1	Introduction	7
	C4.2	Back Analysis and Pore Pressure Sensitivity Assessments	7
	C4.3	Seismic Analysis	8
C5.	Exami	nation of Remediation Options	9
	C5.1	Purpose of Options Assessment	ç
	C5.2	Proposed Remedial Measures	S
	C5.3	Options Examined - Discussion	g
		C5.3.1 Soil nails	11
	C5.4	C5.3.2 Benched profile  Mitigation Cost Consideration and Cost Indication	11 13
CC	Limita	•	
C6.			14
C7.	Refere	ences	15
Tal	ole in	dex	
	e C-1	Summary of accompanying Muriwai landslide risk assessment reports	3
	e C-2	Slope stability sensitivity analysis by modification of Ru for $\Phi$ ' = 39 degrees and c' of 21 kPa	7
	e C-3	Geotechnical parameters	8
Tabl	e C-4	Peak ground acceleration (PGA) derivation parameters for slope stability seismic	c
Tabl	e C-5	case Soil nail option – materials, quantities and spacings proposed	2 11
	e C-6	Remedial option construction consideration comparison (more X symbols equals	• 1
		less desirable)	13

#### Figure index

Figure C-1	Muriwai location showing the February 2023 landslides mapped by GHD (blue lines)	2
Figure C-2	Assessment area plan indicating the major February 2023 slip areas and the analysed cross-section A-A (retrieved from Google Earth Pro and GHD Atlas). A close-up view of Figure A125 (see Appendix A) showing the analysed cross section 'A' relative to other slope profiles, cross sections and boreholes.	4
Figure C-3	Indicative comparison of cross section slope profiles at February 2023 landslide sites. The slope profiles at the upper slope have a similar geometry. The thick orange line is the analysed profile.	5
Figure C-4	Simplified ground model used for the analyses	6
Figure C-5	Example of typical small, roped access rig used to install anchors or nails on	
_	steep slopes.	9
Figure C-6	Example of surface erosion prevention matting and mesh for use with soil nails	
	on relatively steep slopes.	10
Figure C-7	Soil nail option	11
Figure C-8	Illustration of benching option	12

Appendices - Slope stability analysis output figures

#### C1. Introduction

#### C1.1 Purpose of this Report

GHD has been engaged by Auckland Council (AC)¹ to carry out landslide risk assessments as well as to provide associated landslide risk management advice and geotechnical investigations in the Waitakere area, specifically for the residential areas of Muriwai, Piha and Karekare.

The purpose of this report is to present a slope stability and back analysis assessment of one of the large, failed slopes at the escarpment to the east of Muriwai township. The objective of the analyses was to estimate rock or soil strength parameters that could be used to inform conceptual remediation options to demonstrate the engineering measures required to stabilise the escarpment.

A two-dimensional Limit Equilibrium Analysis was carried out to estimate material parameters applicable to the failed zone. The analysis has also assessed the influence of changing pore pressure levels. The seismic performance of the slopes was also assessed, considering factors such as design life, site soil class, peak ground acceleration, and compliance with the NZ Building Code. We have considered commonly acceptable mitigation approaches and provided rough cost estimates for implementing the options investigated.

Figure C-1 shows the site location and the mapped landslides in the area.

<sup>&</sup>lt;sup>1</sup> Under Contract CW198379, Master Services Agreement CCCS: CW74240 dated 7/09/2019

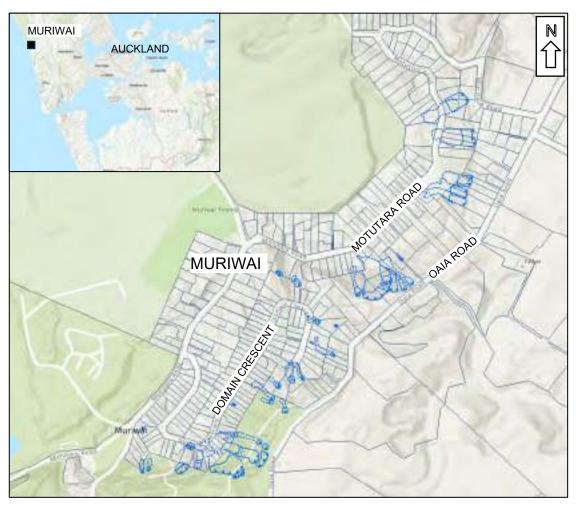


Figure C-1 Muriwai location showing the February 2023 landslides mapped by GHD (blue lines)

#### C1.2 Scope

The following scope of works has been undertaken:

- Conduct back analyses using Slope/W on recently failed slopes in Muriwai to derive material parameters for the assessment of remedial options.
- Quantify the sectional area of landslides by overlaying pre- and post-failure ground profiles.
- Perform a sensitivity analysis on moisture levels within the slope to assess their impact on slope stability, comparing with rainfall data.
- Explore mitigation options for the escarpment below Oaia Road based on the stability analysis results, targeting a Factor of Safety of 1.5 or greater for static analyses and a target Factor of Safety of unity for Damage Control Limit State seismic cases.
- Assess the seismic performance by determining the Importance Level, assigning Site Soil Class, deriving a
  Peak Ground Acceleration, and ensuring compliance with the NZ Building Code.
- Consider the NZ National Seismic Hazard Model for updated guidance.
- Exclude simultaneous occurrence of extreme weather events and large earthquakes. The coinciding of two such low probability events is not required by design codes.
- Examine a flatter benched profile and soil nailing with inclined drains as remedial options.
- Provide hand sketches and cost estimates for the proposed mitigation options.

This technical memorandum has been prepared by GHD for Auckland Council. This memo should be read in conjunction with all other GHD design documentation for the project.

### **C2.** Report Structure

The accompanying GHD Engineering Geology report provides a detailed description of the site as well as discussion of site geology and geomorphology, historical landsliding, landslide mapping, landslide classification and slope processes. The reader is advised to consult the accompanying GHD reports for further information not contained herein.

Table C-1 presents a summary of the figures referred to in this report (see Appendix A of the overall report).

Table C-1 Summary of accompanying Muriwai landslide risk assessment reports

Report Section	Description
Overall Report	Waitakere Coastal Communities Landslide Risk Assessment (Muriwai)
Appendix A	Figures
Appendix B	Engineering Geological Report
Appendix C	Slope Stability Assessment Report (this report)
Appendix D	RAMMS debris flow analysis
Appendix E	Landslide Risk Assessment
Appendix F	Geotechnical Investigations Report
Appendix G	Geotechnical Laboratory Testing Report

#### C3. Geotechnical Information

#### **C3.1** Representative Cross Section

The cross section shown in Figure C-2 was selected for assessment purposes as being a conservative (i.e. steep) example of the range of failure geometries. The cross-section extends for approximately 260 m horizontally approximately 100 m vertically. A comparison of landslide cross section profiles is presented in Figure C-3.

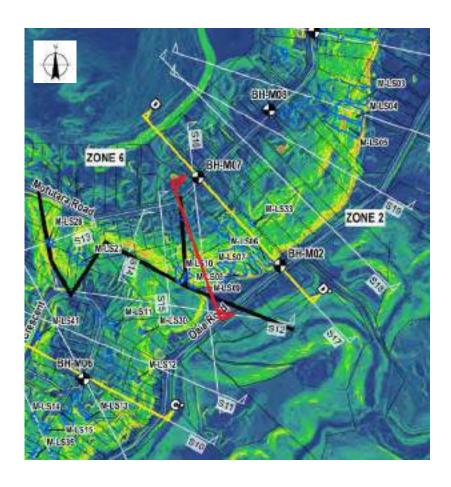


Figure C-2 Assessment area plan indicating the major February 2023 slip areas and the analysed cross-section A-A (retrieved from Google Earth Pro and GHD Atlas). A close-up view of Figure A125 (see Appendix A) showing the analysed cross section 'A' relative to other slope profiles, cross sections and boreholes.

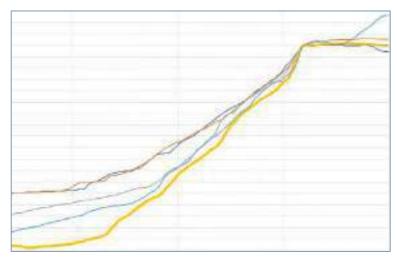


Figure C-3 Indicative comparison of cross section slope profiles at February 2023 landslide sites. The slope profiles at the upper slope have a similar geometry. The thick orange line is the analysed profile.

#### C3.2 Ground Model

This analysis preceded detailed site mapping and subsurface investigations by GHD (see Appendix B of the GHD landslide risk assessment). Based on initial site observations and the published literature, we have modelled the slope as Awhitu Group comprising the following:

- Weakly cemented sand (sandstone) with localised silt/clay. This comprises the upper three-quarters of the slope profile. This area was the initiation point of the landslides.
- A lower, relatively stronger sandstone. Field observations indicate that the lower slope was relatively stable.

This is consistent with the companion Engineering Geological report (Appendix B) and the 1:250,000 published geological map (Edbrooke 2001).

For the purposes of our analysis, we have made a nominal subdivision with weaker sandstone overlying a higher strength sandstone.

We employed Ru values to model varying degrees of saturation as an alternative to groundwater level, which was unknown at the time of landsliding in February 2023.

The ground model is shown in Figure C-4.

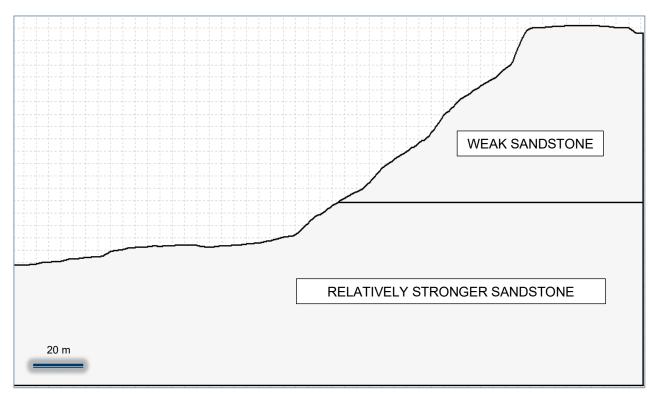


Figure C-4 Simplified ground model used for the analyses

## C4. Analysis

#### C4.1 Introduction

The February 2023 landslides occurred during heavy rainfall that caused elevated, destabilising pore-water pressures. The failure surface is characterised by its shallow depth, yet it spans a significant horizontal distance and reaches high elevations, as shown in the Appendix.

Slope stability analyses were carried out using Slope W version 2021.3 (a GeoStudio Package). As part of the back analyses and feasibility assessments, we examined circular, non-circular, shallow, and irregular user-defined slip surfaces. We also employed Ru values to model varying degrees of saturation. The Morgenstern-Price method was chosen as it is suitable for analysing slope stability problems with these features.

## C4.2 Back Analysis and Pore Pressure Sensitivity Assessments

The methodology adopted for the back analysis was as follows:

- 1. The slip to be examined was assumed to have occurred solely within the upper, weaker Kahu Sand weakly cemented sandstone.
- 2. A single set of c-phi effective stress parameters was assumed to be applicable.
- 3. No foliation or structural anisotropy was considered applicable.
- 4. As the failure occurred following heavy rain, we varied Ru within the slope stability model from what is considered to be a "steady state / typical long term" value of 0.125 to relatively highly saturated values of 0.25 to 0.35. We assumed these latter values to be representative of pore pressure levels that may exist after a period of prolonged and heavy rain.
- 5. In order to derive the geotechnical parameters, we fixed the phi value at 39 degrees. This is considered to represent an upper bound value that may be assigned to a naturally occurring granular material.
- 6. With the phi value fixed, the effective cohesion was varied until Factors of Safety were derived indicating a progression from marginal stability to "failure" as the Ru value was increased.

Table C-2 shows the results of the sensitivity analysis as Ru was increased. It will be seen that at an Ru value of 0.3, failure of the slope effectively occurs. This is an indication that the parameters utilised are providing reasonable agreement with observed behaviour.

Table C-2 Slope stability sensitivity analysis by modification of Ru for  $\Phi$ ' = 39 degrees and c' of 21 kPa

Ru adopted	FoS derived
0.125	1.24
0.150	1.20
0.200	1.12
0.250	1.03
0.300	0.95 (slope failure)
0.350	0.87

Table C-3 confirms the parameters derived for the Awhitu Sand from the back analysis. These are considered acceptable for a cemented sand. They align well with the ranges provided in publications (e.g., Collins & Sitar 2009). These then, were the geotechnical parameters carried forward to the analyses examining remedial works. Results from the back analyses are included in Appendix C1.

Table C-3 Geotechnical parameters

Material description	Unit weight (kN/m³)	Effective cohesion c' (kPa)	Angle of internal friction Φ' (°)
Weak sandstone	18	21	39

## C4.3 Seismic Analysis

The seismic demand was derived in accordance with the New Zealand Bridge Manual (2022). The peak ground acceleration (PGA) for slope stability analysis was determined using the equation below:

$$PGA = C_{0,1000} \frac{R_u}{1.3} fg$$

NZTA Bridge Manual (2022), Section 6.2.2

Where the coefficients are provided in Table C-4 and g is 9.81 m/s2.

Table C-4 Peak ground acceleration (PGA) derivation parameters for slope stability seismic case

Parameter / Variable	Value	Source
Design life	50 years	Client-specified
Importance Level (IL)	3	NZS1170.0:2002, Table 3.2.
Annual probability of exceedance for the ultimate limit state for earthquake actions (DCLS)	1/1000	NZTA Bridge Manual, Table 2.3
Subsoil class	Likely D as the sand is ~100 m deep. Intrusive site investigation is being employed to help with ground profiling.	NZS1170.5:2004, Clause 3.1.3.2 - 3.1.3.6
1000-year return period PGA coefficient (C0,1000)	0.19	NZTA Bridge Manual, Table C6.1
Return Period Factor (Ru)	1.3	NZS1170.5:2004, Table 3.5
Site subsoil class factor (f)	1.0	NZTA Bridge Manual, Clause 6.2.2

Based on the above, the PGA is determined to be 0.19 g, which aligns with the PGA values for the ULS case in Auckland for a range of return periods of 500 to 2500 years given in Appendix A of Module 1 (MBIE, November 2021).

## C5. Examination of Remediation Options

## **C5.1** Purpose of Options Assessment

The purpose of conceptual remedial measures is to provide the indicative effort required to inform discussion of whether mitigating debris flow would be practical. It is intended to provide information on two options that may be used to increase slope stability. Other engineering options are available, but exploring these is outside the scope of our work.

## **C5.2** Proposed Remedial Measures

Two potential remediation options have been examined. These are:

- a) Strengthening the slope by using soil nails and inclined drains
- b) Excavating the slope to a flatter, more stable, benched profile that satisfies New Zealand code-based stability criteria.

Details of the work carried out to examine their feasibility follows.

## **C5.3 Options Examined - Discussion**

#### C5.3.1 Soil nails

The following design elements have been considered:

- No shotcrete facing.
- Installation of drains to reduce the pore water pressure within the slope.
- Nails to be installed by roped access method involving small, portable rigs similar to that shown in Figure C-5.
- Surface erosion prevention matting is installed to prevent loss of material at the surface from the space between the nails (see Figure C-6).



Figure C-5 Example of typical small, roped access rig used to install anchors or nails on steep slopes.



Figure C-6 Example of surface erosion prevention matting and mesh for use with soil nails on relatively steep slopes.

Soil nail feasibility calculations were carried out in accordance with the following guidance document:

• FHWA. Geotechnical Engineering Circular No. 7 - Soil Nail Walls. 2015 (FHWA-NHI-14-007)

The recommended minimum Factors of Safety for "Overall Stability" for this option requires the following Factor of Safety:

- For Static Loading = 1.5
- For Seismic Loading = 1.1

The soil nail array derived satisfying the above criteria is shown in the Figure C-7 below. To facilitate initial pricing of the option, details of the key materials, quantities and spacings proposed are shown in the Table C-5.

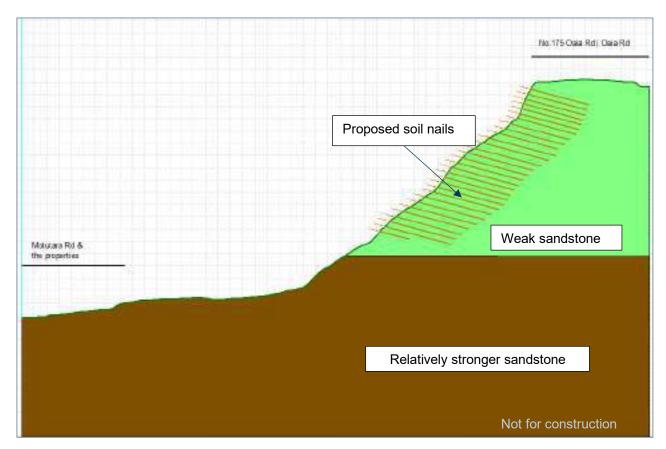


Figure C-7 Soil nail option

Table C-5 Soil nail option – materials, quantities and spacings proposed

Soil nail length (m)	Number of nail rows	Grid (m x m)	Steel bar diameter (mm)	Grade (MPa)	Bond diameter (mm)
28	30	2.0 x 2.0	25	500	120

Construction of the soil nailed option would need to include, but not be limited to, the following processes:

- Obtaining of any necessary easements if the nails were to extend over private property boundaries
- Vegetation removal and/or trimming as required
- Clearing the slope face of any debris or loose material
- Installation of the soil nails via the roped access method chosen
- Installing inclined drains to alleviate the soil pore pressure

## C5.3.2 Benched profile

The solution examined has assumed the use of benches nominally 5 m high, each with a horizontal platform of approximately 4 m width. It is assumed that the face of each bench will be sloped back at 2 vertical to 1 horizontal. Although not an essential requirement of the design, inclined drains may also be employed with this option to increase stability.

Conventional, relatively large plant could be used to construct this option employing a "top-down" methodology. For safety reasons, the plant used would be set back at a suitably safe distance from the edge of the slope edge as the works progress downwards.

The option derived involves cutting the crest of the slope back by a horizontal distance of 20 m.

The volume of material to be removed under this option would be approximately 320 m3 per linear metre of remediated slip. The benching layout is shown in Figure C-8.

The stability calculations for this option were carried in accordance with the NZTA Bridge Manual (2022), which also satisfies the Auckland Code of Practice for Land Development and Subdivision (2023) requirements.

The recommended minimum Factors of Safety for "Overall Stability" for this option requires the following Factor of Safety:

- For Static Loading = 1.5
- For Seismic Loading = 1.0

Analysis results are included in Appendix C3.

#### Note on displacement-based acceptance criteria:

For seismic analyses, the NZTA Bridge Manual allows for displacement-based acceptance criteria for infrastructure such as filled embankments and other earthworks. For the landslip examined, and in particular the benching option, we considered that displacement-based acceptance criteria would not be suitable. This is because, unlike an embankment constructed from engineered granular material, there is more uncertainty regarding the geology and behaviour in a slope cut in natural materials. If such an approach were allowed, there could be a risk that movements lead to crest tension cracks which could then fill with water and unacceptably compromise stability. Given the consequences of a significant failure of such a high cut face in proximity to residential areas, it was decided that a displacement-based approach was not acceptable for the seismic cases for this project. For these reasons, a factor of safety of unity was targeted for the DCLS seismic case.

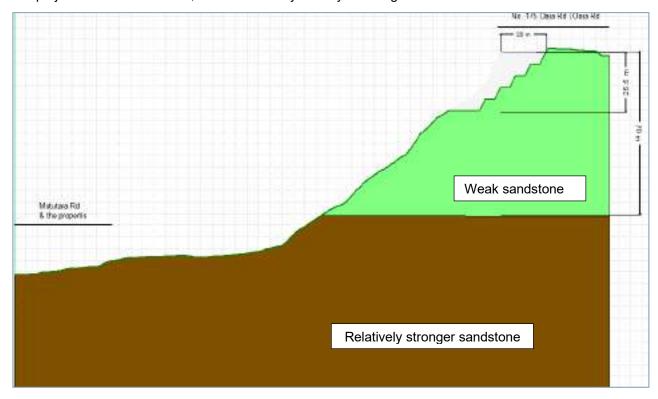


Figure C-8 Illustration of benching option

Construction of the benching option would need to include, but not be limited to, the following processes:

- Obtain any necessary easements if the benches were to extend over private property boundaries
- Preparation of a stable platform for plant
- Vegetation removal and/or trimming as required
- Apply erosion protection measures
- Consider suitable drainage system
- Top-down excavation processes

## **C5.4** Mitigation Cost Consideration and Cost Indication

Construction considerations of the two remedial options are included in Table C-6 to highlight the challenges with both options.

Costs associated with remediation is not possible without a more advanced design, paired with a detailed methodology. No consideration has been given to legal or consenting costs of either option.

We propose the following nominal order of magnitude constructed costs for either option:

- Several hundred thousand dollars per lineal metre of remediated slope.
- Millions of dollars to repair damage to existing February 2023 slips.
- Tens of millions of dollars to include the slope that did not experience landslide.

Table C-6 Remedial option construction consideration comparison (more X symbols equals less desirable)

Construction Consideration	Soil Nails		Benched Profile	
Site access (considers plant size and truck movements)	XX	Smaller plant	XXXXX	Large trucks. Damage to local roads from heavy truck movement.
Duration (machinery efficiency)	XXXXX	Smaller plant and hand work	XXX	Large machinery
Machinery size	X	Small rigs	XXXXX	Large trucks
Environmental (dust and erosion)	Х	Drilling dust	xxxxx	Large exposed area
Environmental (noise)	XXXX	Loud drilling	XXXX	Loud large machinery
Safety risk to contractors	XXX	Many hours working at height on abseil	XXX	Fall from slope edge
Earthworks soil disposal	Х	No disposal	XXXXX	Off site disposal
Change to existing slope profile	X	Strengthens in situ slope	xxxxx	Requires removal of slope, including buildings and infrastructure to the east of Muriwai. Requires bespoke stormwater design and infrastructure.
Post construction maintenance	XXXXX	Regular and expensive maintenance	XX	Minor earthworks and ongoing control of stormwater

## C6. Limitations

This report has been prepared by GHD Limited (GHD) for Auckland Council and may only be used and relied on by Auckland Council for the purpose agreed between GHD and Auckland Council as set out in Section 1 of this report.

GHD otherwise disclaims responsibility to any person other than Auckland Council arising in connection with this report. GHD also excludes implied warranties and conditions, to the extent legally permissible.

The services undertaken by GHD in connection with preparing this report were limited to those specifically detailed in the report and are subject to the scope limitations set out in the report.

The opinions, conclusions and any recommendations in this report are based on conditions encountered and information reviewed at the date of preparation of the report. GHD has no responsibility or obligation to update this report to account for events or changes occurring subsequent to the date that the report was prepared.

The opinions, conclusions and any recommendations in this report are based on assumptions made by GHD described in this report (refer Section 1 of this report). GHD disclaims liability arising from any of the assumptions being incorrect.

GHD does not accept responsibility arising from, or in connection with, varied conditions and any change in conditions. GHD is also not responsible for updating this report if the conditions change.

An understanding of the geotechnical site conditions depends on the integration of many pieces of information, some regional, some site specific, some structure specific and some experienced based. Hence this report should not be altered, amended, abbreviated, or issued in part in any way without prior written approval by GHD. GHD does not accept liability in connection with the issuing of an unapproved or modified version of this report.

Verification of the geotechnical assumptions and/or model is an integral part of the design process - investigation, construction verification, and performance monitoring. If the revealed ground or groundwater conditions vary from those assumed or described in this report the matter should be referred back to GHD.

## C7. References

- Edbrooke, S.W. (compiler), 2001. Geology of the Auckland Area. Institute of Geological and Nuclear Sciences
   1:250,000 Geological Map 3. Institute of Geological and Nuclear Sciences Ltd, Lower Hutt.
- New Zealand Transport Agency (NZTA), Bridge Manual (SP/M/022) (Third edition, Amendment 4).
- Collins, B. D., & Sitar, N. (2009). Geotechnical properties of cemented sands in steep slopes. *Journal of geotechnical and geoenvironmental engineering*, 135(10), 1359-1366.
- Federal Highway Administration (FHWA), (2015). Soil nail walls reference manual (FHWA-NHI-14-007).
   Washington, DC: FHWA.
- Auckland Council (2023). The Auckland Code of Practice for Lad Development and Subdivision (Version 2.0) (Chapter 2).
- MBIE and NZGS (2021). "Geotechnical Earthquake Engineering Practice: Module 1 Overview of the Guidelines". Ministry of Business, Innovation and Employment (MBIE) and New Zealand Geotechnical Society (NZGS).

# Appendix Slope stability analysis output figures

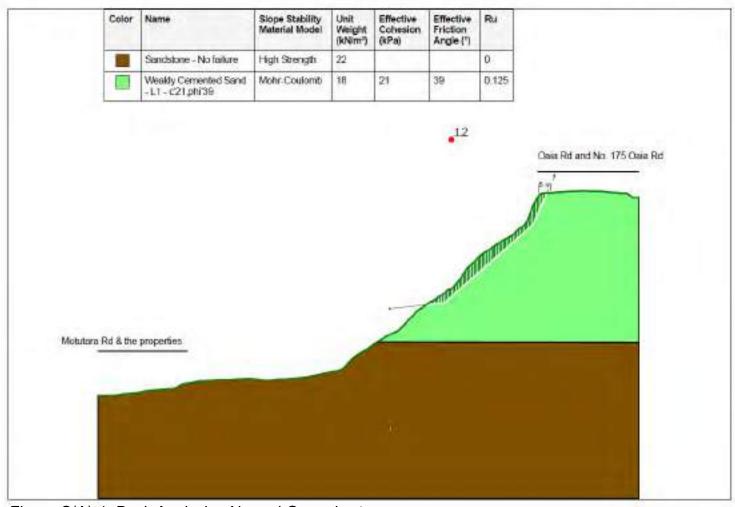


Figure C(A)-1. Back Analysis - Normal Groundwater

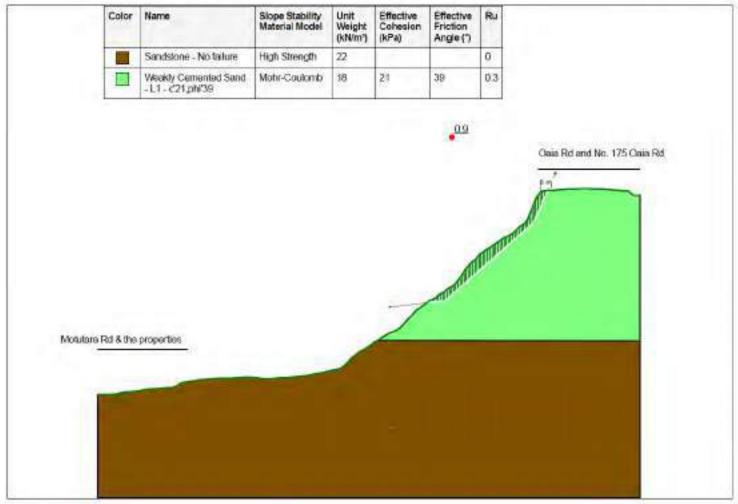


Figure C(A)-2. Back Analysis - Extreme Groundwater

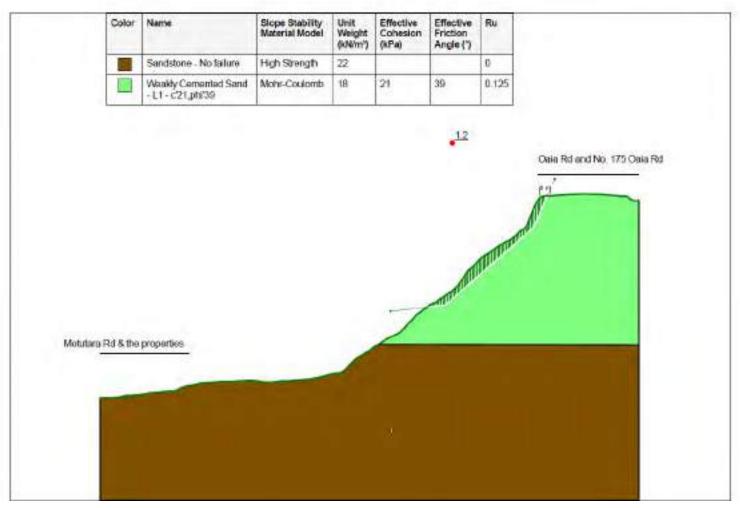


Figure C(A)-3. Nail Option - Normal Groundwater

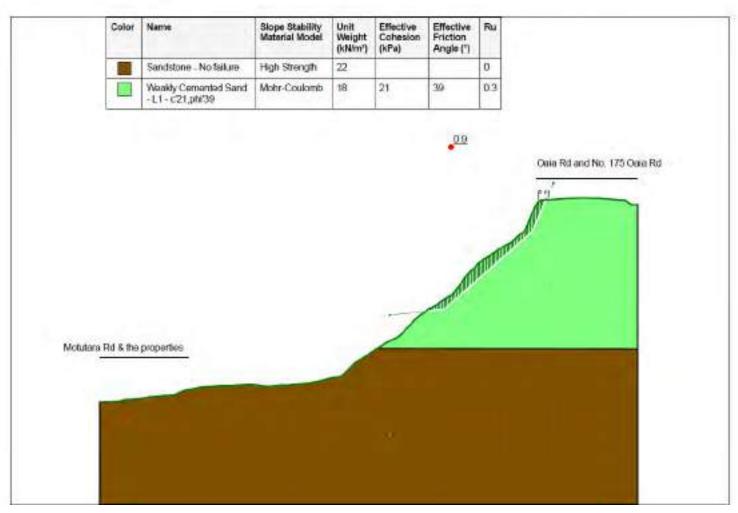


Figure C(A)-4. Nail Option - Extreme Groundwater

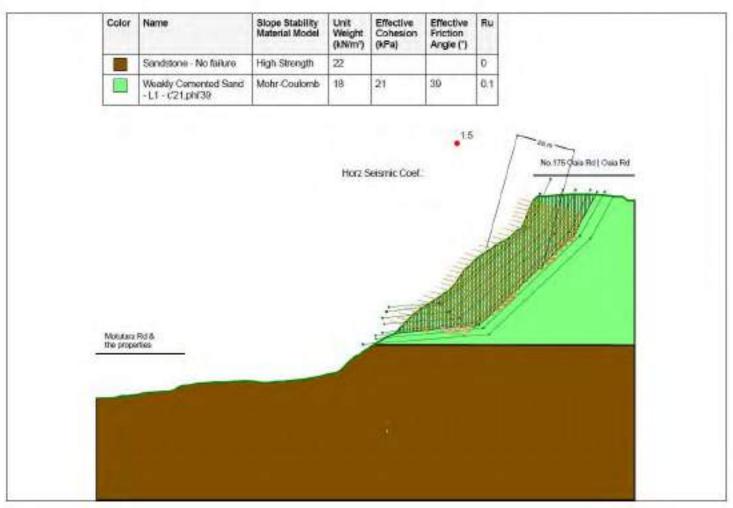


Figure C(A)-5. Nail Option - Nail Length (Static Case)

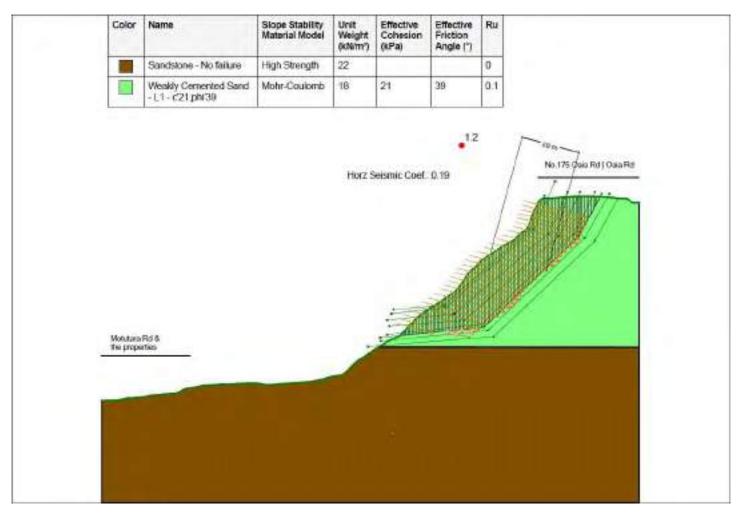


Figure C(A)-6. Nail Option - Nail Length (Seismic Case)

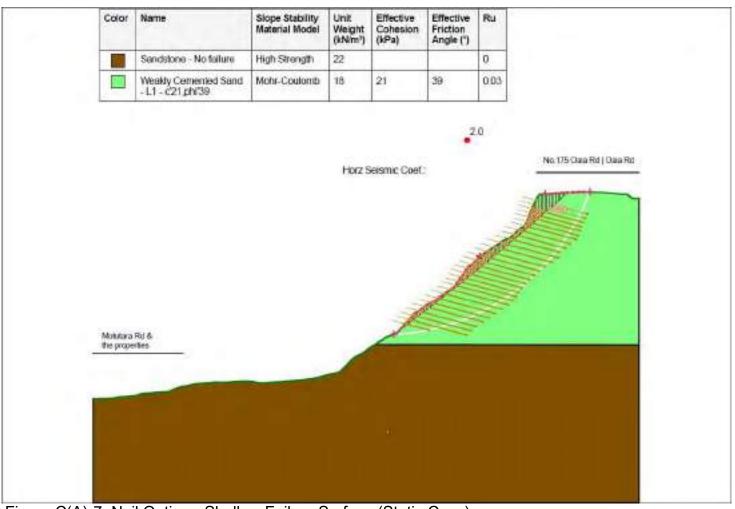


Figure C(A)-7. Nail Option - Shallow Failure Surface (Static Case)

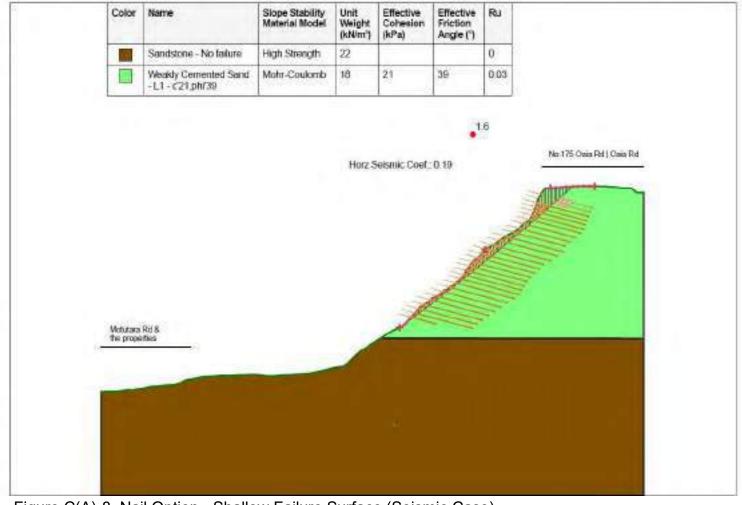


Figure C(A)-8. Nail Option - Shallow Failure Surface (Seismic Case)

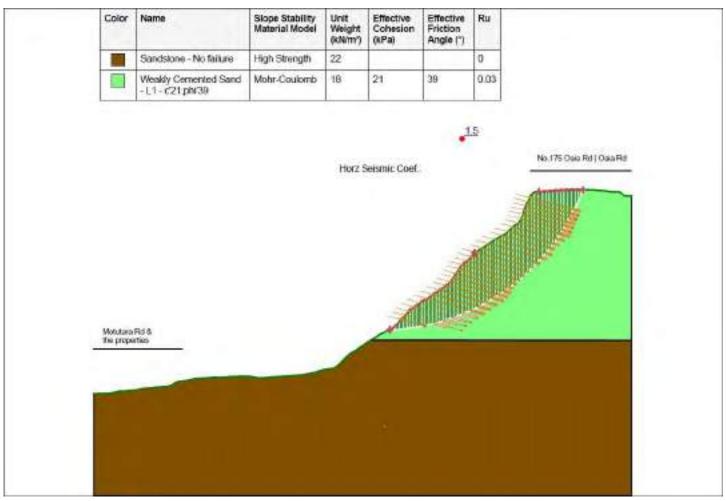


Figure C(A)-9. Nail Option - Deep Failure Surface (Static Case)

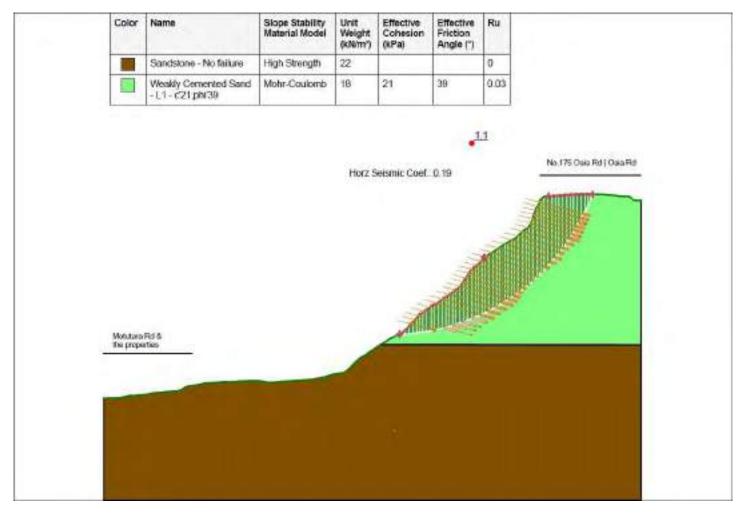


Figure C(A)-10. Nail Option - Deep Failure Surface (Seismic Case)

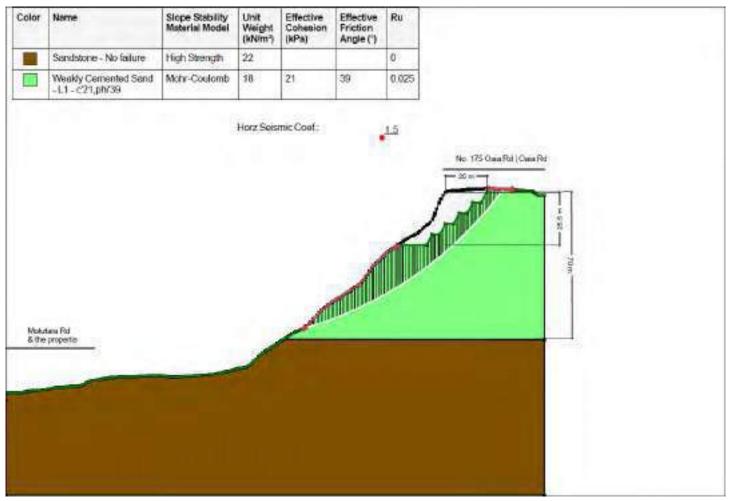


Figure C(A)-11. Bench Option - Static Case

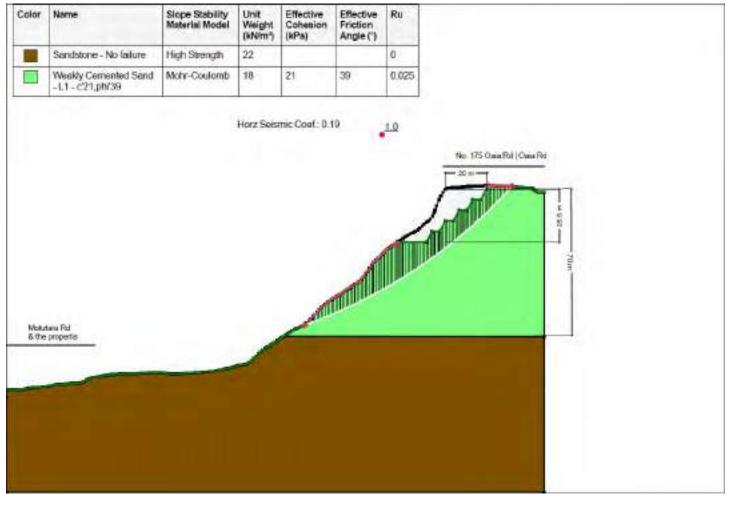


Figure C(A)-12. Bench Option - Seismic Case



# Appendix D RAMMS Debris Flow Analysis

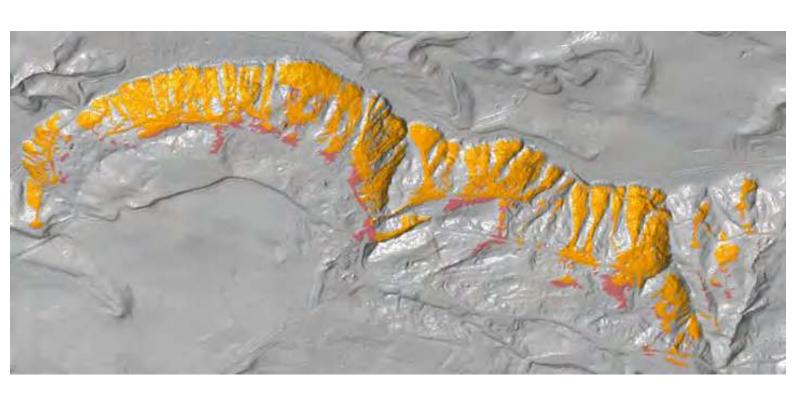


## Waitakere Coastal Communities Landslide Risk Assessment

Appendix D – Muriwai RAMMS debris flow analysis report

Auckland Council
15 May 2024

→ The Power of Commitment



Project n	ame	Waitakere Coastal Communities Landslide Risk Assessment					
Docume	nt title	Waitakere Coastal Communities Landslide Risk Assessment   Appendix D – Muriwai RAMM debris flow analysis report					RAMMS
Project n	umber	12612462					
File name	е	12612462_Apper	ndix D RAMMS_F	INALRev2.docx			
Status	Revision	Author	Reviewer		Approved for	issue	
Code			Name	Signature	Name	Signature	Date
S4	0	Matt Howard	Don Macfarlane	Dringolan	Roy Pearson	Roy Prarson	03/11/2023
S4	1	Matt Howard	Don Macfarlane	Delugation	Roy Pearson	Roy Prarson	30/04/2024
S4	2	Matt Howard	Don Macfarlane	Delugolen	Roy Pearson	Roy Prarson	15/05/2024
[Status code]							
[Status code]							

#### **GHD Limited**

Contact: Matt Howard, Technical Director - Engineering Geologist | GHD

27 Napier Street, GHD Centre Level 3

Freemans Bay, Auckland 1010, New Zealand

T +64 9 370 8000 | F +64 9 370 8001 | E aklmail@ghd.com | ghd.com

#### © GHD 2024

This document is and shall remain the property of GHD. The document may only be used for the purpose for which it was commissioned and in accordance with the Terms of Engagement for the commission. Unauthorised use of this document in any form whatsoever is prohibited.

## **Contents**

D1.	Introd	uction	1
	D1.1	Purpose of this report	•
	D1.2	Background	•
	D1.3	Scope	
	D1.4	Report structure	2
D2.	RAMM	S Debris Flow Modelling	4
	D2.1	Description of software	4
	D2.2	Ground surface model	4
	D2.3	Input parameter options	2
	D2.4	Model calibration and selected input parameters  2.4.1 Calibration purpose and input parameter selection Geomorphological Zone 5  2.4.2 Calibration observations	6 6 8
	D2.5	Sensitivity analysis	Ç
	D2.6	Inferred future landslide source areas	10
D3.	Final r	nodel and analysis results	10
	D3.1	Final simulation input parameters	10
		Geomorphological Zone 5	10
	D3.2	RAMMS debris flow results	11
	D3.3	Data presentation in plans	11
	D3.4	Simulated escarpment debris flow results compared to property placard status	11
	D3.5	Quantification of overlap of actual compared with modelled debris flow runout area	12
D4.	Concl	usions	13
D5.	Limita	tions	14
Tal	ole in	dev	
ıaı	oie iii	uex	
	e D1 e D2	Summary of accompanying Muriwai landslide risk assessment reports List of RAMMS debris flow simulation plans in Appendix A that are associated with this report	2
Tabl	e D3	Landslides used to calibrate the RAMMS simulation. Shading is used to show groupings of landslides. Landslide ID is GHD-named (see Appendix B for full list	_
Tabl	e D4	of landslides). Selected input values for calibration (bold is conservative)	<i>1</i> 8
	e D5	Landslides used to calibrate the RAMMS simulation. Shading is used to show groupings of landslides. Landslide ID is GHD-named (see Appendix B for full list	
Tabl	e D6	of landslides). Selected input values for calibration	<b>.</b>
	e Do e D7	Frictional parameters for the predicted debris flow runout. Conservative (worse case) and optimistic values are presented for comparison.	10

Table D8	Frictional parameters for the predicted debris flow runout. Conservative (worse case) and optimistic values are presented for comparison.	10
Table D9	Summary of calculations for overlap of actual compared with RAMMS modelled debris flow runout area	12
Table D10	Values calculated for fitting parameter $\Omega$	12
Figure ind	ex	
Figure D1	Location of landslides used for RAMMS calibration	7
Figure D2	Best calibration of large slides southeast of Domain Crescent (M-LS18A, 18B, 19A, 19B, 20A, 20B, 21, 22 & 23). Mu = 0.225, Xi = 87.5, showing with 0.01-5 m filter. Note small landslide on the left that modelled as travelling further than	
	observed.	17
Figure D3	Best calibration of large slides at north end of Motutara Road (ID M-LS01 and M-LS02). Mu = 0.225, Xi = 87.5, showing with 0.01-5 m filter. Note modelled debris flow lobe is wider than observed.	17
Figure D4	Best calibration of large slides at Motutara Road (M-LS03, M-LS04A and M-LS04B). Mu = $0.225$ , Xi = $87.5$ , showing with $0.01-5$ m filter	18
Figure D5	Best calibration of large slide at Motutara Road (M-LS06, 07, 08, 09, 10, 33 & 34). Mu = 0.225, Xi = 87.5, showing with 0.01-5 m filter	18
Figure D6	The selection of the RAMMS momentum-based 'Percentage total momentum' stop criteria (for Xi = 150 m/s² and Mu = 0.2). a) The percentage value of less than 5% shows a wide, creeping debris flow at the end of the simulation (showing 0-5 m maximum debris thickness). For scenarios above 5% the simulated debris extents is similar. b) The relationship between Moving Percent with time. This shows that a lower percentage total volume Stop Criteria (left), indicated by the red line, leads to longer runout times than when a higher percentage total volume is selected (right). If the lower percentage is used, the result is a debris flow extent that slowly expands towards the end of the simulation.	19
Figure D7	Zone 5 RAMMS simulation showing how the use of (Revision 0) analysis parameters are overly conservative. White arrows show the debris travelling beyond the mapped landslide extents.	20
Figure D8	Zone 5 RAMMS calibration using parameters that gives the best match to observed landslide runout	20
Figure D9	Potential landslide failure zones have been defined by GHD based on having similar geomorphology (ground shape) and geology to February 2023 landslide source areas. The above example shows a potential landslide source zone (grey outline) that has similar bowl-shaped characteristics to recently failed blue areas. Background surface model has a 'hill shade' applied to highlight the geomorphology. Location is below the escarpment and west of Oaia Road (see Figure A115 in Appendix A).	21
Figure D10	Comparison of RAMMS input parameter Mu (basal friction), with a) Mu = 0.3 and b) Mu = 0.15. All other parameters are unchanged. Note that simulated debris travelled much further with the lower Mu value.	22
Figure D11	Comparison of RAMMS input parameter Xi (viscous-turbulent friction), with a) Xi = 200 and b) Xi=75. All other parameters are unchanged. Note that the results are nearly identical, and the simulation is not sensitive to Xi.	23
Figure D12	Comparison of RAMMS input parameter Xi (viscous-turbulent friction), with the simulated debris flow extent of Xi = 87.5 m/s <sup>2</sup> (the GHD-selected value) and 150 m/s <sup>2</sup> (RAMMS, 2022 mid-range value) overlain to highlight the difference. Each	-

pixel is 1 m $^2$ . a) is uphill of Domain Crescent and b) is uphill of Motutara Road. The difference in debris flow extent is mostly less than 1 m (horizontal). Broader, less channelised flows travel slightly further with Xi =150 m/s $^2$ .	24
An example of the comparison of the erosional parameters input parameter showing negligible difference between the high and low erosion scenarios, compared with when no erosion features are used.	25
Multiple block release versus individual release comparison. The debris flow runout for three landslide sources was simulated individually (light pink and dark pink on the right image), then all three sources were simulated simultaneously (red shading). Each pixel is 1 m <sup>2</sup> . This shows that modelling failures from numerous landslides increases the debris flow runout distance only slightly – typically less than 1 m horizontally, but up to 4 m in some areas.	26
Example of where the predicted red debris flow has been manually smoothed (left side) compared with the right side of the red shading, which is the RAMMS output.	26
An example of where the red debris flow shading has been removed from the landslide source (bottom of picture), but has been left in when near a dwelling (top of picture)	27
An example of simplification of the predicted debris extent (shown in orange in this work-in-progress example). The thick red line is the edge of the predicted zone in the figures, with the small patches that are less than 0.5 m (shown as grey) not included.	27
An oblique view of predicted debris flow showing how isolated islands can occur due to the highs and lows of the surface topography.	28
Illustration of the area parameters used for calibration quantification	28
Parameters α, β and γ for each landslide	29
Ternary plot showing the debris flow simulated with RAMMS for the observed landslides used for calibration. Note that the latest calibration data is used for the	30
	The difference in debris flow extent is mostly less than 1 m (horizontal). Broader, less channelised flows travel slightly further with Xi =150 m/s². An example of the comparison of the erosional parameters input parameter showing negligible difference between the high and low erosion scenarios, compared with when no erosion features are used. Multiple block release versus individual release comparison. The debris flow runout for three landslide sources was simulated individually (light pink and dark pink on the right image), then all three sources were simulated simultaneously (red shading). Each pixel is 1 m². This shows that modelling failures from numerous landslides increases the debris flow runout distance only slightly – typically less than 1 m horizontally, but up to 4 m in some areas. Example of where the predicted red debris flow has been manually smoothed (left side) compared with the right side of the red shading, which is the RAMMS output. An example of where the red debris flow shading has been removed from the landslide source (bottom of picture), but has been left in when near a dwelling (top of picture)  An example of simplification of the predicted debris extent (shown in orange in this work-in-progress example). The thick red line is the edge of the predicted zone in the figures, with the small patches that are less than 0.5 m (shown as grey) not included.  An oblique view of predicted debris flow showing how isolated islands can occur due to the highs and lows of the surface topography. Illustration of the area parameters used for calibration quantification Parameters $\alpha$ , $\beta$ and $\gamma$ for each landslide Ternary plot showing the debris flow simulated with RAMMS for the observed

## **Appendices**

Appendix D-1 Figures

## **D1.** Introduction

## D1.1 Purpose of this report

GHD has been engaged by Auckland Council (AC)<sup>1</sup> to carry out landslide risk assessments as well as to provide associated landslide risk management advice and geotechnical investigations in the Waitakere area, specifically for the residential areas of Muriwai, Piha and Karekare.

The purpose of this assessment is to present the results of a RAMMS computer-simulated three-dimensional debris flow assessment undertaken to provide guidance on the potential effects of future events on dwellings in Muriwai. In addition, a sensitivity analysis of input parameters is presented. The analysis focus is on the large-scale hazard from the 80 m-high escarpment to the east of Muriwai township that experienced damaging landslides in February 2023. The results from the analysis provide an important part of the GHD loss of life risk study (see Appendix E of the overall report) that will support decision-making by AC on the long-term suitability of sites and dwellings for occupancy.

This report is an appendix to the overall GHD landslide risk report and should be read in conjunction with it, as well as associated appendices. The covering report contains additional background information and the results of other assessments carried out by GHD that are not included herein.

## D1.2 Background

Two significant rainfall events affected the Waitakere area in late January and early February, resulting from the impacts of ex-tropical cyclones Hale and Gabrielle, respectively.

The Cyclone Gabrielle weather event of 14 February 2023 resulted in widespread catastrophic flooding and slope instability in the settlement of Muriwai where several debris avalanches (which included rocks and trees) occurred, some of which turned into saturated debris flows as they travelled downslope. These flows resulted in damage to buildings and infrastructure. Two fatalities occurred due to impact of landslides on private dwellings. This tragic event was similar to a 1965 storm event that also claimed two lives.

Following the event, rapid building assessment of residential properties was undertaken in Muriwai, with some houses having access by owners restricted (a yellow placard – e.g. access in daylight hours only) and some for which no access was permitted (a red placard).

The modelling of potential debris flows was identified as an important element of understanding the ongoing future risk to the Muriwai community.

## D1.3 Scope

The scope for this work is as follows:

- Establish a ground surface model using data provided by AC.
- Calibrate RAMMS input parameters to replicate the observed runout distance of February 2023 debris flows.
- Identify areas of the escarpment that could be susceptible to future landslides in rare, large rainfall events
- Using RAMMS, simulate the failure of future landslide source areas leading to large-scale, destructive landslides.
- Conduct a RAMMS analysis specifically for Geomorphological Zone 5, which is located at the southern end of Muriwai between Domain Crescent and Waitea Road.
- Provide a plan of the area potentially affected by debris flows of sufficient thickness that could cause loss of life (i.e. greater than 0.5 m).

<sup>&</sup>lt;sup>1</sup> Under Contract CW198379, Master Services Agreement CCCS: CW74240 dated 7/09/2019

AC requested that this study be limited to the assessment of the effect from 'large scale<sup>2'</sup> landslide hazards originating from the main escarpment located to the south-east of Muriwai because the initial placard assessment was largely aimed at mitigating risks associated with these landslide hazards. Consequently, this report does not consider smaller, more localised landslide hazards that could originate (or may have already initiated) from other areas in Muriwai such as within the footprint of individual residential properties. The exception to this is 3 specific property's (85 and 87 Domain Crescent and 207 Motutara Road). The basis for this is outlined in Section 1.3 (footnote 3) of the Overall Report.

This report has been prepared by GHD for Auckland Council and may only be used and relied on by Auckland Council for the purpose agreed between GHD and Auckland Council as set out in section 1.1 of this report.

GHD otherwise disclaims responsibility to any person other than Auckland Council arising in connection with this report. GHD also excludes implied warranties and conditions, to the extent legally permissible.

## D1.4 Report structure

The accompanying GHD Engineering Geology report provides a detailed description of the site as well as discussion of site geology and geomorphology, historical landsliding, landslide mapping, landslide classification and slope processes. The reader is advised to consult the accompanying GHD reports for further information not contained herein. A list of report sections is presented in Table D1. A3 plans referred to in this report are listed in Table D2 and RAMMS output figures are presented in Appendix D-1.

Table D1 Summary of accompanying Muriwai landslide risk assessment reports

Report Section	Description
Overall Report	Waitakere Coastal Communities Landslide Risk Assessment (Muriwai)
Appendix A	Figures
Appendix B	Engineering Geological Report
Appendix C	Slope Stability Assessment
Appendix D	RAMMS debris flow analysis (this report)
Appendix E	Landslide Risk Assessment
Appendix F	Geotechnical Investigations Report

Table D2 List of RAMMS debris flow simulation plans in Appendix A that are associated with this report

	Maximum debris height extents for best case, predicted and worst case scenarios -(greater than
A201	0.01 m deep) - overview
A202	Predicted maximum debris height (greater than 0.01 m deep) - overview
A203 – A205	Predicted maximum debris height (greater than 0.01 m deep) - close-up
A206	Maximum debris height extents (greater than 0.5 m deep) - overview
A207 – A209	Maximum debris height extents (greater than 0.5 m deep) - close-up

<sup>&</sup>lt;sup>2</sup> In this report 'large scale' landslide hazards refers to landslides originating from the main escarpment that typically have a volume of more than about 50 m³ with the potential to cause total or partial collapse of a dwelling.

## D2. RAMMS Debris Flow Modelling

## **D2.1** Description of software

The RAMMS Debris flow module (RAMMS) is a three-dimensional numerical software package developed by the WSL Institute for Snow and Avalanche Research and is used to simulate the runout of debris-laden flows in complex terrain. Version 1.8.0 was used for this analysis.

RAMMS is a credible modelling tool that is frequently used in New Zealand and internationally. Like most similar modelling techniques, RAMMS is a simplification of a process that is inherently complex and unpredictable. Consideration of observed landslide behaviour is essential to obtain credible results.

The extent of simulated debris flows can be presented as 'heat maps' of depth, maximum depth, maximum velocity or maximum pressure. We have attributed the vulnerability metric of maximum depth in the risk analysis (see Appendix E of the overall report) as being the most relevant to understanding the potential hazard to occupants of dwellings. RAMMS outputs are therefore presented as maximum depth and the modelled landslide runout zones are referred to in this report as the 'Predicted modelled debris runout zone'.

#### D2.2 Ground surface model

RAMMS uses a surface 'digital elevation' model (DEM) as the base layer for its calculations. It is important to have a representative surface model that accurately depicts slopes, ridges and channels, all of which influence the path of debris flows. Surface models that are insufficiently detailed may give overly conservative results, as the software perceives unrealistically smooth terrain. The RAMMS (2022)<sup>3</sup> guidance document is not definitive on the minimum spacing, but our experience is that a surface model should have points at or closer than 1 m.

We obtained data from AC and publicly available sources. The surface model used included the following:

- LiDAR surface data (1 m point spacing) and aerial imagery (0.15 m resolution) obtained 2016-2018 (provided by AC)
- LiDAR surface data (1 m point spacing) and aerial imagery (0.15 m resolution) obtained 2023 (provided by AC) following Cyclone Gabrielle
- Mapped landslide extents recorded remotely and from GHD 2023 field mapping (see the Engineering Geology Report – Appendix B of the overall report)

Surface data is processed to remove vegetation and dwellings.

Our RAMMS simulation considers whether a pre or post February 2023 DEM is appropriate. The pre 2023 event DEM was used to calibrate existing landslides and the post event DEM was used to model future debris flows as the terrain has been altered by recent debris deposition. Comparison of the elevation of the two DEMs has identified that there is a difference between each model of 0.3 m, which may reflect the accuracy of one or both of the models. This is discussed in more detail in section B3.1.1 of the Engineering Geology Report – Appendix B of the overall report.

### D2.3 Input parameter options

Debris flows involve a dynamic interaction of flowing material that is part liquid and part solid. As the mass descends the slope this ratio constantly changes, resulting in complex dynamics within the flow and between the flow and ground. To simulate this, RAMMS uses some input parameters that are described in detail in the supplier user manual (RAMMS, 2022).

The following describes the RAMMS parameters that can be varied:

<sup>&</sup>lt;sup>3</sup> RAMMS (2022). RAMMS: DEBRISFLOW User Manual v.8.0. Davos, Switzerland: ETH

#### Hydrograph and block release

Debris flows are often associated with large, basin-shaped catchments where debris is entrained within floodwaters in a river channel and discharged at the top of a fan 'apex'. A hydrograph can be used as an input to describe the expected flow over time, which is often developed for a particular catchment. This influences the discharge and duration of debris flow.

Block release is where a thickness of debris for a defined area is released. Block release can be applied to multiple areas per simulation. The initial February 2023 landslides are interpreted as being a solid detachment of weakly cemented sandstone that liquefied during descent. RAMMS does not specifically model this scenario – this is accounted for in the calibration of the input parameters.

#### Debris flow material properties

- Frictional parameter Mu (μ), which is unitless. It is a measure the basal friction the friction that occurs during interaction between the surface of the flow and the ground surface below. Landslides with higher Mu values result in shorter and more narrow runouts. RAMMS (2022) suggests a starting Mu value of approximately 0.2, with 0.05 0.4 providing realistic results values. Outside this range is not recommended, with Mu of zero giving visco-plastic behaviour and greater than 0.4 seldom producing useful simulation results.
- Frictional parameter Xi (ξ), in units of m/s². This represents the viscous-turbulent properties of the landslide slurry. Higher Xi values indicate more laminar flows that travel further. RAMMS (2022) recommends that Xi is between 100 and 200 m/s² for granular flow (solid-dominated).
- Flow density ( $\rho$ ), in units of kg/m<sup>3</sup>. Density represents the bulk density of solids and fluids within the flow. RAMMS (2022) recommends a value of 2000 kg/m<sup>3</sup> if details of the landslide are not available.

#### Stop Criteria

There are two 'Stop Criteria' that dictate when a simulation stops running in RAMMS. The simulation will stop at whichever criteria is fulfilled first. The purpose of this is to avoid misleading results due to the expansion of the debris mass at the end of the movement when most energy has been expended. The criteria are:

- The momentum-based 'Percentage total momentum' (energy cutoff). The default setting in RAMMS is 5%, i.e., when 95% of the mass has stopped. This can be adjusted to account for faster or slower mass movement speeds. The RAMMS (2022) suggested range for reasonable results is between 1% and 10%. For a value that is too low, the debris flow will continue to creep at extremely low velocity (i.e. the simulation lasts too long) and for a too high value the simulation will terminate prematurely.
- The centre-of-mass based 'Centre-of-mass velocity threshold' (m/s). The default setting in RAMMS is 0.2 m/s, i.e., the model terminates when the centre of mass velocity is below this value. This value is useful for address slow, creeping mass movements, but is not appropriate where there is more than one landslide being activated simultaneously. For Muriwai a value of zero is appropriate.
- End Time (s) This represents the amount of time the simulation will allow the landslide to flow for. It is desirable to have a simulation end due to the Stop Criteria of the landslide or due to low flow rates ('low flux'). It is less desirable to have a 'time end condition', which indicates neither the target stopping criteria nor low flux condition has been met.

#### **Erosion function**

The erosion function predicts the depth of erosion of sediment caused by debris flows. This can be used to predict the increase in volume of a debris flow as it travels along a channel. The erosion parameters are: erosion density (of the landslide debris); erosion rate of material from the channel; potential erosion depth; the critical shear stress where erosion can occur, and; the maximum erosion depth. The disadvantage of incorporating erosion is that you cannot specify the release volume before the simulation starts as it is created as a function of the debris flow.

#### Filtering of depth results

The results of the RAMMS analysis can be filtered to show the depth range of interest. This can be done to remove the presence of thin, non-life-threatening debris at landslide margins.

#### Effect of vegetation and buildings

The influence of trees acting to impede or add to debris flow damage on February 2023 landslides has been observed. Similarly, buildings may alter the natural path of part or all of a debris flow. It is possible to apply an impassable zone to physically block a simulated debris flow, but predicting the behaviour of individual trees and buildings in an area-wide study is not possible and has not been applied.

## D2.4 Model calibration and selected input parameters

### 2.4.1 Calibration purpose and input parameter selection

Calibration of a RAMMS model with actual debris flow observations is important to account for the unique material and terrain characteristics in a particular location. At the large escarpment south-east of Muriwai there are more than ten large (several tens of metres wide) landslide source areas, all in similar Awhitu Group weakly cemented sandstone (see Appendix B of the overall report for a description of the Engineering Geology). This provides a compelling dataset of landslides and associated debris runout to guide assumptions on future large slope failures on the escarpment. Aligning the RAMMS model with existing failures provides confidence in its application elsewhere on the escarpment.

We calibrated the RAMMS model against the February 2023 landslides shown in Figure D1 and Table D3. In addition, the following values were selected:

- Block release' of debris
- Stop Criteria:
  - The momentum-based 'Percentage total momentum' 5% was selected. The process for making the selection is presented in Figure D6.
  - The centre-of-mass based 'Centre-of-mass velocity threshold' 0 m/s was selected, which is appropriate for multiple release areas/catchments.
  - End time this varied between simulations due to the parameters of the RAMMS calculation for the 'predicted modelled' scenario. All simulations had an end time of 180 seconds. These met the desirable condition of 'low flux'.
- Erosion function this was not used for calibration, as the concentrated channelised flow described in RAMMS (2022) is not observed at Muriwai, with more distributed flows being evident.
- Simulations have been filtered to show maximum depths of greater than 10 mm so that comparisons with actual landslide extents is possible.

The release areas were defined in RAMMS using the mapped source area extents and estimated depth. It was noted that some landslides comprise individual, large source areas, while others have numerous, smaller source areas, with debris combining further downslope. We used both of these configurations for our calibration to represent these cases. The 2016 surface DEM was used to best represent the ground conditions existing at the time of the recent landslides. All RAMMS output figures are presented in Appendix D-1 of this report.

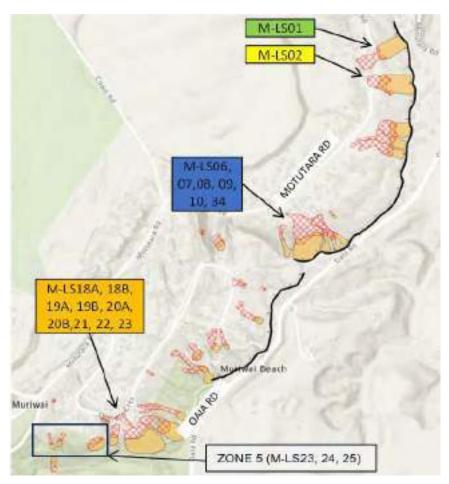


Figure D1 Location of landslides used for RAMMS calibration

Table D3 Landslides used to calibrate the RAMMS simulation. Shading is used to show groupings of landslides. Landslide ID is GHD-named (see Appendix B for full list of landslides).

Landslide ID No.	Release Area (m²)	Average Release Thickness (m)	Released Volume (m³)
M-LS01	2400	0.5	1220
M-LS02	1800	0.5	900
M-LS06	400	0.25	101
M-LS07	400	0.25	100
M-LS08	900	0.25	200
M-LS09	1900	0.75	1500
M-LS10	400	0.25	100
M-LS34	600	0.25	100
M-LS18A	200	0.25	50
M-LS18B	200	0.5	100
M-LS19A	800	0.25	200
M-LS19B	2000	0.25	500
M-LS20A	200	0.5	100
M-LS20B	3600	0.75	2700
M-LS21	500	0.25	100

Landslide ID No.	Release Area (m²)	Average Release Thickness (m)	Released Volume (m³)
M-LS22	200	0.25	50
M-LS23	700	0.5	400

Where parameters were recommended by RAMMS, these were initially applied and modified to obtain a runout extent that best matched what was observed. This was done by showing the mapped landslide extents beneath a transparent RAMMS overlay. The selected input parameters are presented in Table D4. Calibrated, best-fit output images are presented as Figure D2 to Figure D5.

Table D4 Selected input values for calibration (bold is conservative)

Parameter	Units	Typical Range (bold is conservative)	Range tested	Selected Value For Calibration
Density* (p)	kg/m³	1800 - <b>2000</b>	-	2000
Basal Friction (Mu)	n/a	<b>0.1</b> - 0.4	<b>0.05</b> - 0.5	0.225
Viscous turbulent (Xi)	m/s <sup>2</sup>	100 - <b>200</b>	5 - 200	87.5

#### Geomorphological Zone 5

The study area has been divided geomorphologically into six landslide 'zones' based on the surface topography, February 2023 landslide characteristics and general geomorphology. The purpose of this is to differentiate areas according to their susceptibility for large-scale landslides. The basis for the zoning and the zone characteristics are described in Section B5.3 of the Engineering Geology Report – Appendix B of the overall report.

There are similarities between Zone 5 and the main escarpment (i.e. Zone 2 to Zone 4), however, the source area is not as high, has different topography and may have groundwater conditions that are more favourable to slope stability. We assess this to mean that the potential extent of future debris flow in Zone 5 is better evaluated by having a specific RAMMS calibration for simulation purposes<sup>4</sup>. The landslides calibrated in Zone 5 were M-LS23, M-LS24 and M-LS25 (see Table D5). The release thickness for each landslide was adjusted with the RAMMS input values in Table D6 to best match observed landslide debris runout.

Table D5 Landslides used to calibrate the RAMMS simulation. Shading is used to show groupings of landslides. Landslide ID is GHD-named (see Appendix B for full list of landslides).

Landslide ID No.	Release Area (m²)	Average Release Thickness (m)	Released Volume (m³)
M-LS23	700	0.3	210
M-LS24	130	0.2	26
M-LS25	130	0.1	13

Table D6 Selected input values for calibration

Parameter	Units	Selected Value For Calibration
Density* (p)	kg/m³	2000
Basal Friction (Mu)	n/a	0.4
Viscous turbulent (Xi)	m/s <sup>2</sup>	500

<sup>&</sup>lt;sup>4</sup> The Zone 5-specific information contained in this report have been previously documented in a letter to AC on 6 December, titled Muriwai Zone 5 reassessment of landslide risk following updated RAMMS debris flow modelling

#### 2.4.2 Calibration observations

In general, the RAMMS modelling was able to be broadly matched to the total travel distance of the February 2023 landslides observed in the field. The following were observed during the calibration process:

- Simulated small debris flows travelled significantly further than in reality (see Figure D2 for an example of this). This is likely due to the resistance generated by large trees and dense vegetation. In addition, other factors may mean there is an insufficient supply of liquefied debris. Small debris flows would require a specific calibration to provide a credible model.
- The debris flow terminal lobe modelled as being wider in the northern part of Motutara Road (see Figure D3). This could be due to the influence of large trees or buildings, several of which were destroyed in the event.
- Relatively thin layers (less than 200 mm) of debris modelled as affecting areas that were not damaged by debris flows (see Figure D4).
- Stop criteria the default values provided in RAMMS are adequate, as confirmed by our stop criteria analysis (see Figure D6).

## D2.5 Sensitivity analysis

A sensitivity analysis tests the influence of individual model parameters to help understand the relative importance of the elements upon which the model is based. It provides focus for the critical input parameters. The process involves performing repeated RAMMS simulations with a change in one parameter, usually to an extreme high and/or low value. The parameters that were tested are discussed below.

#### Basal friction parameter Mu

This was tested in approximately 20 simulations using a range of Mu = 0.05 to 0.5. The RAMMS simulation was very sensitive to Mu, with runout varying by more than 50 m downslope (see Figure D10).

#### Viscous-turbulent frictional parameter Xi

This was tested in approximately 16 simulations using a range of Xi = 5 to 200 m/s $^2$ . The results are nearly identical showing the simulation is not sensitive to Xi (see Figure D11). A comparison of the debris flow extent of Xi = 87.5 m/s $^2$  (the GHD-selected value) and 150 m/s $^2$  (RAMMS, 2022 mid-range value) also showed minimal difference in debris flow extent – mostly less than 1 m horizontally (see Figure D12). Broader, less channelised flows travel slightly further with Xi =150 m/s $^2$ .

#### **Erosion function**

Although the erosion function was not considered appropriate for use at Muriwai, the sensitivity of its use was tested by comparing the simulated distribution of debris with the function turned on and off. This confirmed that the simulation is not sensitive to the erosion function (see Figure D13).

#### Multiple block release

Our simulation does not predict which landslide sources will become debris flows in a particular event, instead presenting the debris flow potential for all sources at one time. We have tested to see if there is an effect of multiple adjacent simulated landslides coalescing and travelling further than would be the case of an individual landslide. To do this, the debris flow runout for three landslide sources was simulated individually, then all three sources were simulated simultaneously (see Figure D14).

This showed that modelling coalescing of failures from numerous landslides increases the debris flow runout distance only slightly at Muriwai – typically less than 1 m horizontally, but up to 4 m in some areas.

#### D2.6 Inferred future landslide source areas

Potential landslide failure zones have been identified based on having similar geomorphology (ground shape) and geology to February 2023 landslide source areas. For example, the bowl-shaped head-scarp shape of recent landslides observed at the crest of the escarpment is similar to the shape of the escarpment where failures did not occur in 2023 (see Figure D9 in Appendix D-1) but have almost certainly occurred at some time in the past. The susceptibility of landslides across the study area has been inferred as variable, however, as a function of the local topographical landform. This is defined as 'geomorphological landslide zones' and outlined in further detail in Section B6.3.. We have assumed that future landslides on the escarpment have the potential to fail with similar damaging effects as the February 2023 landslides. Inferred future landslides were used as RAMMS debris flow source areas.

## D3. Final model and analysis results

## D3.1 Final simulation input parameters

The key parameters of Mu and Xi used for the prediction of future failure runout distances (the 'predicted' scenario) are those calibrated from the extent of February 2023 debris flow runouts. In addition, we tested the runout using conservative and non-conservative values (see Table D7).

The post-February 2023 DEM was used to model future potential debris flow. The release area applied to all landslide source areas (i.e., existing landslide areas and potential future landslide areas).

Table D7 Frictional parameters for the predicted debris flow runout. Conservative (worse case) and optimistic values are presented for comparison.

RAMMS input type	Input parameter Mu	Input parameter Xi (m/s²)	Colour in Fig A201	Colour in A203- A206
Predicted	0.225	87.5		
Non-conservative (optimistic)	0.3	75		Not shown
Conservative (worst case)	0.15	200		

#### Geomorphological Zone 5

The parameters used in Zone 5 are presented in Table D8.

Table D8 Frictional parameters for the predicted debris flow runout. Conservative (worse case) and optimistic values are presented for comparison.

RAMMS input type	Input parameter Mu	Input parameter Xi (m/s²)	Colour in Fig A201	Colour in A203- A206
Predicted	0.4	500		
Non-conservative (optimistic)	0.4	500		Not shown
Conservative (worst case)	0.4	100		

#### D3.2 RAMMS debris flow results

The outputs from the RAMMS debris flow analysis have been filtered and variously presented to illustrate a scientific and defensible modelling approach. Care should be taken to use the information in the intended context.

The presented A3 results figures associated with this report (listed in Table D2 and presented in Appendix A) in the escarpment area are as follows:

- A201 which shows the modelled debris extents for the non-conservative (optimistic) case, predicted and conservative (worst) case scenarios. It is filtered to show all depth above 0.01 m (1 cm). Importantly, it shows the 'F-angle' estimated runout zone used by AC to inform property the initial placard assignment.
   This should be viewed only for general information and understanding RAMMS.
- A202-A205 shows the modelled debris extents and maximum depth for the predicted scenario. It is filtered to show all depth above 0.01 m (1 cm).
  - This should be viewed only for general information and understanding RAMMS.
- A206-A209 show the predicted modelled runout for debris flows that are greater than 0.5 m (50 cm) deep. Debris flows of or greater than this depth are considered to have the potential to severely damage or destroy a dwelling, if impacted (detailed in Section E4.6 of Risk Assessment Report in Appendix E).
   These should be viewed to understand the potential modelled effects of debris flows on individual dwellings.

The above results include the Zone 5-specific modelling.

## D3.3 Data presentation in plans

We have made the following modifications to the raw RAMMS output to clarify the information in Figures A206-A209:

- Smoothing of lines the output is a blocky line that has been manually smoothed (see Figure D15).
- Removing debris flow shading from the landslide source area the RAMMS output shows red shaded debris in the source area. This has been removed so this area is not obscured. Occasionally it is left in where a dwelling is nearby to demonstrate the hazard (see Figure D16).
- In some areas there are small zones a few metres wide that have less than 0.5 m debris thickness modelled. For simplicity, these have not been shown as the hazard to dwellings is not changed by them (see Figure D17).
- Isolated zones of predicted debris flow there are some instances of isolated zones, or islands, of
  modelled debris. These do not intuitively look correct, however, they can be explained as being due to the
  flow passing over uneven terrain and being below the 0.5 m filter when going over a crest (e.g. as for a
  waterfall) and accumulating in a low point (see Figure D18).

# D3.4 Simulated escarpment debris flow results compared to property placard status

The following observations can be made about the extent of predicted <u>escarpment</u> RAMMS debris flow results (greater than 0.5 m thick, i.e. potentially causing fatalities) in relation to red placarded properties:

- The modelled debris flow reaches approximately two-thirds of red placarded properties.
- Most of these properties are close to the escarpment (i.e., the landslide source)
- Localised topographic variations have directed simulated debris flows towards some houses and away from others.

Yellow placarded properties are mostly outside of the predicted simulated debris flow of greater than 0.5 m.

# D3.5 Quantification of overlap of actual compared with modelled debris flow runout area

To measure the agreement of our RAMMS calibration with debris flow runout extents, we support our qualitative, visual comparison of modelled results with a quantitative assessment using the methodology set out in Heiser et al. (2017)<sup>5</sup>. This quantifies the amount of overlap between landslide debris runout and that modelled in RAMMS. The parameters used and calculations are presented in Table D9. A visual representation of the assessment is presented in Figure D19.

Table D9 Summary of calculations for overlap of actual compared with RAMMS modelled debris flow runout area

Parameter	Formulae	Comments
Ω: Fitting parameter	$\Omega = \alpha - \beta - \gamma$	Possible range of 1 (perfect fit) to -1 (no overlap)
α: Overlap ratio	$\alpha = \frac{X}{T}$	Is the ratio of overlap runout area (X) to the total combined footprint of the simulated and observed runout area (T)
β: Underestimation ratio	$\beta = \frac{U}{T}$	Is the ratio of underestimation of debris in the model (underestimated modelled runout area (U) / the total combined footprint of the simulated and observed runout area (T))
γ: Overestimation ratio	$\gamma = \frac{O}{T}$	Is the ratio of overestimation of debris in the model (overestimated modelled runout area (O) / the total combined footprint of the simulated and observed runout area (T))

Graphs showing the relative amounts of the overlap parameters are presented in Figure D20 and Figure D21 in Appendix D-1. This analysis indicates the following:

- More than half of the RAMMS simulated debris flow area overlap with the observed runout area for each landslide sources considered in the calibration process (i.e. α is greater than 50%)
- There is minimal underestimation of the runout by the RAMMS simulation (i.e. β is less than 0.1)
- There is some overestimation of the runout by the RAMMS simulation (i.e. γ is between 0.2 and 0.5)

The resultant fitting parameter ( $\Omega$ ) values are all greater than zero, indicating a reasonable fit that is not overly dominated by underestimation or overestimation. We interpret this to mean that that the calibration has a reasonable balance of fit.

Table D10 Values calculated for fitting parameter  $\Omega$ 

Landslide Area ID	Ω
M-LS01	0.2
M-LS02	0.3
M-LS03- M-LS04	0.4
M-LS06-LS10, M-LS34	0.5
M-LS18- M-LS22	0.2
M-LS23	0.1

<sup>&</sup>lt;sup>5</sup> Heiser M., Scheidl C. and Kaitna R. (2017). Evaluation concepts to compare observed and simulated deposition areas of mass movements. Comput Geosci, 21:335-343

# **D4.** Conclusions

- A robust RAMMS debris flow analysis has been conducted using simulated landslide sources areas similar to the damaging February 2023 Cyclone Gabrielle, and from potential, future sources.
- Geomorphological Zone 5 landslides have been used to calibrate specific parameters for RAMMS analysis due to the relatively short debris flow runout distance when compared to other zones.
- A quantitative comparison of the actual landslide runout areas with that determined from RAMMS simulation indicates a reasonable fit.
- The predicted outcome of the simulation is that over 40 currently red-placarded dwellings could be subjected to impact by escarpment landslide debris that is greater than 0.5 m thick as shown on Figures A206 and A209. This has been assessed by GHD's risk assessment in Appendix E as having the potential to cause fatalities, especially if large trees are mobilised by the landslide.
- Yellow placarded properties are largely beyond the extent of the escarpment landslide debris that is greater than 0.5 m thick.
- The RAMMS predicted runout extent of damaging debris (i.e. more than 0.5 m maximum thickness) is in broad agreement with the 'F-angle' empirical landslide hazard prediction work undertaken by AC to allocate the original emergency property placards.

#### **D5.** Limitations

This report has been prepared by GHD Limited (GHD) for Auckland Council and may only be used and relied on by Auckland Council for the purpose agreed between GHD and Auckland Council as set out in Section 1 of this report.

GHD otherwise disclaims responsibility to any person other than Auckland Council arising in connection with this report. GHD also excludes implied warranties and conditions, to the extent legally permissible.

The services undertaken by GHD in connection with preparing this report were limited to those specifically detailed in the report and are subject to the scope limitations set out in the report.

The opinions, conclusions and any recommendations in this report are based on conditions encountered and information reviewed at the date of preparation of the report. GHD has no responsibility or obligation to update this report to account for events or changes occurring subsequent to the date that the report was prepared.

The opinions, conclusions and any recommendations in this report are based on assumptions made by GHD described in this report (refer Section 1 of this report). GHD disclaims liability arising from any of the assumptions being incorrect.

An understanding of the geotechnical site conditions depends on the integration of many pieces of information, some regional, some site specific, some structure specific and some experienced based. Hence this report should not be altered, amended, abbreviated, or issued in part in any way without prior written approval by GHD. GHD does not accept liability in connection with the issuing of an unapproved or modified version of this report.

Verification of the geotechnical assumptions and/or model is an integral part of the design process - investigation, construction verification, and performance monitoring. If the revealed ground or groundwater conditions vary from those assumed or described in this report the matter should be referred back to GHD.

# Appendices

# Appendix D-1

**Figures** 

The following is a presentation of RAMMS debris flow analyses outputs. All figures have North to the top of the page.

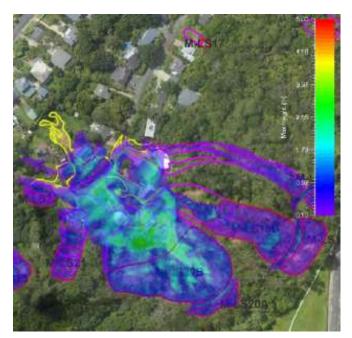


Figure D2 Best calibration of large slides southeast of Domain Crescent (M-LS18A, 18B, 19A, 19B, 20A, 20B, 21, 22 & 23). Mu = 0.225, Xi = 87.5, showing with 0.01-5 m filter. Note small landslide on the left that modelled as travelling further than observed.

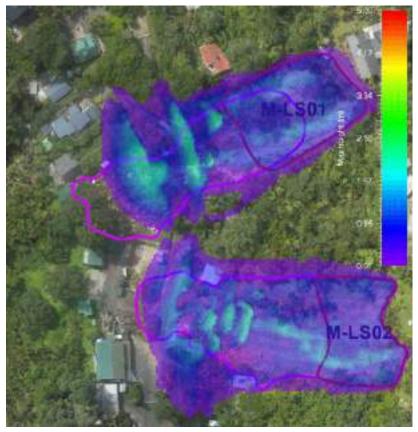


Figure D3 Best calibration of large slides at north end of Motutara Road (ID M-LS01 and M-LS02). Mu = 0.225, Xi = 87.5, showing with 0.01-5 m filter. Note modelled debris flow lobe is wider than observed.



Figure D4 Best calibration of large slides at Motutara Road (M-LS03, M-LS04A and M-LS04B). Mu = 0.225, Xi = 87.5, showing with 0.01-5 m filter

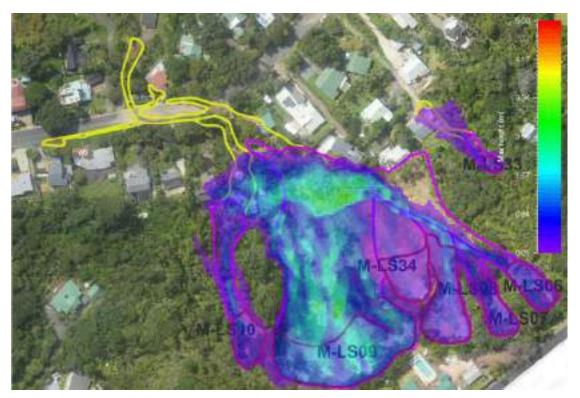
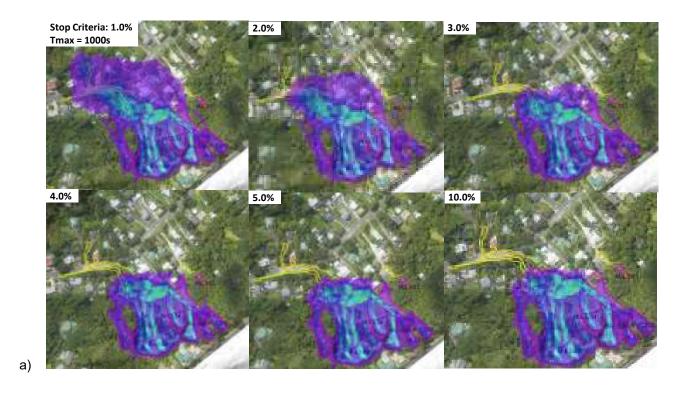
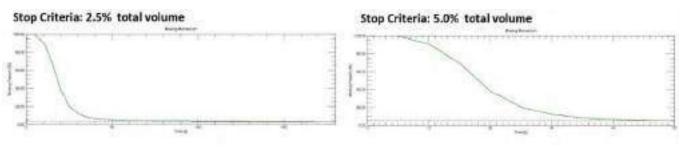


Figure D5 Best calibration of large slide at Motutara Road (M-LS06, 07, 08, 09, 10, 33 & 34). Mu = 0.225, Xi = 87.5, showing with 0.01-5 m filter





b)

Figure D6 The selection of the RAMMS momentum-based 'Percentage total momentum' stop criteria (for  $Xi = 150 \text{ m/s}^2$  and Mu = 0.2).

a) The percentage value of less than 5% shows a wide, creeping debris flow at the end of the simulation (showing 0-5 m maximum debris thickness). For scenarios above 5% the simulated debris extents is similar.

b) The relationship between Moving Percent with time. This shows that a lower percentage total volume Stop Criteria (left), indicated by the red line, leads to longer runout times than when a higher percentage total volume is selected (right). If the lower percentage is used, the result is a debris flow extent that slowly expands towards the end of the simulation.

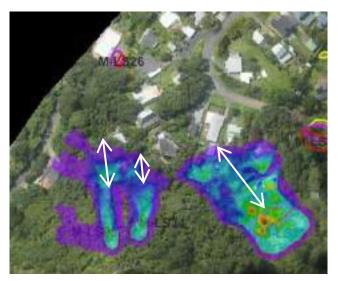


Figure D7 Zone 5 RAMMS simulation showing how the use of (Revision 0) analysis parameters are overly conservative. White arrows show the debris travelling beyond the mapped landslide extents.

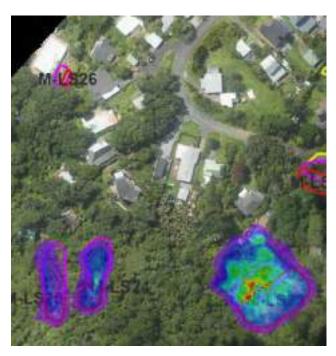
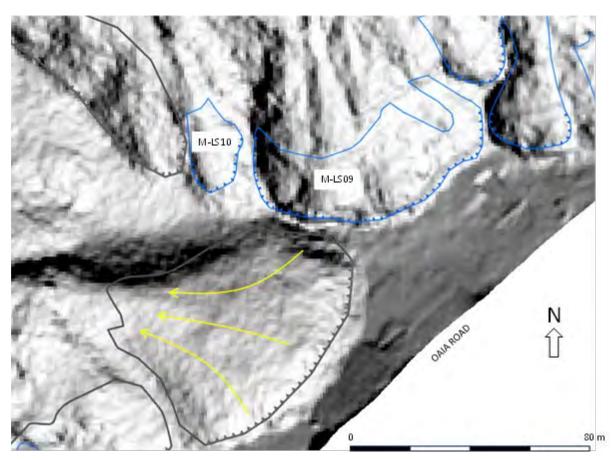


Figure D8 Zone 5 RAMMS calibration using parameters that gives the best match to observed landslide runout



Potential landslide failure zones have been defined by GHD based on having similar geomorphology (ground shape) and geology to February 2023 landslide source areas. The above example shows a potential landslide source zone (grey outline) that has similar bowl-shaped characteristics to recently failed blue areas. Background surface model has a 'hill shade' applied to highlight the geomorphology. Location is below the escarpment and west of Oaia Road (see Figure A115 in Appendix A).

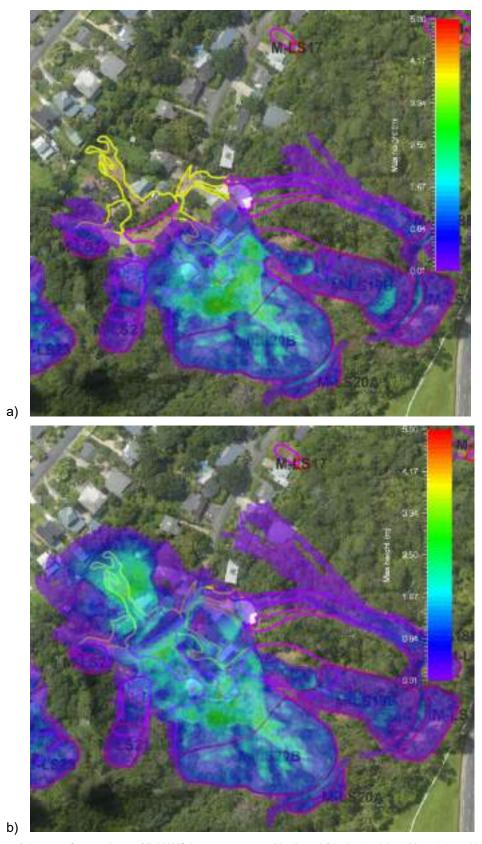
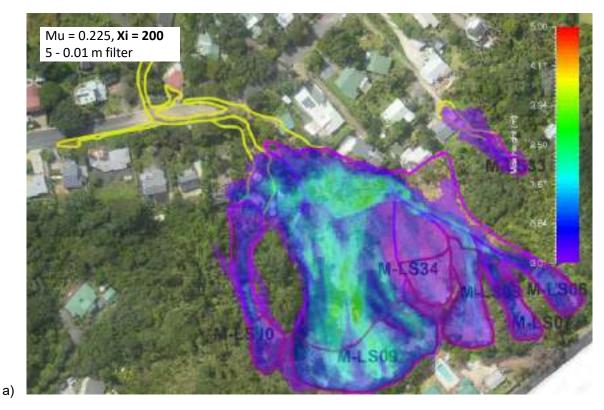


Figure D10 Comparison of RAMMS input parameter Mu (basal friction), with a) Mu = 0.3 and b) Mu = 0.15. All other parameters are unchanged. Note that simulated debris travelled much further with the lower Mu value.



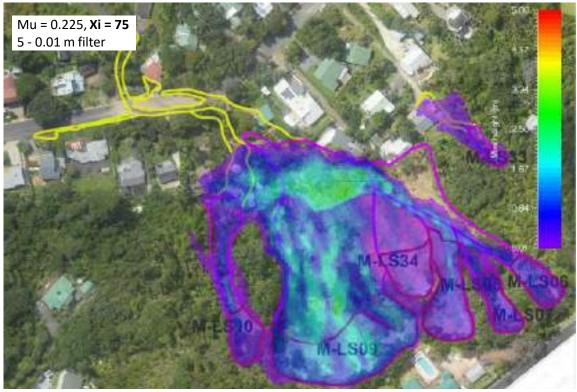
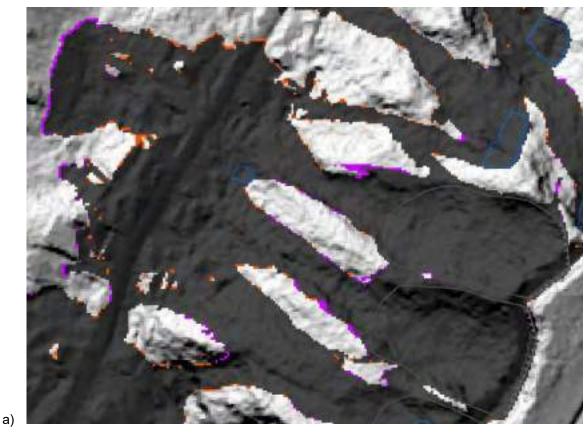


Figure D11 Comparison of RAMMS input parameter Xi (viscous-turbulent friction), with a) Xi = 200 and b) Xi=75. All other parameters are unchanged. Note that the results are nearly identical, and the simulation is not sensitive to Xi.

b)



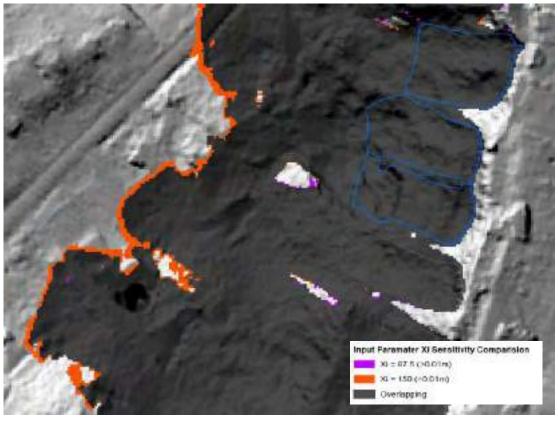


Figure D12 Comparison of RAMMS input parameter Xi (viscous-turbulent friction), with the simulated debris flow extent of Xi =  $87.5 \text{ m/s}^2$  (the GHD-selected value) and  $150 \text{ m/s}^2$  (RAMMS, 2022 mid-range value) overlain to highlight the difference. Each pixel is 1 m². a) is uphill of Domain Crescent and b) is uphill of Motutara Road. The difference in debris flow extent is mostly less than 1 m (horizontal). Broader, less channelised flows travel slightly further with Xi =  $150 \text{ m/s}^2$ .

b)

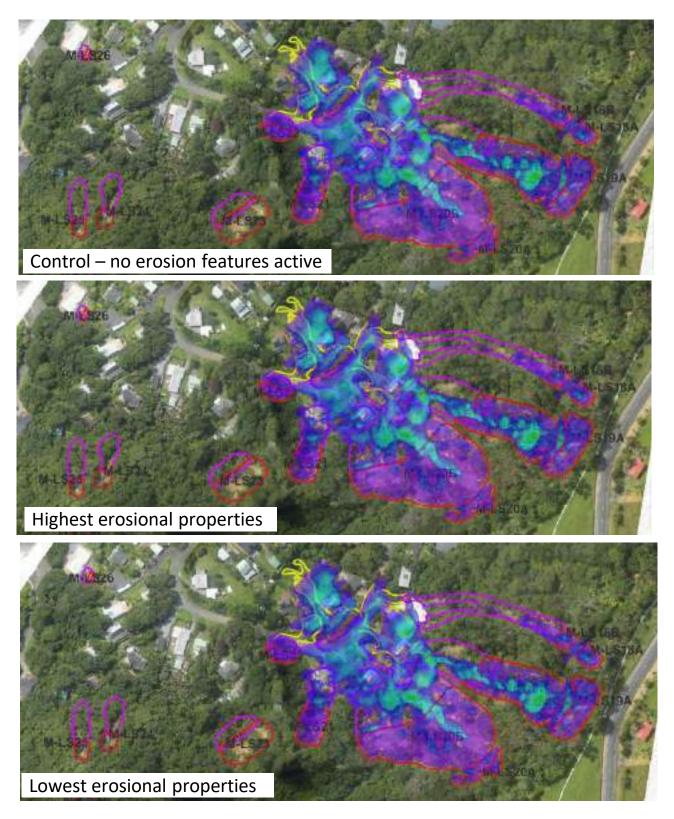


Figure D13 An example of the comparison of the erosional parameters input parameter showing negligible difference between the high and low erosion scenarios, compared with when no erosion features are used.

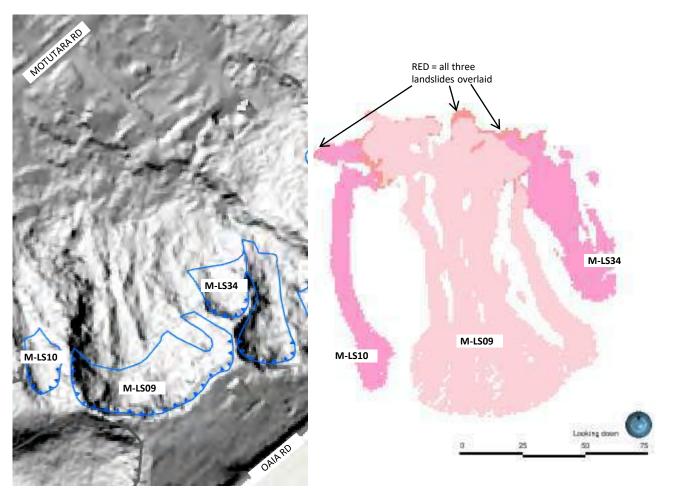


Figure D14 Multiple block release versus individual release comparison. The debris flow runout for three landslide sources was simulated individually (light pink and dark pink on the right image), then all three sources were simulated simultaneously (red shading). Each pixel is 1 m². This shows that modelling failures from numerous landslides increases the debris flow runout distance only slightly – typically less than 1 m horizontally, but up to 4 m in some areas.

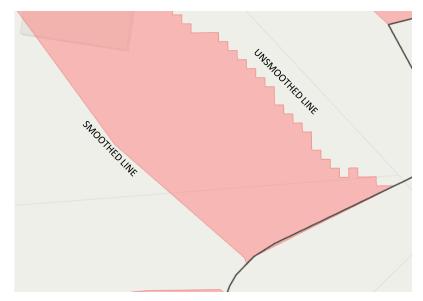


Figure D15 Example of where the predicted red debris flow has been manually smoothed (left side) compared with the right side of the red shading, which is the RAMMS output.

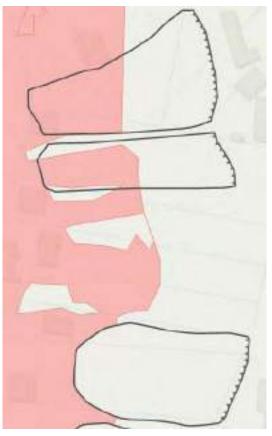


Figure D16 An example of where the red debris flow shading has been removed from the landslide source (bottom of picture), but has been left in when near a dwelling (top of picture)

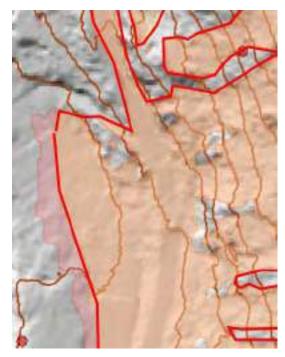


Figure D17 An example of simplification of the predicted debris extent (shown in orange in this work-in-progress example). The thick red line is the edge of the predicted zone in the figures, with the small patches that are less than 0.5 m (shown as grey) not included.

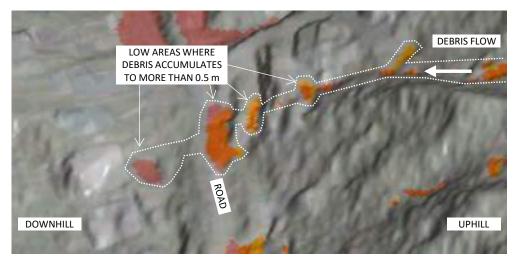


Figure D18 An oblique view of predicted debris flow showing how isolated islands can occur due to the highs and lows of the surface topography.

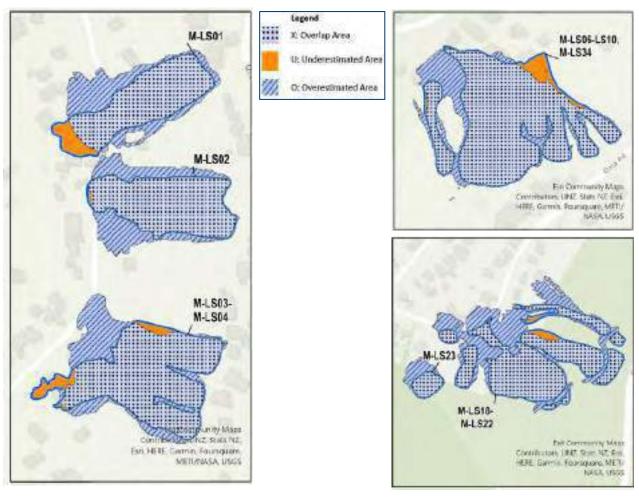


Figure D19 Illustration of the area parameters used for calibration quantification

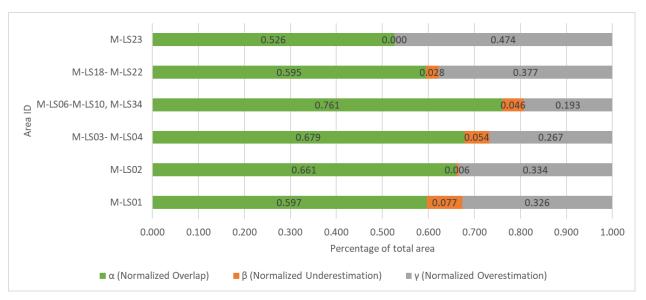


Figure D20 Parameters  $\alpha$ ,  $\beta$  and  $\gamma$  for each landslide

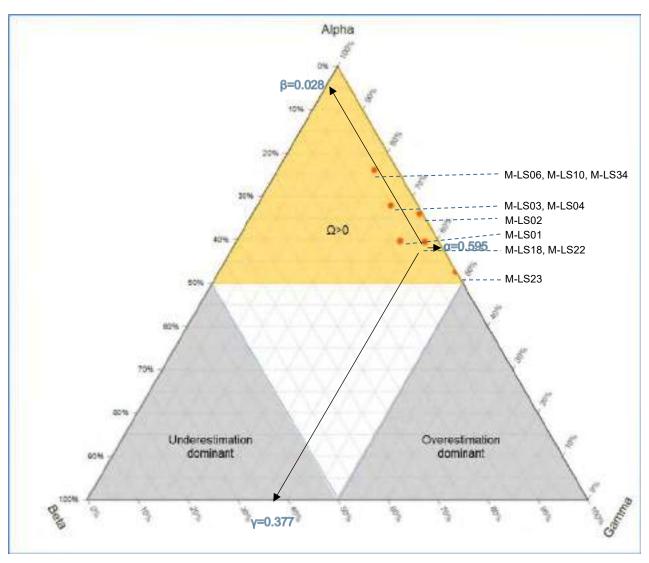


Figure D21 Ternary plot showing the debris flow simulated with RAMMS for the observed landslides used for calibration. Note that the latest calibration data is used for the landslides in Zone 5.

# Appendix E

**Landslide Risk Assessment** 

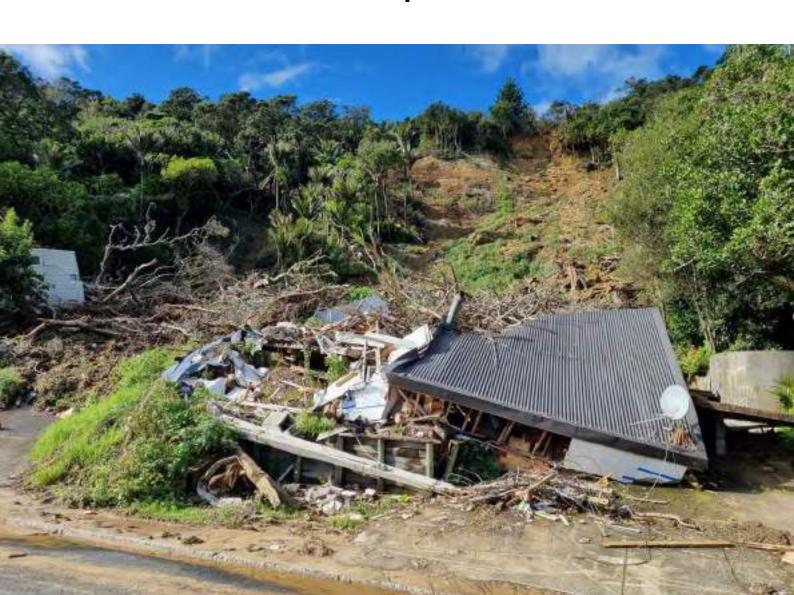


# Waitakere Coastal Communities

**Appendix E – Muriwai Landslide Risk Assessment Report** 

Auckland Council
15 May 2024

→ The Power of Commitment



Project n	name	Waitakere Coas	Waitakere Coastal Communities Landslide Risk Assessment				
Docume	nt title	Waitakere Coastal Communities   Appendix E – Muriwai Landslide Risk Assessment Report				Report	
Project n	number	12612462					
File nam	е	12612462_Appe	endix E Risk_FINALI	Rev2.docx			
Status Revision Author Reviewer			Approved for issue				
Code			Name	Signature	Name	Signature	Date
S4	0	A. Hunter	Don Macfarlane	Drugolen	Roy Pearson	Roy Prarson	03/11/2023
S4	1	A. Hunter M. Howard	Don Macfarlane	Majolen	Roy Pearson	Roy Pearson	30/04/2024
S4	2	A. Hunter M. Howard	Don Macfarlane	Molyplan	Roy Pearson	Roy Prarson	15/05/2024

#### **GHD Limited**

Contact: Matt Howard, Technical Director - Engineering Geology | GHD

27 Napier Street, GHD Centre Level 3

Freemans Bay, Auckland 1010, New Zealand

T +64 9 370 8000 | F +64 9 370 8001 | E aklmail@ghd.com | ghd.com

#### © GHD 2024

This document is and shall remain the property of GHD. The document may only be used for the purpose for which it was commissioned and in accordance with the Terms of Engagement for the commission. Unauthorised use of this document in any form whatsoever is prohibited.

# **Contents**

E1.	Introdu	uction	1
	E1.1	Purpose of this report	1
	E1.2	Background	1
	E1.3	Scope	1
	E1.4	Report structure	2
E2.	Lands	ide Risk Estimation	4
	E2.1	Background	4
	E2.2	Risk assessment methodology	5
	E2.3	Risk Evaluation	6
	E2.4	Landslide Risk Assessment Uncertainty	6
	E2.5	Hazard Characterisation	7
		E2.5.1 Landslide Hazards	7
		E2.5.2 Landslide runout	7
		2.5.2.1 RAMMS debris flow modelling 2.5.2.2 Empirical landslide runout assessment	8
	E2.6	2.5.2.2 Empirical landslide runout assessment  Likelihood of landsliding (P <sub>(H)</sub> )	8 8
	LZ.0	E2.6.1 Rainfall and relationship to landsliding	8
		E2.6.2 Partitioning of likelihood	9
	E2.7	Probability of spatial impact (P <sub>(S:H)</sub> )	10
		E2.7.1 Landslide upslope of dwelling	10
		E2.7.2 Landslide below dwelling	10
	E2.8	Temporal probability (P <sub>(T:S)</sub> )	10
	E2.9	Vulnerability (V <sub>(D:T)</sub> )	11
	E2.10	Risk estimation	18
E3.	Conclu	usions	22
	E3.1	Loss of life risk from debris flow	22
		E3.1.1 Geomorphological Zone 1	22
		E3.1.2 Geomorphological Zone 2	22
		E3.1.3 Geomorphological Zone 3	23
		E3.1.4 Geomorphological Zone 4	23
		E3.1.5 Geomorphological Zone 5 E3.1.6 Geomorphological Zone 6	24 24
	E3.2	Loss of life risk for 85 and 87 Domain Crescent and 207 Motutara Road	24
	E3.2	Closure	24 25
E4.	Refere		26
E5.	Limita		27
_5.	Liiiita		21

# Table index

Summary of accompanying Muriwai reports	3
List of maps and images in Appendix A that are associated with this report	3
AGS Suggested Tolerable loss of life individual risk	6
Summary of adopted P <sub>(H'2)</sub> factors for LS1a and LS1b	10
Summary of vulnerability values adopted for the Waitakere area	11
Summary of adopted vulnerability probability factors	18
Summary of risk estimation for each hazard type by Geomorphological Zone	19
Summary of risk estimation, Zone 1	22
Summary of risk estimation, Zone 2	23
Summary of risk estimation, Zone 3	23
Summary of risk estimation, Zone 4	23
Summary of risk estimation, Zone 5	24
Summary of risk estimation, Zone 6	24
Summary of unmitigated risk estimation for 85 and 87 Domain Crescent and 207 Motutara Road, Muriwai	25
	List of maps and images in Appendix A that are associated with this report AGS Suggested Tolerable loss of life individual risk Summary of adopted P <sub>(H'2)</sub> factors for LS1a and LS1b Summary of vulnerability values adopted for the Waitakere area Summary of adopted vulnerability probability factors Summary of risk estimation for each hazard type by Geomorphological Zone Summary of risk estimation, Zone 1 Summary of risk estimation, Zone 2 Summary of risk estimation, Zone 3 Summary of risk estimation, Zone 4 Summary of risk estimation, Zone 5 Summary of risk estimation, Zone 6 Summary of unmitigated risk estimation for 85 and 87 Domain Crescent and 207

# Figure index

Figure E1	Framework for landslide risk management.	5
Figure E2	Example of a dwelling completely destroyed on Motutara Road where two fatalities occurred.	12
Figure E3	View of same dwelling pictured in Figure E2 showing overall view of landslide with accumulated vegetation at toe of slide.	12
Figure E4	Example of a dwelling on Domain Crescent completely destroyed by landslide with large pile of accumulated vegetation debris on upslope side.	13
Figure E5	View of upslope side of completely destroyed timber frame dwelling. Note large pile of accumulated vegetation debris on left.	13
Figure E6	View of the same dwelling pictured in Figure E5 taken further upslope. Note mixture of soil debris and vegetation. Residence has been moved several metres downslope.	14
Figure E7	View of remains of completely destroyed house on slope above Motutara Road. Note mixture of soil debris and vegetation.	14
Figure E8	Debris flow vulnerability (physical vulnerability) curves as a function of the flow depth, flow velocity, and impact pressure (Kang 2016).	15
Figure E9	Example of a dwelling on Domain Crescent where ground floor of the structure has collapsed causing house to topple over with the upper storey remaining largely intact.	16
Figure E10	View of side profile of dwelling pictured in Figure E9, showing collapse of the ground floor and build-up of vegetation debris at rear.	16
Figure E11	Aerial view of dwelling pictured in Figure E10. The debris flow originated at the far right of the photo.	17
Figure E12	Side view of home above Motutara Road. Note tilting of upper storey wall and deformed window frame.	17
Figure E13	View of upslope side of dwelling pictured in Figure E12 showing accumulated landslide debris against rear wall.	18

# **Appendices**

AC flood frequency memo (20/09/2023)
85 Domain Crescent Landslide Risk Assessment
87 Domain Crescent Landslide Risk Assessment
207 Motutara Road Landslide Risk Assessment

# E1. Introduction

#### **E1.1** Purpose of this report

GHD has been engaged by Auckland Council (AC) to carry out landslide risk assessments as well as to provide landslide risk management advice and geotechnical investigations in the Waitakere area, specifically for the residential areas of Muriwai, Piha and Karekare.

The purpose of this assessment is to present the results of a Quantitative Landslide Risk Assessment (QRA) carried out to estimate the risk of Loss of Life posed by large-scale<sup>1</sup> landslides to individuals in dwellings at Muriwai. We understand the outcome of the QRA will be used to inform future planning decisions, dwelling hazard designations and the revision of current building placards attached following Cyclone Gabrielle.

This report is an appendix to the overall GHD landslide risk report and should be read in conjunction with it, as well as associated appendices. The overall report contains additional background information and the results of other assessments carried out by GHD that are not included in this report. In particular, the GHD Muriwai Engineering Geological Report (hereafter referred to as the Appendix B report) provides a detailed description of the site as well as discussion of site geology and geomorphology, historical landsliding, landslide mapping, landslide classification and slope processes.

#### E1.2 Background

Two significant rainfall events affected the Waitakere area in late January and early February, resulting from the impacts of ex-tropical cyclones Hale and Gabrielle, respectively.

The Cyclone Gabrielle weather event of 14 February 2023 resulted in widespread catastrophic flooding and slope instability in the settlement of Muriwai where several debris avalanches (which included rocks and entrained trees) occurred, some of which turned into saturated debris flows. These flows resulted in damage to buildings and infrastructure. Two fatalities occurred due to impact of landslides on private dwellings. In 1965 a storm also triggered landslides that destroyed dwellings and claimed two lives at Muriwai.

Following the event, rapid building assessment of residential properties was undertaken by Auckland Council in Muriwai, with some houses having access by owners restricted (a yellow placard – e.g. access in daylight hours only) and some for which no access was permitted (a red placard). AC adjusted the location of placards following an area-wide Fahrböschung angle ('F-angle') assessment<sup>2</sup>. The current classifications are indicated by red or yellow dots in the attached figures.

The 'F-angle' assessment roughly estimates the maximum likely distance that a landslide will travel, taking into account the relative location of potentially at-risk properties to the source of risk, i.e. the hazardous slopes of the Muriwai Escarpment. Although the assessment criteria are relatively simplistic and conservative, the 'F-angle' provides a technical basis for classifying (placarding) properties quickly, which was appropriate for the rapid building assessments undertaken where decisions to evacuate people were required urgently.

#### E1.3 Scope

AC requested that this study be limited to the assessment of risks posed by 'large scale' landslide hazards originating from the main escarpment located to the south-east of Muriwai because the initial placard assessment was largely aimed at mitigating risks associated with these landslide hazards. Consequently, this report does not consider smaller, more localised landslide hazards that could originate (or may have already initiated) from other areas in Muriwai, such as within the footprint of individual dwellings, except for three specific properties attached to this report (Appendix E-2, E-3, E-4). Further clarification of this is given in Section 1.3 (footnote 3).

<sup>&</sup>lt;sup>1</sup> In this report 'large scale' landslide hazards refer to landslides originating from the main escarpment that typically have a volume of more than about 50 m³ with the potential to cause total or partial collapse of a dwelling.

<sup>&</sup>lt;sup>2</sup> Documented in an internal AC memo dated 9/03/2023, document ID: AKLCGEO-1790012875-1831

Smaller landslide hazards may include existing geohazards that have resulted from recent failures with the potential to pose risk to life in the immediate short-term (i.e. within the next few years) such as regression of translational failures that occur downslope of dwelling, failure of over-steepened fill and cut slopes, rockfall hazards associated with exposed rock faces/headscarps and/or loose debris remaining upslope of dwellings.

In addition, other possible geotechnical slope instability hazards relating to modified slopes (i.e. human made) may also exist and have potential to pose a risk to life - such as failures of fills, cuttings and damaged retaining walls. This represents hazards that may have a range of likelihood from *almost certain* to *possible*<sup>3</sup>.

The QRA has been carried out in general accordance with the Australian Geomechanics Society Practice Note Guidelines for Landslide Risk Management, commonly known as AGS (2007c). A "risk to property" assessment was not part of our scope of work, which is specifically targeted on risk to life.

Dwellings that have been assessed to be in the path of landslide runout are considered as the elements at risk for this assessment. The risks posed to individuals in the 'open', such as people outside houses or situated on other public property such as roads, are not considered in this report.

Excluded from this report is consideration of the risk relating to dwellings located along the crest of the main escarpment (i.e. the west side of Oaia Road) that could be undermined by the regression of the escarpment edge during future landslide events. Commentary on escarpment edge regression is to be included in a separate, future study.

This report has appended to it landslide risk assessment reports for three individual properties at 85 and 87 Domain Crescent and 207 Motutara Road, Muriwai (see Appendix E-2, E-3 and E-4, respectively).

This assessment considers geotechnical matters only. There may be other non-geotechnical considerations that affect the final property risk categorisation or placard designation of which GHD are not aware, such as flood risk or structural damage to property.

Although considered unlikely, GHD reserves the right to amend the opinions, conclusions and recommendations provided within this report, should additional geotechnical information become available.

This report has been prepared by GHD for Auckland Council and may only be used and relied on by Auckland Council for the purpose agreed between GHD and Auckland Council as set out in section 1.1 of this report.

GHD otherwise disclaims responsibility to any person other than Auckland Council arising in connection with this report. GHD also excludes implied warranties and conditions, to the extent legally permissible.

The services undertaken by GHD in connection with preparing this report were limited to those specifically detailed in the report and are subject to the scope limitations set out in the report.

The opinions, conclusions and any recommendations in this report are based on conditions encountered and information reviewed at the date of preparation of the report. GHD has no responsibility or obligation to update this report to account for events or changes occurring subsequent to the date that the report was prepared.

The opinions, conclusions and any recommendations in this report are based on assumptions made by GHD described in this report. GHD disclaims liability arising from any of the assumptions being incorrect.

#### E1.4 Report structure

This report accompanies numerous other assessments associated with the Muriwai landslides. A list of companion reports is presented in Table E1. A3 plans referred to in this report are listed in Table E2 and additional images and data are presented in Appendices B-1, B-2 and B-3.

<sup>&</sup>lt;sup>3</sup> The terminology used when referencing probabilities has been adopted from the Qualitative Measures of Likelihood table for assessing risk to property in AGS (2007c). For this assessment, these terms and associated probabilities are Certain = 0.99, Almost Certain = 0.1, Likely = 0.01, Possible = 0.001, Unlikely = 0.0001, Very Unlikely = >0.0001

Table E1 Summary of accompanying Muriwai reports

Report Section	Description
Overall Report	Waitakere Coastal Communities Landslide Risk Assessment (Muriwai)
Appendix A	Figures
Appendix B	Engineering Geological Report
Appendix C	Slope Stability Assessment
Appendix D	RAMMS Debris Flow Analysis
Appendix E	Landslide Risk Assessment (this report)
Appendix F	Geotechnical Investigations Report

Table E2 List of maps and images in Appendix A that are associated with this report

Figure No.	Description		
GENERAL SITE	GENERAL SITE LAYOUT		
A101	OVERVIEW		
ENGINEERING	GEOLOGICAL PLANS		
A111	LEGEND		
A112	OVERVIEW		
A113 -A116	CLOSE-UP PLANS		
CROSS SECTIO	CROSS SECTIONS		
A120	CROSS SECTION A-A'		
A121	CROSS SECTION B-B'		
A122	CROSS SECTION C-C'		
A123	CROSS SECTION D-D'		
A124	CROSS SECTION E-E'		
GEOMORPHO	LOGICAL LANDSLIDE ZONES		
A125	SLOPE RELIEF AND PROFILE COMPARISON PLAN		

# E2. Landslide Risk Estimation

## E2.1 Background

The 1998 Thredbo landslide (New South Wales, Australia), in which 18 persons were killed, highlighted the challenges faced from building upon steep slopes and led to the development of the Australian Geomechanics Society Landslide Risk Management (LRM) guidelines, published in 2007 and now commonly referred to as AGS (2007). This suite of guidelines is recognised nationally (Australia) and internationally as world-leading practice. The reader of this report is encouraged to consult the freely available LRM resources which can be accessed at: <a href="https://landsliderisk.org/">https://landsliderisk.org/</a>.

Distilled down to its simplest form, AGS 2007c requires any landslide risk assessment to answer five questions as follows:

- What might happen? (Hazard Identification)
- How likely is it? (Likelihood or Frequency Analysis)
- What damage or injury might occur? (Consequence Analysis)
- How important is it? (Risk Estimation and Risk Evaluation)
- What can be done about it? (Risk Management).

The "Practice Note Guidelines for Landslide Risk Management" (AGS 2007c) provide technical guidance in relation to the processes and tasks to be undertaken by geotechnical practitioners who prepare LRM reports, including appropriate methods and techniques. The Practice Note is a statement of what constitutes good practice by a competent practitioner for LRM, including defensible and up to date methodologies, and provides guidance on the quality of assessment and reporting, including the outcomes to be achieved and how they are to be achieved.

The framework for landslide risk management is presented in Figure E1 and represents a framework widely used internationally.

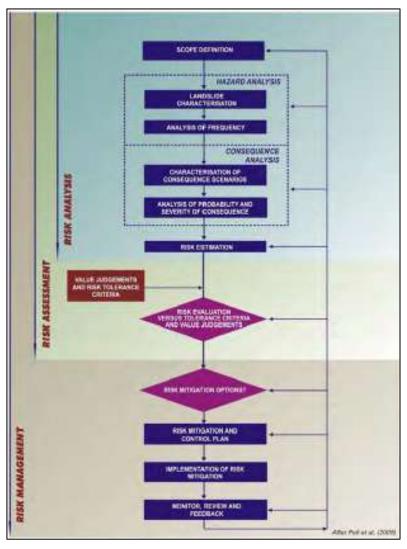


Figure E1 Framework for landslide risk management.

#### E2.2 Risk assessment methodology

AGS (2007c) requires risks to loss of life to be estimated quantitatively for the person-most-at-risk. The person-most-at-risk will often but not always be the person with the greatest spatial temporal probability (i.e. the person most exposed to the risk). The Individual Risk-to-Life is defined as the risk of fatality or injury to any identifiable (named) individual who lives within the zone impacted by the landslide; or who follows a particular pattern of life that might subject him or her to the consequences of the landslide. The risk of 'loss-of-life' to an individual is calculated from:

 $\mathbf{R}_{(LoL)} = \mathbf{P}_{(H)} \times \mathbf{P}_{(S:H)} \times \mathbf{P}_{(T:S)} \times \mathbf{V}_{(D:T)}$ 

Where:

 $\mathbf{R}_{(LoL)}$  is the risk (annual probability of loss of life (death) of an individual).

 $\mathbf{P}_{(H)}$  is the annual probability of the landslide.

 $\mathbf{P}_{\text{(S:H)}}$  is the probability of spatial impact of the landslide impacting a building (location) taking into account the

travel distance and travel direction given the event.

 $\mathbf{P}_{(T:S)}$  is the temporal spatial probability (e.g. of the building or location being occupied by the individual) given

the spatial impact and allowing for the possibility of evacuation given there is warning of the landslide

occurrence.

 $V_{(D:T)}$  is the vulnerability of the individual (probability of loss of life of the individual given the impact).

The main objectives of risk evaluation are usually to compare the assessed risk to risk levels that are acceptable or tolerable to the community, and therefore to decide whether to accept, tolerate or treat the risks, and to set priorities for remediation. The Tolerable Risk Criteria are usually imposed by the regulator, unless agreed otherwise with the owner/client. AGS (2007d) provides discussion and gives the AGS recommendations in relation to tolerable risk for loss of life. These are discussed in Section E2.3.

#### **E2.3** Risk Evaluation

The main objectives of risk evaluation are usually to compare the assessed risk to risk levels that are acceptable or tolerable to the community, and therefore to decide whether to accept, tolerate or treat the risks and to set priorities for remediation. The Tolerable Risk Criteria are usually imposed by the regulator, unless agreed otherwise with the owner/client. AGS (2007d) provides discussion and gives the AGS recommendations in relation to tolerable risk for loss of life. These are summarized in the table below.

Table E3 AGS Suggested Tolerable loss of life individual risk

Situation	Suggested Tolerable Loss of Life Risk for the person most at risk	
Existing Slope / Existing Development	10 <sup>-4</sup> per annum (1E-4 pa), or 1 in 10,000 pa	
New Constructed Slope / New Development / Existing Landslide	10 <sup>-5</sup> per annum (1E-5 pa), or 1 in 100,000 pa	

It is important to distinguish between "acceptable risks" and "tolerable risks". AGS (2007c) states that:

**Tolerable risks** are risks within a range that society can live with so as to secure certain benefits. It is a range of risk regarded as non-negligible and needing to be kept under review and reduced further if practicable.

**Acceptable risks** are risks which everyone affected is prepared to accept. Acceptable risks are usually considered to be one order of magnitude lower than the Tolerable risks.

Appended to this report are GHD landslide risk assessment reports for three individual properties at 85 and 87 Domain Crescent and 207 Motutara Road, that were carried out at the request of AC (see Appendix E-2, E-3, and E-4, respectively). These differ from this area-wide risk study as they pertain to the hazard from localised slope instability within the property boundary. The methodology for these is explained in full in the report for each site and further details are not discussed in this report (the summary of risk for these sites is reproduced in Section E3.2 of this report).

#### **E2.4** Landslide Risk Assessment Uncertainty

The process of risk assessment involves estimation of likelihood, consequence and risks based on available information for the study site. By its very nature much of the data, including historical and current inventories, may be incomplete while understanding of the triggering events has a degree of uncertainty attached to it. Judgement is required to estimate the nature and size of potential hazards, their frequency of occurrence and their impact on a variety of elements at risk. As these judgements are based on the knowledge, experience and understanding of the assessor, it is not unusual for different assessors to make different judgements about the level of risk.

The thought process used in establishing likelihoods, consequences and determining spatial and temporal factors for properties at Muriwai has been documented for transparency. It is important to recognise the inherent imprecisions associated with the risk assessment process given the limitations of the inputs outlined above. Generally, the levels of likelihoods and risks should be thought of as being within a range of typically +/- half an order of magnitude at best.

While the basis for the judgements contained in this report are well documented, and the levels of risk considered to be good representations of reality, the accuracy and precision of the process should not be overestimated and should always be used in an appropriate manner in combination with risk management including mitigation and treatment options.

#### **E2.5** Hazard Characterisation

#### E2.5.1 Landslide Hazards

AGS (2007c) generally states that all credible hazards originating on, above and below the sites should be assessed. This is generally a predictive exercise based on knowledge and understanding of the geological and geomorphological setting with a view to assembling historical evidence for past hazard events.

As noted above, the risk assessment presented in this report is limited to the assessment of risks posed by 'large scale' landslide hazards originating from the main escarpment located to the south-east of Muriwai. Smaller, more localised landslide hazards that could originate (or may have already initiated) from other areas in Muriwai such as small slips within the footprint of individual properties are not considered in this report, unless they have caused widespread damage.

The Appendix B report provides a detailed description of the landslide hazards at the site. The following summary provides an overview of the February 2023 landslides for context in this report.

Based on the GHD mapping and observations, the majority of the landslides<sup>4</sup> originating from the main escarpment comprised an initial translational failure. These failures were typically quite shallow, often in the order of 0.5 m to 1 m deep. Following initial failure, many of the landslide masses developed into rapid debris flows travelling various distances downslope, with some debris crossing Domain Crescent and Motutara Road.

In the southern part of the escarpment (i.e. Geomorphological Zone 3 as defined in the Appendix B report) the debris flows are typically more channelised flows, being somewhat confined by topographic features such as gullies. While this also occurs in the northern parts of the escarpment (i.e. Geomorphological Zone 2), these features are less prevalent in that zone, and the debris flows are commonly broader.

The width of the mapped landslide main (head) scarps / landslide crowns ranges from about 10 m to in excess of 50 m across the main escarpment. The width of the zone of deposited debris at the toe of each landslide varies depending on the extent of channelisation, with some landslide debris spreading out and increasing while in other areas the debris becomes more confined and narrows. The mapped landslides have estimated volumes ranging in the order from tens to thousands of cubic metres.

The landslide hazards considered as part of this assessment are as follows:

- LS1a (Landslide Hazard 1a): Landslides originating from the upper sections of the main escarpment that subsequently form debris flows that travel towards houses / dwellings located on or at the toe of the escarpment. This hazard is representative of the extensive landsliding that occurred across the escarpment in February 2023. This hazard affects areas of the site in the 'predicted modelled debris runout zone' as defined in Section 2.5.2.1.
- LS1b (Landslide Hazard 1b): Hazard as described in LS1a above however a more conservative (i.e. longer) modelled landslide runout zone has been adopted (See Section 2.5.2.1 below).
- LS2a (Landslide Hazard 2a): Landslides originating from the upper sections of the main escarpment that subsequently form debris flows that travel towards houses / dwellings located on or at the toe of the escarpment that are more frequent but less damaging than LS1a. This hazard is analogous to the more localised landsliding that occurred during the 1965 landslide event.
- LS2b (Landslide Hazard 2b): Hazard as described in LS2a above however a more conservative (i.e. longer) modelled landslide runout zone has been adopted (See Section 2.5.2.1 below).

#### E2.5.2 Landslide runout

The landslide runout was assessed using numerical modelling methods discussed below. The dwellings that have been assessed to be in the path of landslide runout are considered as the elements at risk for this assessment. The risks posed to individuals in the 'open', such as people outside houses or situated on other public property such as roads, are not considered in this report.

<sup>&</sup>lt;sup>4</sup> Landslide terminology used in this report generally follows the scheme proposed by Cruden & Varnes (1996).

#### 2.5.2.1 RAMMS debris flow modelling

The 'RAMMS:Debrisflow module' (RAMMS) was used to assess landslide runout and the spatial extent of areas potentially affected by landsliding. RAMMS is a numerical software package developed by the WSL Institute for Snow and Avalanche Research and is used to simulate the runout of debris-laden flows in complex terrain. The modelled landslide runout zones are referred to in this report as the 'Predicted modelled debris runout zone'. This assessment is discussed in the Muriwai RAMMS debris flow analysis report in Appendix D.

The risk assessment presented in this report has relied on the outputs of the RAMMS modelling as the basis for determining areas of the site that could be affected by landsliding. The predicted modelled debris runout zones are presented in Figures A206 to A209 in Appendix A.

#### 2.5.2.2 Empirical landslide runout assessment

Empirical methods have been used to further compare the landslide runout distances predicted using RAMMS and the observed landslide runouts. The empirical methods typically predicted a similar landslide runout to the observed landslide runouts This assessment is discussed in the Appendix B report.

#### E2.6 Likelihood of landsliding $(P_{(H)})$

#### E2.6.1 Rainfall and relationship to landsliding

Council provided GHD with an assessment of available rainfall data associated with Cyclone Gabrielle (Auckland Council 2023) (AC memo). During Cyclone Gabrielle, the tipping bucket rain gauge at Muriwai failed and was inundated by flood waters. The AC memo also provided rainfall analysis using AC's Quantitative Precipitation Estimate (QPE) Rain Radar System, which is a real-time rainfall product that utilises the MetService radar. The rainfall data presented by AC indicates a peak rainfall total for Muriwai during the event of 146.9 mm, occurring over 12-hour period. This total is more than the 100-year event at a 12-hour duration. The data suggests that for the 12-hour duration rainfall, the Annual Recurrence Interval (ARI) is more than 100 years and may be in the order of 250 years. However, we understand that the calculation above the 100-year assessment becomes increasingly unreliable, primarily as a result of the relatively short statistical rainfall records available in New Zealand. For the other durations modelled, the rainfall was below the 100-year event.

The AC memo recommended that an envelope of "risk" is estimated as the ARI figures will change over time as these events are incorporated into the statistical record. The AC memo states that, in general, it is considered reasonable to consider the Cyclone Gabrielle event to be in the range of 100 to 250 year ARI. For this assessment we have assumed that the annual likelihood of a landslide event occurring that is similar in magnitude to the February 2023 event, is about 1 in 100 (i.e., 0.01). This is considered to have a *likely* probability of occurrence as per AGS (2007c) Appendix C criteria.

The assumption of 1 in 100 based on rainfall frequency is a simplifying and possibly conservative assumption that we consider reasonable. It does not consider other factors that could potentially affect stability (antecedent conditions, geology, groundwater conditions, slope height and angle, vegetation, surface water management-overland flow path, overflow from water storage tanks, effect of effluent disposal field), all of which are difficult to quantify.

Based on discussions with AC, we understand that no reliable storm ARI value is available for the 1965 landslide event due to the lack of data. Hayward (2022) states that the 1965 landslides followed 2 days of unusually heavy rain, with a nearby gauge recording 95 mm on August 25 to 26, plus 45 mm in the 12 hours preceding the landslides that occurred on August 27, 1965. However, the author goes on to mention that this is somewhat less than that recorded officially for the 3-day period at Whenuapai (220 mm) and Manukau Heads (190 mm). Review of publicly available NIWA rainfall data suggests the ARI for a 3-day rainfall event of similar magnitude is less than 100. Considering the 1965 landslide event affected a considerably smaller area of the Muriwai escarpment than the recent 2023 event, suggests that the triggering rainfall event was smaller. Given the uncertainties above, we have assumed that a rainfall event with an ARI of about 50, could trigger a similar landslide event to that experienced in 1965.

The AC memo further recommended that risk assessment reports consider the potential for climate change to increase the frequency of high intensity rainfall. We understand that the National Institute of Water and

Atmospheric Research (NIWA) has projected a 20% increase in rainfall intensity over the next 100 years which suggests that a 250-year ARI event could increase to a 50-year ARI event. Consequently, we have also included sensitivity checks using more frequent ARI values as discussed in Section E2.6.2.

#### E2.6.2 Partitioning of likelihood

The rainfall events discussed in Section E2.6.1, the estimation of recurrence intervals for those events and the occurrence of the observed hazards, form the basis for the estimated probability of occurrence for the landslide hazards. However, observations of the recent and past events noted that not all similar slopes failed as a result of the initiating storm event and as such, additional considerations for probability of occurrence have been included within the analysis by using conditional probabilities as follows:

$$P_{(H)} = P_{(H'1)} \times P_{(H'2)}$$

Where:

 $P_{(H'1)}$  = Probability that the rainfall threshold for the landslide hazard is exceeded, which is taken as a proxy for landslide initiation. This is assumed to be 1 in 100 or 0.01 for LS1a and LS1b (see Section E2.6.1) or 1 in 50 or 0.02 under the influence of future climate change. For LS2a and LS2b,  $P_{(H'1)}$  is assumed to be 1 in 50 or 0.02. Under the influence of future climate change we have assumed the ARI for the same event will be twice as likely (i.e. an ARI 100 event becomes an ARI 50 event).

 $P_{(H'2)}$  = Probability that the slope for the specific assessment fails, which we relate to the proportion of the area of actual failed slopes out of the total area of all slopes present. This probability is based on a spatial analysis of the total area of failed landslides slopes compared to the total area of all slopes in each of the geomorphological zones defined in the Appendix B report. The adopted  $P_{(H'2)}$  values for LS1a and LS1b are presented in Table E4.

Geomorphological Zones 1 and 6 have both been assigned likelihood values that differ from those of other geomorphological zones. As discussed in the Appendix B report, no landslides were triggered in Zone 1 and only relatively localised small-scale landslides with limited runout were triggered in Zone 6. However, historical landslide headscarp features are apparent in the LiDAR data across these areas and we interpret this to mean that these areas are susceptible to large, potentially damaging landslides, especially in future storm events that are larger than Cyclone Gabrielle. On this basis, we consider a  $P_{(H'2)}$  value that is greater than zero for the  $P_{(H'1)}$  0.01 (i.e. 1 in 100-year storm) event. Given there were either no or very limited landslides observed in these zones in February 2023, we have adopted a  $P_{(H'2)}$  value of 0.01. There is no basis for estimating the potential for landslides during less frequent, more intense storms, i.e. a 1 in 1000-year storm ( $P_{(H'1)}$  of 0.001).

For Zones 2, 3 and 4 the adopted  $P_{(H'2)}$  value for LS2a / LS21b is 0.02 based on spatial analysis of historical mapping of the 1965 landslide area.

Table E4 Summary of adopted P<sub>(H'2)</sub> factors for LS1a and LS1b

Geomorphological zone	P <sub>(H'2)</sub>
1	0.01
2	0.29
3	0.07
4	0.56
5	0.06
6	0.01

# E2.7 Probability of spatial impact $(P_{(S:H)})$

#### E2.7.1 Landslide upslope of dwelling

The AGS definition of spatial probability is represented by single term  $P_{(S:H)}$  and is described as the probability of spatial impact by the landslide on the element at risk, given the landslide occurs and taking into account the travel direction and travel distance or reach.

For areas of the site located within the predicted modelled debris runout zones (LS1a, LS2a),  $P_{(S:H)} = 1$ .

For areas of the site located within the conservative modelled debris runout zones (LS1b, LS2b), we have assumed that P<sub>(S:H)</sub> is about one order of magnitude lower (i.e. about a 10% probability of exceeding the predicted modelled debris runout zones). P<sub>(S:H)</sub> is therefore = 0.1.

#### E2.7.2 Landslide below dwelling

Landslides below dwellings are not considered in this study as all landslides occurred on the escarpment, upslope of the dwellings, which are located at the toe of the slope. Dwellings at the top of the escarpment (i.e. on the west side of Oaia Road) that could be undermined by the regression of the escarpment edge in future landslide events are reported in a separate, future study.

# E2.8 Temporal probability $(P_{(T:S)})$

This assessment has not considered specific occupancy scenarios for each individual dwelling. We acknowledge that the occupancy of each dwelling could vary significantly depending on the demographics of the residents and the usage of the dwelling. For example, some may be predominantly used as holiday accommodation, occupied mainly on weekends, whereas others could be permanently occupied by working families. For risk assessments conducted at this scale, and given potential future planning decisions, it is typically not appropriate to consider unique occupancy scenarios because the usage of each dwelling will likely change each time the ownership of the property changes.

We have not considered the possibility that individuals could evacuate before the landslide event occurs as the landslide history at Muriwai suggests landslides occur rapidly with few obvious signs of failure prior to the event occurring. It is also not reasonable to expect individuals to be aware of potential landsliding should the rainfall triggering event occur during the night.

This assessment has assumed the following occupancies:

- Dwellings are typically occupied for 15 hours each day during weekdays;
- On weekends, dwellings are occupied for about 20 hours each day;

The percentage of time a dwelling is occupied is therefore about 68%.

Any further delineations of the spatial variations in occupancy (i.e. if a bedroom is at the front or the rear of the house etc) are not considered feasible or warranted within the context of the precision of this assessment.

# E2.9 Vulnerability $(V_{(D:T)})$

AGS (2007c, Appendix F) includes a table of vulnerability values for various inundation and building damage scenarios as adapted by Finlay et al (1999). It is important to note that the AGS (2007c) vulnerability table does not adequately cater for all the building damage scenarios GHD has observed in the Waitakere area. GHD has therefore further adapted this table and combined it with information from the TfNSW Guide to Slope Risk Analysis (2014) as well as observations of damage to buildings and structures resulting from the recent landslides in the Waitakere area (Table E5).

These values have been used as a guide and expert judgement has been applied to select a value within the range of values where appropriate.

Table E5 Summary of vulnerability values adopted for the Waitakere area

Case	Range	Typical value used in assessments	Comments
Person in a building that collapses under impact from debris flow	0.8 -1.0	0.9	Death is almost certain. Evacuation unlikely to occur
If building is inundated with debris and the person is buried	0.8 -1.0	0.8	Very high potential for death Evacuation unlikely to occur
If building is inundated with debris but no collapse occurs and the person is not buried	0.01 -0.1	0.1	High chance of survival Evacuation unlikely to occur
If the debris strikes the building only	0.001-0.05	0.01	High chance of survival

Most dwellings constructed below the escarpment at Muriwai comprise timber frame structures with various forms of lightweight cladding such as weatherboard and fibre cement. The extent of damage to dwellings varied considerably depending on where each was located with respect to the path of each landslide. During the mapping and reconnaissance visits undertaken by GHD it was commonly observed that total destruction occurred to the structure when the flow height of the landslide exceeded approximately 0.5 m. Figure E2 presents an example of a dwelling that was completely destroyed, sadly resulting in two fatalities. It is important to note that total destruction also occurred to many other dwellings in Muriwai that had already been evacuated. Had evacuation not occurred the survivability in many of these properties would have been very low.

As discussed in the Appendix B report, the 1965 Muriwai landslides destroyed two dwellings, killing two of four people who were occupying one of the houses. One house was completely destroyed by the landslide and collapsed while the other was "swept off its foundation" and carried across Domain Crescent where it came to rest surrounded by debris (Hayward 2022).

In many observed instances trees entrained in the landslide mass played a large role in the destruction of dwellings in the 2023 event (Figure E4 to Figure E7). Accumulations of trees and other vegetation were commonly rafted and entrained towards the top of each slide mass which subsequently impacted the upslope side of dwellings. The thickness of these accumulated piles of vegetation debris sometimes exceeded 3 m. It is clear that the direct impact effects of the vegetation piles into dwellings were responsible for extensive damage and complete destruction in a number of circumstances.



Figure E2 Example of a dwelling completely destroyed on Motutara Road where two fatalities occurred.



Figure E3 View of same dwelling pictured in Figure E2 showing overall view of landslide with accumulated vegetation at toe of slide.



Figure E4 Example of a dwelling on Domain Crescent completely destroyed by landslide with large pile of accumulated vegetation debris on upslope side.



Figure E5 View of upslope side of completely destroyed timber frame dwelling. Note large pile of accumulated vegetation debris on left.



Figure E6 View of the same dwelling pictured in Figure E5 taken further upslope. Note mixture of soil debris and vegetation. Residence has been moved several metres downslope.



Figure E7 View of remains of completely destroyed house on slope above Motutara Road. Note mixture of soil debris and vegetation.

The observations of building damage at Muriwai are in good agreement with a study by Kang et al. (2016) that compared physical vulnerability of different types of building structures to debris flow events. In this context, physical vulnerability is a representation of the expected degree of loss and is quantified on a scale of 0 (no

damage) to 1 (total destruction) (Fell et al. 2005). This should not be confused with the vulnerability to individuals (probability of loss of life of the individual given the impact). Kang et al. (2016) developed a number of vulnerability curves using the degree of damage to buildings coupled with intensities of the debris flow events (Figure E8).

The Kang et al. (2016) vulnerability curves for both flow depth and velocity typically are in good agreement with the Muriwai observations and modelling. For example, total destruction of a timber frame structure becomes increasingly likely as the flow depth approaches 1 m thickness.

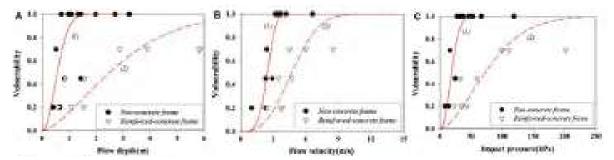


Figure E8 Debris flow vulnerability (physical vulnerability) curves as a function of the flow depth, flow velocity, and impact pressure (Kang 2016).

Despite the total destruction of many houses in Muriwai, a number of houses were impacted by more than 0.5 m thickness of debris and associated vegetation and were not completely destroyed. For example, Figure E9 to Figure E11 shows a two-storey dwelling on Domain Crescent that toppled over, leaving the upper storey largely intact. The ground floor of the structure has completely collapsed and is inundated with debris. In this example, had individuals been present on the ground floor it is unlikely they would have survived. However, the survivability on the upper floor is assessed to be relatively high, perhaps only leading to injuries should individuals have been present. This example demonstrates the challenges of adopting a representative vulnerability value for individuals occupying a single dwelling.

Figure E12 and Figure E13 present another example of a two-storey timber frame house impacted by a landslide. The dwelling has deformed as is evident by the tilting of walls and distortion of door frames, but the structure is largely intact, and no inundation appears to have occurred. The survivability from this damage is also considered to be very high.

There are many factors that could have contributed to some houses experiencing significantly less damage than others, despite the reasons not being immediately obvious based on observations alone. For example, the flow velocity in some instances may have been very low by the time the distal end of the flow reached a house. Alternatively, the construction methods of some houses may be more resistant to landslide impacts than others. Given these uncertainties it is not reasonable or practical to assign unique vulnerability values to different dwellings at the site.



Figure E9 Example of a dwelling on Domain Crescent where ground floor of the structure has collapsed causing house to topple over with the upper storey remaining largely intact.



Figure E10 View of side profile of dwelling pictured in Figure E9, showing collapse of the ground floor and build-up of vegetation debris at rear.



Figure E11 Aerial view of dwelling pictured in Figure E10. The debris flow originated at the far right of the photo.



Figure E12 Side view of home above Motutara Road. Note tilting of upper storey wall and deformed window frame.



Figure E13 View of upslope side of dwelling pictured in Figure E12 showing accumulated landslide debris against rear wall.

Table E6 presents a summary of the adopted vulnerability probability factors used in this assessment.

Table E6 Summary of adopted vulnerability probability factors

Hazard	Vulnerability (V <sub>(D:T)</sub> )	Comments
LS1a	0.8	Building is likely to be inundated and may collapse. Very high potential for death. Evacuation unlikely to occur. Since 1965, four fatalities have occurred at Muriwai where building collapse has occurred.
LS1b	0.8	Building is likely to be inundated and may collapse. Very high potential for death. Evacuation unlikely to occur. Since 1965, four fatalities have occurred at Muriwai where building collapse has occurred.
LS2a	0.8	Building is likely to be inundated and may collapse. Very high potential for death. Evacuation unlikely to occur. Since 1965, four fatalities have occurred at Muriwai where building collapse has occurred.
LS2b	0.8	Building is likely to be inundated and may collapse. Very high potential for death. Evacuation unlikely to occur. Since 1965, four fatalities have occurred at Muriwai where building collapse has occurred.

# E2.10 Risk estimation

A summary of the risk estimation for each Geomorphological Zone is presented in Table E7 below. A sensitivity check assuming a higher probability of occurrence for  $P_{(H)}$  is included for comparative purposes. As can be seen, this increases the risk and, in some cases in Zones 1 and 6, changes the risk evaluation.

Table E7 Summary of risk estimation for each hazard type by Geomorphological Zone

Geomorphological Zone	Hazard	Description	lan	obability of the idslide P(H)	Spatial probability	Temporal probability	Vulnerability	Risk	Risk Evaluation*
			P <sub>(H'1)</sub>	P <sub>(H'2)</sub>	P <sub>(S:H)</sub>	P <sub>(T:S)</sub>	V <sub>(D:T)</sub>	R <sub>(LOL)</sub>	
1	LS1a	Debris Flow upslope of dwelling	0.010	0.01	1.00	0.68	0.80	5.4 x 10 <sup>-5</sup>	Tolerable
	LS1a	Sensitivity Check (Debris Flow upslope of dwelling)	0.020	0.01	1.00	0.68	0.80	1.1 x 10 <sup>-4</sup>	Not tolerable
	LS1b	Debris Flow upslope of dwelling (longer modelled runout)	0.010	0.01	0.10	0.68	0.80	5.4 x 10 <sup>-6</sup>	Acceptable
	LS1b	Sensitivity Check (Debris Flow upslope of dwelling)	0.020	0.01	0.10	0.68	0.80	1.1 x 10 <sup>-5</sup>	Tolerable
	LS2a	Debris Flow upslope of dwelling (more frequent, less widespread)	0.010	0.01	1.00	0.68	0.80	5.4 x 10 <sup>-5</sup>	Tolerable
	LS2a	Sensitivity Check (Debris Flow upslope of dwelling)	0.020	0.01	1.00	0.68	0.80	1.1 x 10 <sup>-4</sup>	Not tolerable
	LS2b	Debris Flow upslope of dwelling (more frequent, less widespread with longer modelled runout)	0.010	0.01	0.10	0.68	0.80	5.4 x 10 <sup>-6</sup>	Acceptable
	LS2b	Sensitivity Check (Debris Flow upslope of dwelling)	0.020	0.01	0.10	0.68	0.80	1.1 x 10 <sup>-5</sup>	Tolerable
2	LS1a	Debris Flow upslope of dwelling	0.010	0.29	1.00	0.68	0.80	1.6 x 10 <sup>-3</sup>	Not tolerable
	LS1a	Sensitivity Check (Debris Flow upslope of dwelling)	0.020	0.29	1.00	0.68	0.80	3.2 x 10 <sup>-3</sup>	Not tolerable
	LS1b	Debris Flow upslope of dwelling (longer modelled runout)	0.010	0.29	0.10	0.68	0.80	1.6 x 10 <sup>-4</sup>	Not tolerable
	LS1b	Sensitivity Check (Debris Flow upslope of dwelling)	0.020	0.29	0.10	0.68	0.80	3.2 x 10 <sup>-4</sup>	Not tolerable
	LS2a	Debris Flow upslope of dwelling (more frequent, less widespread)	0.020	0.02	1.00	0.68	0.80	2.2 x 10 <sup>-4</sup>	Not tolerable
	LS2a	Sensitivity Check (Debris Flow upslope of dwelling)	0.040	0.02	1.00	0.68	0.80	4.4 x 10 <sup>-4</sup>	Not tolerable
	LS2b	Debris Flow upslope of dwelling (more frequent, less widespread with longer modelled runout)	0.020	0.02	0.10	0.68	0.80	2.2 x 10 <sup>-5</sup>	Tolerable
	LS2b	Sensitivity Check (Debris Flow upslope of dwelling)	0.040	0.02	0.10	0.68	0.80	4.4 x 10 <sup>-5</sup>	Tolerable
3	LS1a	Debris Flow upslope of dwelling	0.010	0.07	1.00	0.68	0.80	3.8 x 10 <sup>-4</sup>	Not tolerable
	LS1a	Sensitivity Check (Debris Flow upslope of dwelling)	0.020	0.07	1.00	0.68	0.80	7.6 x 10 <sup>-4</sup>	Not tolerable
	LS1b	Debris Flow upslope of dwelling (longer modelled runout)	0.010	0.07	0.10	0.68	0.80	3.8 x 10 <sup>-5</sup>	Tolerable
	LS1b	Sensitivity Check (Debris Flow upslope of dwelling)	0.020	0.07	0.10	0.68	0.80	7.6 x 10 <sup>-5</sup>	Tolerable
	LS2a	Debris Flow upslope of dwelling (more frequent, less widespread)	0.020	0.02	1.00	0.68	0.80	2.2 x 10 <sup>-4</sup>	Not tolerable
	LS2a	Sensitivity Check (Debris Flow upslope of dwelling)	0.040	0.02	1.00	0.68	0.80	4.4 x 10 <sup>-4</sup>	Not tolerable
	LS2b	Debris Flow upslope of dwelling (more frequent, less widespread with longer modelled runout)	0.020	0.02	0.10	0.68	0.80	2.2 x 10 <sup>-5</sup>	Tolerable

Geomorphological Zone	Hazard	Description	Annual p	robability of the andslide P <sub>(H)</sub>	Spatial probability	Temporal probability	Vulnerability	Risk	Risk Evaluation*
			P <sub>(H'1)</sub>	P <sub>(H'2)</sub>	P <sub>(S:H)</sub>	P <sub>(T:S)</sub>	V <sub>(D:T)</sub>	R <sub>(LOL)</sub>	
	LS2b	Sensitivity Check (Debris Flow upslope of dwelling)	0.040	0.02	0.10	0.68	0.80	4.4 x 10 <sup>-5</sup>	Tolerable
4	LS1a	Debris Flow upslope of dwelling	0.010	0.56	1.00	0.68	0.80	3.0 x 10 <sup>-3</sup>	Not tolerable
	LS1a	Sensitivity Check (Debris Flow upslope of dwelling)	0.020	0.56	1.00	0.68	0.80	6.1 x 10 <sup>-3</sup>	Not tolerable
	LS1b	Debris Flow upslope of dwelling (longer modelled runout)	0.010	0.56	0.10	0.68	0.80	3.0 x 10 <sup>-4</sup>	Not tolerable
	LS1b	Sensitivity Check (Debris Flow upslope of dwelling)	0.020	0.56	0.10	0.68	0.80	6.1 x 10 <sup>-4</sup>	Not tolerable
	LS2a	Debris Flow upslope of dwelling (more frequent, less widespread)	0.020	0.02	1.00	0.68	0.80	2.2 x 10 <sup>-4</sup>	Not tolerable
	LS2a	Sensitivity Check (Debris Flow upslope of dwelling)	0.040	0.02	1.00	0.68	0.80	4.4 x 10 <sup>-4</sup>	Not tolerable
	LS2b	Debris Flow upslope of dwelling (more frequent, less widespread with longer modelled runout)	0.020	0.02	0.10	0.68	0.80	2.2 x 10 <sup>-5</sup>	Tolerable
	LS2b	Sensitivity Check (Debris Flow upslope of dwelling)	0.040	0.02	0.10	0.68	0.80	4.4 x 10 <sup>-5</sup>	Tolerable
5	LS1a	Debris Flow upslope of dwelling	0.010	0.06	1.00	0.68	0.80	3.3 x 10 <sup>-4</sup>	Not tolerable
	LS1a	Sensitivity Check (Debris Flow upslope of dwelling)	0.020	0.06	1.00	0.68	0.80	6.5 x 10 <sup>-4</sup>	Not tolerable
	LS1b	Debris Flow upslope of dwelling (longer modelled runout)	0.010	0.06	0.10	0.68	0.80	3.3 x 10 <sup>-5</sup>	Tolerable
	LS1b	Sensitivity Check (Debris Flow upslope of dwelling)	0.020	0.06	0.10	0.68	0.80	6.5 x 10 <sup>-5</sup>	Tolerable
	LS2a	Debris Flow upslope of dwelling (more frequent, less widespread)	0.020	0.02	1.00	0.68	0.80	2.2 x 10 <sup>-4</sup>	Not tolerable
	LS2a	Sensitivity Check (Debris Flow upslope of dwelling)	0.040	0.02	1.00	0.68	0.80	4.4 x 10 <sup>-4</sup>	Not tolerable
	LS2b	Debris Flow upslope of dwelling (more frequent, less widespread with longer modelled runout)	0.020	0.02	0.10	0.68	0.80	2.2 x 10 <sup>-5</sup>	Tolerable
	LS2b	Sensitivity Check (Debris Flow upslope of dwelling)	0.040	0.02	0.10	0.68	0.80	4.4 x 10 <sup>-5</sup>	Tolerable
6	LS1a	Debris Flow upslope of dwelling	0.010	0.01	1.00	0.68	0.80	5.4 x 10 <sup>-5</sup>	Tolerable
	LS1a	Sensitivity Check (Debris Flow upslope of dwelling)	0.020	0.01	1.00	0.68	0.80	1.1 x 10 <sup>-4</sup>	Not tolerable
	LS1b	Debris Flow upslope of dwelling (longer modelled runout)	0.010	0.01	0.10	0.68	0.80	5.4 x 10 <sup>-6</sup>	Acceptable
	LS1b	Sensitivity Check (Debris Flow upslope of dwelling)	0.020	0.01	0.10	0.68	0.80	1.1 x 10 <sup>-5</sup>	Tolerable
	LS2a	Debris Flow upslope of dwelling (more frequent, less widespread)	0.010	0.01	1.00	0.68	0.80	5.4 x 10 <sup>-5</sup>	Tolerable
	LS2a	Sensitivity Check (Debris Flow upslope of dwelling)	0.020	0.01	1.00	0.68	0.80	1.1 x 10 <sup>-4</sup>	Not tolerable
	LS2b	Debris Flow upslope of dwelling (more frequent, less widespread with longer modelled runout)	0.010	0.01	0.10	0.68	0.80	5.4 x 10 <sup>-6</sup>	Acceptable

Geomorphological Zone	Hazard	Description	land	oability of the slide (H)	Spatial probability	Temporal probability	Vulnerability	Risk	Risk Evaluation*
			P <sub>(H'1)</sub>	P <sub>(H'2)</sub>	P <sub>(S:H)</sub>	$P_{(T:S)}$	$V_{(D:T)}$	$R_{(LOL)}$	
	LS2b	Sensitivity Check (Debris Flow upslope of dwelling)	0.020	0.01	0.10	0.68	0.80	1.1 x 10 <sup>-5</sup>	Tolerable

<sup>\*</sup>The evaluation is a guide only based on recommendations from AGS (2007) which provides a suggested tolerable annual Loss of Life Risk for the person most at risk (existing slopes) is 1 x 10<sup>-4</sup> (1 in 10,000).

# E3. Conclusions

The travel paths for the assessed landslide hazards are based on the 'predicted modelled debris runout zone' as discussed in Section E2.5 (see Figures A206 to A209 in Appendix A). The estimated risks presented in this report for debris flow hazards only apply to areas of the site located within these zones. A summary of the estimated risks is presented below.

We emphasise that this evaluation is a guide only based on recommendations from AGS (2007) which provides a suggested tolerable Loss of Life Risk for the person most at risk (existing slopes).

#### E3.1 Loss of life risk from debris flow

## E3.1.1 Geomorphological Zone 1

With regards to the LS1a hazard, these risks have been assessed to be tolerable according to the evaluation against the AGS (2007c) suggested tolerable Loss of Life Risk limit for the person most at risk. The risk associated with LS2a has also been estimated to be below the AGS (2007c) suggested tolerable Loss of Life Risk limit. Using a higher likelihood related to climate change for each of these cases would result in higher levels of risk evaluated as not tolerable against the AGS (2007c) recommended criteria (see Table E3).

Table E8 Summary of risk estimation, Zone 1

Geomorphological Zone	Hazard	Description	Risk Evaluation
1	LS1a	Debris Flow upslope of dwelling	Tolerable
	LS1b	Debris Flow upslope of dwelling (longer modelled runout)	Acceptable
	LS2a	Debris Flow upslope of dwelling (more frequent, less widespread)	Tolerable
	LS2b	Debris Flow upslope of dwelling (more frequent, less widespread with longer modelled runout)	Tolerable

# E3.1.2 Geomorphological Zone 2

With regards to hazards LS1a, LS1b and LS2a, we have estimated these risks to **exceed** the AGS (2007c) suggested tolerable Loss of Life Risk for the person most at risk (Table E9). Using a higher likelihood related to climate change for each of these cases also results in higher levels of risk evaluated as not tolerable against the AGS (2007c) recommended criteria (see Table E3).

Table E9 Summary of risk estimation, Zone 2

Geomorphological Zone	Hazard	Description	Risk Evaluation
2	LS1a	Debris Flow upslope of dwelling	Not tolerable
	LS1b	Debris Flow upslope of dwelling (longer modelled runout)	Not tolerable
	LS2a	Debris Flow upslope of dwelling (more frequent, less widespread)	Not tolerable
	LS2b	Debris Flow upslope of dwelling (more frequent, less widespread with longer modelled runout)	Tolerable

# E3.1.3 Geomorphological Zone 3

With regards to hazards LS1a and LS2a, we have estimated these risks to **exceed** the AGS (2007c) suggested tolerable Loss of Life Risk for the person most at risk (Table E10). Using a higher likelihood related to climate change for each of these cases also results in higher levels of risk evaluated as not tolerable against the AGS (2007c) recommended criteria (see Table E3).

Table E10 Summary of risk estimation, Zone 3

Geomorphological Zone	Hazard	Description	Risk Evaluation
3	LS1a	Debris Flow upslope of dwelling	Not tolerable
	LS1b	Debris Flow upslope of dwelling (longer modelled runout)	Tolerable
	LS2a	Debris Flow upslope of dwelling (more frequent, less widespread)	Not tolerable
	LS2b	Debris Flow upslope of dwelling (more frequent, less widespread with longer modelled runout)	Tolerable

# E3.1.4 Geomorphological Zone 4

With regards to hazards LS1a, LS1b and LS2a, we have estimated these risks to **exceed** the AGS (2007c) suggested tolerable Loss of Life Risk for the person most at risk (Table E11). Using a higher likelihood related to climate change for each of these cases also results in higher levels of risk evaluated as not tolerable against the AGS (2007c) recommended criteria (see Table E3).

Table E11 Summary of risk estimation, Zone 4

Geomorphological Zone	Hazard	Description	Risk Evaluation*
4	LS1a	Debris Flow upslope of dwelling	Not tolerable
	LS1b	Debris Flow upslope of dwelling (longer modelled runout)	Not tolerable
	LS2a	Debris Flow upslope of dwelling (more frequent, less widespread)	Not tolerable
	LS2b	Debris Flow upslope of dwelling (more frequent, less widespread with longer modelled runout)	Tolerable

## E3.1.5 Geomorphological Zone 5

With regards to hazards LS1a and LS2a, we have estimated these risks to **exceed** the AGS (2007c) suggested tolerable Loss of Life Risk for the person most at risk (Table E12). Using a higher likelihood related to climate change for each of these cases also results in higher levels of risk evaluated as not tolerable against the AGS (2007c) recommended criteria (see Table E3).

Table E12 Summary of risk estimation, Zone 5

Geomorphological Zone	Hazard	Description	Risk Evaluation
5	LS1a	Debris Flow upslope of dwelling	Not tolerable
	LS1b	Debris Flow upslope of dwelling (longer modelled runout)	Tolerable
	LS2a	Debris Flow upslope of dwelling (more frequent, less widespread)	Not tolerable
	LS2b	Debris Flow upslope of dwelling (more frequent, less widespread with longer modelled runout)	Tolerable

## E3.1.6 Geomorphological Zone 6

With regards to the LS1a hazard, these risks have been assessed to be tolerable according to the evaluation against the AGS (2007c) suggested tolerable Loss of Life Risk limit for the person most at risk as presented in Table E13. The risk associated with LS2a has also been estimated to be below the AGS (2007c) suggested tolerable Loss of Life Risk limit. Using a higher likelihood related to climate change for each of these cases would result in higher levels of risk evaluated as not tolerable against the AGS (2007c) recommended criteria (see Table E3).

Table E13 Summary of risk estimation, Zone 6

Geomorphological Zone	Hazard	Description	Risk Evaluation
6	LS1a	Debris Flow upslope of dwelling	Tolerable
	LS1b	Debris Flow upslope of dwelling (longer modelled runout)	Acceptable
	LS2a	Debris Flow upslope of dwelling (more frequent, less widespread)	Tolerable
	LS2b	Debris Flow upslope of dwelling (more frequent, less widespread with longer modelled runout)	Tolerable

# E3.2 Loss of life risk for 85 and 87 Domain Crescent and 207 Motutara Road

The unmitigated risk for 85 and 87 Domain Crescent in Zone 3 and 207 Motutara Road in Zone 2 is summarised in Table E14 (see Appendix E-2, E-3 and E-4 respectively).

Table E14 Summary of unmitigated risk estimation for 85 and 87 Domain Crescent and 207 Motutara Road, Muriwai

Hazard	Description	Risk Evaluation
LS1 – 85 Domain Crescent	Landslide upslope of dwelling	Not tolerable
LS1 – 87 Domain Crescent	Landslide upslope of dwelling	Not tolerable
LS1 – 207 Motutara Road	Landslide upslope of dwelling	Tolerable
LS2 – 207 Motutara Road	Regression of existing landslide	Not tolerable

# E3.3 Closure

This report has presented the results of a quantitative risk assessment to estimate the risk of Loss of Life posed by large-scale landslides to individuals in dwellings at Muriwai. This assessment has only considered the 'large scale' landslide hazards originating from the main escarpment located to the south-east of Muriwai. This assessment has not considered risks to dwellings at the crest of the escarpment (i.e. along Oaia Road) that are susceptible to undermining due to regression of the escarpment.

We understand Council are currently reviewing their tolerable and acceptable risk criteria for risks associated with landsliding. We recommend Council review the risk assessment presented in this report against the Council's own risk criteria to inform decisions on future land planning, dwelling hazard designations and the revision of current building placards.

As discussed above, this report considers geotechnical matters only. There may be other non-geotechnical considerations that affect final placard designation of which GHD are not aware, such as flood risk and structural damage to property.

# E4. References

AGS (2000). Landslide risk management concepts and guidelines. Australian Geomechanics Society. Australian Geomechanics Vol 35, No 1, 49-92

AGS (2002). Landslide risk management concepts and guidelines. Australian Geomechanics Society. Australian Geomechanics Vol 37, No 2, 1-44

AGS (2007a). Guideline for Landslide Susceptibility, Hazard and Risk Zoning for Land Use Management. Australian Geomechanics Society, Australian Geomechanics, Vol 42, No1.

AGS (2007b). Commentary on Guideline for Landslide Susceptibility, Hazard and Risk Zoning for Land Use Management, Australian Geomechanics Society, Australian Geomechanics, Vol 42, No1.

AGS (2007c). Practice Note Guidelines for Landslide Risk Management Australian Geomechanics Society. Australian Geomechanics, Vol 42, No1.

AGS (2007d). Commentary on Practice Note Guidelines for Landslide Risk Management. . Australian Geomechanics, Vol 42, No1.

Cruden D.M. & Varnes D. J. (1996). Landslide types and processes. In: Turner A.K.; Schuster R.L. (eds) Landslides: Investigation and Mitigation. Transportation Research Board, U.S. National Academy of Sciences, Special Report, 247: 36-75.

P J Finlay, G R Mostyn & R Fell (1999). 'Landslides: Prediction of Travel Distance and Guidelines for Vulnerability of Persons'. Proc 8th. Australia New Zealand Conference on Geomechanics, Hobart. Australian Geomechanics Society, ISBN 1 86445 0029, Vol 1, pp.105-113.

Hayward, B., (2022). The tragic 1965 Muriwai Landslide. Geocene 28: 2-5

Heim, A. (1932). Landslides and human lives (Bergstruz and Menchen leben). Translated by N. Skermer. BiTech Publishers, Vancouver, B.C., 195 p

Hsu, K.J. (1975) Catastrophic debris streams (sturzstroms) generated by rockfalls. Geological Society of America Bulletin, Vol 86, pp. 129-140.

Kang, Hs., Kim, Yt. (2016) The physical vulnerability of different types of building structure to debris flow events. Nat Hazards 80, 1475–1493. https://doi.org/10.1007/s11069-015-2032-z

New South Wales Government, Transport for New South Wales 'Guide to Slope Risk Analysis' Version 4, April 2014.

# E5. Limitations

This report has been prepared by GHD Limited (GHD) for Auckland Council and may only be used and relied on by Auckland Council for the purpose agreed between GHD and Auckland Council as set out in Section 1 of this report.

GHD otherwise disclaims responsibility to any person other than Auckland Council arising in connection with this report. GHD also excludes implied warranties and conditions, to the extent legally permissible.

The services undertaken by GHD in connection with preparing this report were limited to those specifically detailed in the report and are subject to the scope limitations set out in the report.

The opinions, conclusions and any recommendations in this report are based on conditions encountered and information reviewed at the date of preparation of the report. GHD has no responsibility or obligation to update this report to account for events or changes occurring subsequent to the date that the report was prepared.

The opinions, conclusions and any recommendations in this report are based on assumptions made by GHD described in this report (refer Section 1 of this report). GHD disclaims liability arising from any of the assumptions being incorrect.

GHD does not accept responsibility arising from, or in connection with, varied conditions and any change in conditions. GHD is also not responsible for updating this report if the conditions change.

An understanding of the geotechnical site conditions depends on the integration of many pieces of information, some regional, some site specific, some structure specific and some experienced based. Hence this report should not be altered, amended, abbreviated, or issued in part in any way without prior written approval by GHD. GHD does not accept liability in connection with the issuing of an unapproved or modified version of this report.

Verification of the geotechnical assumptions and/or model is an integral part of the design process - investigation, construction verification, and performance monitoring. If the revealed ground or groundwater conditions vary from those assumed or described in this report the matter should be referred back to GHD.

# Appendices

# Appendix E-1

AC flood frequency memo (20/09/2023)



Memo 20/09/2023

To: Debbie Fellows, Matt Howard cc: Jin Lee, Nicole Li, Ross Roberts

From: Kris Fordham

Subject: GUIDELINES ON THE USE OF AGS2007 FOR LANDSLIDE RISK

ASSESSMENT IN AUCKLAND FOLLOWING THE 2023 FLOODING AND

**CYCLONE** 

#### INTRODUCTION

It is anticipated that the use of the <u>AGS2007 guidelines</u> will form a core part of the risk assessment process for recovery in Auckland. This guidance has been developed to support practitioners in implementing the AGS guidelines by providing location and event specific information and advice, along with lessons learned from earlier implementations.

This guideline will be revised regularly as more information becomes available, and as new lessons are learned.

Risk assessment is expected to be undertaken on a site-specific basis. Nothing in this document relieves the person undertaking the risk assessment of their obligations to properly assess the conditions at each location and to make an assessment relevant to the site. These general guidelines may support this process, but deviation from the guidelines is to be expected where conditions dictate.

#### DERIVING PROBABILITY OF A LANDSLIDE OCCURRING

In the 2007 update of the AGS guidelines, it was noted that some practitioners were incorrectly deriving indicative probability values for risk to life analysis. The 2000 version Appendix G Likelihood table was being used from left to right; that is a descriptor was selected from the description (or even by preference for the descriptor), and then the indicative probability assigned accordingly. This method is wrong. The Likelihood Table was reordered to indicate the correct sequence of logic from left to right and as discussed in section C5.4.2, an estimate of the probability should be made based on apparent performance, trigger probabilities etc, and then the descriptor assigned accordingly.

The tables provided in Appendix C of AGS2007c should be used from left to right; use Approximate Annual Probability or Description to assign Descriptor, not vice versa.

#### GENERAL CONSIDERATIONS FOR RAINFALL ARI

#### Short-term vs Long-term risk

In many cases there will be a requirement to assess the short-term risk (for the purposes of RBA placarding and building occupation) and the long-term risk (for risk categorisation and consenting if remedial works are required).

#### **Short-term considerations**

Short-term risk (nominally 1 year) will not need to consider the potential for climate change to increase the frequency of high-intensity rainfall. However, consideration should be given to the extremely wet 2023 summer which has led to unusually high groundwater levels. This could mean that landslides are more likely than normal in smaller rainfall events.

#### Long-term considerations

Long-term risk (nominally 100 years) should consider the potential for climate change to increase the frequency of high intensity rainfall.

More information on this can be found:

- In a summary of Auckland climate projections prepared by NIWA (2018):
   <a href="https://knowledgeauckland.org.nz/media/1171/tr2017-031-2-auckland-region-climate-change-projections-and-impacts-summary-revised-jan-2018.pdf">https://knowledgeauckland.org.nz/media/1171/tr2017-031-2-auckland-region-climate-change-projections-and-impacts-summary-revised-jan-2018.pdf</a>
- In a technical paper: <a href="https://www.nzgs.org/libraries/climate-change-sustainable-development-and-geotechnical-engineering-a-new-zealand-framework-for-improvement/">https://www.nzgs.org/libraries/climate-change-sustainable-development-and-geotechnical-engineering-a-new-zealand-framework-for-improvement/</a>

#### ASSESSING THE ARI OF THE CYCLONE GABRIELLE EVENT - MURIWAI

Based on the best available data from rain radar, the rain experienced during Cyclone Gabrielle in Muriwai was >100-year event at a 12-hour duration.

This was a significant event for the region which came off the back of a significant "wet" period, including the event on the 27th of January 2023.

In Muriwai there are two sources of rainfall data available for analysis.

- 1. Physical TB3 tipping bucket rain gauge.
- 2. Auckland Councils Quantitative Precipitation Estimate (QPE) Rain Radar System.

#### TB3 tipping bucket rain gauge.

Unfortunately, during Cyclone Gabrielle, the tipping bucket rain gauge at Muriwai failed and was inundated by flood waters. This event record presented below in

**Figure** 1 is compromised as a result but provides an indication of the rainfall intensities at Muriwai prior to the site failing.

Prior to the gauge failing (01:15 am on the 14th), the gauge had recorded 129mm of rain with a peak 6-hour total of 88mm of rain, which is >20-year event (TP108, Auckland design rainfall depths).

Due to the missing record and the site being inundated during the event, this record is not recommended to be used to describe the event.

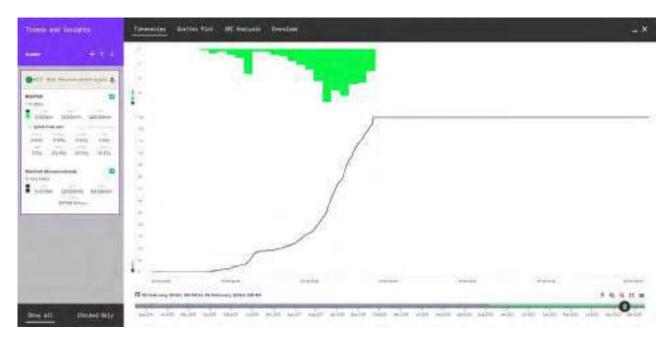


Figure 1: Muriwai TB3 tipping bucket rain gauge hourly totals and cumulative total. (note, the event is missing data from 01:15am 14th February due to being inundated)

#### Quantitative Precipitation Estimate (QPE) Rain Radar System.

The QPE rain radar system is a real-time rainfall product which utilises the Metservice radar (reflectivity), which is transformed using a relationship to rainfall depths based on the tipping bucket gauge network. The result is spatially representative rainfall depths across the region, as shown in **Figure 2**.

This product enables full, region wide analysis of extreme rainfall events in catchments where rain gauges are not located and when a gauge fails, as in the case with the Muriwai gauge.

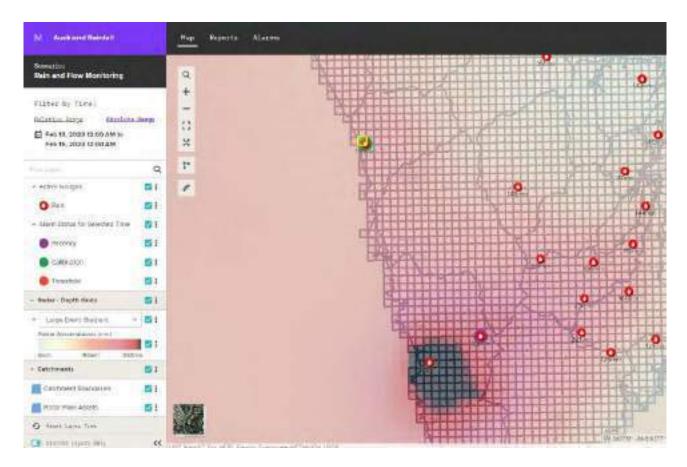


Figure 2; QPE Rain radar depth accumulations 13 February 2023 to 15 February 2023. The yellow grid location is the rainfall at the raingauge location at Muriwai

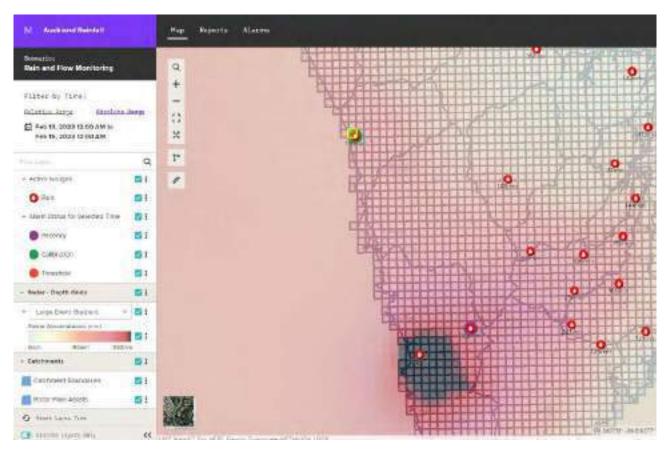


Figure 3: QPE Rain radar depths in Muriwai 13 February 2023 to 15 February 2023

**Figure 4** below shows the Depth-duration-Frequency curve for the QPE grid location at Muriwai. The X-axis shows duration, y axis shows depth in a given event, and the curves show the expected rainfall depths for a range of ARIs from 2 to 100-year return period (TP108, Auckland design rainfall depths).

What happened during the event is plotted in purple. This analysis and the figures in table 1 shows that the peak rainfall total during the event of 146.9mm occurred over 12-hour period. This total is >100-year event at a 12-hour duration.



Figure 4: Depth-duration-Frequency curve for the QPE grid location at Muriwai (90767).

Table 1: Depth-duration-table for the QPE grid location at Muriwai (90767).

Duretion	Depth	Tpt06		
10 min	4.4 mm	0.35 years		
20 min	8.4 mm	0.38 years		
30 min	311 mm	0.44 years		
1 Nour	20.1 mm	0:85 years		
2 hour	35.0 mm	2.05 years		
6 hour	mm ITB	23.46 years		
12 hour	146.9 mm	>100 years		
24 hour	985.2 mm	79.78 years		

Table 2: Depth-duration table from NIWA (HIRDSv4) including 250-year return period, with the 12-hour duration highlighted

Site Details	Historical Data	RCP2.6 Scenario	RCP4.5 Scenario	RICPS 0 Scenario	RCP9.5 Scenario	
Rainfell dep	oths (mm) :: Histo	rical Data				
ARI	ALP	10m	20m	30m	1h	2h
1.58	0.633	10.7	13.9	16.2	21.2	27.6
2	0.500	11.7	15.1	17.6	23,0	30.1
5	0.200	14.9	19.3	22.5	29.4	38.5
10	0.100	17,2	22.3	26.0	34,1	44.6
20	0.050	19,5	25.3	29,6	36.8	50.8
30	0.033	20.9	27.1	31.7	41.6	54.5
40	0.025	21.9	28.4	33.2	43.6	57,1

#### Conclusions

The above information suggests that for the 12-hour duration rainfall the ARI is >100 years, and may be in the order of 250 years. However, the calculation above the 100-year assessment becomes increasingly unreliable, primarily because of the relatively short rainfall record available in New Zealand.

For the other durations modelled, the rainfall was below the 100-year event.

#### 2023 Rainfall and antecedent conditions

The rain experienced in the Auckland region since the 1st of January 2023 has been historically significant.

During the period from the 1st of January to the 15th of February, 491mm of rainfall has fallen at Muriwai. Compared to the average rainfall for Muriwai for January of 70mm, indicates just how much rain has fallen at this location.



Figure 5: QPE Rain radar depths in Muriwai 1 January 2023 to 15 February 2023

#### **Caveats**

This interpretation is using data sampled from the rain gauges that doesn't include the statistics from the recent events that Auckland has experienced – the theory is that including these events in the record will shift and change the return periods and depth for all of Auckland.

Auckland Council have commissioned NIWA to undertake the analysis to re-run HIRDS 4 for Auckland to include the recent 3 years of extreme rainfall data – the results of this are expected by November 2023.

#### Recommendations

There are several different methods to extrapolate return periods which will all give very different and uncertain results.

It is recommended that for reporting purposes that an envelope of "risk" is determined as the ARI figures will change over time. In general for Muriwai it is considered reasonable to consider the event to be in the range of 100-250 year ARI.

For long-term risk assessment a 20% increase in rainfall intensity over the period has been projected by NIWA. A simplistic assessment (without climate modelling input) suggests this would change a 250-year ARI event to a 50-year ARI event. Risk assessment should consider both the current and future risk by re-calculating the risk taking into account this increased frequency.

For short-term risk assessments consideration should be given to the anticident ground saturation that is likely to persist at least through the winter of 2023.

#### ASSESSING THE ARI OF THE CYCLONE GABRIELLE EVENT – PIHA & KAREKARE

Based on the best available data from rain radar, the rain experienced during Cyclone Gabrielle in Piha was >100-year event at a 6-hour duration.

This was a significant event for the region which came off the back of a significant "wet" period, including the event on the 27th of January 2023.

In Piha there are two sources of rainfall data available for analysis.

- 1. Physical TB3 tipping bucket rain gauge.
- 2. Auckland Councils Quantitative Precipitation Estimate (QPE) Rain Radar System.

#### TB3 tipping bucket rain gauge.

During Cyclone Gabrielle, the tipping bucket rain gauge at Piha recorded 349.5mm of rain. This event record is presented below in **Figure 6** 



Figure 6: Piha TB3 tipping bucket rain gauge hourly totals and cumulative total

#### Quantitative Precipitation Estimate (QPE) Rain Radar System.

The QPE rain radar system is a real-time rainfall product which utilises the Metservice radar (reflectivity), which is transformed using a relationship to rainfall depths based on the tipping bucket gauge network. The result is spatially representative rainfall depths across the region, as shown in figure 7. This product enables full, region wide analysis of extreme rainfall events.

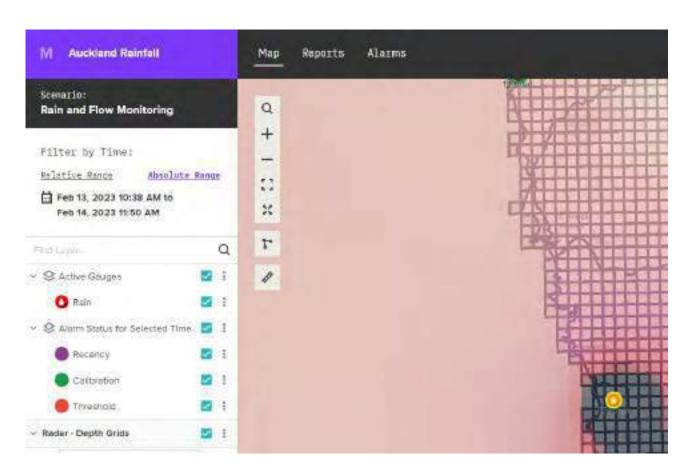


Figure 7: QPE Rain radar depth accumulations 13 February 2023 to 15 February 2023. The yellow grid location is the rainfall at the rain gauge location at Piha

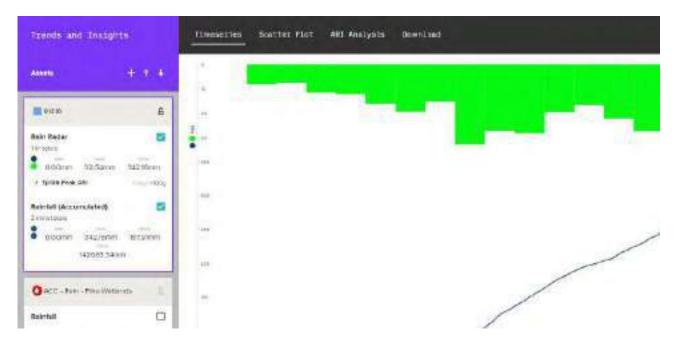


Figure 8: QPE Rain radar depths in Piha 13 February 2023 to 15 February 2023

**Figure 9** below shows the Depth-duration-Frequency curve for the QPE grid location at Piha. The X-axis shows duration, y axis shows depth in a given event, and the curves show the expected rainfall depths for a range of ARIs from 2 to 100-year return period (TP108, Auckland design rainfall depths).

What happened during the event is plotted in purple. This analysis and the figures in table 3 shows that the rainfall total exceeded the 100-year event from a 6 to 24 hour duration.

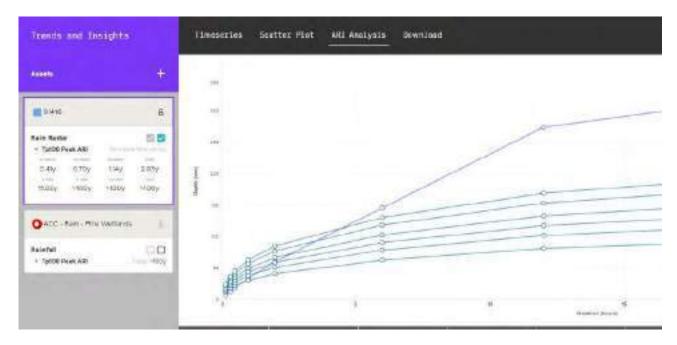
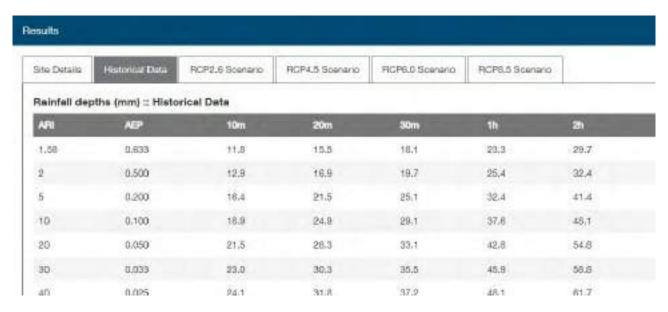


Figure 9: Depth-duration-Frequency curve for the QPE grid location at Piha (91416).

Table 3: Depth-duration-table for the QPE grid location at Piha (91416).

Duration	Depth		
10 min	6.3 mm		
20 min	12.2 mm		
30 min	18.0 mm		
1 hour	33.4 mm		
2 hour	60.0 mm		

Table 4: Depth-duration table from NIWA (HIRDSv4) including 250-year return period.



#### **Conclusions**

The above data suggests that for the 6 to 24-hour duration the ARI is >100 years and may be in the order of 250 years. However, the calculation above the 100-year assessment becomes increasingly unreliable, primarily as a result of the relatively short statistical rainfall records available in New Zealand.

For the other durations modelled, the rainfall was below the 100-year event.

#### 2023 Rainfall and antecedent conditions

The rain experienced in the Auckland region since the 1st of January 2023 has been historically significant.

During the period from the 1st of January to the 15th of February, 704 mm of rainfall has fallen at Piha. Compared to the average rainfall for Piha for January of 70mm, indicates just how much rain has fallen at this location.

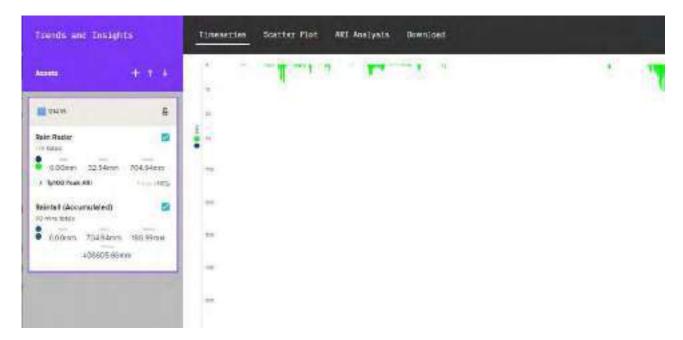


Figure 10: QPE Rain radar depths in Piha 1 January 2023 to 15 February 2023

#### **Caveats**

This interpretation is using data sampled from the rain gauges that doesn't include the statistics from the recent events that Auckland has experienced – the theory is that including these events in the record will shift and change the return periods and depth for all of Auckland.

Auckland Council have commissioned NIWA to undertake the analysis to re-run HIRDS 4 for Auckland to include the recent 3 years of extreme rainfall data – the results of this are expected by November 2023.

#### Recommendations

There are several different methods to extrapolate return periods which will all give very different and uncertain results.

It is recommended that for reporting purposes that an envelope of "risk" is determined as the ARI figures will change over time and as these events are incorporated into the statistical record. In

general, for Piha it is considered reasonable to consider the event to be in the range of 100-250 year ARI.

For long-term risk assessment a 20% increase in rainfall intensity over the period has been projected by NIWA. A simplistic assessment (without climate modelling input) suggests this would change a 250-year ARI event to a 50-year ARI event. Risk assessment should consider both the current and future risk by re-calculating the risk considering this increased frequency.

For short-term risk assessments consideration should be given to the antecedent ground saturation that is likely to persist at least through the winter of 2023.

# ASSESSING THE ARI OF THE AUCKLAND ANNIVERSARY FLOODS – CENTRAL AUCKLAND

Auckland experienced its largest ever rain event on the 27<sup>th</sup> January 2023. The majority of urban Auckland received rainfall in excess of the 100 year event. Thousands of houses and commercial buildings were inundated with floodwater.

Extreme rainfall was widespread across the region, with a wide front tracking in a southerly direction from the Northeast, impacting the Hibiscus Coast, North Shore, West, and Central Auckland before passing to the South of the Auckland Region.

While the rain was widespread across the region, including reported flooding in the Northern and Southern Rural areas, it was our urban city catchments which bore the brunt of the event and have experienced significant flooding issues.

Regionally there are two sources of rainfall data available for analysis.

- 1. Physical TB3 tipping bucket rain gauge.
- 2. Auckland Councils Quantitative Precipitation Estimate (QPE) Rain Radar System.

#### TB3 tipping bucket rain gauge.

Rainfall totals during the period from 00:00am Friday 27/01/2023 to 07:00am Saturday 28/01/2023 were in excess of 230mm at many locations across the region's urban extents, with the maximum recorded total during this period being 318mm. Most of the rain fell in a 4 hour period. The Onehunga @ Harbourside rain gauge measured 146 mm of rainfall in a 2-hour period, the average total rainfall for January is 73.8mm.

Table 5: Summary rainfall statistics by stormwater operational area 12am 27 Jan to 7am 28 Jan

		00 27 Jan Jan) mm	1 Hour Total mm			
	Max	Average	Max	Average		
North	284	193	75	46		
Central/West	286	217	91	50		
South	263	163	75	32		

Summary figures are calculated from all rain gauges in each of the 3 sub-regional areas. i.e., the max is the rain gauge in each area with the highest total for the event. The average is the average rain across all the rain gauges in that sub region. For example, in North there are 25 rain gauges which were averaged to get 193mm

#### Quantitative Precipitation Estimate (QPE) Rain Radar System.

The QPE rain radar system is a real-time rainfall product which utilises the Metservice radar (reflectivity), which is transformed using a relationship to rainfall depths based on the tipping bucket gauge network. The result is spatially representative rainfall depths across the region, as shown in **Figure 11**.

This product enables full, region wide analysis of extreme rainfall events.

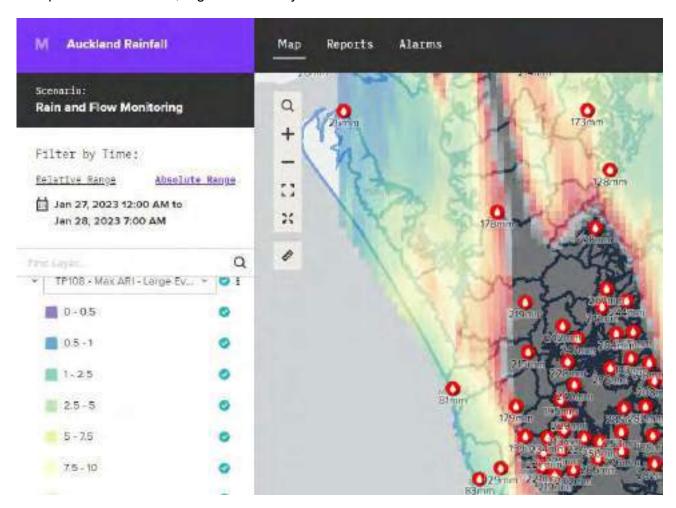


Figure 11: Recorded Rainfall Radar Max Average Recurrence Interval (ARI). The black area is where rainfall was greater than a 100yr ARI (for any of the 10,20,30 min and 1,2,6,12,24-hour durations) In the black area the event was greater than 100yr for the vast majority of durations.

#### **Conclusions**

The above data suggests that for the majority of the region the ARI for this event is >100 years and may be in the order of 250 years. However, the calculation above the 100-year assessment becomes increasingly unreliable, primarily because of the relatively short statistical rainfall records available in New Zealand.

Further analysis of this event by NIWA (<a href="https://niwa.co.nz/news/auckland-suffers-wettest-month-in-history">https://niwa.co.nz/news/auckland-suffers-wettest-month-in-history</a>) highlights the extreme nature of this event, indicating that this event could be described a "at least a 1-in-200-year event".

#### **Caveats**

This interpretation is using data and models sampled from rain gauges that doesn't include the statistics from the recent events that Auckland has experienced, the theory is that including these events in the record will shift and change the return periods and depth for all of Auckland. Auckland Council have commissioned NIWA to undertake the analysis to re-run HIRDS 4 for Auckland to include the recent 3 years of extreme rainfall data – the results of this are expected by November 2023.

#### Recommendations

There are several different methods to extrapolate return periods which will all give very different and uncertain results.

It is recommended that for reporting purposes that an envelope of "risk" is determined as the ARI figures will change over time and as these events are incorporated into the statistical record. In general, for the Auckland Anniversary floods it is considered reasonable to consider the event to be in the range of 100-250 year ARI.

For long-term risk assessment a 20% increase in rainfall intensity over the period has been projected by NIWA. A simplistic assessment (without climate modelling input) suggests this would change a 250-year ARI event to a 50-year ARI event. Risk assessment should consider both the current and future risk by re-calculating the risk considering this increased frequency. For short-term risk assessments consideration should be given to the antecedent ground saturation that is likely to persist at least through the winter of 2023.

For further information or clarification of the figures presented please contact the undersigned.

Kris Fordham | Mātanga Aporei - Principal Hydrometric Analytics Te Tari o Ngā Waiora - Healthy Waters | Infrastructure and Environmental Services

Mobile 021625340

Auckland Council, Level 17, Auckland House, 135 Albert Street, Auckland 1010

Visit our Website: www.aucklandcouncil.govt.nz

# Appendix E-2

85 Domain Crescent Landslide Risk Assessment



# Waitākere Coastal Communities Landslide Risk Assessment

85 Domain Crescent, Muriwai

Auckland Council
30 April 2024

→ The Power of Commitment



Project n	ame	AC Geo Panel - Waitākere Coastal Communities LHRA						
Docume	nt title	Waitākere Coastal Communities Landslide Risk Assessment   85 Domain Crescent, Muriwai						
Project n	umber	12612462						
File name	e	12612462- RiskAssess	s85 Domain Muriw	aiFINAL.docx				
Status Revision		Author	Reviewer		Approved for issue			
Code			Name	Signature	Name	Signature	Date	
S4	0	Ryan Hayes	Don Macfarlane	Melyplan	Matt Howard	Moward	30/04/2024	
[Status code]								
[Status code]								
[Status code]								

#### **GHD Limited**

Contact: Matt Howard, Technical Director - Engineering Geology | GHD

27 Napier Street, GHD Centre Level 3

Freemans Bay, Auckland 1010, New Zealand

T +64 9 370 8000 | F +64 9 370 8001 | E aklmail@ghd.com | ghd.com

#### © GHD 2024

This document is and shall remain the property of GHD. The document may only be used for the purpose for which it was commissioned and in accordance with the Terms of Engagement for the commission. Unauthorised use of this document in any form whatsoever is prohibited.

# **Contents**

1.	Intro	duction	4				
	1.1	Background	4				
	1.2	Purpose of this report	4				
	1.3	Scope	4				
	1.4	Our Approach	5				
2.	Site o	conditions	6				
	2.1	Site description	6				
	2.2	Site services and sources of water	8				
	2.3	2.3 Published geology					
	2.4	2.4 Historical data summary					
	2.5	Engineering geological model	12				
		2.5.1 Awhitu Sand Formation	12				
		2.5.2 General landslide characteristics	12				
		2.5.3 Landslide impacting the site	12				
3.		slide risk estimation	18				
	3.1	Hazard characterisation	18				
	3.2	Likelihood of landsliding (P <sub>(H)</sub> )	18				
		3.2.1 Likelihood of LS1 3.2.2 Likelihood of LS2	18				
	2.2		18				
	3.3	Probability of spatial impact (P <sub>(S:H)</sub> ) 3.3.1 Probability of spatial impact (LS1)	18 20				
		3.3.2 Probability of spatial impact (LS2)	20				
	3.4	Temporal spatial probability (P <sub>(T:S)</sub> )	20				
	3.5	Vulnerability $(V_{(D:T)})$	20				
	3.6	Unmitigated Risk Estimation	20				
4.	Conc	lusion and recommendation	21				
5.		ations	22				
1.	Over		24				
2.		slide Risk Management Framework	24				
۷.	2.1	Background	24				
	2.2	Risk Estimation Methodology	25				
	2.3	Landslide Risk Assessment Uncertainty	26				
3.		rd Characterisation	26				
٥.	3.1	Defining the Most Likely Significant Landslide	26				
	3.2	Description of Other Landslide Types	29				
	3.3	General Descriptors for Size Classification of Landslides.	29				
4		·	29				
4.	4.1	The Most Likely Significant Landslide	29				
	4.1 4.2	The Most Likely Significant Landslide  Auckland Council Guidance on Frequency for Most Likely Significant Landslide	30				
		1 , , , , ,					
	4.3	Other Lanushue Mazarus	31				

5.	Probability of Spatial Impact P <sub>(S:H)</sub>					
	5.1 T	The Most Likely Significant Landslide - Upslope of Site	31			
		The Most Likely Significant Landslide – Under the Dwelling/Building and/or Downslope Below the Dwelling/Building	32			
		Other landslides – Upslope of the study site	32			
		Other landslides – under buildings and downslope of the building	32			
		Temporal Spatial Probability P <sub>(T:H)</sub>	32			
6.	Vulnerab	ility V <sub>(D:T)</sub>	33			
		Most likely significant Landslide	33			
7.	Risk Eva	luation	33			
8.	Referenc	es	34			
Tak	ole inde	ex execution and the second execution are second exe				
Table	e 2.1	Summary of historical data	10			
Table		Historical geotechnical reports summary	11			
Table	_	Summary of unmitigated risk estimation for each hazard type by domain.	21			
	e A3.1	Landslide size classification	29			
	e A6.1	Summary of Vulnerability Values adopted	33			
Table	e A7.1	AGS Suggested Tolerable loss of life individual risk.	34			
Fig	ure ind	lex				
Figur	e 2.1	Site location along Domain Crescent	7			
Figur	e 2.2	Overland flow paths and underground services for the site (source: Auckland Council GeoMaps).	8			
	e 2.3	Excerpt of the Waitākere 1:50,000 scale geological map (Hayward, 1983), illustrating the underlying geology at the site location.	ç			
Figur	e 2.4	Interpreted geological cross section (Excerpt from Soil & Rock Consultants, 2001 (note: this report was issued for the proposed building which has since been constructed)	11			
Figur	e 2.5	GHD site mapping of the landslide (completed 11 December 2023)	13			
•	e 2.6	Landslide locations relative to the site shown on February 2023 aerial image.	14			
•	e 2.7	Landslide location relative to the site shown on LiDAR Hillshade (source:	•			
9		Auckland Council Feb 2023).	14			
Figur	e 2.8	Exposed headscarp of landslide.	15			
Figur	e 2.9	Failure surface (evacuated zone) exhibiting evidence of post failure erosion. Looking upslope.	15			
		Debris piled up at the rear of dwelling (estimated up to 1.5 m thick)	16			
Figur	e 2.11	Damage caused by landslide includes racking of entire building (exhibited by bending of exterior wall)	16			
•	e 2.12	Indicative cross section A-A' through 85 Domain Crescent	17			
Figur	e 3.1	Slope map of 85 Domain Crescent and surrounding area. Slope angles based on 2023 DTM data.				

Flow accumulation map of 85 Domain Crescent and surrounding area. Indicates preferential flow path for surface water. Modelling based on 2023 DTM data.	19
Framework for landslide risk management.	25
The number or frequency of mapped debris flows (on the x axis) as categorised by volume increments for mapped source areas of debris flows (on the y axis in m³) in Karekare and Piha.	27
Travel angle vs volume of source area for the Karekare and Piha debris flows	27
Plot of only those debris flows known to have caused some degree of damage to dwellings and buildings. Note Class 1 = Complete destruction/collapse of building, Class 2 = Partial destruction/collapse of building, significant inundation and Class 3 = Limited damage to building but no collapse or inundation, damage is other property infrastructure e.g., access stairs.	28
	preferential flow path for surface water. Modelling based on 2023 DTM data. Framework for landslide risk management.  The number or frequency of mapped debris flows (on the x axis) as categorised by volume increments for mapped source areas of debris flows (on the y axis in m³) in Karekare and Piha.  Travel angle vs volume of source area for the Karekare and Piha debris flows Plot of only those debris flows known to have caused some degree of damage to dwellings and buildings. Note Class 1 = Complete destruction/collapse of building, Class 2 = Partial destruction/collapse of building, significant inundation

# **Appendices**

Appendix A AGS (2007) Background Appendix B Glossary of Terms

#### 1. Introduction

#### 1.1 Background

Two significant rainfall events affected the Waitakere area in late January and early February, resulting from the impacts of ex-tropical cyclones Hale and Gabrielle, respectively.

The Cyclone Gabrielle weather event of 14 February 2023 resulted in widespread catastrophic flooding and slope instability in the settlement of Muriwai where several debris avalanches (which included rocks and trees) occurred, some of which turned into saturated debris flows as they travelled downslope. These flows resulted in damage to buildings and infrastructure. Two fatalities occurred due to impact of landslides on private dwellings. This tragic event was similar to a 1965 storm event that also claimed two lives.

Following the February event, rapid building assessment of residential properties was undertaken in Muriwai, with some houses having access by owners restricted (a yellow placard – e.g. access in daylight hours only) and some for which no access was permitted (a red placard).

GHD has been engaged by Auckland Council (AC)¹ to carry out landslide risk assessments and to provide associated landslide risk management advice and geotechnical investigations recommendations in the Waitakere area, specifically for the residential areas of Muriwai, Piha and Karekare. These assessments were necessary due to widespread, damaging landslides associated with Cyclone Gabrielle in February 2023. GHD has completed a landslide risk assessment², whereby some properties were identified as having an unacceptably high risk of being impacted by future large landslides.

# 1.2 Purpose of this report

The residential property at 85 Domain Crescent, Muriwai ('the site') has been assessed by GHD as having an acceptable risk from large scale landslides<sup>3</sup> (see the November 2023 report). However, a localised, damaging landslide has occurred, and the purpose of this assessment is to carry out a Quantitative Landslide Risk Assessment (QRA) to estimate the risk of Loss of Life to individuals at the property. The outcome of the QRA will be used to inform subsequent property risk categorisation and building placard designation review by AC.

# 1.3 Scope

The scope of work requested by AC is as follows:

- Review available historical and recent imagery including LiDAR.
- Review pertinent historical data and GHD work undertaken as part of the wider Muriwai landslide risk assessment reported in GHD (November 2023).
- Undertake a site engineering geological assessment of landslide hazards at the impacted property.
- Undertake a QRA where landslide hazards have been identified that pose a Loss of Life landslide risk using the Australian Geomechanics Society Practice Note Guidelines for Landslide Risk Management, commonly known as AGS (2007c).
- Deliver report(s) documenting the QRA inputs and outcome.

Specifically excluded are an assessment of property risk, site specific subsurface geotechnical investigations, service inspections, and groundwater monitoring.

This assessment considers geotechnical matters only. There may be other non-geotechnical considerations that affect the final property risk categorisation or placard designation of which GHD are not aware, such as flood risk and structural damage to property.

<sup>&</sup>lt;sup>1</sup> Under Contract CW198379, Master Services Agreement CCCS: CW74240 dated 7/09/2019

<sup>&</sup>lt;sup>2</sup> Dated 03/11/2023, document file ref 12612462\_Overall Report FINALRev0.docx

<sup>&</sup>lt;sup>3</sup> In the GHD November 2023 report, 'large scale' landslide hazards refers to landslides originating from the main escarpment that typically have a volume of more than about 50 m3 with the potential to cause total or partial collapse of a dwelling.

Identification of options for the mitigation of geotechnical hazards has not been undertaken as part of this study.

Although considered unlikely, GHD reserves the right to amend the opinions, conclusions and recommendations provided within this report, should additional geotechnical information become available.

# 1.4 Our Approach

GHD have completed a landslide risk assessment for Muriwai which assessed the risk to life of large-scale landslide hazards to inform possible future dwelling hazard designations. The assessment was limited to 'large scale' landslide hazards originating from the main escarpment located to the south-east of Muriwai because the initial placard assessment was largely aimed at mitigating risks associated with these.

Smaller, more localised landslide hazards that could originate (or may have already initiated) from other areas in Muriwai such as within the footprint of individual residential properties were not considered in the risk assessment. However, these have the potential to cause damage to dwellings and subsequently pose a risk to life for residents, partly due to the relatively steep topography and the potential for high travel velocity.

The approach of identifying landslide hazards over large and common source areas, such as that used for the November 2023 Muriwai assessment, does not capture numerous, smaller scale landslides. For this reason, a QRA is presented for the individual property (85 Domain Crescent) based on an assessment of the site that includes site observations and a desktop review of available information. The results aid with informing the QRA with regards to the presence of existing and historical landslide hazards and site-specific slope conditions.

The QRA undertaken for this report assesses risk to life to occupants of the dwelling. The assessment considers a number of hazard scenarios as follows:

- the most likely significant landslide hazard based on the observed hazards with respect to the
  mapped landslides and their distribution within the broader landscape. In addition, considerations of the
  hazard relationship to topography, position on the hillslope and proximity to the elements at risk are also
  included. This represents a credible hazard scenario following a triggering event with a similar frequency
  as the February 2023 event.
- 2. Existing geohazards that have resulted from recent failures with the potential to pose risk to life, such as regression and/or remobilisation of translational failures that are upslope or downslope of a dwelling or failure of oversteepened fill and cut slopes. These represent hazards that exist at the site and may be initiated by a more frequent triggering event.
- Other possible geotechnical slope instability hazards that have potential to pose a risk to life such as
  failures of fills, cuttings and failed retaining walls. These also represent hazards that may be triggered by
  a more frequent event.

The process of risk assessment involves estimation of likelihood, consequence and risks based on available information for the study site. The methodology used for the QRA is outlined in Appendix A. The site-specific input parameters and uncertainties are described in Section 3.

A glossary of terminology is presented in Appendix B.

# 2. Site conditions

#### 2.1 Site description

The site is located at 85 Domain Crescent, Muriwai, legally described as Lot 64 DP 39644 and it has an approximate area of 845 m<sup>2</sup>. A GHD engineering geologist inspected the site on 11 December 2023. No inspection was undertaken within or under the house, however, an insurance assessment report that was made available to us by AC provides photos of the interior<sup>4</sup>.

As shown in Figure 2.1, the affected property is located on the lower portion of the approximately 80 m high main escarpment that is aligned to the northeast and separates the township between lower-lying plateaus to the west (near sea level), and higher areas to the south and east. Locally, the main escarpment extends from Domain Crescent at its base at an elevation of approximately 60 m RL, to Oaia Road at its crest at an elevation of approximately 150 m RL. The slopes encompassing the site have an average slope angle of approximately 32°.

The dwelling is a three-storey structure that sits on timber poles and it is located near the base of the slope, adjacent to Domain Crescent. The building platform may have been modified to accommodate the structure, and the dwelling is accessed via a concrete driveway. A steep (generally 30-40°) natural, vegetated slope behind the dwelling extends to an elevation of approximately 100 m above sea level, where it meets a prominent north-trending ridgeline at the eastern extent of the property boundary.

Two 'large' landslides (mapped on Figure 2.1) originating to the west of the site occurred during Cyclone Gabrielle but did not affect the dwelling. A third, smaller scale, localised failure originating from within the property boundary at approx. 83 m RL developed into a debris flow which impacted the rear of the dwelling causing structural damage.

One of the large-scale failures originating on slopes at higher elevations above the site (approx. 120 m RL) developed into a channelised debris flow reaching Domain Crescent. Silt discharge from the debris partially inundated the elevated timber deck on southern side of the dwelling.

<sup>&</sup>lt;sup>4</sup> Tonkin + Taylor, 19 June 2023. Claim for Natural Disaster (Landslip) Damage Sarah Gerritsen, 85 Domain Crescent, Muriwai, Auckland, 0881 EQC/Insurer Claim Number C90154866

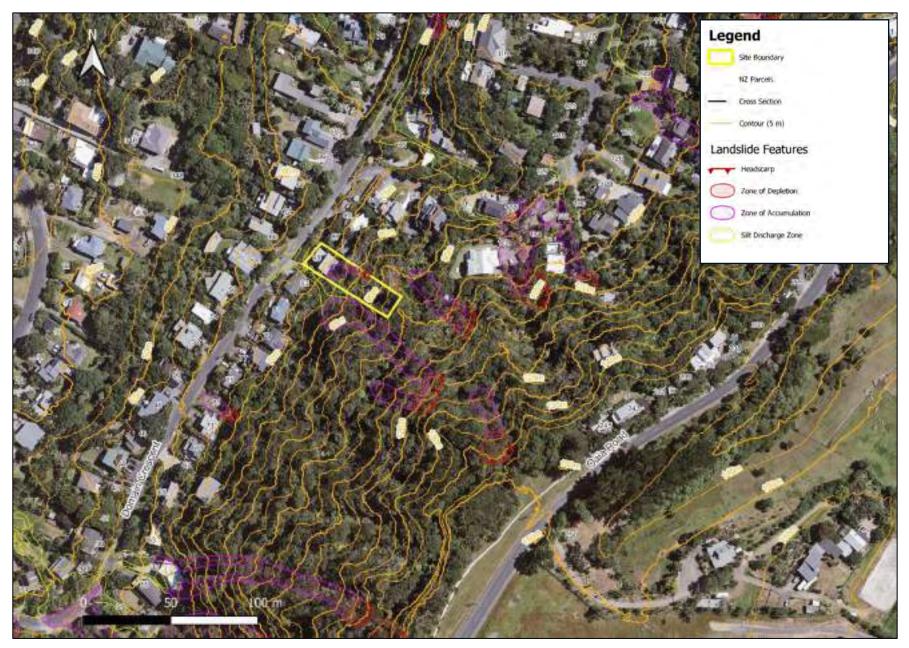


Figure 2.1 Site location along Domain Crescent

#### 2.2 Site services and sources of water

Auckland Council's GeoMaps presents relevant underground services and hydrologic information for the site. An excerpt of the data is presented in Figure 2.2.

Two overland flow paths are mapped to the north and south of the property boundary originating at approximately 105 m RL and 75 m RL, respectively, connecting approximately 50 m downslope, west of the dwelling. Both overland flow paths have a catchment size of approximately 2000 m<sup>2</sup> – 4000 m<sup>2</sup>.

The travel paths of the debris associated with the two large scale landslides above the site, to the north and south, appear to correlate with the mapped overland flow paths.

No underground services associated with water are mapped on the slopes above the dwelling.

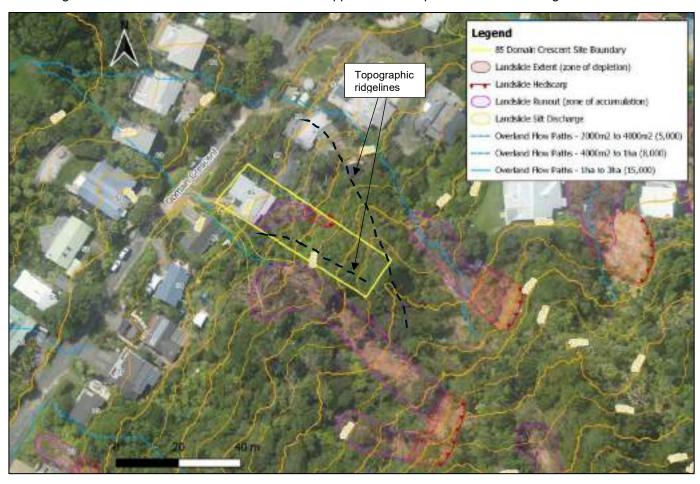


Figure 2.2 Overland flow paths and underground services for the site (source: Auckland Council GeoMaps).

# 2.3 Published geology

The published 1:50,000 scale geological map of the area (Hayward, 1983) indicates the site is entirely underlain by the Awhitu Sand Formation (mp), part of the Kaihu Group (Figure 2.3).

Awhitu Sands ('qs') are Pliocene aged (less than 2 Mya) characterised as 'coarse sand, clayey, often limonitised (as laterally discontinuous layers), with minor tuff, lignite and siltstone' (Hayward, 1983). The formation originated as coastal sand deposits. Awhitu Sands are generally oxidised to an orange-brown colour when exposed at the surface, resulting in a weak iron-cementation that allows for the development of large, more than 50 m high steep slopes, such as the escarpment.

The formation is weakly bedded and cross-bedded at the sub metre scale. Locally the formation is inferred to dip north and eastward at a shallow angle. Occurrences of silty/clayey horizons are occasionally visible in outcrop and have been encountered within boreholes, however it is unclear how persistent they are spatially.

Although not mapped, more recent colluvium material formed as a result of ongoing erosion and periodic landsliding associated with escarpment recession is likely present on the basal/lower slopes of the escarpment.

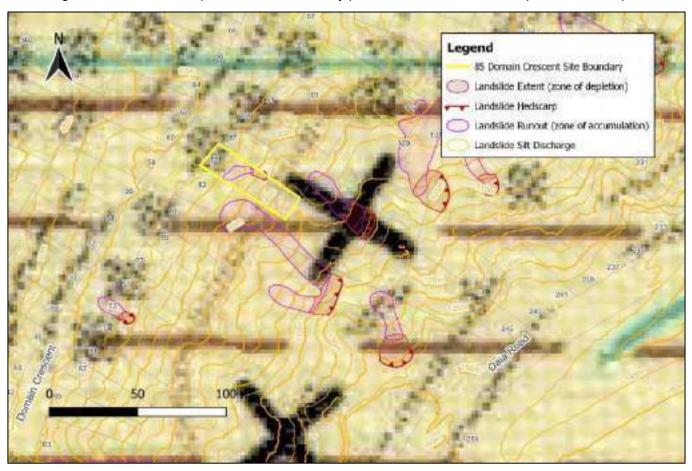


Figure 2.3 Excerpt of the Waitākere 1:50,000 scale geological map (Hayward, 1983<sup>5</sup>), illustrating the underlying geology at the site location.

<sup>&</sup>lt;sup>5</sup> Hayward, B.W. 1983: Sheet Q11, Waitakere. Geological Map of New Zealand 1:50,000 Map

# 2.4 Historical data summary

A summary of the historical data relevant to 85 Domain Crescent is presented in Table 2.1.

Table 2.1 Summary of historical data

	Applicable data available	Notes
Historic aerial photos	- 1940 - 1950 - 1953 - 1975 - 2000 - 2004 - 2008 - 2010-2011 - 2015-2017 - 2022	<ul> <li>No obvious evidence of instability was identified from the historical aerials within the property itself.</li> <li>Evidence of wider scale erosion evident from 1940, where many of the spurs leading off main escarpment are bare as well as section of the crest of the escarpment. Suggests ongoing erosion of surficial soil. No regression of escarpment observed.</li> <li>Photos sourced from Retrolens and Auckland Council Geomaps.</li> </ul>
NZ Geotechnical database	One borehole (BH-MH05) completed by GHD in August 2023. Located 15 m west of south-west corner of property boundary (see Figure 2.6).	<ul> <li>10.95 m deep borehole.</li> <li>0 – 5.6 m: Ancient colluvial deposits generally comprising sandy silt and silty sand.</li> <li>5.6 – 10.95 m: Awhitu sand formation comprising variably cemented sand (medium dense to very dense)</li> </ul>
Council GeoMaps	Overland flow data from Auckland City Council ArcGIS.	- Discussed in Section 2.2.
Rapid building Assessment Geotech reporting	N/A	N/A
Independent geotechnical reports	Soil & Rock Consultants (2001) report for proposed house extension. Babbage Consultants geotechnical appraisal advice (2000) Tonkin & Taylor (2023) EQC report	- Summarised in Table 2.2 below.
Anecdotal information	N/A	N/A
LiDAR Imagery Feb 2023 Digital Terrain Model.		<ul> <li>Headscarps in the escarpment crest suggest ongoing recession through debris flows.</li> <li>Headscarps also seen on smaller ridgelines extending down the escarpment.</li> <li>Possible hummocky ground on the natural slopes above the dwelling on 85 Domain Crescent.</li> </ul>

Geotechnical report	Relevant comments
Soil & Rock consultants – Geotechnical investigation for proposed extension to existing dwelling (Jan 2001)	<ul> <li>Evidence of shallow surface creep over the property with the formation of terracettes and the presence of hummocky ground on steeper slopes and shallow rooting trees frequently exhibiting downslope leaning.</li> <li>No evidence of obvious large scale instability just shallow surface creep.</li> <li>Local topography indicates that surface runoff from above the dwelling is concentrated into an overland flow path feature that runs through the southern corner of the property and continues through into the adjacent property to the southwest.</li> <li>Four hand augers were completed to depths of 2.3 to 3.4 m encountered loose to medium dense sand silts and silty sands overlying dense to very dense (cemented) silts/sands. Subsurface interpretation of the site illustrated on Figure 2.4 below.</li> <li>An inground barrier pile wall was recommended to support the proposed cut bench.</li> </ul>
Babbage Consultants – Geotechnical appraisal and advice re: slip affecting 60 Domain Crescent (June 2000)	<ul> <li>Slopes below the road (Domain Crescent) failed, developing into a debris flow, leaving a 5-6 m high scarp.</li> <li>Stormwater pipes observed protruding from scarp.</li> <li>The cause of the slip likely water entry into the slope through the pipes. Progressive landslide movement may have restricted stormwater discharge.</li> <li>No signs of movement observed affecting No. 85. The slopes above the house however clearly exhibiting evidence of periodic localised movement.</li> </ul>
Tonkin & Taylor – Claim for Natural Disaster (Landslip) Damage (EQC report)	<ul> <li>Details property damage including damage to dwelling (racking and twisting entire building), inundation of deck and damage to services.</li> <li>Determined that there is an imminent risk of regression of the landslip headscarp.</li> <li>Recommended conceptual remedial works include; BioCoir matting over failed surface, hydroseeding, construction of a timber pole catch fence following removal of debris.</li> </ul>

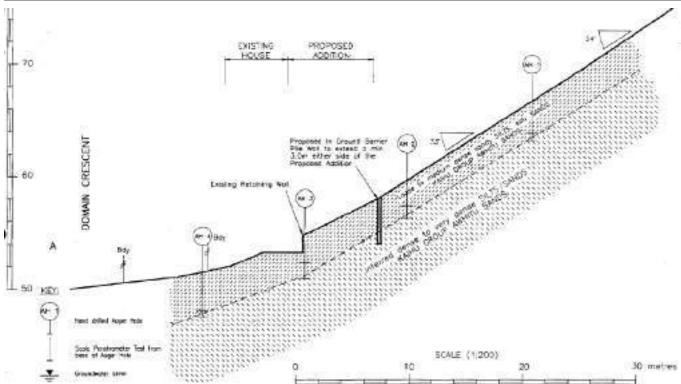


Figure 2.4 Interpreted geological cross section (Excerpt from Soil & Rock Consultants, 2001 (note: this report was issued for the proposed building which has since been constructed)

# 2.5 Engineering geological model

#### 2.5.1 Awhitu Sand Formation

Awhitu Sands are exposed within the entire escarpment and have generally been described as medium dense to very dense sands overlying massive, extremely weak, moderately weathered, iron-cemented fine to coarse sandstone. Irregular layers of clay and silt rich material are typically spaced every 5-10 m and relatively thin (less than 1.0 m and often less than 0.1 m). The strength profile of the Awhitu Sands displays a relatively linear increase with depth.

The in-situ nature of the Awhitu Sands suggests they are relatively permeable. However, as discussed in the November report there is also significant evidence for perched groundwater tables shown by:

- Multiple occurrences of groundwater seeps or springs emerging within the middle and base of the escarpment slope face, from above underlying (presumed aquiclude) layers of clay and silt rich beds as well as heavily oxidised iron pans
- Variable and sharply changing weathering profile with localised layers of cemented iron oxidised sand between un-oxidised material at depth.

#### 2.5.2 General landslide characteristics

As described in the November report (GHD 2023), the landslides identified across Muriwai following the February 2023 event can be categorised into two types based on their physical characteristics as follows:

**Large slips**: typical headscarp widths of 30-70 m, with source and debris runout areas more than 100 m in length, often extending well past the base of the escarpment onto the flatter slopes below, and

**Smaller isolated slips**: generally with headscarp widths of less than 30 m and extending less than 50 m. As a result debris from these landslides generally did not reach the base of the escarpment.

#### 2.5.3 Landslide impacting the site

The landslide that occurred within the site is illustrated by site mapping on Figure 2.5 and is also shown in the context of different imagery on Figure 2.6 and Figure 2.7 below. An interpretive cross section prepared through the site is presented in Figure 2.12. Ground conditions have been interpreted from a combination of historical data, site mapping and nearby geotechnical investigation data. The cross section is indicative only and may not be representative of actual conditions.

The landslide headscarp (Figure 2.8) has an approximate width of 7 m and is approximately 10 m above the rear of the dwelling near the crest of a ridgeline. Following a high degree of ground saturation, it initiated on a 30-35° vegetated slope as a shallow (~ 0.5 m deep) translational failure (Figure 2.9) which developed into a debris flow, likely entraining additional material on its descent. The initial landslide source volume was approximately 20 m³, increasing to approximately 60-80 m³ following entrainment. The landslide impacted the rear of the dwelling (Figure 2.10). The resulting damage to the dwelling included widespread structural deformation (see Figure 2.11 and T+T, 2023) with no immediate building collapse. Inundation of the of the decking was also recorded, which, according to our mapping is likely a result of secondary silt discharge from the large-scale landslide that occurred to the south of the site.

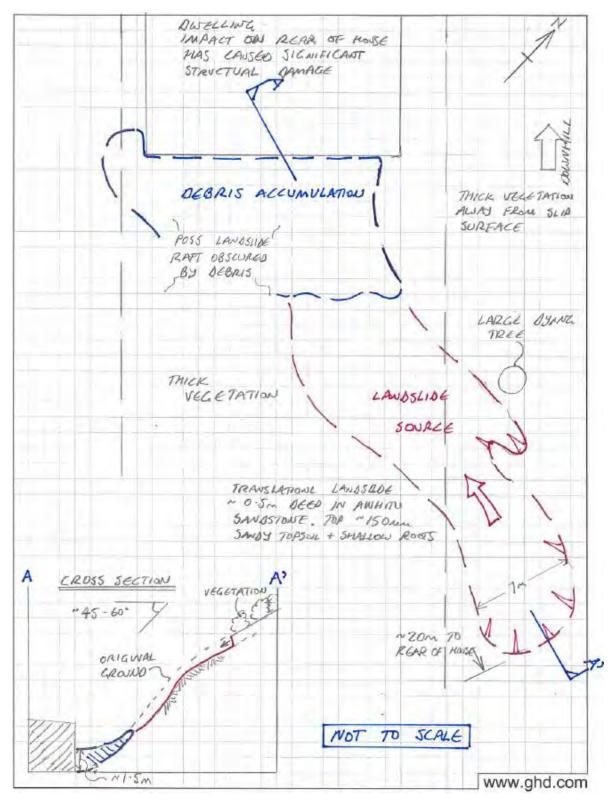


Figure 2.5 GHD site mapping of the landslide (completed 11 December 2023)



Figure 2.6 Landslide locations relative to the site shown on February 2023 aerial image.

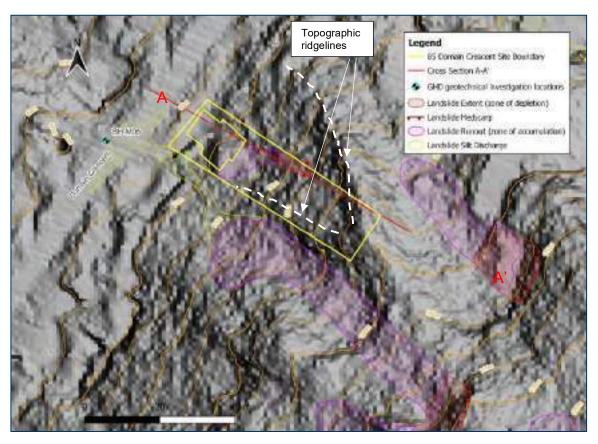


Figure 2.7 Landslide location relative to the site shown on LiDAR Hillshade (source: Auckland Council Feb 2023).



Figure 2.8 Exposed headscarp of landslide.



Figure 2.9 Failure surface (evacuated zone) exhibiting evidence of post failure erosion. Looking upslope.



Figure 2.10 Debris piled up at the rear of dwelling (estimated up to 1.5 m thick)



Figure 2.11 Damage caused by landslide includes racking of entire building (exhibited by bending of exterior wall)

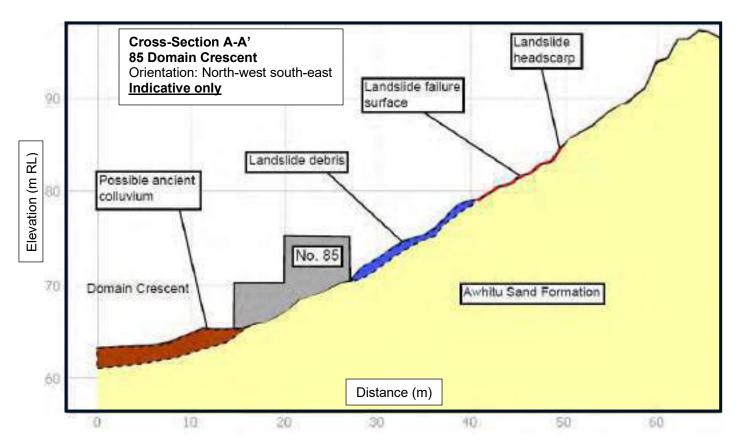


Figure 2.12 Indicative cross section A-A' through 85 Domain Crescent

# 3. Landslide risk estimation

The Australian Geomechanics Society Landslide Risk Management guidelines, published in 2007 and now commonly referred to as AGS (2007), have been adopted for the following unmitigated loss of life landslide risk assessment. Appendix A provides background information and guidance on how the methodology has been applied for assessing risk to life at the site.

The existing dwelling (or a new dwelling of similar construction occupying the same location) has been considered as the element at risk for this assessment. Our assessment assumes the recent landslide debris has been removed. Where appropriate, sensitivity checks have been undertaken for comparative purposes.

#### 3.1 Hazard characterisation

The landslide hazards considered as part of this assessment are as follows:

- LS1 (Landslide Hazard 1) The most likely future landslide to occur somewhere on the slopes above the property. The landslide would be a shallow failure with a volume in the order of 40 m³ that develops into a debris flow entraining additional downslope material. The assumed landslide characteristics have been inferred from observations of the previous failure and landslides to occur elsewhere in Muriwai. The possible source area considered for a future landslide above the dwelling, highlighted on Figure 3.1 and Figure 3.2 below, is constrained by two relatively prominent ridgelines.
- LS2 (Landslide Hazard 2) Regression of the existing landslide headscarp. This is likely to have a volume somewhat smaller than the landslide that occurred in February 2023.

# 3.2 Likelihood of landsliding (P<sub>(H)</sub>)

The basis for estimating probability of occurrence for each landslide hazard considered as part of this assessment in provided in Appendix A and the probabilities adopted are provided below.

#### 3.2.1 Likelihood of LS1

Two considerations of probability for occurrence for the most likely future landslide are:

- P<sub>(H'1)</sub> is the probability that the rainfall threshold for the most likely significant landslide is exceeded, which is taken as a proxy for landslide initiation. This is assumed to be 1 in 100 or **0.01** (see analysis by AC in Appendix A) or 1 in 50 or **0.02** under the influence of future climate change.
- P<sub>(H'2)</sub> is the probability that a slope above the dwellings fails. A single landslide occurred on the slopes above the dwelling. Considering the total area of the slopes above the dwelling with similar conditions, and therefore considered susceptible to failure, an estimate of 5% failed during the February 2023 rainfall event. Given that a significant portion of the possible source area is directly above the dwelling, an increased value of P<sub>(H'2)</sub> = 0.1 has been adopted.

#### 3.2.2 Likelihood of LS2

Given the current condition of the exposed landslide headscarp, it is considered that regression of the existing landslide will occur in the same location during a relatively frequent rainfall event. A value of  $P_{(H'1)}$  of **1 in 10** or **0.1** is adopted whilst  $P_{(H'2)}$  is considered certain and a value of **1.0** is adopted.

# 3.3 Probability of spatial impact $(P_{(S:H)})$

Our estimate of spatial probability is based on several factors which depend on the landslide hazards being considered and site-specific slope conditions. Our approach is detailed in Appendix A. Figure 3.1 and Figure 3.2

below provide an indication of the slope conditions at 85 Domain Crescent and the surrounding area (slope angles and inferred preferential flow paths, respectively).

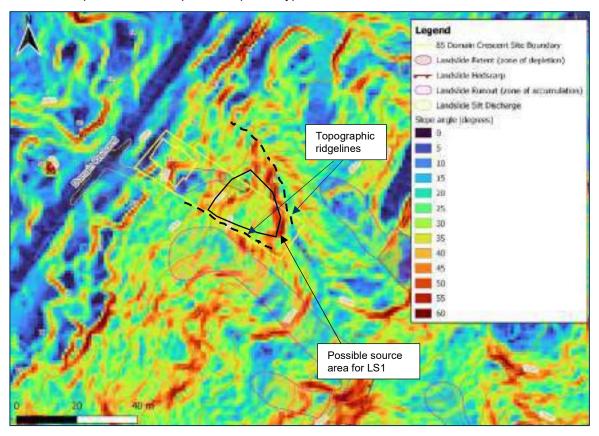


Figure 3.1 Slope map of 85 Domain Crescent and surrounding area. Slope angles based on 2023 DTM data.

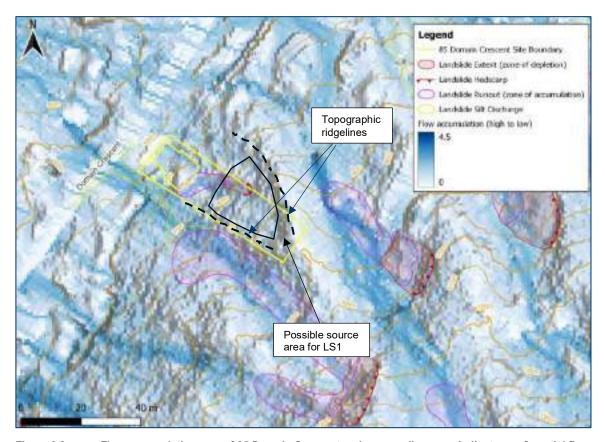


Figure 3.2 Flow accumulation map of 85 Domain Crescent and surrounding area. Indicates preferential flow path for surface water. Modelling based on 2023 DTM data.

#### 3.3.1 Probability of spatial impact (LS1)

Two conditional factors are considered for the most likely significant landslide:

- P(s:H:1) is the probability that if the landslide occurs it travels in the direction of the site. Based on the position of the dwelling at the base of a relatively planar slope exhibiting a somewhat concave geomorphology at its crest, a landslide initiating in the possible source area above the site (Figure 3.1) would likely travel downslope (northwest) towards the dwelling. Based on the flow accumulation plot (Figure 3.2) a landslide is unlikely to take a preferential flow path. A value of 1.0 is adopted.
- P(s::H:2) is the probability that if the landslide occurs it will reach the property. The natural slopes above are generally steep (30-40°). Based on an approximate landslide volume of 40 m³, an adopted travel angle of 35° (Appendix A methodology based on data from Piha and Karekare) would project the landslide to the rear of the dwelling. Empirical methods in the GHD (2023) Muriwai risk assessment report indicate that, based on a downslope angle of approximately 35°, the predicted travel distance angle would be approximately 30° (for an unconfined travel path). This values also generally agrees with published data in Hunter & Fell (2002). This would project the landslide beyond the dwelling. A probability value of 1.0 has been adopted as a conservative approach.

#### 3.3.2 Probability of spatial impact (LS2)

Landslide hazard LS2 involves upslope or lateral regression of the existing landslide.

- If the existing landslide hazard were to reactivate and result in regression of the headscarp, it is likely that the new landslide would follow the same path as the previous one, and hence travel towards the rear of the dwelling. As such a probability of **1.0** has been adopted for P(s:H'1).
- Regression of the existing landslide is expected to result in mobilisation of a somewhat smaller volume of debris. Given the observed behaviour of the previous slide (impacting the rear of the dwelling) and the topography of the site, any future failure is judged certain to almost certain to reach the dwelling. As such, a value of 0.8 is adopted for P(s::H'2).

# 3.4 Temporal spatial probability $(P_{(T:S)})$

As discussed in Appendix A, a temporal spatial probability of **0.68** is the adopted value for each property and has been used in this assessment.

# 3.5 Vulnerability $(V_{(D:T)})$

In the event a debris flow reaches the dwelling from the slopes above, the flow depth is likely to be in the order of 1.0 m. The flow is likely to have a higher volume and velocity than the previous landslide increasing the potential to result in inundation or partial collapse of the building. Given the extent of structural damage as a result of the previous landslide, a value of **0.8** is adopted for LS1.

In the event that regression of the existing landslide occurs on the slope above the dwelling, it is expected that debris would impact the rear of the dwelling but not result in building collapse. Based on the vulnerability table in Appendix A, a value of **0.1** is adopted for LS2.

# 3.6 Unmitigated Risk Estimation

A summary of the risk estimation for each conceivable landslide hazard is presented in Table 3.1 below. A sensitivity check assuming a higher probability of occurrence for P<sub>(H)</sub> is included for comparative purposes.

Table 3.1 Summary of unmitigated risk estimation for each hazard type by domain.

Hazard	Annual probability of the landslide	Spatial probability	Temporal probability	Vulnerability	Risk	Risk evaluation*
	$P_{(H)} = P_{(H'1)} x$ $P_{(H'2)}$	$P_{(S:H)} = P_{s':H'1)} x$ $P_{(S':H'2)}$	P <sub>(T:S)</sub>	<b>V</b> (D:T)	R <sub>(LOL)</sub>	
LS1 (most likely future landslide hazard)	0.01 x 0.1	1.0 x 1.0	0.68	0.8	5.4 x 10 <sup>-4</sup>	Not tolerable
LS1 Sensitivity check	0.02 x 0.1	1.0 x 1.0	0.68	0.8	1.1 x 10 <sup>-3</sup>	Not tolerable
LS2 (regression of existing landslide hazard)	0.1 x 1.0	1.0 x 1.0	0.68	0.1	6.8 x 10 <sup>-3</sup>	Not tolerable
LS2 Sensitivity check	0.2 x 1.0	1.0 x 1.0	0.68	0.1	1.4 x 10 <sup>-2</sup>	Not tolerable

<sup>\*</sup>The evaluation is a guide only based on recommendations from AGS (2007) which provides a suggested tolerable Loss of Life Risk for the person most at risk.

We acknowledge that assessing risk has an inherent degree of uncertainty and may only be accurate to within half an order of magnitude. This level of uncertainty would not change the outcome of the analysis. Refer to Appendix for further discussion.

#### 4. Conclusion and recommendation

This report has presented the results of a quantitative risk assessment for unmitigated loss of life in relation the property located at 85 Domain Crescent, Muriwai, Waitākere. Two landslide hazards (LS1 and LS2) have formed the basis of this assessment.

Assessment of the most likely future landslide (LS1) estimates the annual risk to loss of life for the person most at risk to be approximately **5.4 x 10**-4. This risk is higher than the AGS (2007c) suggested tolerable Loss of Life Risk for the person most at risk (see Appendix A).

Assessment of the failure of the existing landslide hazard (LS2) estimates the annual risk to loss of life for the person most at risk to be approximately **6.8 x 10**-3. This risk is significantly higher than the AGS (2007c) suggested tolerable Loss of Life Risk for the person most at risk (see Appendix A).

Potential remedial measures to lower the risk level from the existing landslide hazard (LS2) may be possible. However, identifying such measures is outside of the scope of this study.

As discussed above, this report considers geotechnical matters only. There may be other non-geotechnical considerations that affect final placard designation of which GHD are not aware, such as flood risk and structural damage to property.

We understand AC are currently reviewing their tolerable and acceptable risk criteria for risks associated with landsliding. We recommend Council review the risk assessment presented in this report against the AC risk criteria to assess whether it is appropriate to assess the property risk categorisation and remove or re-assess the current placard designation for the site.

#### 5. Limitations

This report has been prepared by GHD for Auckland Council and may only be used and relied on by Auckland Council for the purpose agreed between GHD and Auckland Council as set out in section 1.2 of this report.

GHD otherwise disclaims responsibility to any person other than Auckland Council arising in connection with this report. GHD also excludes implied warranties and conditions, to the extent legally permissible.

The services undertaken by GHD in connection with preparing this report were limited to those specifically detailed in the report and are subject to the scope limitations set out in the report.

The opinions, conclusions and any recommendations in this report are based on conditions encountered and information reviewed at the date of preparation of the report. GHD has no responsibility or obligation to update this report to account for events or changes occurring subsequent to the date that the report was prepared.

The opinions, conclusions and any recommendations in this report are based on assumptions made by GHD described in this report (refer section 1.2 of this report). GHD disclaims liability arising from any of these assumptions being incorrect.

An understanding of the geotechnical site conditions depends on the integration of many pieces of information, some regional, some site specific, some structure specific and some experienced based. Hence this report should not be altered, amended, abbreviated, or issued in part in any way without prior written approval by GHD. GHD does not accept liability in connection with the issuing of an unapproved or modified version of this report.

Verification of the geotechnical assumptions and/or model is an integral part of the design process - investigation, construction verification, and performance monitoring. If the revealed ground or groundwater conditions vary from those assumed or described in this report the matter should be referred back to GHD.

This risk assessment does not mean that there will be no further landsliding impacting this property or group of properties.

# Appendix A

AGS (2007) Background

#### 1. Overview

This appendix document outlines the methods and procedures used to estimate risks to loss of life for the person-most-at-risk at the site described in the covering report. This document should be read in conjunction with the covering report as it contains information not presented in the covering report. This document should not be separated from the main report.

# 2. Landslide Risk Management Framework

# 2.1 Background

The 1998 Thredbo landslide, in which 18 persons were killed, highlighted the challenges faced from building upon steep slopes and led to the development of the Australian Geomechanics Society Landslide Risk Management guidelines, published in 2007 and now commonly referred to as AGS (2007). The suite of guidelines is recognised nationally (Australia) and internationally as world-leading practice. The reader of this report is encouraged to consult the freely available LRM resources which can be accessed at: <a href="https://landsliderisk.org/">https://landsliderisk.org/</a>.

The "Practice Note Guidelines for Landslide Risk Management" (AGS 2007c), provide technical guidance in relation to the processes and tasks undertaken by geotechnical practitioners who prepare LRM reports including appropriate methods and techniques. The Practice Note is a statement of what constitutes good practice by a competent practitioner for LRM, including defensible and up to date methodologies and provides guidance on the quality of assessment and reporting, including the outcomes to be achieved and how they are to be achieved.

The framework for landslide risk management is presented in the figure below and represents a framework widely used internationally.

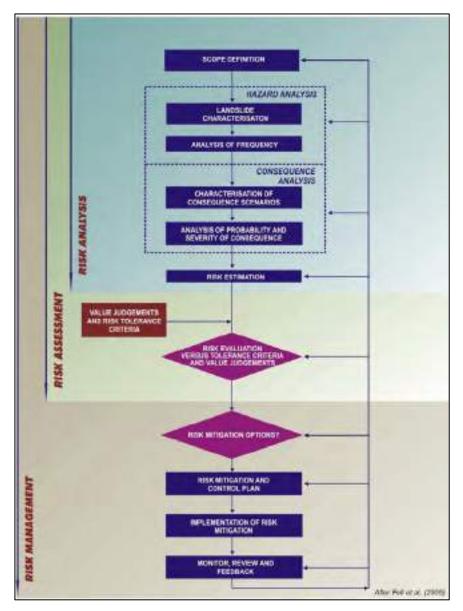


Figure A1 Framework for landslide risk management.

# 2.2 Risk Estimation Methodology

AGS (2007c) requires risks to loss of life to be estimated quantitatively for the person-most-at-risk. The person-most-at-risk will often but not always be the person with the greatest spatial temporal probability (i.e. the person most exposed to the risk). The Individual Risk-to-Life is defined as the risk of fatality or injury to any identifiable (named) individual who lives within the zone impacted by the landslide; or who follows a particular pattern of life that might subject him or her to the consequences of the landslide. The risk of 'loss-of-life' to an individual is calculated from:

$$\mathbf{R}_{(LoL)} = \mathbf{P}_{(H)} \times \mathbf{P}_{(S:H)} \times \mathbf{P}_{(T:S)} \times \mathbf{V}_{(D:T)}$$

Where:

**R**(LoL) is the risk (annual probability of death of an individual).

 $\mathbf{P}_{(H)}$  is the annual probability of the landslide (event).

 $\mathbf{P}_{(S:H)}$  is the probability of spatial impact of the event impacting an individual taking into account the travel distance and travel direction given the event. For example, the probability of an individual in a building or in the open being impacted by a rockfall / landslide at a given location.

 $\mathbf{P}_{(T:S)}$  is the temporal spatial probability (e.g. of the building or location being occupied by the individual at the time of impact) given the spatial impact and allowing for the possibility of evacuation given there is warning of the event occurrence.

 $\mathbf{V}_{(D:T)}$  is the vulnerability of the individual (probability of loss of life of the individual given the impact).

# 2.3 Landslide Risk Assessment Uncertainty

The process of risk assessment involves estimation of likelihood, consequence and risks based on available information for the study site. By its very nature, much of the data, including historical and current inventories may be incomplete whilst an understanding of the triggering events has a degree of uncertainty attached to it. Judgement is required to estimate the nature and size of potential hazards, their frequency of occurrence and their impact on a variety of elements at risk. As these judgements are based on the knowledge, experience and understanding of the assessor, it is not unusual for different assessors to make different judgements about the level of risk.

The thought process used in establishing likelihoods, consequences and determining spatial and temporal factors for properties has been documented for transparency. The structure of the risk assessment process is well defined and values for some input parameters have been tabulated to guide standard approaches by different assessors. However, this should not be mistaken for precision given the limitations of the inputs outlined above. Generally, the levels of likelihoods and risks should be thought of as being within a range of typically +/- half an order of magnitude.

While the basis for the judgements contained in this report are well documented, and the levels of risk considered to be good representations of reality, the accuracy and precision of the process should not be overestimated and should always be used in an appropriate manner in combination with risk management including mitigation and treatment options.

# 3. Hazard Characterisation

AGS (2007c) generally states that all credible hazards originating on, above and below the sites should be assessed. This is generally a predictive exercise based on knowledge and understanding of the geological and geomorphological setting with a view to assembling historical evidence for past hazard events.

#### 3.1 Defining the Most Likely Significant Landslide

Following Cyclone Gabrielle, small landslides within the Muriwai area were often noted to be shallow translational slides developed in the upper residual profile of the Awhitu Sand Formation which, under saturation, transition into debris flows. Detailed analysis by GHD of the mapped landslides within the Karekare and Piha areas, which included size, estimated volume, travel distance and travel angle, was undertaken to characterise the nature and distribution of landslides following the rainfall events that occurred in early 2023, particularly the Cyclone Gabrielle rainfall event, has been used as a basis for defining the magnitude of the 'most significant landslide' for the site.

A total of 80 landslides were mapped throughout Karekare and Piha following the storm events in Jan and Feb 2023. These landslides were then grouped into categories of volume in 50 m³ increments. Results for an assessment of "frequency as categorised by volume" is shown in Figure 1 below.

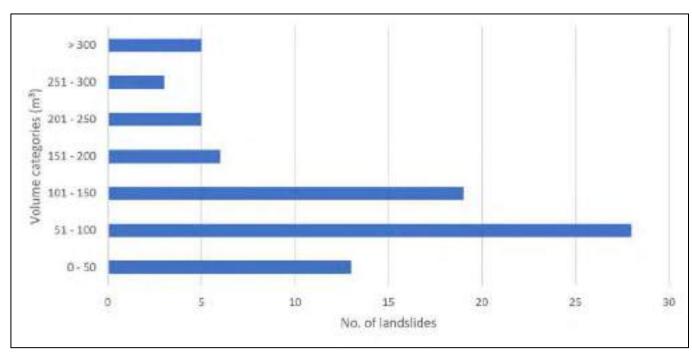


Figure A2 The number or frequency of mapped debris flows (on the x axis) as categorised by volume increments for mapped source areas of debris flows (on the y axis in  $m^3$ ) in Karekare and Piha.

In addition, detailed information regarding volume size, travel angle, travel distance, confinement (either unconfined or channelized) and the degree of damage caused by slides impacting dwellings and building was also collated and a number of additional graphs were developed as below:

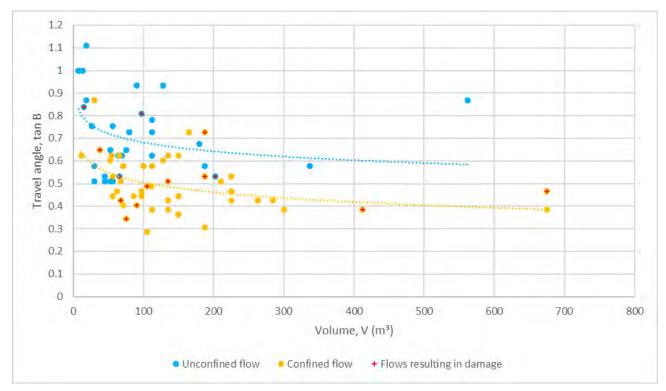


Figure A3 Travel angle vs volume of source area for the Karekare and Piha debris flows

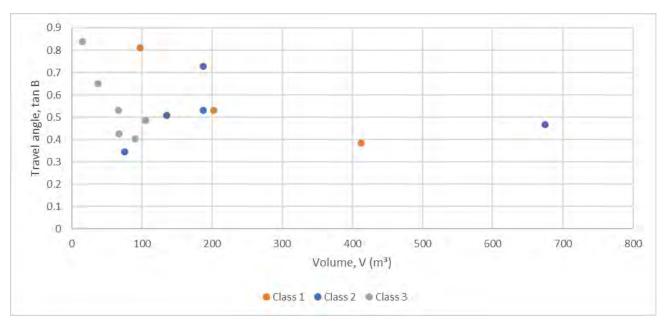


Figure A4 Plot of only those debris flows known to have caused some degree of damage to dwellings and buildings. Note Class 1 = Complete destruction/collapse of building, Class 2 = Partial destruction/collapse of building, significant inundation and Class 3 = Limited damage to building but no collapse or inundation, damage is other property infrastructure e.g., access stairs.

This assessment highlights a number of important points relating the nature of these hazards including:

- Whilst a range of volumes of source areas for debris flow was noted, the most common or likely sized event was of the order of 50-100 m<sup>3</sup> as determined by the frequency plot.
- Many smaller volume source areas for debris flows (less than 75 m³) typically only caused some lesser damage to buildings but once the volume increased above 100 m³, then the vast majority of debris flows were noted to have caused partial or full collapse of dwellings and buildings.
- The greater the volume of the source area, the lower the travel angle and the greater the runout or travel distance.
- Unconfined debris flows generally have a higher travel angle compared to confined or channelized debris
  flows of the same volume. This means that confined or channelised debris flows have a longer runout or
  travel distance and hence have more potential to impact elements at risk further down the slope.

Based on this site-specific data and analysis, GHD has adopted a working definition for these risk assessments of what is termed the **most likely significant landslide** as follows:

- The volume of most likely significant landslides is assumed to be 100 m<sup>3</sup>.
- This volume has been shown to cause significant building damage resulting in partial to full dwelling and building collapse.
- As a result, this hazard is considered to have a high probability for causing loss of life.
- Where this hazard is unconfined, the adopted travel angle based on Figure 3 has been taken as Tan (B) = 0.69 or approx. = 35°
- Where this hazard is confined or channelised the adopted travel angle based on Figure 3 has been taken as Tan (B) = 0.50 or approx. = 26.5°
- Comparison with Figure 6 from Hunter and Fell (2002) suggests the site derived travel angles are generally consistent with other data presented in that plot.

The definition of the **most likely significant landslide** is considered to be a reasonably conservative but not overly cautious estimate of the potential hazard that may affect the site. This is based on an assessment of an overview of landslides that GHD has observed in Muriwai, Karekare and Piha in 2023.

It is noted however that in some specific circumstances, larger recent debris flows may have occurred in close proximity to the site under investigation. As such, where there is evidence for a larger hazard, the assessor may

choose to adopt a larger volume event based on judgement and knowledge of that particular site. In this case other values for travel angle can be read from Figure 3.

IMPORTANT NOTE: It is duly acknowledged that volume alone does not necessarily account for the full potential of a debris flow to cause significant damage and other factors such as the degree of channelization, the additional entrainment of volume within a channel, the degree of saturation of the debris materials, the location of the source area on the hillslope, the direction of travel, the distance of travel and the velocity of the hazard at the point of impact all play important roles in the destructive capacity of any debris flow. Some of these factors are considered within the risk assessment process as conditional probabilities in spatial considerations.

# 3.2 Description of Other Landslide Types

As discussed in the scope of the covering report, other landslide hazards may exist at the site under assessment. These may include existing geohazards that have resulted from recent failures with the potential to pose risk to life in the immediate short-term (i.e. within the next few years) such as regression of translational failures to occur downslope of dwelling, failure of over-steepened fill and cut slopes, rockfall hazards associated with exposed rock faces/headscarps and/or loose debris remaining upslope of dwellings.

In addition, other possible geotechnical slope instability hazards relating to modified slopes (i.e. human made) may also exist and have potential to pose a risk to life - such as failures of fills, cuttings and failed retaining walls. This represents hazards that may have a range of likelihood from almost certain to possible.

Where appropriate, descriptions and definitions for each of these hazards are provided in the covering report on a case-by-case basis and will be specific to the observed hazard and actual conditions at this site.

# 3.3 General Descriptors for Size Classification of Landslides.

Generalized or relative descriptions of size classification systems for landslides vary significantly depending on the country of origin and the nature of the landslide hazards typically encountered. For the purposes of these assessments, GHD proposes to use the following size classification descriptions adopted from the Transport for New South Wales (TfNSW) Guide to Slope Risk Analysis Version 4 (TfNSW 2014) (see Table 3.1 below).

Relative size term	Volume range	Typical mid-range dimensions (width x length x depth in metres)
Very small	<20 m3	4 x 4 x 0.5
Small	20 to 200 m3	10 x 10 x1
Medium	200 to 2000 m3	20 x 20 x 2.5
Large	2000 to 20000 m3	40 x 40 x 5
Very large	>20,000 m3	60 x 60 x 8

Table A3.1 Landslide size classification

# 4. Likelihood P<sub>(H)</sub>

Likelihood or annual probability of occurrence of the landslide,  $P_{(H)}$ , is one of the most critical but difficult to estimate factors as part of the risk assessment process.

# 4.1 The Most Likely Significant Landslide

The recent flood / storm events, the estimation of recurrence intervals for that event and the occurrence of the observed hazards form the basis for the current estimated probability of occurrence for the most likely significant landslide hazard. However, observations of the recent events noted that not all similar slopes failed as a result of

the initiating storm event and as such, an additional consideration for probability of occurrence has been included within the analysis by using conditional probabilities as follows:

$$P_{(H)} = P_{(H'1)} \times P_{(H'2)}$$

Where:

 $P_{(H^1)}$  = Probability that the rainfall threshold for the most credible significant landslide is exceeded which is taken as a proxy for landslide initiation. This is assumed to be 1 in 100 or 0.01 (see analysis and discussion by Auckland Council below) or 1 in 50 or 0.02 under the influence of future climate change.

 $P_{(H'2)}$  =Probability that the slope for the specific assessment fails, which relates to how many of the actual slopes failed out of the total number of all slopes present. This probability is typically based a on spatial analysis of the total area of failed landslides slopes compared to the total area of all slopes for the geomorphic setting in which the site is located.

# 4.2 Auckland Council Guidance on Frequency for Most Likely Significant Landslide

Council provided GHD with an assessment of available rainfall data associated with Cyclone Gabrielle (Auckland Council 2023) (AC memo). During Cyclone Gabrielle, the tipping bucket rain gauge at Muriwai failed and was inundated by flood waters. The AC memo also provided rainfall analysis using AC's Quantitative Precipitation Estimate (QPE) Rain Radar System, which is a real-time rainfall product that utilises the MetService radar. The rainfall data presented by AC indicates a peak rainfall total for Muriwai during the event of 146.9mm, occurring over 12-hour period. This total is >100-year event at a 12-hour duration. The data suggests that for the 12-hour duration rainfall, the Annual Recurrence Interval (ARI) is >100 years and may be in the order of 250 years. However, we understand that the calculation above the 100-year assessment becomes increasingly unreliable, primarily as a result of the relatively short statistical rainfall records available in New Zealand. For the other durations modelled, the rainfall was below the 100-year event.

The AC memo recommended that an envelope of "risk" is estimated as the ARI figures will change over time and as these events are incorporated into the statistical record. The AC memo states that in general, it is considered reasonable to consider the Cyclone Gabrielle event to be in the range of 100-250 year ARI. For this assessment we have assumed that the annual likelihood of a landslide event occurring that is similar in magnitude to the February 2023 event, is about 1 in 100 (i.e., 0.01). This is considered to have a *likely* probability of occurrence.

The assumption of 1 in 100 based on rainfall frequency is a simplifying and possibly conservative assumption that we consider reasonable. It does not consider other factors that could potentially affect stability (antecedent conditions, geology, groundwater conditions, slope height and angle, vegetation, surface water management-overland flow path, overflow from water storage tanks, effect of effluent disposal field), all of which are difficult to quantify.

The AC memo further recommended that risk assessment reports consider the potential for climate change to increase the frequency of high intensity rainfall. We understand that the National Institute of Water and Atmospheric Research (NIWA) has projected a 20% increase in rainfall intensity over the next 100 years which suggests that a 250-year ARI event could increase to a 50-year ARI event. Consequently, we have also included a sensitivity check based on a 50-year ARI event.

We draw the reader's attention to Section 3 of this report and reiterate that AGS (2007c) generally states that all credible hazards originating on, above and below the sites should be assessed. This report has conformed to this requirement and assessed landslide hazards that were observable during the site mapping and/or able to be interpreted via other means such as readily available aerial photographs, lidar data etc. It should be recognised that specific hazards such as rockfalls, failed retaining walls, over-steepened cuts/fill batters may have likelihoods in the *Certain to Almost Certain* range and are more likely to occur in the short term.

#### 4.3 Other Landslide Hazards

Where other slope failures and instabilities as described in Section 3.2 are considered, individual assessments of  $P_{(H)}$ , the probability of occurrence, are made on the basis of expert judgment, performance of similar landslides in the area and recent site observations.

When considering hazards that may pose immediate or short-term risks to life it is probable that such hazards will have high likelihoods of occurrence that could be triggered by relatively frequent events. As a result, such hazard may have likelihoods in the *Certain to Almost Certain* range as per the ASGS2007 qualitative descriptors for likelihood.

# 5. Probability of Spatial Impact P<sub>(S:H)</sub>

The AGS definition of spatial probability is represented by single term  $P_{(S:H)}$  and is described as the probability of spatial impact by the landslide on the element at risk, given the landslide occurs and taking into account the travel distance and travel direction.

# 5.1 The Most Likely Significant Landslide - Upslope of Site

A number of conditional factors may be involved in the spatial distribution for the most likely significant landslide, and for further transparency, the following methodology has been adopted:

$$P_{(S:H)} = P_{(S':H'1)} \times P_{(S':H'2)}$$

#### Where:

- P(s::H'1) = The probability that if the landslide occurs it travels in the direction of the site under assessment. If the slopes above are consistent, and planar then probability is assumed to be 0.8 to 1.0 depending on the topography; if the originating landslide enters a channel that is directed onto the property then probability is assumed to be 1.0, or if the landslide enters a channel that is directed away from the sites then the probability is assumed to be 0.05 taking account of a small probability that the landslide may super elevate and leave the channel.
- P<sub>(S':H'2)</sub> = The Probability that if the landslide occurs it will travel to at least the site under assessment and will impact the property. This is to be based on two considerations as follows:
  - 1. Modelled Behaviour based on travel distance analysis undertaken by GHD for 80 observed landslides slides in the Karekare and Piha areas (see Figure A3). Either probability = 1.0 if the travel angle projects past the dwelling, = 0.5 if the travel angle projects to the rear of the dwelling or = 0.0 if the travel angle falls short of the dwelling.

#### And/or

- 2. Observational behaviour: based on site observations of whether the previous landslides within close proximity to the study site, travelled sufficient distance to reach the site under assessment; if yes Probability = 1.0, if no, then probability = 0
- NOTE 1: The GHD analysis of travel distance highlights the effect of channelisation which shows confined debris flows travel further (i.e., they have a lower travel angle) than those which are unconfined on consistent or planar slopes. Such considerations are included on a site-by-site basis. Interestingly, this event-specific analysis also generally agrees with findings presented in Hunter and Fell (2002).
- NOTE 2: Where significant debris flows have occurred in close proximity to the site under assessment, and
  the observed travel distance is greater than that estimated using the modelled approach, the preferred GHD
  approach is to use the greater of the two travel distances to assess spatial impact.

# 5.2 The Most Likely Significant Landslide – Under the Dwelling/Building and/or Downslope Below the Dwelling/Building

Based on the possible failure area:

- If the failure area is > ~5 m from the dwelling then the value for P<sub>(S:H)</sub> will be 0 as a landslide occurring at that location will not impact dwelling. (The general assumption is that the landslide headscarp would have a length of 5m based on size of most likely significant landslide).
- If the failure area is within ~5m from the dwelling (like above) then the value for P<sub>(S:H)</sub> will be 0.5 to account for uncertainty of it encroaching within the footprint of the dwelling.
- If the failure area encompasses a significant portion of the dwelling then the value for P<sub>(S:H)</sub> will be 1.0 as there is a certain probability it will impact the dwelling.

Estimates of how far back the most significant landslide will regress are difficult to model without a detailed slope stability analysis and sufficiently accurate soil and rock inputs. This would require an intrusive geotechnical investigation which is outside the scope of this study.

GHD has adopted a more empirical approach that assesses the spatial extent of lateral downslope movement of the most likely significant landslide based on direct observations of existing landslides in close proximity to the site under assessment. In the absence of other information, a similar extent of regression has been applied to any future slides. An estimate of P<sub>(S:H)</sub> can then be made as to the potential interaction with the element at risk.

# 5.3 Other landslides – Upslope of the study site

Other types of potential landslides situated above dwellings and buildings on the site under assessment, should be assessed in a similar manner to the most likely significant landslide. Estimates of travel distance are taken from Hunter and Fell (2002) and/or previous local knowledge and/or observation of similar landslides in the area.

When undertaking short term assessments, hazards involving reactivation of existing landslides that are located upslope of the study site that didn't previously reach the site must be taken account. In addition, remobilisation of debris from any upslope landslides must also be assessed for their potential of runout or travel distance using Hunter and Fell (2002).

Similarly potential failures of modified slopes such as cuttings or fills located above or directly adjacent to dwellings and buildings must also be assessed for their spatial impact and the methods of assessment follow the same approach.

# 5.4 Other landslides – under buildings and downslope of the building

A similar approach to that taken for other landslides upslope has been adopted. Observation of existing failures and how much lateral downslope movement can be used as a proxy for what may occur in the future under a regression type scenario.

# 5.5 Temporal Spatial Probability P<sub>(T:H)</sub>

These risk assessments have not considered specific occupancy scenarios for each individual residence. We acknowledge that the occupancy of each residence could vary significantly depending on the demographics of the residents and the usage of the residence. For example, some residences may be predominantly used as holiday accommodation, occupied mainly on weekends, whereas other residences could be permanently occupied by working families.

This assessment has assumed the following occupancies:

- Residences are typically occupied for 15 hours each day during weekdays;
- On weekends, residences are occupied for about 20 hours each day;

The percentage of time a residence is occupied is therefore about 68%.

Any further delineation of the spatial variations in occupancy (i.e. if a bedroom is at the front or the rear of the house etc) are not considered feasible or warranted within the context of the precision of this assessment.

# 6. Vulnerability $V_{(D:T)}$

#### 6.1 Most likely significant Landslide

AGS (2007c) includes a table of vulnerability values for various inundation and building damage scenarios as adapted by Finlay et al (1999). It is important to note that the AGS (2007c) vulnerability table doesn't adequately cater for all the building damage scenarios GHD has observed in Muriwai, Karekare and Piha. GHD has therefore further adapted this table and combined it with information from the TfNSW Guide to Slope Risk Analysis (2014) as well as observations of damage to buildings and structures resulting from the recent landslides in Muriwai, Karekare and Piha.

The table of vulnerability values used in this assessment is presented in Table A6.1. These values have been used as a guide and expert judgement has been applied to select a value within the range of values where appropriate on a site-specific basis.

Table A6.1 Summary of Vulnerability Values adopted

•		Total all a talls	
Case	Range	Typical value to be used in this assessment	Comments
Person in a building that collapses under impact from debris flow	0.8 -1.0	0.9	Death is almost certain. Evacuation unlikely to occur
If building is inundated with debris and the person is buried	0.8 -1.0	0.8	Very high potential for death Evacuation unlikely to occur
If building is inundated with debris but no collapse occurs and the person is not buried	0.01 -0.1	0.1	High chance of survival Evacuation unlikely to occur
If the debris strikes the building only	0.001-0.05	0.01	Very high chance of survival
If failure occurs below the building and results in significant collapse	0.5-0.8	0.6	Moderate to high potential for death. No forewarning signs with evacuation unlikely to occur.
If failure occurs below the building and results in partial collapse	0.01 -0.1	0.05	High chance of survival. Signs of building distress should provide occupants with opportunity to take evasive action.
If failure occurs below the building and results in damage. No collapse occurs.	0.001-0.05	0.005	Very high chance of survival. Evacuation almost certain.

# 7. Risk Evaluation

The main objectives of risk evaluation are usually to compare the assessed risk to risk levels that are acceptable or tolerable to the community, and therefore to decide whether to accept, tolerate or treat the risks and to set

priorities for remediation. The Tolerable Risk Criteria are usually imposed by the regulator, unless agreed otherwise with the owner/client. AGS (2007d) provides discussion and gives the AGS recommendations in relation to tolerable risk for loss of life. These are summarized in the table below.

Table A7.1 AGS Suggested Tolerable loss of life individual risk.

Situation	Suggested Tolerable Loss of Life Risk for the person most at risk
Existing Slope / Existing Development	10 <sup>-4</sup> per annum (1E-4 pa) or 1 in 10,000 pa
New Constructed Slope / New Development / Existing Landslide	10 <sup>-5</sup> per annum (1E-5 pa) or 1 in 100,000 pa

It is important to distinguish between "acceptable risks" and "tolerable risks". AGS (2007c) states that tolerable risks are risks within a range that society can live with so as to secure certain benefits. It is a range of risk regarded as non-negligible and needing to be kept under review and reduced further if practicable. Acceptable risks are risks which everyone affected is prepared to accept. Acceptable risks are usually considered to be one order of magnitude lower than the Tolerable risks.

# 8. References

Auckland Council (2023). 'Guidelines on the use of AGS (2007) for landslide risk assessment in Auckland following the 2023 flooding and cyclone'. Memorandum dated 20 September 2023.

Australian Geomechanics Vol 42 No 1 March 2007 Extract "Practice Note Guidelines for Landslide Risk Management 200" AGS (2007c)

P J Finlay, G R Mostyn & R Fell (1999). 'Landslides: Prediction of Travel Distance and Guidelines for Vulnerability of Persons'. Proc 8th. Australia New Zealand Conference on Geomechanics, Hobart. Australian Geomechanics Society, ISBN 1 86445 0029, Vol 1, pp.105-113.

Hunter. G., & Fell. R. (2002).' Estimation of Travel Distance for Landslides in Soil Slopes'. Australian Geomechanics, Vol 37, No2.

New South Wales Government, Transport for New South Wales 'Guide to Slope Risk Analysis' Version 4, April 2014.

# Appendix B

**Glossary of Terms** 

#### **DEFINITION OF TERMS**

**Acceptable Risk** – A risk which, for the purposes of life or work, society is prepared to accept as it is with no regard to its management. Society does not generally consider expenditure in further reducing such risks iustifiable.

**Authority** or **Council** having statutory responsibility for community activities, community safety and development approval or management of development within its defined area/region

**Consequence** – The outcomes or potential outcomes arising from the occurrence of a landslide expressed qualitatively or quantitatively, in terms of loss, disadvantage or gain, damage, injury or loss of life.

**Creep Failure** – A time-dependant deformation mechanism where constant stress is applied to a material. Creep failure can be identified by ridges the ground surface and curved tree trunks.

**Dropout –** A landslide feature occurring along the length of the road-side on the downslope edge. Drop outs can result in the undermining the road carriageway.

**Elements at Risk** – The population, buildings and engineering works, economic activities, public services utilities, infrastructure and environmental features in the area potentially affected by landslides.

Entrainment - The process of surface sediment transportation through water and mass movement.

**Frequency** – A measure of likelihood expressed as the number of occurrences of an event in a given time. See also Likelihood and Probability of Occurrence.

**Hazard** – A condition with the potential for causing an undesirable consequence. The description of landslide hazard should include the location, volume (or area), classification and velocity of the potential landslides and any resultant detached material, and the probability of their occurrence within a given period of time.

**Individual Risk to Life –** The risk of fatality or injury to any identifiable (named) individual who lives within the zone impacted by the landslide or who follows a particular pattern of life that might subject him or her to the consequences of the landslide.

**Landslide** - A landslide is defined as the movement of a mass of rock, debris, or earth down a slope. The most widely used landslide classification system is that proposed by Cruden and Varnes in 1996 (after Varnes 1954 and Varnes 1978). This has been updated by Hungr, et al., 2014. In its most simple form two nouns are used to describe, firstly the type of material involved and secondly, the mechanism of failure, i.e., rock fall, debris flow.

**Landslide inventory** – An inventory of the location, classification, volume, activity and date of occurrence of landsliding

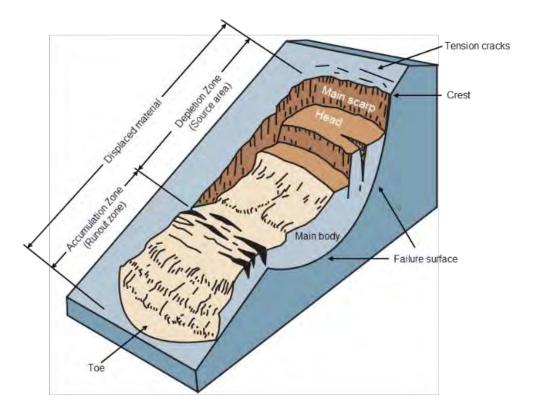
**Landslide Risk -** Landslide risk is defined herein as the likelihood that a particular landslide will occur and the possible consequences to a specific element at risk (property or human life) taking account of both spatial and temporal considerations.

**Landslide Susceptibility –** A quantitative or qualitative assessment of the classification, volume (or area) and spatial distribution of landslides which exist or poten**t**ially may occur in an area. Susceptibility may also include a description of the velocity and intensity of the existing or potential landsliding.

#### **Landslide Classification** – Referenced from Varnes, 1978.

Landslide Type	Landslide Description	Illustration
Rotational sliding	The landslide failure surface is curved concavely upward and the movement of mass is mainly rotational. Rotational movement causes back tilting of the displaced material near the headscarp.	
Translational sliding	The landslide mass moves along a planar failure surface with minor rotational movement.	
Earth flow		
	The movement of saturated fine- grained materials or clay bearing rocks. The displaced material forms a characteristic hourglass shape with an elongated flow path.	towns or the state of the state
Debris flow	The rapid movement of saturated, loose material caused by heavy precipitation and surface water flow. Commonly occurring on steep slopes.	
Debris avalanche	A type of debris flow that is extremely rapid.	
Rock fall	The separation of rocks and boulders along fractures, joints and bedding planes on steep slopes or cliffs. The movement is heavily influenced by mechanical weathering of the rock mass and gravity.	

Landslide characteristics – Modified after Varnes, 1978.



**Likelihood** – Used as a qualitative description of probability or frequency of the event/landslide.

**Overland Flow Path** – The predicated flow path of stormwater over the topography.

**Permeability** – The capacity of a material to allow water to pass through it. Clay materials are impermeable whereas gravels and sands are porous and therefore permeable.

**Probability** – A measure of the degree of certainty. This measure has a value between zero (impossibility) and 1.0 (certainty). It is an estimate of the likelihood of the magnitude of the uncertain quantity or the likelihood of the occurrence of the uncertain future event. There are two main interpretations:

(i) Statistical – frequency or fraction – The outcome of a repetitive experiment of some kind like flipping coins. It also includes the idea of population variability. Such a number is called an "objective" or relative frequentist probability because it exists in the real world and is in principle measurable by doing the experiment. (ii) Subjective probability (degree of belief) – Quantified measure of belief, judgement, or confidence in the likelihood of a outcome, obtained by considering all available information honestly, fairly and with a minimum of bias. Subjective probability is affected by the state of understanding of a process, judgement regarding an evaluation or the quality and quantity of information. It may change over time as the state of knowledge changes.

Probability of Occurrence – used interchangeably with Likelihood.

**Quantitative Risk Analysis** – an analysis based on numerical values of the probability, vulnerability and consequences, and resulting in a numerical value of the risk.

**Recurrence Interval (repeat period)** – An estimated value of how often an event occurs based on the average time between passed events.

**Regression** – The continual movement of a landslide downslope and or widening/retreat of the headscarp.

The **Regulator** will be the responsible body/authority for setting Acceptable/Tolerable Risk Criteria to be adopted for the community/region/activity, which will be the basis for setting levels for Acceptable and Tolerable Risk in the application of the risk assessment guidelines.

**Risk** – A measure of the probability and severity of an adverse effect to health, property or the environment. Risk is often estimated by the product of probability x consequences. However, a more general interpretation of risk involves a comparison of the probability and consequences in a non-product form.

**Risk Analysis –** The use of available information to estimate the risk to individuals, population, property or the environment from hazards. Risk analyses generally contain the following steps: scope definition, hazard identification and risk estimation.

Risk Assessment – The process of risk analysis and risk evaluation.

**Risk Control or Risk Treatment** – The process of decision making for managing risk and the implementation or enforcement of risk mitigation measures and the re-evaluation of its effectiveness from time to time, using the results of risk assessment as one input.

**Risk Estimation** – The process used to produce a measure of the level of health, property or environmental risks being analysed. Risk estimation contains the following steps: frequency analysis, consequence analysis and their integration.

**Risk Evaluation** – The stage at which values and judgements enter the decision process, explicitly or implicitly, by including consideration of the importance of the estimated risks and the associated social, environmental, and economic consequences, in order to identify a range of alternatives for managing the risks.

Risk Management – The complete process of risk assessment and risk control (or risk treatment).

Runout Distance – The horizontal distance from the source area to the distal toe.

Susceptibility - see Landslide Susceptibility

**Temporal-Spatial Probability** – The probability that the element at risk is in the affected area at the time of the landslide.

**Tolerable Risk** – A risk within a range that society can live with so as to secure certain net benefits. It is a range of risk regarded as non-negligible and needing to be kept under review and reduced further if possible.

Transgression-regression cycles – Sedimentary deposits formed from cycles of sea level rise and fall.

**Travel Angle –** The angle from the crest of the source area to the distal toe of the debris (run out zone)

**Vulnerability** – The degree of loss to a given element or set of elements within the area affected by the landslide hazard. It is expressed on a scale of 0 (no loss) to 1 (total loss). For property, the loss will be the value of the damage relative to the value of the property; for persons, it will be the probability that a particular life (the element at risk) will be lost, given the person(s) is affected by the landslide.



# Appendix E-3

87 Domain Crescent Landslide Risk Assessment

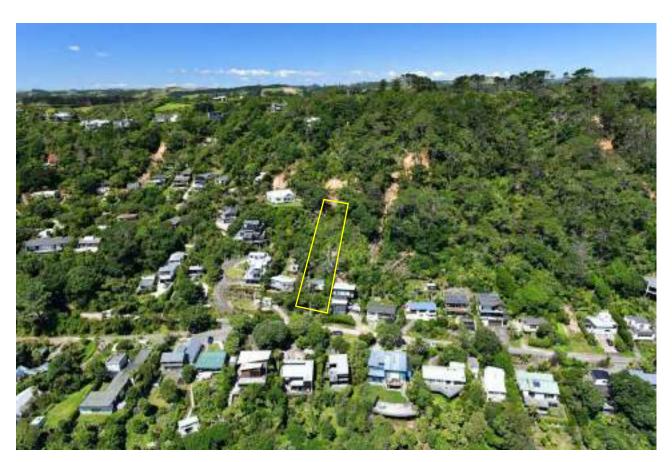


# Waitākere Coastal Communities Landslide Risk Assessment

87 Domain Crescent, Muriwai

Auckland Council
28 March 2024

→ The Power of Commitment



Project r	name	AC Geo Panel - Waitākere Coastal Communities LHRA					
Docume	nt title	Waitākere Coastal Communities Landslide Risk Assessment   87 Domain Crescent, Muriwai					
Project r	number	12612462					
File nam	е	12612462- RiskAssess87 Domain MuriwaiFINALR1.docx					
Status Revision		Author Reviewer		Approved for issue			
Code			Name	Signature	Name	Signature	Date
S4	1	Ryan Hayes	Don Macfarlane	Majoren	Roy Pearson	Roy Prarso	28/03/2024
[Status code]							
[Status code]							
[Status code]							

#### **GHD Limited**

**GHD** 

27 Napier Street, GHD Centre Level 3 Freemans Bay, Auckland 1010, New Zealand

T +64 9 370 8000 | F +64 9 370 8001 | E aklmail@ghd.com | ghd.com

#### © GHD 2024

This document is and shall remain the property of GHD. The document may only be used for the purpose for which it was commissioned and in accordance with the Terms of Engagement for the commission. Unauthorised use of this document in any form whatsoever is prohibited.

# **Contents**

1.	Intro	duction	3
	1.1	Background	3
	1.2	Purpose of this report	3
	1.3	Scope	3
	1.4	Our Approach	4
2.	Site o	conditions	5
	2.1	Site description	5
	2.2	Published geology	8
	2.3	Historical data summary	ç
	2.4	Engineering geological model	10
		2.4.1 Awhitu Sand Formation	10
		2.4.2 General landslide characteristics	10
		2.4.3 Landslide affecting the site	10
3.	Land	slide risk estimation	14
	3.1	Hazard characterisation	14
	3.2	Likelihood of landsliding (P <sub>(H)</sub> )	14
		3.2.1 Likelihood of LS1	14
	3.3	Probability of spatial impact (P <sub>(S:H)</sub> )	14
		3.3.1 Probability of spatial impact (LS1)	16
	3.4	Temporal spatial probability (P <sub>(T:S)</sub> )	17
	3.5	Vulnerability (V <sub>(D:T)</sub> )	17
	3.6	Unmitigated Risk Estimation	17
4.	Mitiga	ation option	18
	4.1	General	18
	4.2	Selected mitigation option	18
	4.3	Mitigated loss of life risk estimation	20
	4.4	Mitigation costs	21
5.	Conc	lusion	22
6.	Limit	ations	23
Та	ble ir	ndex	
Tab	le 2.1	Summary of historical data	g
Tab	le 3.1	Summary of unmitigated risk estimation for each hazard type by domain.	17
Tab	le 4.1	Summary of unmitigated v mitigated loss of life risk estimation for 87 Domain Crescent	21

# Figure index

Figure 2.1	Steep vegetated slope at the rear of the dwelling	6
Figure 2.2	Steep vegetated slope at the rear of the dwelling	6
Figure 2.3	Site location along Domain Crescent	7
Figure 2.4	Excerpt of the Waitākere 1:50,000 scale geological map (Hayward, 1983),	_
	illustrating the underlying geology at the site location.	8
Figure 2.5	GHD site mapping of the landslide affecting the site	11
Figure 2.6	Landslide location relative to the site shown on LiDAR Hillshade (source:	
	Auckland Council Feb 2023).	11
Figure 2.7	Indicative cross section A-A' through 87 Domain Crescent	12
Figure 2.8	Exposed headscarp of landslide.	12
Figure 2.9	Failure surface (evacuated zone) exhibiting evidence of post failure erosion.	
	Looking upslope.	13
Figure 2.10	Debris piled up at the rear of the dwelling at No. 85 Domain Crescent (estimated up to 1.5 m thick)	13
Figure 3.1	Slope map of 87 Domain Crescent and surrounding area. Slope angles based on 2023 DTM data.	15
Figure 3.2	Flow accumulation map of 87 Domain Crescent and surrounding area. Indicates preferential flow path for surface water. Modelling based on 2023 DTM data.	16
Figure 4.1	Example of proprietary flexible debris flow barrier	19
Figure 4.2	Example of a pressure post that can be used at the end of flexible barriers that may be used at property boundaries	19
Figure 4.3	Site plan showing proposed mitigation option for 87 Domain Crescent	20

# **Appendices**

Appendix A AGS (2007) Background Appendix B Glossary of Terms

# 1. Introduction

# 1.1 Background

Two significant rainfall events affected the Waitakere area in late January and early February, resulting from the impacts of ex-tropical cyclones Hale and Gabrielle, respectively.

The Cyclone Gabrielle weather event of 14 February 2023 resulted in widespread catastrophic flooding and slope instability in the settlement of Muriwai where several debris avalanches (which included rocks and trees) occurred, some of which turned into saturated debris flows as they travelled downslope. These flows resulted in damage to buildings and infrastructure. Two fatalities occurred due to impact of landslides on private dwellings. This tragic event was similar to a 1965 storm event that also claimed two lives.

Following the February event, rapid building assessment of residential properties was undertaken in Muriwai, with some houses having access by owners restricted (a yellow placard – e.g. access in daylight hours only) and some for which no access was permitted (a red placard).

GHD has been engaged by Auckland Council (AC)¹ to carry out landslide risk assessments and to provide associated landslide risk management advice and geotechnical investigations recommendations in the Waitakere area, specifically for the residential areas of Muriwai, Piha and Karekare. These assessments were necessary due to widespread, damaging landslides associated with Cyclone Gabrielle in February 2023. GHD has completed a landslide risk assessment², whereby some properties were identified as having an unacceptably high risk of being impacted by future large landslides.

# 1.2 Purpose of this report

The residential property at 87 Domain Crescent, Muriwai ('the site') has been assessed by GHD as having an acceptable risk from large scale landslides<sup>3</sup> (see the November 2023 report). However, a localised, damaging landslide has occurred near the property, and the purpose of this assessment is to carry out a Quantitative Landslide Risk Assessment (QRA) to estimate the risk of Loss of Life to individuals at the property. The outcome of the QRA will be used to inform subsequent property risk categorisation and building placard designation review by AC.

# 1.3 Scope

The scope of work requested by AC was as follows:

- Review available historical and recent imagery including LiDAR.
- Review pertinent historical data and GHD work undertaken as part of the wider Muriwai landslide risk assessment reported in GHD (November 2023).
- Undertake a site engineering geological assessment of landslide hazards relevant to the property.
- Undertake a QRA where landslide hazards have been identified that pose a Loss of Life landslide risk using the Australian Geomechanics Society Practice Note Guidelines for Landslide Risk Management, commonly known as AGS (2007c).
- Deliver report(s) documenting the QRA inputs and outcome.

Specifically excluded are an assessment of property risk, site specific subsurface geotechnical investigations, service inspections, and groundwater monitoring.

This assessment considers geotechnical matters only. There may be other non-geotechnical considerations that affect the final property risk categorisation or placard designation of which GHD are not aware, such as flood risk and structural damage to property.

<sup>&</sup>lt;sup>1</sup> Under Contract CW198379, Master Services Agreement CCCS: CW74240 dated 7/09/2019

<sup>&</sup>lt;sup>2</sup> Dated 03/11/2023, document file ref 12612462\_Overall Report FINALRev0.docx

<sup>&</sup>lt;sup>3</sup> In the GHD November 2023 report, 'large scale' landslide hazards refers to landslides originating from the main escarpment that typically have a volume of more than about 50 m3 with the potential to cause total or partial collapse of a dwelling.

Identification of options for the mitigation of geotechnical hazards has not been undertaken as part of this study.

Although considered unlikely, GHD reserves the right to amend the opinions, conclusions and recommendations provided within this report, should additional geotechnical information become available.

# 1.4 Our Approach

GHD have completed a landslide risk assessment for Muriwai that assessed the risk to life of large-scale landslide hazards to inform possible future dwelling hazard designations. The assessment was limited to 'large scale' landslide hazards originating from the main escarpment located to the south-east of Muriwai because the initial placard assessment was largely aimed at mitigating risks associated with these.

Smaller, more localised landslide hazards that could originate (or may have already initiated) from other areas in Muriwai such as within the footprint of individual residential properties were not considered in the overall risk assessment. However, these have the potential to cause damage to dwellings and subsequently pose a risk to life for residents, partly due to the relatively steep topography and the potential for high travel velocity.

The approach of identifying landslide hazards over large and common source areas, such as that used for the November 2023 Muriwai assessment, does not capture numerous, smaller scale, localised landslides. For this reason, a QRA is presented for the site based on an assessment that includes site observations and a review of the GHD (2023) report.

The QRA undertaken for this report only assesses risk to life to occupants of the dwelling due to landsliding. The assessment considers a number of hazard scenarios as follows:

- 1. the most likely significant landslide hazard based on the observed hazards with respect to the mapped landslides and their distribution within the broader landscape. In addition, considerations of the hazard relationship to topography, position on the hillslope and proximity to the elements at risk are also included. This represents a credible hazard scenario following a triggering event with a similar frequency as the February 2023 event.
- 2. Existing geohazards that have resulted from recent failures with the potential to pose risk to life, such as regression and/or remobilisation of translational failures that are upslope or downslope of a dwelling, or failure of oversteepened fill and cut slopes. These represent hazards that exist at the site and may be triggered by a more frequent event in the range of certain to almost certain<sup>4</sup> to occur.
- 3. Other possible geotechnical slope instability hazards that have the potential to pose a risk to life, such as failures of fills, cuttings and failed retaining walls. These represent hazards that may have a range of likelihood from *almost certain to possible*.

The process of risk assessment involves estimation of likelihood, consequence and risks based on available information for the study site. The methodology used for the QRA is outlined in Appendix A. The site-specific input parameters and uncertainties are described in Section 3.

A glossary of terminology is presented in Appendix B.

<sup>&</sup>lt;sup>4</sup> The terminology used when referencing probabilities has been adopted from the Qualitative Measures of Likelihood table for assessing risk to property in AGS (2007c). For this assessment, these terms and associated probabilities are Certain = 0.99, Almost Certain = 0.1, Likely = 0.01, Possible = 0.001, Unlikely = 0.0001, Very Unlikely = >0.0001

# 2. Site conditions

# 2.1 Site description

The site is located at 87 Domain Crescent, Muriwai, legally described as Lot 63 DP 39644 and it has an approximate area of 827 m<sup>2</sup>. As shown in Figure 2.1, the property is located on Domain Crescent on the lower portion of the approximately 80 m high main escarpment that is aligned to the northeast and separates the township between lower-lying plateaus to the west (near sea level), and higher areas to the south and east. Locally, the escarpment extends from Domain Crescent at its base (at an elevation of approximately 60 m RL), to Oaia Road at its crest (at an elevation of approximately 150 m RL).

There is a single dwelling on the property located towards the base of the slope, adjacent to Domain Crescent. The dwelling is constructed on timber poles built into the slope which has been modified slightly to accommodate it. The natural, vegetated slope behind the dwelling (Figure 2.1 and Figure 2.2) has an average slope gradient of approximately 35° which increases to approximately 60° where it meets a prominent north-trending ridgeline at the eastern extent of the property boundary.

Two 'large' landslides originating at an elevation of approximately 110 m above the site occurred during Cyclone Gabrielle but did not affect the dwelling. A third, smaller scale, localised failure originating within the neighbouring property (No. 85) that partly encroaches within the property boundary of No.87 (mapped on Figure 2.3) at approx. 83 m RL developed into a debris flow which travelled in a southwest direction impacting the rear of the neighbours dwelling (No. 85) causing structural damage.

Two overland flow paths are mapped from Auckland Council's GeoMaps to the north and south of the property boundary (Figure 2.3) originating at approximately 105 m RL and 75 m RL to the southeast of the dwelling. Both overland flow paths have a catchment size of approximately 2000 m² to 4000 m². The travel paths of the debris associated with the two large scale landslides above the site, to the north and south, appear to correlate with the mapped overland flow paths. No overland flow paths are mapped on the slopes within the property boundary.



Figure 2.1 Steep vegetated slope at the rear of the dwelling



Figure 2.2 Steep vegetated slope at the rear of the dwelling



Figure 2.3 Site location along Domain Crescent

# 2.2 Published geology

The published 1:50,000 scale geological map of the area (Hayward, 1983) indicates the site is entirely underlain by the Awhitu Sand Formation (mp), part of the Kaihu Group (Figure 2.4).

Awhitu Sands ('qs') are Pliocene aged (less than 2 Mya) characterised as 'coarse sand, clayey, often limonitised (as laterally discontinuous layers), with minor tuff, lignite and siltstone' (Hayward, 1983). The formation originated as coastal sand deposits. Awhitu Sands are generally oxidised to an orange-brown colour when exposed at the surface, resulting in a weak iron-cementation that allows for the development of large, more than 50 m high steep slopes, such as the escarpment.

The formation is weakly bedded and cross-bedded at the sub metre scale. Locally the formation is inferred to dip north and eastward at a shallow angle. Occurrences of silty/clayey horizons are occasionally visible in outcrop and have been encountered within boreholes, however it is unclear how persistent they are spatially.

Although not mapped, more recent colluvium material formed as a result of ongoing erosion and periodic landsliding associated with escarpment recession is likely present on the basal/lower slopes of the escarpment.

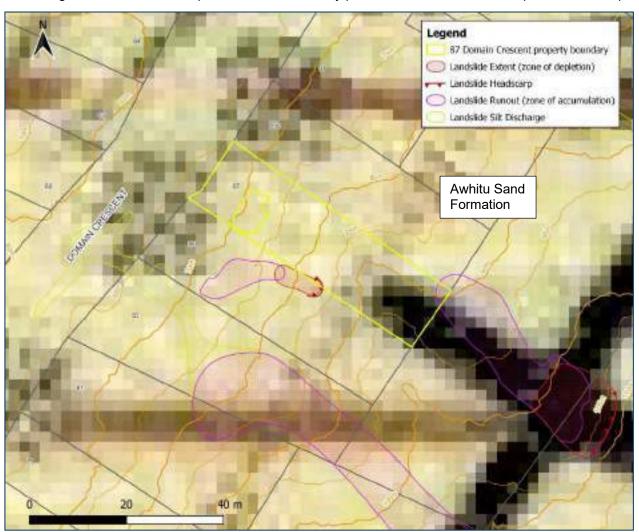


Figure 2.4 Excerpt of the Waitākere 1:50,000 scale geological map (Hayward, 1983<sup>5</sup>), illustrating the underlying geology at the site location.

\_

<sup>&</sup>lt;sup>5</sup> Hayward, B.W. 1983: Sheet Q11, Waitakere. Geological Map of New Zealand 1:50,000 Map

# 2.3 Historical data summary

A summary of the historical data relevant to 87 Domain Crescent is presented in Table 2.1.

Table 2.1 Summary of historical data

	Applicable data available	Note	es
Historic aerial photos	1940, 1950, 1953, 1975, 2000, 2004, 2008, 2010-2011, 2015-2017, 2022	-	No obvious evidence of instability was identified from the historical aerials within the property itself.
			Evidence of wider scale erosion evident from 1940, where many of the spurs leading off main escarpment are bare as well as section of the crest of the escarpment. Suggests ongoing erosion of surficial soil. No regression of escarpment observed. Photos sourced from Retrolens and Auckland
			Council Geomaps.
NZ Geotechnical database	One borehole (BH-MH05, Figure 2.1)	-	10.95 m deep borehole.
	completed by GHD in August 2023.  Located 30 m west of south-west	-	0 – 5.6 m: Ancient colluvial deposits generally comprising sandy silt and silty sand.
	corner of property boundary.		5.6 – 10.95 m: Awhitu sand formation comprising variably cemented sand (medium dense to very dense)
Council GeoMaps	Overland flow data from Auckland City Council ArcGIS.	-	Discussed in Section 2.1.
Rapid building Assessment Geotech reporting	N/A	N/A	
Independent geotechnical reports	N/A	N/A	
Anecdotal information	N/A	N/A	
LiDAR Imagery	Feb 2023 Digital Terrain Model.	-	Headscarps in the escarpment crest suggest ongoing recession through debris flows.
			Headscarps also seen on smaller ridgelines extending down the escarpment. However no clear evidence of these in the ridgeline within the property.
			Possible hummocky ground on the natural slopes above the dwelling leading up to the ridgeline on 87 Domain Crescent.

# 2.4 Engineering geological model

#### 2.4.1 Awhitu Sand Formation

Awhitu Sands are exposed within the entire escarpment and have generally been described as medium dense to very dense sands overlying massive, extremely weak, moderately weathered, iron-cemented fine to coarse sandstone. Irregular layers of clay and silt rich material are typically spaced every 5-10 m and relatively thin (less than 1.0 m and often less than 0.1 m). The strength profile of the Awhitu Sands displays a relatively linear increase with depth.

The in-situ nature of the Awhitu Sands suggests they are relatively permeable. However, as discussed in the November report there is also significant evidence for perched groundwater tables shown by:

- Multiple occurrences of groundwater seeps or springs emerging within the middle and base of the escarpment slope face, from above underlying (presumed aquiclude) layers of clay and silt rich beds as well as heavily oxidised iron pans
- Variable and sharply changing weathering profile with localised layers of cemented iron oxidised sand between un-oxidised material at depth.

#### 2.4.2 General landslide characteristics

As described in the November report (GHD 2023), the landslides identified across Muriwai following the February 2023 event can be categorised into two types based on their physical characteristics as follows:

**Large slips**: typical headscarp widths of 30-70 m, with source and debris runout areas more than 100 m in length, often extending well past the base of the escarpment onto the flatter slopes below, and

**Smaller isolated slips**: generally with headscarp widths of less than 30 m and extending less than 50 m. As a result debris from these landslides generally did not reach the base of the escarpment.

# 2.4.3 Landslide affecting the site

The landslide that occurred above the site, within the neighbour's property, is illustrated by site mapping on Figure 2.5 and is also shown in the context of LiDAR Hillshade imagery on Figure 2.6 below. An interpretive cross section prepared through the site is presented in Figure 2.7. Ground conditions have been interpreted from a combination of historical data, site mapping and nearby geotechnical investigation data. The cross section is indicative only and may not be representative of actual conditions.

The landslide headscarp (Figure 2.8) has an approximate width of 7 m and is approximately 10 m above the rear of the dwelling, close to the crest of a ridgeline. Following a high degree of ground saturation, the landslide initiated on a 30-35° vegetated slope as a shallow (~ 0.5 m deep) translational failure (Figure 2.9) which developed into a debris flow, entraining additional material on its descent. The initial landslide source volume was approximately 20 m³, increasing to approximately 60-80 m³ following entrainment. The landslide impacted the rear of the neighbouring dwelling (Figure 2.10). No landslide debris entered the property of No. 87.



Figure 2.5 GHD site mapping of the landslide affecting the site

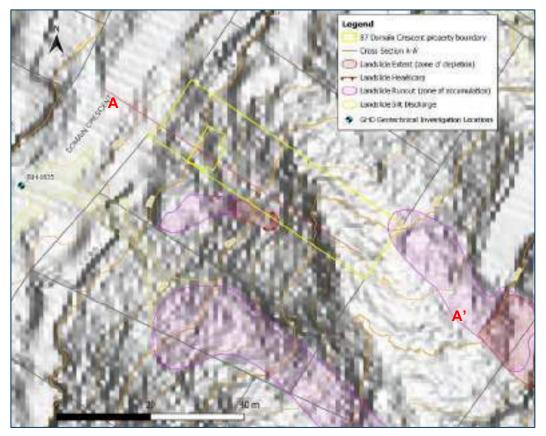


Figure 2.6 Landslide location relative to the site shown on LiDAR Hillshade (source: Auckland Council Feb 2023).

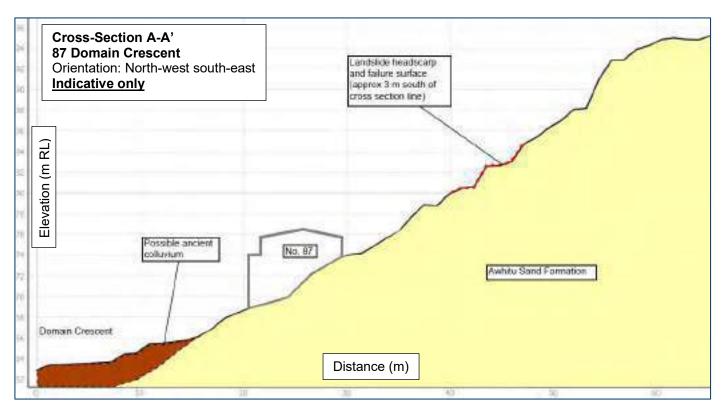


Figure 2.7 Indicative cross section A-A' through 87 Domain Crescent



Figure 2.8 Exposed headscarp of landslide.



Figure 2.9 Failure surface (evacuated zone) exhibiting evidence of post failure erosion. Looking upslope.



Figure 2.10 Debris piled up at the rear of the dwelling at No. 85 Domain Crescent (estimated up to 1.5 m thick)

# 3. Landslide risk estimation

The Australian Geomechanics Society Landslide Risk Management guidelines, published in 2007 and now commonly referred to as AGS (2007), have been adopted for the following unmitigated loss of life landslide risk assessment. Appendix A provides background information and guidance on how the methodology has been applied for assessing risk to life at the site.

The existing dwelling has been considered as the element at risk for this assessment. Where appropriate, sensitivity checks have been undertaken for comparative purposes.

#### 3.1 Hazard characterisation

The landslide hazard considered as part of this assessment is as follows:

LS1 (Landslide Hazard 1) – The most likely future landslide to occur somewhere on the slopes above the property. The landslide would be a shallow failure with a volume in the order of 20-40 m³ that develops into a debris flow entraining additional downslope material. The assumed landslide characteristics have been inferred from observations of the previous failure and landslides to occur elsewhere in Muriwai. The possible source area considered for a future landslide above the dwelling, highlighted on Figure 3.1 and Figure 3.2 below, is constrained by two relatively prominent ridgelines.

# 3.2 Likelihood of landsliding $(P_{(H)})$

The basis for estimating probability of occurrence for the landslide hazard considered as part of this assessment is provided in Appendix A and the probabilities adopted are provided below.

#### 3.2.1 Likelihood of LS1

Two considerations of probability for occurrence for the most likely future landslide are:

- P<sub>(H'1)</sub> is the probability that the rainfall threshold for the most likely significant landslide is exceeded, which is taken as a proxy for landslide initiation. This is assumed to be 1 in 100 or **0.01** (see analysis by AC in Appendix A) or 1 in 50 or **0.02** under the influence of future climate change.
- P(H'2) is the probability that the slope above the dwellings fails. A single landslide occurred on the slopes above and near the dwelling. Considering the total area of the slope above the dwelling with similar conditions, and therefore considered susceptible to failure, an estimate of 5% failed during the February 2023 rainfall event. A value of P(H'2) = 0.05 has been adopted.

# 3.3 Probability of spatial impact $(P_{(S:H)})$

Our estimate of spatial probability is based on several factors which depend on the landslide hazards being considered and site-specific slope conditions. Our approach is detailed in Appendix A. Figure 3.1 and Figure 3.2 below provide an indication of the slope conditions at 87 Domain Crescent and the surrounding area (slope angles and inferred preferential flow paths, respectively).

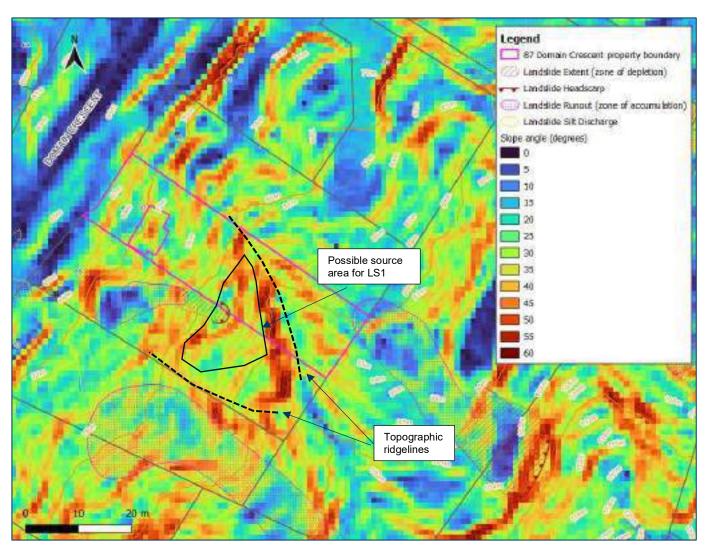


Figure 3.1 Slope map of 87 Domain Crescent and surrounding area. Slope angles based on 2023 DTM data.

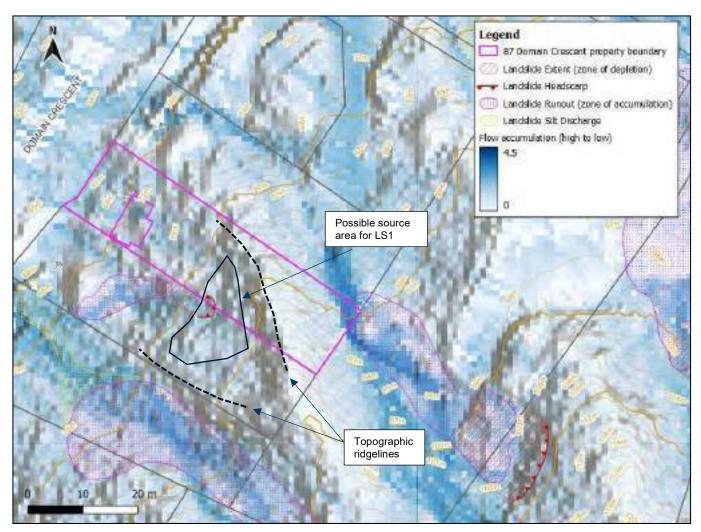


Figure 3.2 Flow accumulation map of 87 Domain Crescent and surrounding area. Indicates preferential flow path for surface water. Modelling based on 2023 DTM data.

# 3.3.1 Probability of spatial impact (LS1)

Two conditional factors are considered for the most likely significant landslide:

- P(S:H'1) is the probability that if the landslide occurs it travels in the direction of the site. Based on the position of the dwelling at the base of a relatively planar slope exhibiting a somewhat concave geomorphology at its crest, a landslide initiating in the possible source area above the site (Figure 3.1) would likely travel downslope (northwest) towards the dwelling. Based on the flow accumulation plot (Figure 3.2) and the topographic contours shown in Figure 2.3, we judge that a landslide is unlikely to take a preferential flow path which diverts it away from the dwelling. A value of 1.0 is adopted.
- P(s::H'2) is the probability that if the landslide occurs it will reach the dwelling. The natural slopes above are generally steep (~35°). Based on the landslide volume approach (using an approximate landslide volume of 50 m³), a travel angle of 35° would be adopted (Appendix A methodology based on data from Piha and Karekare). This would project the landslide to the rear of the dwelling.
  - Empirical methods in the GHD (2023) Muriwai risk assessment report indicate that, based on a downslope angle approach (using approximately 35°), the predicted travel distance angle would be approximately 30° (for an unconfined travel path). This value also generally agrees with published data in Hunter & Fell (2002) (approximately 32°). This would project the landslide beyond the dwelling. Therefore, a probability of impact value of **1.0** has been adopted as a conservative approach.

# 3.4 Temporal spatial probability (P<sub>(T:S)</sub>)

As discussed in Appendix A, a temporal spatial probability of **0.68** is the adopted value for each property and has been used in this assessment.

# 3.5 Vulnerability $(V_{(D:T)})$

In the event a debris flow reaches the dwelling from the slopes above, it is likely to be small<sup>6</sup> in size and have a flow depth in the order of 1.0 m. Given the landslide is likely to initiate at similar elevation to the previous landslide to occur on the neighbouring property, it is assumed it will have a similar behaviour, impacting the rear of the dwelling resulting in significant structural damage and potential collapse. A value of **0.8** is adopted for LS1.

# 3.6 Unmitigated Risk Estimation

A summary of the risk estimation for each conceivable landslide hazard is presented in Table 3.1 below. A sensitivity check assuming a higher probability of occurrence for  $P_{(H)}$  is included for comparative purposes.

Table 3.1 Summary of unmitigated risk estimation for each hazard type by domain.

Hazard	Annual probability of the landslide	Spatial probability	Temporal probability	Vulnerability	Risk	Risk evaluation*
	$P_{(H)} = P_{(H'1)} \times P_{(H'2)}$	$P_{(S:H)} = P_{s':H'1)} x$ $P_{(S':H'2)}$	P <sub>(T:S)</sub>	<b>V</b> (D:T)	R <sub>(LOL)</sub>	
LS1 (most likely future landslide hazard)	0.01 x 0.05	1.0 x 1.0	0.68	0.8	2.7 x 10 <sup>-4</sup>	Not tolerable
LS1 Sensitivity check	0.02 x 0.05	1.0 x 1.0	0.68	0.8	5.4 x 10 <sup>-4</sup>	Not tolerable

<sup>\*</sup>The evaluation is a guide only based on recommendations from AGS (2007) which provides a suggested tolerable Loss of Life Risk for the person most at risk.

We acknowledge that assessing risk has an inherent degree of uncertainty and may only be accurate to within half an order of magnitude. This level of uncertainty would not change the outcome of the analysis. Refer to Appendix A for further discussion.

<sup>&</sup>lt;sup>6</sup> Table A3.1 Landslide size classification in Appendix A

# 4. Mitigation option

#### 4.1 General

A mitigation measure has been selected that could be adopted at this site to lower the risk level associated with future landslides (LS1) occurring above the site to a tolerable level. The following section provides a high-level conceptual mitigation option for the dwelling with an estimated cost using the principles used by GHD for other properties in Muriwai<sup>7</sup>.

Landslide hazard 1 (LS1) is considered as the hazard requiring mitigation and for the purpose of this assessment it is assumed that the landslide would occur on the slopes directly above the dwelling, have a maximum volume of approximately 40 m³ and an estimated velocity of rapid to very rapid8.

The selection is based on existing information and site knowledge. Some of the considerations when selecting a suitable mitigation option include:

- The slope angle and foundation conditions of the proposed barrier location. This is an important consideration for mass gravity embankment-type barriers.
- Site conditions that may enable or limit access for construction.
- The location of the property boundary, with the aim of locating the mitigation structure within this.
- The volume capacity of the proposed debris flow barrier.
- The barrier will require ongoing inspection and maintenance, which is a future liability for the owner.
- The barrier will require access to enable removal of debris.
- The locations and limitations associated with the presence of trees needs to be considered in the design and construction of barriers.
- Whether the site is within a Significant Ecological Area (SEA) where modification of the environment may trigger Resource Consent requirements.

# 4.2 Selected mitigation option

A flexible debris flow 'fence type' barrier has been selected as the most feasible option to mitigate the risk to the dwelling on the site. The limited access at the rear of the property and the steep slope conditions preclude alternative options such as a mass gravity embankment-type barrier. As shown in Figure 4.1 below, the flexible barrier comprises mesh supported by steel posts with upslope and lateral wire support ropes that are anchored several metres into the ground. An example of a commercially available proprietary system that could be adopted is a Geobrugg SL150 (3.5 m constructed height) or a modified RXI300 (5 m constructed height) or equivalent.

<sup>&</sup>lt;sup>7</sup> Reported in GHD report, dated 12 October 2023 'Muriwai debris flow mitigation', reference 12612462\_MitigationOptionsMuriwai final draft <sup>8</sup> Cruden, D., & Varnes, D. (1996). Landslide types and processes. In K. Turner & R. Schuster (Eds.), Landslides: Investigation and Mitigation (Chap. 3, pp. 36–75). Transportation Research Board: Washington.



Figure 4.1 Example of proprietary flexible debris flow barrier

Elements of the barrier system may be exchanged to accommodate specific site conditions. An example of this is where an end terminal is located close to a property boundary. Wire ropes attached to the top of the barrier end post attach to ground anchors several metres upslope and laterally. A pressure post can replace this end post to keep hardware within the property (see Figure 4.2).

The proposed barrier location is above the dwelling at an approximate elevation of 76 m RL and has an approximate length of 10 m (Figure 4.3 below).



Figure 4.2 Example of a pressure post that can be used at the end of flexible barriers that may be used at property boundaries

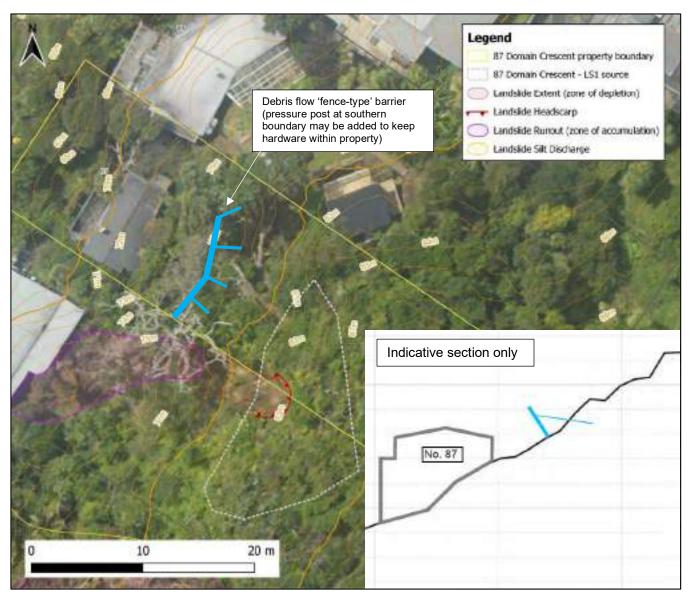


Figure 4.3 Site plan showing proposed mitigation option for 87 Domain Crescent

Some of the key site-specific factors to be considered in the design and construction of this mitigation option include:

- Part of the barrier is located outside of the property boundary (within 85 Domain Crescrent).
- Access is considered to be 'hard' as there is no clear access to the proposed barrier location, which is on a slope of approximately 35°. Enabling works are likely required.
- The property is within the Significant Ecological Area (SEA) and damage to trees/vegetation would be likely for both access and construction.
- The subsurface conditions are likely to comprise medium dense to very dense sands overlying massive, extremely weak sandstone.
- Based on an estimated volume of debris of 40 m<sup>3</sup>, a fence type barrier height of 3.5 m would be adequate.

# 4.3 Mitigated loss of life risk estimation

Table 4.1 below presents the resulting risk estimation following implementation of the selected mitigation option. The mitigated risk assessment only considers the failure of the barrier and therefore the spatial probability has been reduced by two orders of magnitude (i.e to 1% probability of failure). This is to reflect the unlikely potential for the barrier to become ineffective and therefore fail to prevent the landslide from reaching the dwelling.

Table 4.1 Summary of unmitigated v mitigated loss of life risk estimation for 87 Domain Crescent

Property	Hazard	Annual probability of the landslide P <sub>(H)</sub>	Spatial probability P <sub>(S:H)</sub>	Temporal Spatial probability P <sub>(T:S)</sub>	Vulnerability V <sub>(D:T)</sub>	Unmitigated Risk (from Risk Assessment Report)	
						Risk R <sub>(LOL)</sub>	Risk Evaluation
Unmitigated Risk	LS1	0.01 x 0.05	1.0	0.68	0.8	2.7 x 10 <sup>-4</sup>	Not tolerable
Mitigated Risk		0.01 x 0.05	0.01	0.68	0.8	2.7 x 10 <sup>-6</sup>	Acceptable
Unmitigated Risk	LS1	0.02 x 0.05	1.0	0.68	0.8	5.4 x 10 <sup>-4</sup>	Not tolerable
Mitigated Risk	(Sensitivity case)	0.02 x 0.05	0.01	0.68	0.8	5.4 x 10 <sup>-6</sup>	Acceptable

Values in italics represent a sensitivity check which considers a higher annual probably of occurrence.

# 4.4 Mitigation costs

The cost for the proposed mitigation is a high-level estimate based on generic designs. The contingency (uncertainty) is considered high. Geobrugg have provided advice and cost estimates for a flexible debris flow barrier which have been used to inform our total estimate. Whole of life costs have also been considered (e.g. inspections, maintenance).

The total (construct and maintain) P50 expected estimate is in the order of **\$215,000** ex GST. An additional cost of \$35,000 ex GST for SEA consenting has also been allowed for, giving a total cost of \$250,000 ex GST.

We would like to emphasize that the concept and estimated cost presented are high level and indicative only. Further design effort by others is required to better define the details and costs.

# 5. Conclusion and recommendation

This report has presented the results of a quantitative risk assessment for unmitigated loss of life in relation the property located at 87 Domain Crescent, Muriwai, Waitākere. One landslide hazard (LS1) has formed the basis of this assessment.

Assessment of the most likely future landslide (LS1) estimates the annual risk to loss of life for the person most at risk to be approximately **2.7 x 10**-4. This risk is higher than the AGS (2007c) suggested tolerable Loss of Life Risk for the person most at risk (see Appendix A).

Detailed in Section 4, a potential remedial measure to lower the risk level associated with future failures (LS1) above the site includes a dynamic flexible fence-type landslide barrier to catch debris upslope of the existing dwelling at an indicative cost of \$250,000 ex GST. An estimated mitigated annual risk to loss of life for the person most at risk is approximately 2.7 x 10<sup>-6</sup>, which is 'tolerable' (AGS 2007c).

As discussed above, this report considers geotechnical matters only. There may be other non-geotechnical considerations that affect final placard designation of which GHD are not aware, such as flood risk and structural damage to property.

We understand AC are currently reviewing their tolerable and acceptable risk criteria for risks associated with landsliding. We recommend Council review the risk assessment presented in this report against the AC risk criteria to assess whether it is appropriate to assess the property risk categorisation and remove or re-assess the current placard designation for the site.

# 6. Limitations

This report has been prepared by GHD for Auckland Council and may only be used and relied on by Auckland Council for the purpose agreed between GHD and Auckland Council as set out in section 1.2 of this report.

GHD otherwise disclaims responsibility to any person other than Auckland Council arising in connection with this report. GHD also excludes implied warranties and conditions, to the extent legally permissible.

The services undertaken by GHD in connection with preparing this report were limited to those specifically detailed in the report and are subject to the scope limitations set out in the report.

The opinions, conclusions and any recommendations in this report are based on conditions encountered and information reviewed at the date of preparation of the report. GHD has no responsibility or obligation to update this report to account for events or changes occurring subsequent to the date that the report was prepared.

The opinions, conclusions and any recommendations in this report are based on assumptions made by GHD described in this report (refer section 1.2 of this report). GHD disclaims liability arising from any of these assumptions being incorrect.

An understanding of the geotechnical site conditions depends on the integration of many pieces of information, some regional, some site specific, some structure specific and some experienced based. Hence this report should not be altered, amended, abbreviated, or issued in part in any way without prior written approval by GHD. GHD does not accept liability in connection with the issuing of an unapproved or modified version of this report.

Verification of the geotechnical assumptions and/or model is an integral part of the design process - investigation, construction verification, and performance monitoring. If the revealed ground or groundwater conditions vary from those assumed or described in this report the matter should be referred back to GHD.

This risk assessment does not mean that there will be no further landsliding impacting this property or group of properties.

# Appendix A

AGS (2007) Background

# 1. Overview

This appendix document outlines the methods and procedures used to estimate risks to loss of life for the person-most-at-risk at the site described in the covering report. This document should be read in conjunction with the covering report as it contains information not presented in the covering report. This document should not be separated from the main report.

# 2. Landslide Risk Management Framework

# 2.1 Background

The 1998 Thredbo landslide, in which 18 persons were killed, highlighted the challenges faced from building upon steep slopes and led to the development of the Australian Geomechanics Society Landslide Risk Management guidelines, published in 2007 and now commonly referred to as AGS (2007). The suite of guidelines is recognised nationally (Australia) and internationally as world-leading practice. The reader of this report is encouraged to consult the freely available LRM resources which can be accessed at: <a href="https://landsliderisk.org/">https://landsliderisk.org/</a>.

The "Practice Note Guidelines for Landslide Risk Management" (AGS 2007c), provide technical guidance in relation to the processes and tasks undertaken by geotechnical practitioners who prepare LRM reports including appropriate methods and techniques. The Practice Note is a statement of what constitutes good practice by a competent practitioner for LRM, including defensible and up to date methodologies and provides guidance on the quality of assessment and reporting, including the outcomes to be achieved and how they are to be achieved.

The framework for landslide risk management is presented in the figure below and represents a framework widely used internationally.

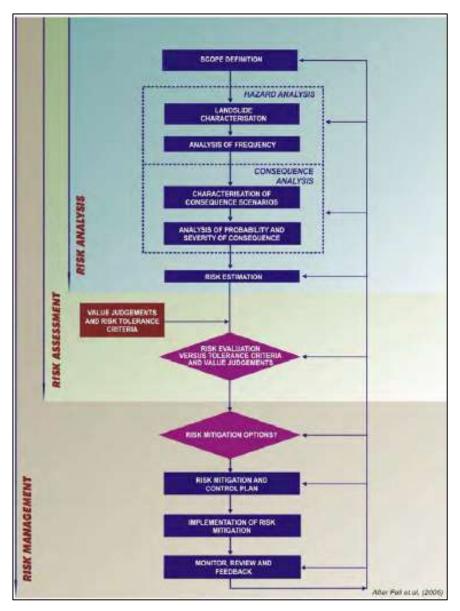


Figure A1 Framework for landslide risk management.

# 2.2 Risk Estimation Methodology

AGS (2007c) requires risks to loss of life to be estimated quantitatively for the person-most-at-risk. The person-most-at-risk will often but not always be the person with the greatest spatial temporal probability (i.e. the person most exposed to the risk). The Individual Risk-to-Life is defined as the risk of fatality or injury to any identifiable (named) individual who lives within the zone impacted by the landslide; or who follows a particular pattern of life that might subject him or her to the consequences of the landslide. The risk of 'loss-of-life' to an individual is calculated from:

$$\mathbf{R}_{(LoL)} = \mathbf{P}_{(H)} \times \mathbf{P}_{(S:H)} \times \mathbf{P}_{(T:S)} \times \mathbf{V}_{(D:T)}$$

Where:

**R**<sub>(LoL)</sub> is the risk (annual probability of death of an individual).

 $\mathbf{P}_{(H)}$  is the annual probability of the landslide (event).

 $\mathbf{P}_{(S:H)}$  is the probability of spatial impact of the event impacting an individual taking into account the travel distance and travel direction given the event. For example, the probability of an individual in a building or in the open being impacted by a rockfall / landslide at a given location.

 $\mathbf{P}_{(T:S)}$  is the temporal spatial probability (e.g. of the building or location being occupied by the individual at the time of impact) given the spatial impact and allowing for the possibility of evacuation given there is warning of the event occurrence.

 $\mathbf{V}_{(D:T)}$  is the vulnerability of the individual (probability of loss of life of the individual given the impact).

# 2.3 Landslide Risk Assessment Uncertainty

The process of risk assessment involves estimation of likelihood, consequence and risks based on available information for the study site. By its very nature, much of the data, including historical and current inventories may be incomplete whilst an understanding of the triggering events has a degree of uncertainty attached to it. Judgement is required to estimate the nature and size of potential hazards, their frequency of occurrence and their impact on a variety of elements at risk. As these judgements are based on the knowledge, experience and understanding of the assessor, it is not unusual for different assessors to make different judgements about the level of risk.

The thought process used in establishing likelihoods, consequences and determining spatial and temporal factors for properties has been documented for transparency. The structure of the risk assessment process is well defined and values for some input parameters have been tabulated to guide standard approaches by different assessors. However, this should not be mistaken for precision given the limitations of the inputs outlined above. Generally, the levels of likelihoods and risks should be thought of as being within a range of typically +/- half an order of magnitude.

While the basis for the judgements contained in this report are well documented, and the levels of risk considered to be good representations of reality, the accuracy and precision of the process should not be overestimated and should always be used in an appropriate manner in combination with risk management including mitigation and treatment options.

# 3. Hazard Characterisation

AGS (2007c) generally states that all credible hazards originating on, above and below the sites should be assessed. This is generally a predictive exercise based on knowledge and understanding of the geological and geomorphological setting with a view to assembling historical evidence for past hazard events.

# 3.1 Defining the Most Likely Significant Landslide

Following Cyclone Gabrielle, small landslides within the Muriwai area were often noted to be shallow translational slides developed in the upper residual profile of the Awhitu Sand Formation which, under saturation, transition into debris flows. Detailed analysis by GHD of the mapped landslides within the Karekare and Piha areas, which included size, estimated volume, travel distance and travel angle, was undertaken to characterise the nature and distribution of landslides following the rainfall events that occurred in early 2023, particularly the Cyclone Gabrielle rainfall event, has been used as a basis for defining the magnitude of the 'most significant landslide' for the site.

A total of 80 landslides were mapped throughout Karekare and Piha following the storm events in Jan and Feb 2023. These landslides were then grouped into categories of volume in 50 m<sup>3</sup> increments. Results for an assessment of "frequency as categorised by volume" is shown in Figure 1 below.

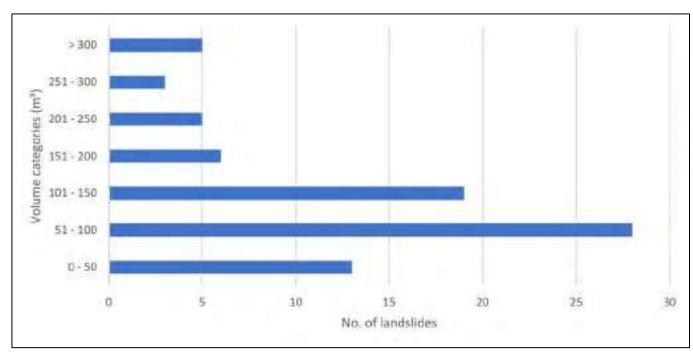


Figure A2 The number or frequency of mapped debris flows (on the x axis) as categorised by volume increments for mapped source areas of debris flows (on the y axis in m³) in Karekare and Piha.

In addition, detailed information regarding volume size, travel angle, travel distance, confinement (either unconfined or channelized) and the degree of damage caused by slides impacting dwellings and building was also collated and a number of additional graphs were developed as below:

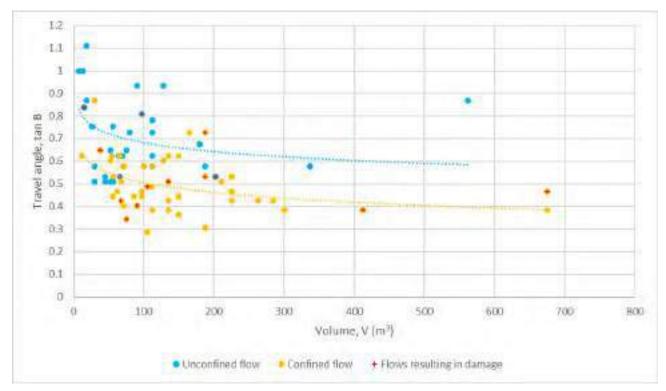


Figure A3 Travel angle vs volume of source area for the Karekare and Piha debris flows

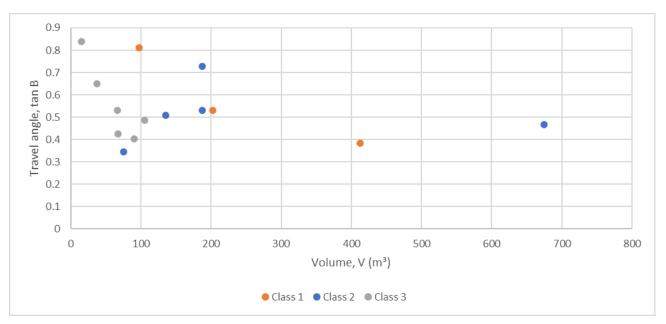


Figure A4 Plot of only those debris flows known to have caused some degree of damage to dwellings and buildings. Note Class 1 = Complete destruction/collapse of building, Class 2 = Partial destruction/collapse of building, significant inundation and Class 3 = Limited damage to building but no collapse or inundation, damage is other property infrastructure e.g., access stairs.

This assessment highlights a number of important points relating the nature of these hazards including:

- Whilst a range of volumes of source areas for debris flow was noted, the most common or likely sized event
  was of the order of 50-100 m<sup>3</sup> as determined by the frequency plot.
- Many smaller volume source areas for debris flows (less than 75 m³) typically only caused some lesser damage to buildings but once the volume increased above 100 m³, then the vast majority of debris flows were noted to have caused partial or full collapse of dwellings and buildings.
- The greater the volume of the source area, the lower the travel angle and the greater the runout or travel distance.
- Unconfined debris flows generally have a higher travel angle compared to confined or channelized debris flows of the same volume. This means that confined or channelised debris flows have a longer runout or travel distance and hence have more potential to impact elements at risk further down the slope.

Based on this site-specific data and analysis, GHD has adopted a working definition for these risk assessments of what is termed the **most likely significant landslide** as follows:

- The volume of most likely significant landslides is assumed to be 100 m<sup>3</sup>.
- This volume has been shown to cause significant building damage resulting in partial to full dwelling and building collapse.
- As a result, this hazard is considered to have a high probability for causing loss of life.
- Where this hazard is unconfined, the adopted travel angle based on Figure 3 has been taken as Tan (B) = 0.69 or approx. = 35°
- Where this hazard is confined or channelised the adopted travel angle based on Figure 3 has been taken as
   Tan (B) = 0.50 or approx. = 26.5°
- Comparison with Figure 6 from Hunter and Fell (2002) suggests the site derived travel angles are generally consistent with other data presented in that plot.

The definition of the **most likely significant landslide** is considered to be a reasonably conservative but not overly cautious estimate of the potential hazard that may affect the site. This is based on an assessment of an overview of landslides that GHD has observed in Muriwai, Karekare and Piha in 2023.

It is noted however that in some specific circumstances, larger recent debris flows may have occurred in close proximity to the site under investigation. As such, where there is evidence for a larger hazard, the assessor may

choose to adopt a larger volume event based on judgement and knowledge of that particular site. In this case other values for travel angle can be read from Figure 3.

IMPORTANT NOTE: It is duly acknowledged that volume alone does not necessarily account for the full potential of a debris flow to cause significant damage and other factors such as the degree of channelization, the additional entrainment of volume within a channel, the degree of saturation of the debris materials, the location of the source area on the hillslope, the direction of travel, the distance of travel and the velocity of the hazard at the point of impact all play important roles in the destructive capacity of any debris flow. Some of these factors are considered within the risk assessment process as conditional probabilities in spatial considerations.

#### 3.2 Description of Other Landslide Types

As discussed in the scope of the covering report, other landslide hazards may exist at the site under assessment. These may include existing geohazards that have resulted from recent failures with the potential to pose risk to life in the immediate short-term (i.e. within the next few years) such as regression of translational failures to occur downslope of dwelling, failure of over-steepened fill and cut slopes, rockfall hazards associated with exposed rock faces/headscarps and/or loose debris remaining upslope of dwellings.

In addition, other possible geotechnical slope instability hazards relating to modified slopes (i.e. human made) may also exist and have potential to pose a risk to life - such as failures of fills, cuttings and failed retaining walls. This represents hazards that may have a range of likelihood from almost certain to possible.

Where appropriate, descriptions and definitions for each of these hazards are provided in the covering report on a case-by-case basis and will be specific to the observed hazard and actual conditions at this site.

### 3.3 General Descriptors for Size Classification of Landslides.

Generalized or relative descriptions of size classification systems for landslides vary significantly depending on the country of origin and the nature of the landslide hazards typically encountered. For the purposes of these assessments, GHD proposes to use the following size classification descriptions adopted from the Transport for New South Wales (TfNSW) Guide to Slope Risk Analysis Version 4 (TfNSW 2014) (see Table 3.1 below).

Relative size term	Volume range	Typical mid-range dimensions (width x length x depth in metres)	
Very small	<20 m3	4 x 4 x 0.5	
Small	20 to 200 m3	10 x 10 x1	
Medium	200 to 2000 m3	20 x 20 x 2.5	
Large	2000 to 20000 m3	40 x 40 x 5	

60 x 60 x 8

Table A3.1 Landslide size classification

Very large

#### 4. Likelihood P<sub>(H)</sub>

Likelihood or annual probability of occurrence of the landslide,  $P_{(H)}$ , is one of the most critical but difficult to estimate factors as part of the risk assessment process.

#### 4.1 The Most Likely Significant Landslide

>20.000 m3

The recent flood / storm events, the estimation of recurrence intervals for that event and the occurrence of the observed hazards form the basis for the current estimated probability of occurrence for the most likely significant landslide hazard. However, observations of the recent events noted that not all similar slopes failed as a result of

the initiating storm event and as such, an additional consideration for probability of occurrence has been included within the analysis by using conditional probabilities as follows:

$$P_{(H)} = P_{(H'1)} \times P_{(H'2)}$$

Where:

 $P_{(H^1)}$  = Probability that the rainfall threshold for the most credible significant landslide is exceeded which is taken as a proxy for landslide initiation. This is assumed to be 1 in 100 or 0.01 (see analysis and discussion by Auckland Council below) or 1 in 50 or 0.02 under the influence of future climate change.

 $P_{(H'2)}$  =Probability that the slope for the specific assessment fails, which relates to how many of the actual slopes failed out of the total number of all slopes present. This probability is typically based a on spatial analysis of the total area of failed landslides slopes compared to the total area of all slopes for the geomorphic setting in which the site is located.

## 4.2 Auckland Council Guidance on Frequency for Most Likely Significant Landslide

Council provided GHD with an assessment of available rainfall data associated with Cyclone Gabrielle (Auckland Council 2023) (AC memo). During Cyclone Gabrielle, the tipping bucket rain gauge at Muriwai failed and was inundated by flood waters. The AC memo also provided rainfall analysis using AC's Quantitative Precipitation Estimate (QPE) Rain Radar System, which is a real-time rainfall product that utilises the MetService radar. The rainfall data presented by AC indicates a peak rainfall total for Muriwai during the event of 146.9mm, occurring over 12-hour period. This total is >100-year event at a 12-hour duration. The data suggests that for the 12-hour duration rainfall, the Annual Recurrence Interval (ARI) is >100 years and may be in the order of 250 years. However, we understand that the calculation above the 100-year assessment becomes increasingly unreliable, primarily as a result of the relatively short statistical rainfall records available in New Zealand. For the other durations modelled, the rainfall was below the 100-year event.

The AC memo recommended that an envelope of "risk" is estimated as the ARI figures will change over time and as these events are incorporated into the statistical record. The AC memo states that in general, it is considered reasonable to consider the Cyclone Gabrielle event to be in the range of 100-250 year ARI. For this assessment we have assumed that the annual likelihood of a landslide event occurring that is similar in magnitude to the February 2023 event, is about 1 in 100 (i.e., 0.01). This is considered to have a *likely* probability of occurrence.

The assumption of 1 in 100 based on rainfall frequency is a simplifying and possibly conservative assumption that we consider reasonable. It does not consider other factors that could potentially affect stability (antecedent conditions, geology, groundwater conditions, slope height and angle, vegetation, surface water management-overland flow path, overflow from water storage tanks, effect of effluent disposal field), all of which are difficult to quantify.

The AC memo further recommended that risk assessment reports consider the potential for climate change to increase the frequency of high intensity rainfall. We understand that the National Institute of Water and Atmospheric Research (NIWA) has projected a 20% increase in rainfall intensity over the next 100 years which suggests that a 250-year ARI event could increase to a 50-year ARI event. Consequently, we have also included a sensitivity check based on a 50-year ARI event.

We draw the reader's attention to Section 3 of this report and reiterate that AGS (2007c) generally states that all credible hazards originating on, above and below the sites should be assessed. This report has conformed to this requirement and assessed landslide hazards that were observable during the site mapping and/or able to be interpreted via other means such as readily available aerial photographs, lidar data etc. It should be recognised that specific hazards such as rockfalls, failed retaining walls, over-steepened cuts/fill batters may have likelihoods in the *Certain to Almost Certain* range and are more likely to occur in the short term.

#### 4.3 Other Landslide Hazards

Where other slope failures and instabilities as described in Section 3.2 are considered, individual assessments of  $P_{(H)}$ , the probability of occurrence, are made on the basis of expert judgment, performance of similar landslides in the area and recent site observations.

When considering hazards that may pose immediate or short-term risks to life it is probable that such hazards will have high likelihoods of occurrence that could be triggered by relatively frequent events. As a result, such hazard may have likelihoods in the *Certain to Almost Certain* range as per the ASGS2007 qualitative descriptors for likelihood.

#### 5. Probability of Spatial Impact P<sub>(S:H)</sub>

The AGS definition of spatial probability is represented by single term  $P_{(S:H)}$  and is described as the probability of spatial impact by the landslide on the element at risk, given the landslide occurs and taking into account the travel distance and travel direction.

## 5.1 The Most Likely Significant Landslide - Upslope of Site

A number of conditional factors may be involved in the spatial distribution for the most likely significant landslide, and for further transparency, the following methodology has been adopted:

$$P_{(S:H)} = P_{(S':H'1)} \times P_{(S':H'2)}$$

#### Where:

- P(s::H'1) = The probability that if the landslide occurs it travels in the direction of the site under assessment. If the slopes above are consistent, and planar then probability is assumed to be 0.8 to 1.0 depending on the topography; if the originating landslide enters a channel that is directed onto the property then probability is assumed to be 1.0, or if the landslide enters a channel that is directed away from the sites then the probability is assumed to be 0.05 taking account of a small probability that the landslide may super elevate and leave the channel.
- P<sub>(S':H'2)</sub> = The Probability that if the landslide occurs it will travel to at least the site under assessment and will impact the property. This is to be based on two considerations as follows:
  - Modelled Behaviour based on travel distance analysis undertaken by GHD for 80 observed landslides slides in the Karekare and Piha areas (see Figure A3). Either probability = 1.0 if the travel angle projects past the dwelling, = 0.5 if the travel angle projects to the rear of the dwelling or = 0.0 if the travel angle falls short of the dwelling.

#### And/or

- 2. Observational behaviour: based on site observations of whether the previous landslides within close proximity to the study site, travelled sufficient distance to reach the site under assessment; if yes Probability = 1.0, if no, then probability = 0
- NOTE 1: The GHD analysis of travel distance highlights the effect of channelisation which shows confined debris flows travel further (i.e., they have a lower travel angle) than those which are unconfined on consistent or planar slopes. Such considerations are included on a site-by-site basis. Interestingly, this event-specific analysis also generally agrees with findings presented in Hunter and Fell (2002).
- NOTE 2: Where significant debris flows have occurred in close proximity to the site under assessment, and
  the observed travel distance is greater than that estimated using the modelled approach, the preferred GHD
  approach is to use the greater of the two travel distances to assess spatial impact.

#### 5.2 The Most Likely Significant Landslide – Under the Dwelling/Building and/or Downslope Below the Dwelling/Building

Based on the possible failure area:

- If the failure area is > ~5 m from the dwelling then the value for P<sub>(S:H)</sub> will be 0 as a landslide occurring at that location will not impact dwelling. (The general assumption is that the landslide headscarp would have a length of 5m based on size of most likely significant landslide).
- If the failure area is within ~5m from the dwelling (like above) then the value for P<sub>(S:H)</sub> will be 0.5 to account for uncertainty of it encroaching within the footprint of the dwelling.
- If the failure area encompasses a significant portion of the dwelling then the value for P<sub>(S:H)</sub> will be 1.0 as there is a certain probability it will impact the dwelling.

Estimates of how far back the most significant landslide will regress are difficult to model without a detailed slope stability analysis and sufficiently accurate soil and rock inputs. This would require an intrusive geotechnical investigation which is outside the scope of this study.

GHD has adopted a more empirical approach that assesses the spatial extent of lateral downslope movement of the most likely significant landslide based on direct observations of existing landslides in close proximity to the site under assessment. In the absence of other information, a similar extent of regression has been applied to any future slides. An estimate of P<sub>(S:H)</sub> can then be made as to the potential interaction with the element at risk.

#### 5.3 Other landslides – Upslope of the study site

Other types of potential landslides situated above dwellings and buildings on the site under assessment, should be assessed in a similar manner to the most likely significant landslide. Estimates of travel distance are taken from Hunter and Fell (2002) and/or previous local knowledge and/or observation of similar landslides in the area.

When undertaking short term assessments, hazards involving reactivation of existing landslides that are located upslope of the study site that didn't previously reach the site must be taken account. In addition, remobilisation of debris from any upslope landslides must also be assessed for their potential of runout or travel distance using Hunter and Fell (2002).

Similarly potential failures of modified slopes such as cuttings or fills located above or directly adjacent to dwellings and buildings must also be assessed for their spatial impact and the methods of assessment follow the same approach.

# 5.4 Other landslides – under buildings and downslope of the building

A similar approach to that taken for other landslides upslope has been adopted. Observation of existing failures and how much lateral downslope movement can be used as a proxy for what may occur in the future under a regression type scenario.

#### 5.5 Temporal Spatial Probability P<sub>(T:H)</sub>

These risk assessments have not considered specific occupancy scenarios for each individual residence. We acknowledge that the occupancy of each residence could vary significantly depending on the demographics of the residents and the usage of the residence. For example, some residences may be predominantly used as holiday accommodation, occupied mainly on weekends, whereas other residences could be permanently occupied by working families.

This assessment has assumed the following occupancies:

- Residences are typically occupied for 15 hours each day during weekdays;
- On weekends, residences are occupied for about 20 hours each day;

The percentage of time a residence is occupied is therefore about 68%.

Any further delineation of the spatial variations in occupancy (i.e. if a bedroom is at the front or the rear of the house etc) are not considered feasible or warranted within the context of the precision of this assessment.

#### 6. Vulnerability $V_{(D:T)}$

#### 6.1 Most likely significant Landslide

AGS (2007c) includes a table of vulnerability values for various inundation and building damage scenarios as adapted by Finlay et al (1999). It is important to note that the AGS (2007c) vulnerability table doesn't adequately cater for all the building damage scenarios GHD has observed in Muriwai, Karekare and Piha. GHD has therefore further adapted this table and combined it with information from the TfNSW Guide to Slope Risk Analysis (2014) as well as observations of damage to buildings and structures resulting from the recent landslides in Muriwai, Karekare and Piha.

The table of vulnerability values used in this assessment is presented in Table A6.1. These values have been used as a guide and expert judgement has been applied to select a value within the range of values where appropriate on a site-specific basis.

Table A6.1 Summary of Vulnerability Values adopted

	<u> </u>		
Case	Range	Typical value to be used in this assessment	Comments
Person in a building that collapses under impact from debris flow	0.8 -1.0	0.9	Death is almost certain. Evacuation unlikely to occur
If building is inundated with debris and the person is buried	0.8 -1.0	0.8	Very high potential for death Evacuation unlikely to occur
If building is inundated with debris but no collapse occurs and the person is not buried	0.01 -0.1	0.1	High chance of survival Evacuation unlikely to occur
If the debris strikes the building only	0.001-0.05	0.01	Very high chance of survival
If failure occurs below the building and results in significant collapse	0.5-0.8	0.6	Moderate to high potential for death. No forewarning signs with evacuation unlikely to occur.
If failure occurs below the building and results in partial collapse	0.01 -0.1	0.05	High chance of survival. Signs of building distress should provide occupants with opportunity to take evasive action.
If failure occurs below the building and results in damage. No collapse occurs.	0.001-0.05	0.005	Very high chance of survival. Evacuation almost certain.

#### 7. Risk Evaluation

The main objectives of risk evaluation are usually to compare the assessed risk to risk levels that are acceptable or tolerable to the community, and therefore to decide whether to accept, tolerate or treat the risks and to set

priorities for remediation. The Tolerable Risk Criteria are usually imposed by the regulator, unless agreed otherwise with the owner/client. AGS (2007d) provides discussion and gives the AGS recommendations in relation to tolerable risk for loss of life. These are summarized in the table below.

Table A7.1 AGS Suggested Tolerable loss of life individual risk.

Situation	Suggested Tolerable Loss of Life Risk for the person most at risk
Existing Slope / Existing Development	10 <sup>-4</sup> per annum (1E-4 pa) or 1 in 10,000 pa
New Constructed Slope / New Development /	10 <sup>-5</sup> per annum (1E-5 pa) or 1 in 100,000 pa
Existing Landslide	

It is important to distinguish between "acceptable risks" and "tolerable risks". AGS (2007c) states that tolerable risks are risks within a range that society can live with so as to secure certain benefits. It is a range of risk regarded as non-negligible and needing to be kept under review and reduced further if practicable. Acceptable risks are risks which everyone affected is prepared to accept. Acceptable risks are usually considered to be one order of magnitude lower than the Tolerable risks.

#### 8. References

Auckland Council (2023). 'Guidelines on the use of AGS (2007) for landslide risk assessment in Auckland following the 2023 flooding and cyclone'. Memorandum dated 20 September 2023.

Australian Geomechanics Vol 42 No 1 March 2007 Extract "Practice Note Guidelines for Landslide Risk Management 200" AGS (2007c)

P J Finlay, G R Mostyn & R Fell (1999). 'Landslides: Prediction of Travel Distance and Guidelines for Vulnerability of Persons'. Proc 8th. Australia New Zealand Conference on Geomechanics, Hobart. Australian Geomechanics Society, ISBN 1 86445 0029, Vol 1, pp.105-113.

Hunter. G., & Fell. R. (2002).' Estimation of Travel Distance for Landslides in Soil Slopes'. Australian Geomechanics, Vol 37, No2.

New South Wales Government, Transport for New South Wales 'Guide to Slope Risk Analysis' Version 4, April 2014.

# Appendix B

**Glossary of Terms** 

#### **DEFINITION OF TERMS**

**Acceptable Risk** – A risk which, for the purposes of life or work, society is prepared to accept as it is with no regard to its management. Society does not generally consider expenditure in further reducing such risks justifiable.

**Authority** or **Council** having statutory responsibility for community activities, community safety and development approval or management of development within its defined area/region

**Consequence** – The outcomes or potential outcomes arising from the occurrence of a landslide expressed qualitatively or quantitatively, in terms of loss, disadvantage or gain, damage, injury or loss of life.

**Creep Failure** – A time-dependant deformation mechanism where constant stress is applied to a material. Creep failure can be identified by ridges the ground surface and curved tree trunks.

**Dropout –** A landslide feature occurring along the length of the road-side on the downslope edge. Drop outs can result in the undermining the road carriageway.

**Elements at Risk** – The population, buildings and engineering works, economic activities, public services utilities, infrastructure and environmental features in the area potentially affected by landslides.

Entrainment – The process of surface sediment transportation through water and mass movement.

**Frequency** – A measure of likelihood expressed as the number of occurrences of an event in a given time. See also Likelihood and Probability of Occurrence.

**Hazard** – A condition with the potential for causing an undesirable consequence. The description of landslide hazard should include the location, volume (or area), classification and velocity of the potential landslides and any resultant detached material, and the probability of their occurrence within a given period of time.

**Individual Risk to Life –** The risk of fatality or injury to any identifiable (named) individual who lives within the zone impacted by the landslide or who follows a particular pattern of life that might subject him or her to the consequences of the landslide.

**Landslide** - A landslide is defined as the movement of a mass of rock, debris, or earth down a slope. The most widely used landslide classification system is that proposed by Cruden and Varnes in 1996 (after Varnes 1954 and Varnes 1978). This has been updated by Hungr, et al., 2014. In its most simple form two nouns are used to describe, firstly the type of material involved and secondly, the mechanism of failure, i.e., rock fall, debris flow.

**Landslide inventory** – An inventory of the location, classification, volume, activity and date of occurrence of landsliding

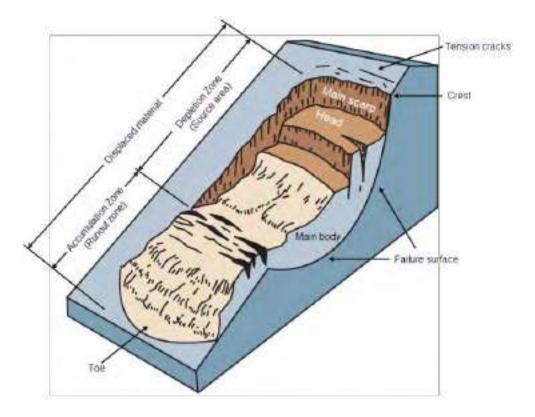
**Landslide Risk -** Landslide risk is defined herein as the likelihood that a particular landslide will occur and the possible consequences to a specific element at risk (property or human life) taking account of both spatial and temporal considerations.

**Landslide Susceptibility –** A quantitative or qualitative assessment of the classification, volume (or area) and spatial distribution of landslides which exist or potentially may occur in an area. Susceptibility may also include a description of the velocity and intensity of the existing or potential landsliding.

#### Landslide Classification – Referenced from Varnes, 1978.

Landslide Type	Landslide Description	Illustration
Rotational sliding	The landslide failure surface is curved concavely upward and the movement of mass is mainly rotational. Rotational movement causes back tilting of the displaced material near the headscarp.	
Translational sliding	The landslide mass moves along a planar failure surface with minor rotational movement.	
Earth flow	The movement of saturated fine- grained materials or clay bearing rocks. The displaced material forms a characteristic hourglass shape with an elongated flow path.	
Debris flow	The rapid movement of saturated, loose material caused by heavy precipitation and surface water flow. Commonly occurring on steep slopes.	
Debris avalanche	A type of debris flow that is extremely rapid.	
Rock fall	The separation of rocks and boulders along fractures, joints and bedding planes on steep slopes or cliffs. The movement is heavily influenced by mechanical weathering of the rock mass and gravity.	

Landslide characteristics – Modified after Varnes, 1978.



**Likelihood** – Used as a qualitative description of probability or frequency of the event/landslide.

Overland Flow Path – The predicated flow path of stormwater over the topography.

**Permeability** – The capacity of a material to allow water to pass through it. Clay materials are impermeable whereas gravels and sands are porous and therefore permeable.

**Probability** – A measure of the degree of certainty. This measure has a value between zero (impossibility) and 1.0 (certainty). It is an estimate of the likelihood of the magnitude of the uncertain quantity or the likelihood of the occurrence of the uncertain future event. There are two main interpretations:

(i) Statistical – frequency or fraction – The outcome of a repetitive experiment of some kind like flipping coins. It also includes the idea of population variability. Such a number is called an "objective" or relative frequentist probability because it exists in the real world and is in principle measurable by doing the experiment. (ii) Subjective probability (degree of belief) – Quantified measure of belief, judgement, or confidence in the likelihood of a outcome, obtained by considering all available information honestly, fairly and with a minimum of bias. Subjective probability is affected by the state of understanding of a process, judgement regarding an evaluation or the quality and quantity of information. It may change over time as the state of knowledge changes.

Probability of Occurrence – used interchangeably with Likelihood.

**Quantitative Risk Analysis** – an analysis based on numerical values of the probability, vulnerability and consequences, and resulting in a numerical value of the risk.

**Recurrence Interval (repeat period)** – An estimated value of how often an event occurs based on the average time between passed events.

**Regression** – The continual movement of a landslide downslope and or widening/retreat of the headscarp.

The **Regulator** will be the responsible body/authority for setting Acceptable/Tolerable Risk Criteria to be adopted for the community/region/activity, which will be the basis for setting levels for Acceptable and Tolerable Risk in the application of the risk assessment guidelines.

**Risk** – A measure of the probability and severity of an adverse effect to health, property or the environment. Risk is often estimated by the product of probability x consequences. However, a more general interpretation of risk involves a comparison of the probability and consequences in a non-product form.

**Risk Analysis –** The use of available information to estimate the risk to individuals, population, property or the environment from hazards. Risk analyses generally contain the following steps: scope definition, hazard identification and risk estimation.

**Risk Assessment** – The process of risk analysis and risk evaluation.

**Risk Control or Risk Treatment** – The process of decision making for managing risk and the implementation or enforcement of risk mitigation measures and the re-evaluation of its effectiveness from time to time, using the results of risk assessment as one input.

**Risk Estimation** – The process used to produce a measure of the level of health, property or environmental risks being analysed. Risk estimation contains the following steps: frequency analysis, consequence analysis and their integration.

**Risk Evaluation** – The stage at which values and judgements enter the decision process, explicitly or implicitly, by including consideration of the importance of the estimated risks and the associated social, environmental, and economic consequences, in order to identify a range of alternatives for managing the risks.

**Risk Management** – The complete process of risk assessment and risk control (or risk treatment).

Runout Distance – The horizontal distance from the source area to the distal toe.

Susceptibility - see Landslide Susceptibility

**Temporal-Spatial Probability** – The probability that the element at risk is in the affected area at the time of the landslide.

**Tolerable Risk** – A risk within a range that society can live with so as to secure certain net benefits. It is a range of risk regarded as non-negligible and needing to be kept under review and reduced further if possible.

Transgression-regression cycles – Sedimentary deposits formed from cycles of sea level rise and fall.

**Travel Angle –** The angle from the crest of the source area to the distal toe of the debris (run out zone)

**Vulnerability** – The degree of loss to a given element or set of elements within the area affected by the landslide hazard. It is expressed on a scale of 0 (no loss) to 1 (total loss). For property, the loss will be the value of the damage relative to the value of the property; for persons, it will be the probability that a particular life (the element at risk) will be lost, given the person(s) is affected by the landslide.



→ The Power of Commitment

# Appendix E-4

207 Motutara Road Landslide Risk Assessment



# Waitākere Coastal Communities Landslide Risk Assessment

207 Motutara Road, Muriwai

Auckland Council
30 April 2024



Project n	ame	AC Geo Panel - Waitākere Coastal Communities LHRA					
Document title Waitākere Coastal Communities Landslide Risk Assessment   207 Motutara Road, M				riwai			
Project n	umber	12612462					
File name	ame 12612462- RiskAssess207 Motutara Rd MuriwaiFINAL.docx						
Status	Revision	Author	Reviewer		Approved for issue		
Code			Name	Signature	Name	Signature	Date
S4	0	Ryan Hayes	Don Macfarlane	Melyplan	Matt Howard	Mouard	30/04/2024
[Status code]							
[Status code]							
[Status code]							

#### **GHD Limited**

Contact: Matt Howard, Technical Director - Engineering Geology | GHD

27 Napier Street, GHD Centre Level 3

Freemans Bay, Auckland 1010, New Zealand

T +64 9 370 8000 | F +64 9 370 8001 | E aklmail@ghd.com | ghd.com

#### © GHD 2024

This document is and shall remain the property of GHD. The document may only be used for the purpose for which it was commissioned and in accordance with the Terms of Engagement for the commission. Unauthorised use of this document in any form whatsoever is prohibited.

#### **Contents**

1.	Intro	duction	4			
	1.1	Background	4			
	1.2	Purpose of this report	4			
	1.3	Scope	4			
	1.4	Our Approach	5			
2.	Site o	conditions	6			
	2.1	Site description	6			
	2.2	Site services and sources of water	8			
	2.3	Published geology	ç			
	2.4	2.4 Historical data summary				
	2.5	Engineering geological model	11			
		2.5.1 Awhitu Sand Formation	11			
		2.5.2 General landslide characteristics	11			
		2.5.3 Landslide impacting the site	11			
3.		slide risk estimation	17			
	3.1	Hazard characterisation	17			
	3.2	Likelihood of landsliding (P <sub>(H)</sub> )	17			
		3.2.1 Likelihood of LS1	17			
	3.3	3.2.2 Likelihood of LS2	17 17			
	ა.ა	Probability of spatial impact (P <sub>(S:H)</sub> ) 3.3.1 Probability of spatial impact (LS1)	19			
		3.3.2 Probability of spatial impact (LS2)	19			
	3.4	Temporal spatial probability (P <sub>(T:S)</sub> )	19			
	3.5	Vulnerability $(V_{(D:T)})$	19			
	3.6	Unmitigated Risk Estimation	19			
4.	Conc	lusion and recommendation	20			
5.	Limit	ations	21			
1.	Over		23			
2.		slide Risk Management Framework	23			
۷.	2.1	Background	23			
	2.2	Risk Estimation Methodology	24			
	2.3	Landslide Risk Assessment Uncertainty	25			
3.		rd Characterisation	25			
٠.	3.1	Defining the Most Likely Significant Landslide	25			
	3.2	Description of Other Landslide Types	28			
	3.3	General Descriptors for Size Classification of Landslides.	28			
4.	Likelihood P <sub>(H)</sub>					
т.	4.1	The Most Likely Significant Landslide	<b>28</b> 28			
	4.2	Auckland Council Guidance on Frequency for Most Likely Significant Landslide	29			
	4.3	Other Landslide Hazards	30			

<b>5</b> .	Probability of Spatial Impact P <sub>(S:H)</sub>			
	5.1 T	he Most Likely Significant Landslide - Upslope of Site	30	
		he Most Likely Significant Landslide – Under the Dwelling/Building and/or ownslope Below the Dwelling/Building	31	
		Other landslides – Upslope of the study site	31	
		Other landslides – under buildings and downslope of the building	31	
		emporal Spatial Probability P <sub>(T:H)</sub>	31	
6.	Vulnerabi		32	
0.		lost likely significant Landslide	32	
7.	Risk Eval	· ·	32	
8.	Reference	<b>3S</b>	33	
Tab	ole inde	e <b>X</b>		
Table	21	Summary of historical data	10	
Table		Summary of unmitigated risk estimation for each hazard type.	20	
Table		Landslide size classification	28	
Table	e A6.1	Summary of Vulnerability Values adopted	32	
Table	e A7.1	AGS Suggested Tolerable loss of life individual risk.	33	
Fig	ure ind	ex		
Figure	e 2.1	Site location at 207 Motutara Road, Muriwai	7	
Figur	e 2.2	Overland flow paths and underground services for the site (source: Auckland Council GeoMaps).	8	
Figur	e 2.3	Excerpt of the Waitākere 1:50,000 scale geological map (Hayward, 1983), illustrating the underlying geology at the site location.	9	
Figur		GHD site mapping of the landslide (completed 12 December 2023)	12	
Figur		Landslide location relative to the site shown on February 2023 aerial image.	13	
Figur	e 2.6	Landslide location relative to the site shown on LiDAR Hillshade (source: Auckland Council Feb 2023).	13	
Figure	o 2 7	Awhitu Sand Formation in the exposed landslide headscarp.	14	
Figur		Close to the lateral extent of the landslide debris at the rear of the dwelling, looking southwest.	14	
Figur	e 2.9	Ponding of water on top of the landslide debris at the rear of the dwelling, looking west.	15	
Figur	e 2.10	Relatively flat area in front of the dwelling, looking east.	15	
-	e 2.11	Indicative interpreted geological cross section through the site at 207 Motutara Road.	16	
Figur	e 3.1	Slope map of 207 Motutara Road and surrounding area. Slope angles based on 2023 DTM data.	18	
Figur		Flow accumulation map of 207 Motutara Road and surrounding area. Indicates preferential flow path for surface water. Modelling based on 2023 DTM data.	18	
Figur	e A1	Framework for landslide risk management.	24	

Figure A2	The number or frequency of mapped debris flows (on the x axis) as categorised by volume increments for mapped source areas of debris flows (on the y axis in	
	m³) in Karekare and Piha.	26
Figure A3	Travel angle vs volume of source area for the Karekare and Piha debris flows	26
Figure A4	Plot of only those debris flows known to have caused some degree of damage to dwellings and buildings. Note Class 1 = Complete destruction/collapse of building, Class 2 = Partial destruction/collapse of building, significant inundation and Class 3 = Limited damage to building but no collapse or inundation, damage	
	is other property infrastructure e.g., access stairs.	27

#### **Appendices**

Appendix A AGS (2007) Background Appendix B Glossary of Terms

#### 1. Introduction

#### 1.1 Background

Two significant rainfall events affected the Waitakere area in late January and early February, resulting from the impacts of ex-tropical cyclones Hale and Gabrielle, respectively.

The Cyclone Gabrielle weather event of 14 February 2023 resulted in widespread catastrophic flooding and slope instability in the settlement of Muriwai where several debris avalanches (which included rocks and trees) occurred, some of which turned into saturated debris flows as they travelled downslope. These flows resulted in damage to buildings and infrastructure. Two fatalities occurred due to impact of landslides on private dwellings. This tragic event was similar to a 1965 storm event that also claimed two lives.

Following the February event, rapid building assessment of residential properties was undertaken in Muriwai, with some houses having access by owners restricted (a yellow placard – e.g. access in daylight hours only) and some for which no access was permitted (a red placard).

GHD has been engaged by Auckland Council (AC)¹ to carry out landslide risk assessments and to provide associated landslide risk management advice and geotechnical investigations recommendations in the Waitakere area, specifically for the residential areas of Muriwai, Piha and Karekare. These assessments were necessary due to widespread, damaging landslides associated with Cyclone Gabrielle in February 2023. GHD has completed a landslide risk assessment², whereby some properties were identified as having an unacceptably high risk of being impacted by future large landslides.

#### 1.2 Purpose of this report

The residential property at 207 Motutara Road, Muriwai ('the site') has been assessed by GHD as having an acceptable risk from large scale landslides<sup>3</sup> (see the November 2023 report). However, a localised, damaging landslide occurred, and the purpose of this assessment is to carry out a Quantitative Landslide Risk Assessment (QRA) to estimate the risk of Loss of Life to individuals at the property from local landsliding. The outcome of the QRA will be used to inform subsequent property risk categorisation and building placard designation review by AC.

#### 1.3 Scope

The scope of work requested by AC was as follows:

- Review available historical and recent imagery, including LiDAR.
- Review pertinent historical data and GHD work undertaken as part of the wider Muriwai landslide risk assessment reported in GHD (2023).
- Undertake a site engineering geological assessment of landslide hazards at the impacted property.
- Undertake a QRA where landslide hazards have been identified that pose a Loss of Life landslide risk using the Australian Geomechanics Society Practice Note Guidelines for Landslide Risk Management, commonly known as AGS (2007c).
- Deliver report(s) documenting the QRA inputs and outcome.

Specifically excluded are an assessment of property risk, site specific subsurface geotechnical investigations, service inspections, and groundwater monitoring.

This assessment considers geotechnical matters only. There may be other non-geotechnical considerations that affect the final property risk categorisation or placard designation of which GHD are not aware, such as flood risk and structural damage to property.

<sup>&</sup>lt;sup>1</sup> Under Contract CW198379, Master Services Agreement CCCS: CW74240 dated 7/09/2019

<sup>&</sup>lt;sup>2</sup> Dated 03/11/2023, document file ref 12612462\_Overall Report FINALRev0.docx

<sup>&</sup>lt;sup>3</sup> In the GHD November 2023 report, 'large scale' landslide hazards refers to landslides originating from the main escarpment that typically have a volume of more than about 50 m3 with the potential to cause total or partial collapse of a dwelling.

Identification of options for the mitigation of geotechnical hazards has not been undertaken as part of this study.

Although considered unlikely, GHD reserves the right to amend the opinions, conclusions and recommendations provided within this report, should additional geotechnical information become available.

#### 1.4 Our Approach

GHD have completed a landslide risk assessment for Muriwai which assessed the risk to life of large-scale landslide hazards to inform possible future dwelling hazard designations. The assessment was limited to 'large scale' landslide hazards originating from the main escarpment located to the south-east of Muriwai because the initial placard assessment was largely aimed at mitigating risks associated with these.

Smaller, more localised landslide hazards that could originate (or may have already initiated) from other areas in Muriwai such as within the footprint of individual residential properties were not considered in the overall risk assessment. However, these have the potential to cause damage to dwellings and subsequently pose a risk to life for residents, partly due to the relatively steep topography and the potential for high travel velocity.

The approach of identifying landslide hazards over large and common source areas, such as that used for the November 2023 Muriwai assessment, does not capture numerous, smaller scale, localised landslides. For this reason, a QRA is presented for the individual property (207 Motutara Road) based on an assessment that includes site observations and a desktop review of available information. The results aid with informing the QRA with regards to the presence of existing and historical landslide hazards and site-specific slope conditions.

The QRA undertaken for this report only assesses risk to life to occupants of the dwelling due to landsliding. The assessment considers a number of hazard scenarios as follows:

- the most likely significant landslide hazard based on the observed hazards with respect to the
  mapped landslides and their distribution within the broader landscape. In addition, considerations of the
  hazard relationship to topography, position on the hillslope and proximity to the elements at risk are also
  included. This represents a credible hazard scenario following a triggering event with a similar frequency
  as the February 2023 event.
- 2. Existing geohazards that have resulted from recent failures with the potential to pose risk to life, such as regression and/or remobilisation of translational failures that are upslope or downslope of a dwelling, or failure of oversteepened fill and cut slopes. These represent hazards that exist at the site and may be triggered by a more frequent event in the range of certain to almost certain<sup>4</sup> to occur.
- 3. Other possible geotechnical slope instability hazards that have potential to pose a risk to life, such as failures of fills, cuttings and failed retaining walls. These represent hazards that may have a range of likelihood from *almost certain to possible*.

The process of risk assessment involves estimation of likelihood, consequence and risks based on available information for the study site. The methodology used for the QRA is outlined in Appendix A. The site-specific input parameters and uncertainties are described in Section 3.

A glossary of terminology is presented in Appendix B.

<sup>&</sup>lt;sup>4</sup> The terminology used when referencing probabilities has been adopted from the Qualitative Measures of Likelihood table for assessing risk to property in AGS (2007c). For this assessment, these terms and associated probabilities are Certain = 0.99, Almost Certain = 0.1, Likely = 0.01, Possible = 0.001, Unlikely = 0.0001, Very Unlikely = >0.0001

#### 2. Site conditions

#### 2.1 Site description

The site is located at 207 Motutara Road, Muriwai, legally described as Lot 1 DP 186496, and has an approximate area of 1535 m<sup>2</sup>. A GHD engineering geologist inspected the site on 12 December 2023. No inspection was undertaken within or under the house. However, a video taken by the homeowner that was made available to us by AC provides an insight into some of the interior damage.

As shown in Figure 2.1, the affected property is located towards the northern end of the township on the western, seaward, side of Motutara Road, approximately 40 m south of Muriwai Lodge. In the area surrounding the site, Motutara Road is positioned on a bench feature which separates the approximately 70 m high, steep main escarpment to the east, and a smaller, approximately 20 m high more localised escarpment, with variably shallow to steep slopes to the east. The property spans most of this escarpment from the driveway entrance at approximately 65 m RL to its western extent at approximately 50 m RL. The slopes within the property are generally quite shallow (10-20°).

There is a single, two storey dwelling on the property which appears to have been constructed on a fill platform at approximately 54 m RL. The natural slopes surrounding the dwelling are generally quite shallow (10-20°) with the exception of the slopes beyond the northeast corner of the dwelling which rise up to Motutara Road at a moderate to steep grade (up to 40°).

Numerous 'large' landslides (mapped on Figure 2.1) originating from the crest and upper slopes of the main escarpment to the east of the site occurred during Cyclone Gabrielle but did not affect the dwelling, terminating at or close to Motutara Road. A smaller scale, localised failure originating from the slopes below Motutara Road, just outside (to the east) of the property boundary, at approx. 65 m RL impacted the eastern side of the dwelling.

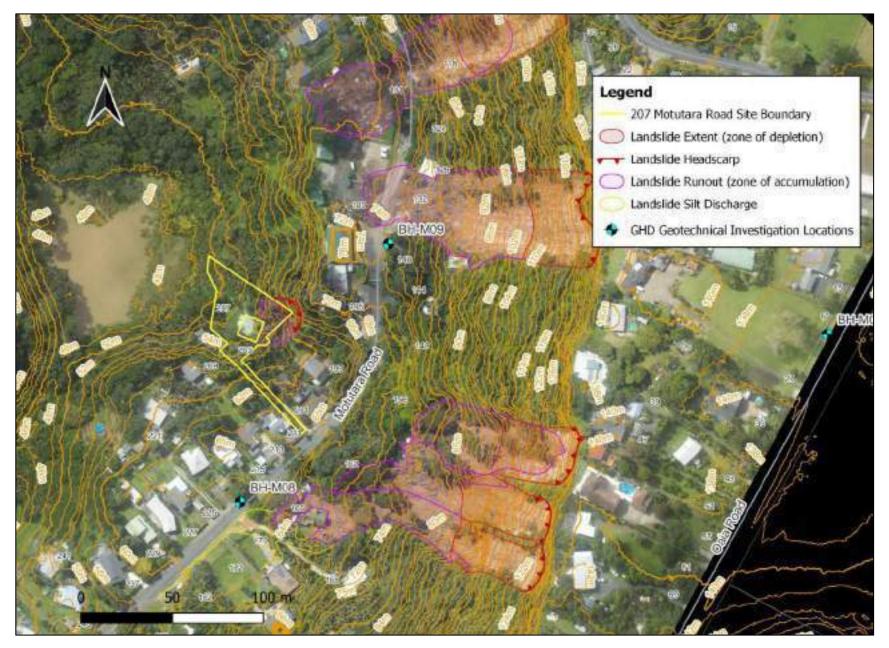


Figure 2.1 Site location at 207 Motutara Road, Muriwai

#### 2.2 Site services and sources of water

Auckland Council's GeoMaps presents relevant underground services and hydrologic information for the site. An excerpt of the data is presented in Figure 2.2.

Two overland flow paths are mapped within the property boundary. One, originating outside the boundary on the slopes above the dwelling to the southeast, is mapped flowing beneath the dwelling into an open watercourse northwest of the property. The second flow path originates in the northwest corner of the property and flows into the same open watercourse. Both overland flow paths have a catchment size of approximately 2000 m<sup>2</sup> – 4000 m<sup>2</sup>.

The landslide that impacted the dwelling does not appear to directly correlate with either of the mapped overland flow paths (see Figure 2.2).

No underground services associated with water are mapped on the slopes above the dwelling.

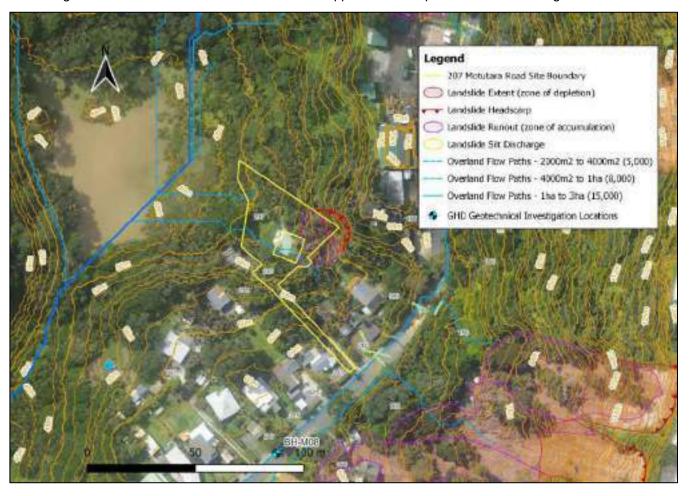


Figure 2.2 Overland flow paths and underground services for the site (source: Auckland Council GeoMaps).

#### 2.3 Published geology

The published 1:50,000 scale geological map of the area (Hayward, 1983) indicates the site is entirely underlain by the Awhitu Sand Formation (qs), part of the Kaihu Group (Figure 2.3). More recently deposited Holocene aged (less than 10 kya) dune sands (qmf) are present at lower elevations, as part of the coastal landscape. These are approximately 100 m west of the property.

Awhitu Sands ('qs') are Pliocene aged (less than 2 Mya) characterised as 'coarse sand, clayey, often limonitised (as laterally discontinuous layers), with minor tuff, lignite and siltstone' (Hayward, 1983). The formation originated as coastal sand deposits. Awhitu Sands are generally oxidised to an orange-brown colour when exposed at the surface, resulting in a weak iron-cementation that allows for the development of large, more than 50 m high steep slopes, such as the escarpment.

The formation is weakly bedded and cross-bedded at the sub metre scale. Locally the formation is inferred to dip north and eastward at a shallow angle. Occurrences of silty/clayey horizons are occasionally visible in outcrop and have been encountered within boreholes, however it is unclear how persistent they are spatially.

Although not mapped, more recent colluvium material formed as a result of ongoing erosion and periodic landsliding associated with escarpment recession is likely present on the basal/lower slopes of the escarpment.

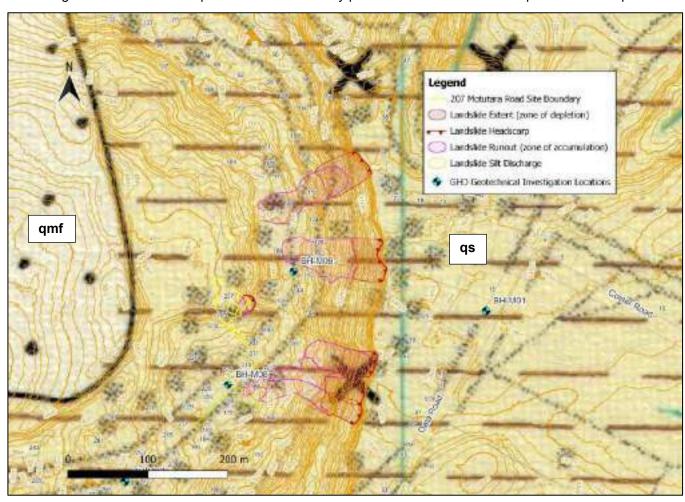


Figure 2.3 Excerpt of the Waitākere 1:50,000 scale geological map (Hayward, 1983<sup>5</sup>), illustrating the underlying geology at the site location.

<sup>&</sup>lt;sup>5</sup> Hayward, B.W. 1983: Sheet Q11, Waitakere. Geological Map of New Zealand 1:50,000 Map

#### 2.4 Historical data summary

A summary of the historical data relevant to 207 Motutara Road is presented in Table 2.1.

Table 2.1 Summary of historical data

	Applicable data available	Notes
Historic aerial photos	- 1940 - 1950 - 1953 - 1975 - 2000 - 2004 - 2008 - 2010-2011 - 2015-2017 - 2022	<ul> <li>No obvious evidence of instability was identified from the historical aerials within the property itself.</li> <li>Evidence of wider scale erosion evident from 1940, where many of the spurs leading off main escarpment are bare as well as sections of the main escarpment crest. Suggests ongoing erosion of surficial soil. No regression of escarpment observed.</li> <li>Photos sourced from Retrolens and Auckland Council Geomaps.</li> </ul>
NZ Geotechnical database	Two boreholes (BH-MH08 and BH-MH09) completed by GHD in July 2023.  Located approx. 50 m south (BH-MH08) and 60 m northeast of property boundary (see Figure 2.1).	<ul> <li>10.95 m deep boreholes drilled at 63 m RL (BH-MH08) and 72 m RL (BH-MH09).</li> <li>BH-MH08 entirely within loose to medium dense silty sand interpreted as Paleo Colluvium</li> <li>BH-MH09 entirely within loose to medium dense silty sand interpreted as Awhitu Sand Formation. A &lt;1 m band of highly weathered, extremely weak sandstone was encountered at 9.6 m</li> </ul>
Council GeoMaps	Overland flow data from Auckland City Council ArcGIS.	- Discussed in Section 2.2.
Rapid building Assessment Geotech reporting	N/A	N/A
Independent geotechnical reports	N/A	N/A
Anecdotal information Landowner video provided in June 2023		Incorporated into Section 2.5
LiDAR Imagery	Feb 2023 Digital Terrain Model.	<ul> <li>Possible historical headscarps in the escarpment suggest ongoing recession through landsliding.</li> <li>Possible hummocky ground on the natural slopes above the dwelling.</li> </ul>

#### 2.5 Engineering geological model

#### 2.5.1 Awhitu Sand Formation

Awhitu Sands are exposed within the entire escarpment and have generally been described as medium dense to very dense sands overlying massive, extremely weak, moderately weathered, iron-cemented fine to coarse sandstone. Irregular layers of clay and silt rich material are typically spaced every 5-10 m and relatively thin (less than 1.0 m and often less than 0.1 m). The strength profile of the Awhitu Sands displays a relatively linear increase with depth.

The in-situ nature of the Awhitu Sands suggests they are relatively permeable. However, as discussed in the November report there is also significant evidence for perched groundwater tables shown by:

- Multiple occurrences of groundwater seeps or springs emerging within the middle and base of the escarpment slope face, from above underlying (presumed aquiclude) layers of clay and silt rich beds as well as heavily oxidised iron pans
- Variable and sharply changing weathering profile with localised layers of cemented iron oxidised sand between un-oxidised material at depth.

#### 2.5.2 General landslide characteristics

As described in the November report (GHD 2023), the landslides identified across Muriwai following the February 2023 event can be categorised into two types based on their physical characteristics as follows:

**Large slips**: typical headscarp widths of 30-70 m, with source and debris runout areas more than 100 m in length, often extending well past the base of the escarpment onto the flatter slopes below, and

**Smaller isolated slips**: generally with headscarp widths of less than 30 m and extending less than 50 m. As a result, debris from these landslides generally did not reach the base of the escarpment.

#### 2.5.3 Landslide impacting the site

The landslide that impacted the dwelling at 207 Motutara Road is illustrated by site mapping on Figure 2.4 and is also shown in the context of different imagery on Figure 2.5 and Figure 2.6 below. An interpretive cross section through the site is presented in Figure 2.11. Ground conditions have been interpreted from a combination of historical data, site mapping and nearby geotechnical investigation data. The cross section is indicative only and may not be representative of actual conditions.

The landslide headscarp (Figure 2.7) has an approximate width of 15 m and is at an elevation approximately 15 m above the rear of the dwelling, near the crest of the localised escarpment below the topographic bench feature on which Motutara Road is located. Following a high degree of ground saturation, it initiated on a 30-40 $^{\circ}$  vegetated slope as a  $\sim$  1-2 m deep translational (with a possible rotational component) failure. The exposed headscarp has left a steeper 45-55 $^{\circ}$  slope profile.

The landslide does not appear to have developed into a debris flow similar to failures seen elsewhere in Muriwai, likely due to its relatively short travel distance. A large volume (potentially up to 300 m³) of landslide debris was deposited at the base of the slope, with a maximum thickness of approximately 2 m impacting the rear of the dwelling (Figure 2.8 and 2.9). A significant portion of the damage to the rear wall of the dwelling was caused by the entrainment of large trees within the debris (Figure 2.9). No building collapse as a result of landslide damage was noted.

Ponding of water on the body of the landslide (Figure 2.9) as well along its lateral extents has occurred following the event and a video provided by the homeowner indicates that water seepage and secondary silt discharge has entered the ground floor of the dwelling. This likely occurred during subsequent relatively frequent rainfall events as a consequence of poor drainage conditions. Figure 2.10 shows landslide debris did not flow around the sides or front of the house.

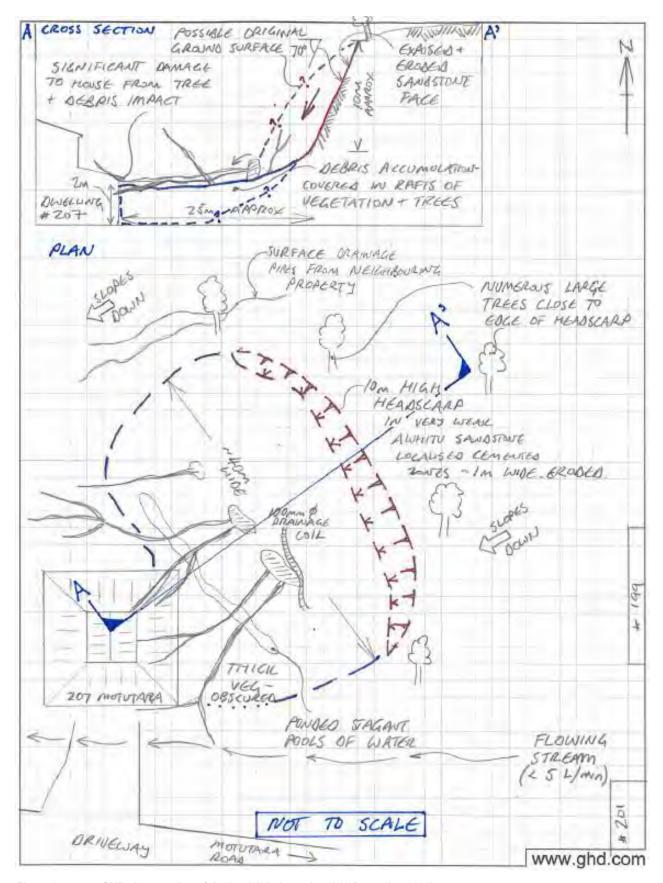


Figure 2.4 GHD site mapping of the landslide (completed 12 December 2023)

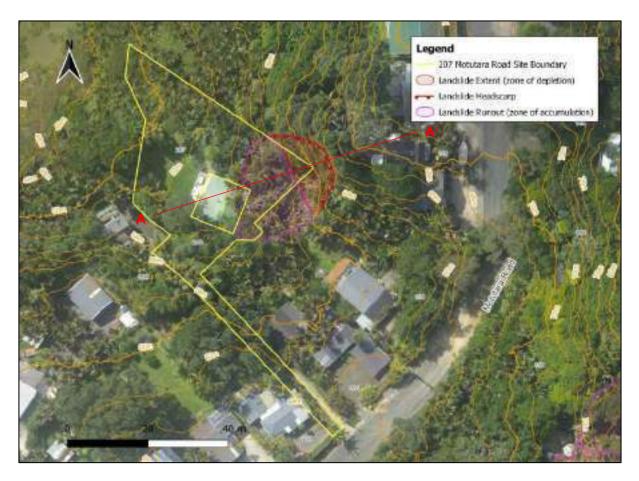


Figure 2.5 Landslide location relative to the site shown on February 2023 aerial image.

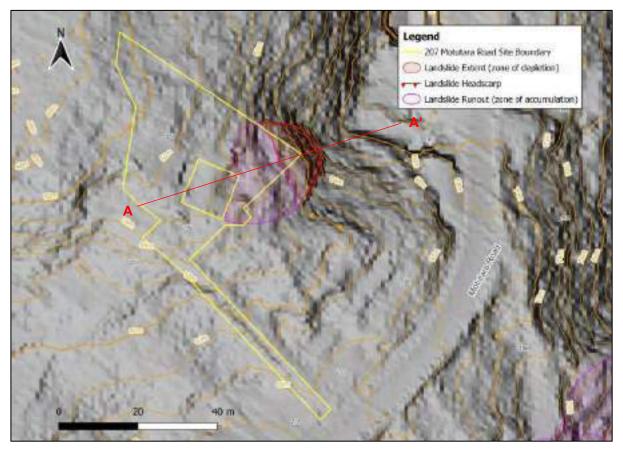


Figure 2.6 Landslide location relative to the site shown on LiDAR Hillshade (source: Auckland Council Feb 2023).



Figure 2.7 Awhitu Sand Formation in the exposed landslide headscarp.



Figure 2.8 Close to the lateral extent of the landslide debris at the rear of the dwelling, looking southwest.



Figure 2.9 Ponding of water on top of the landslide debris at the rear of the dwelling, looking west.



Figure 2.10 Relatively flat area in front of the dwelling, looking east.

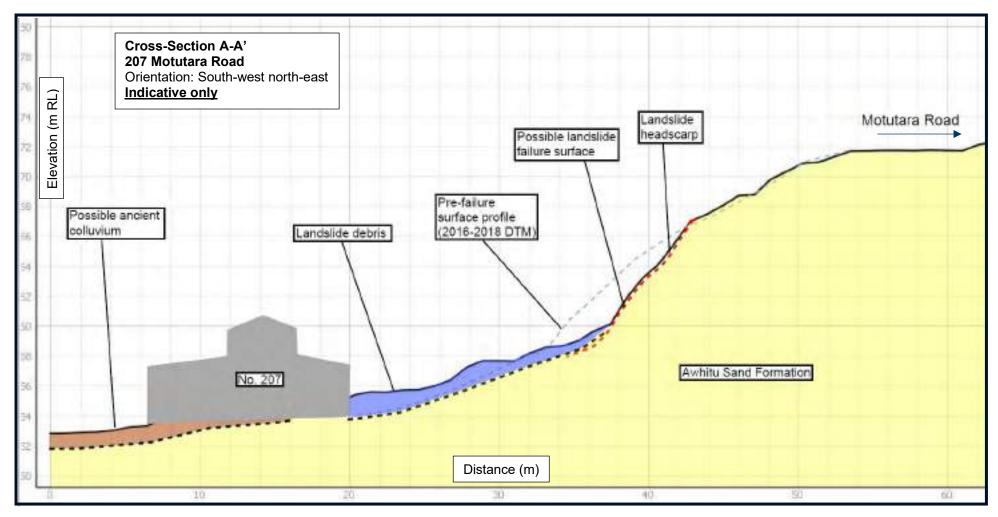


Figure 2.11 Indicative interpreted geological cross section through the site at 207 Motutara Road.

#### 3. Landslide risk estimation

The Australian Geomechanics Society Landslide Risk Management guidelines, published in 2007 and now commonly referred to as AGS (2007), have been adopted for the following unmitigated loss of life landslide risk assessment. Appendix A provides background information and guidance on how the methodology has been applied for assessing risk to life at the site.

The existing dwelling (or a new dwelling of similar construction occupying the same location) has been considered as the element at risk for this assessment. Our assessment assumes the recent landslide debris has been removed. Where appropriate, sensitivity checks have been undertaken for comparative purposes.

#### 3.1 Hazard characterisation

The landslide hazards considered as part of this assessment are as follows:

- LS1 (Landslide Hazard 1) The most likely future landslide to occur on the slopes above the property. The landslide would be a shallow failure, likely occurring on the slope along the existing headscarp on the crest of the escarpment and potentially having a volume in the order of 150 m³. The assumed landslide characteristics have been inferred from observations of the previous failure and landslides to occur elsewhere in Muriwai. The possible source area considered for a future landslide above the dwelling is highlighted on Figure 3.1 and Figure 3.2 below.
- LS2 (Landslide Hazard 2) Regression of the existing landslide headscarp. This is likely to have a volume somewhat smaller than the landslide that occurred in February 2023.

#### 3.2 Likelihood of landsliding (P<sub>(H)</sub>)

The basis for estimating probability of occurrence for each landslide hazard considered as part of this assessment is provided in Appendix A and the probabilities adopted are presented below.

#### 3.2.1 Likelihood of LS1

Two considerations of probability for occurrence for the most likely future landslide are:

- P(H'1) is the probability that the rainfall threshold for the most likely significant landslide is exceeded, which is taken as a proxy for landslide initiation. This is assumed to be 1 in 100 or **0.01** (see analysis by AC in Appendix A) or 1 in 50 or **0.02** under the influence of future climate change.
- P<sub>(H'2)</sub> is the probability that a slope above the dwellings fails. Given the current condition of the slope above the dwelling, it is conservatively considered almost certain to certain that the most likely future landslide would occur directly above the dwelling. A value of P<sub>(H'2)</sub> = 0.5 has been adopted.

#### 3.2.2 Likelihood of LS2

Given the current condition of the exposed landslide headscarp (greater than  $45^{\circ}$  and comprising Awhitu Sands), it is considered that regression of the existing landslide will occur at the same location during a relatively frequent rainfall event. A value of  $P_{(H'1)}$  of **1 in 10** or **0.1** is adopted whilst  $P_{(H'2)}$  is considered certain and a value of **1.0** is adopted.

#### 3.3 Probability of spatial impact (P<sub>(S:H)</sub>)

Our estimate of spatial probability is based on several factors which depend on the landslide hazards being considered and site-specific slope conditions. Our approach is detailed in Appendix A. Figure 3.1 and Figure 3.2

below provide an indication of the slope conditions at 207 Motutara Road and the surrounding area (slope angles and inferred preferential flow paths, respectively).

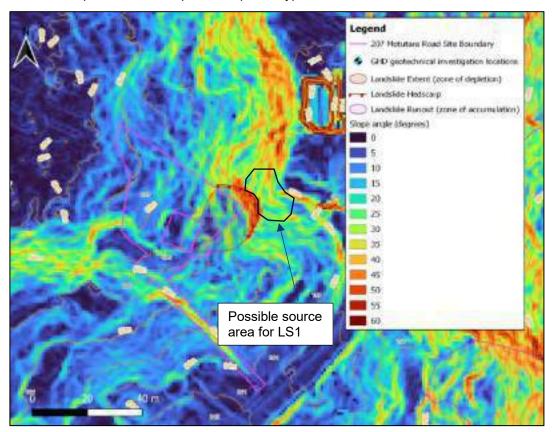


Figure 3.1 Slope map of 207 Motutara Road and surrounding area. Slope angles based on 2023 DTM data.

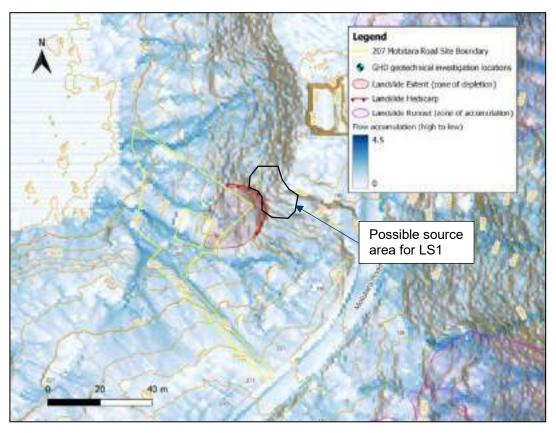


Figure 3.2 Flow accumulation map of 207 Motutara Road and surrounding area. Indicates preferential flow path for surface water. Modelling based on 2023 DTM data.

#### 3.3.1 Probability of spatial impact (LS1)

Two conditional factors are considered for the most likely significant landslide:

- P(s:H:1) is the probability that if the landslide occurs it travels in the direction of (towards) the dwelling. Based on the position of the dwelling at the base of a relatively planar slope exhibiting a somewhat convex geomorphology at its crest, a landslide initiating in the possible source area above the site (Figure 3.1) would likely travel downslope (southwest) towards the dwelling. Based on the flow accumulation plot (Figure 3.2) a landslide is unlikely to take a preferential flow path. A value of 1.0 is adopted.
- P(s:H'2) is the probability that if the landslide occurs it will reach the dwelling. The natural slopes above are generally steep (30-40°). Based on an approximate landslide volume of 150 m³, an adopted travel angle of 33° (Appendix A methodology based on data from Piha and Karekare) would project the landslide to within 5 m of the rear of the dwelling. Empirical methods in the GHD (2023) Muriwai risk assessment report indicate that, based on an average downslope angle of approximately 35°, the predicted travel distance angle would be approximately 30° (for confined and partly confined travel paths. Note: LS1 would have an unconfined travel path). This value also generally agrees with published data in Hunter & Fell (2002). This would project the landslide to the rear of the dwelling. A probability value of **0.5** has been adopted.

#### 3.3.2 Probability of spatial impact (LS2)

Landslide hazard LS2 involves upslope or lateral regression of the existing landslide.

- If the existing landslide hazard were to reactivate and result in regression of the headscarp, it is likely that the new landslide would follow the same path as the previous one, and hence travel towards the rear of the dwelling. As such a probability of **1.0** has been adopted for P(s:H'1).
- Regression of the existing landslide is expected to result in mobilisation of a somewhat smaller volume of debris. Given the observed behaviour of the previous slide (impacting the rear of the dwelling) and the topography of the site, any future failure is judged certain to almost certain to reach the dwelling. As such, a value of **0.8** is adopted for P<sub>(S:H'2)</sub>.

#### 3.4 Temporal spatial probability $(P_{(T:S)})$

As discussed in Appendix A, a temporal spatial probability of **0.68** is the adopted value for each property and has been used in this assessment.

#### 3.5 Vulnerability (V<sub>(D:T)</sub>)

In the event the future most likely landslide reaches the dwelling from the slopes above, the depth of the debris is likely to be in the order of 1-2 m and result in a similar level of damage as the previous landslide (impact the rear of the dwelling but not result in building collapse or significant inundation). The entrainment of vegetation including large trees has the potential to increase the vulnerability. Therefore, a value **0.05** is adopted for LS1.

In the event that regression of the existing landslide occurs on the slope above the dwelling, it is expected that debris with a somewhat smaller volume than previously would strike the rear of the dwelling but not result in building collapse. Based on the vulnerability table in Appendix A, a value of **0.01** is adopted for LS2.

#### 3.6 Unmitigated Risk Estimation

A summary of the risk estimation for each conceivable landslide hazard is presented in Table 3.1 below. A sensitivity check assuming a higher probability of occurrence for  $P_{(H)}$  is included for comparative purposes.

We acknowledge that assessing risk has an inherent degree of uncertainty and may only be accurate to within half an order of magnitude. This level of uncertainty would not change the outcome of the analysis. Refer to Appendix for further discussion.

Table 3.1 Summary of unmitigated risk estimation for each hazard type.

Hazard	Annual probability of the landslide	Spatial probability	Temporal probability	Vulnerability	Risk	Risk evaluation*
	$P_{(H)} = P_{(H'1)} x$ $P_{(H'2)}$	$P_{(S:H)} = P_{s':H'1)} x$ $P_{(S':H'2)}$	P <sub>(T:S)</sub>	<b>V</b> (D:T)	R <sub>(LOL)</sub>	
LS1 (most likely future landslide hazard)	0.01 x 0.5	1.0 x 0.5	0.68	0.05	8.5 x 10 <sup>-5</sup>	Tolerable
LS1 Sensitivity check	0.02 x 0.5	1.0 x 0.5	0.68	0.05	1.7 x 10 <sup>-4</sup>	Not tolerable
LS2 (regression of existing landslide hazard)	0.1 x 1.0	1.0 x 0.8	0.68	0.01	5.4 x 10 <sup>-4</sup>	Not tolerable
LS2 Sensitivity check	0.2 x 1.0	1.0 x 0.8	0.68	0.01	1.1 x 10 <sup>-3</sup>	Not tolerable

<sup>\*</sup>The evaluation is a guide only based on recommendations from AGS (2007) which provides a suggested tolerable Loss of Life Risk for the person most at risk.

#### 4. Conclusion and recommendation

This report has presented the results of a quantitative risk assessment for unmitigated loss of life in relation the property located at 207 Motutara Road, Muriwai, Waitākere. Two landslide hazards (LS1 and LS2) have formed the basis of this assessment.

Assessment of the most likely future landslide (LS1) estimates the annual risk to loss of life for the person most at risk to be approximately **8.5** x **10**-5. This risk is tolerable based on the AGS (2007c) suggested tolerable Loss of Life Risk for the person most at risk (see Appendix A). Our estimate suggests a higher frequency event as a result of climate change could result in a risk marginally higher than the AGS (2007c) suggested tolerable Loss of Life Risk for the person most at risk.

Assessment of further (future) failure of the existing landslide hazard (LS2) estimates the annual risk to loss of life for the person most at risk to be approximately **5.4 x 10<sup>-4</sup>**. This risk is higher than the AGS (2007c) suggested tolerable Loss of Life Risk for the person most at risk (see Appendix A).

Potential remedial measures to lower the risk level from the existing landslide hazard (LS2) may be possible. However, identifying such measures is outside of the scope of this study.

As discussed above, this report considers geotechnical matters only. There may be other non-geotechnical considerations that affect final placard designation of which GHD are not aware, such as flood risk and structural damage to property.

We understand AC are currently reviewing their tolerable and acceptable risk criteria for risks associated with landsliding. We recommend Council review the risk assessment presented in this report against the AC risk criteria to assess whether it is appropriate to assess the property risk categorisation and remove or re-assess the current placard designation for the site.

#### 5. Limitations

This report has been prepared by GHD for Auckland Council and may only be used and relied on by Auckland Council for the purpose agreed between GHD and Auckland Council as set out in section 1.2 of this report.

GHD otherwise disclaims responsibility to any person other than Auckland Council arising in connection with this report. GHD also excludes implied warranties and conditions, to the extent legally permissible.

The services undertaken by GHD in connection with preparing this report were limited to those specifically detailed in the report and are subject to the scope limitations set out in the report.

The opinions, conclusions and any recommendations in this report are based on conditions encountered and information reviewed at the date of preparation of the report. GHD has no responsibility or obligation to update this report to account for events or changes occurring subsequent to the date that the report was prepared.

The opinions, conclusions and any recommendations in this report are based on assumptions made by GHD described in this report (refer section 1.2 of this report). GHD disclaims liability arising from any of these assumptions being incorrect.

An understanding of the geotechnical site conditions depends on the integration of many pieces of information, some regional, some site specific, some structure specific and some experienced based. Hence this report should not be altered, amended, abbreviated, or issued in part in any way without prior written approval by GHD. GHD does not accept liability in connection with the issuing of an unapproved or modified version of this report.

Verification of the geotechnical assumptions and/or model is an integral part of the design process - investigation, construction verification, and performance monitoring. If the revealed ground or groundwater conditions vary from those assumed or described in this report the matter should be referred back to GHD.

This risk assessment does not mean that there will be no further landsliding impacting this property or group of properties.

# Appendix A

AGS (2007) Background

### 1. Overview

This appendix document outlines the methods and procedures used to estimate risks to loss of life for the person-most-at-risk at the site described in the covering report. This document should be read in conjunction with the covering report as it contains information not presented in the covering report. This document should not be separated from the main report.

# 2. Landslide Risk Management Framework

# 2.1 Background

The 1998 Thredbo landslide, in which 18 persons were killed, highlighted the challenges faced from building upon steep slopes and led to the development of the Australian Geomechanics Society Landslide Risk Management guidelines, published in 2007 and now commonly referred to as AGS (2007). The suite of guidelines is recognised nationally (Australia) and internationally as world-leading practice. The reader of this report is encouraged to consult the freely available LRM resources which can be accessed at: <a href="https://landsliderisk.org/">https://landsliderisk.org/</a>.

The "Practice Note Guidelines for Landslide Risk Management" (AGS 2007c), provide technical guidance in relation to the processes and tasks undertaken by geotechnical practitioners who prepare LRM reports including appropriate methods and techniques. The Practice Note is a statement of what constitutes good practice by a competent practitioner for LRM, including defensible and up to date methodologies and provides guidance on the quality of assessment and reporting, including the outcomes to be achieved and how they are to be achieved.

The framework for landslide risk management is presented in the figure below and represents a framework widely used internationally.

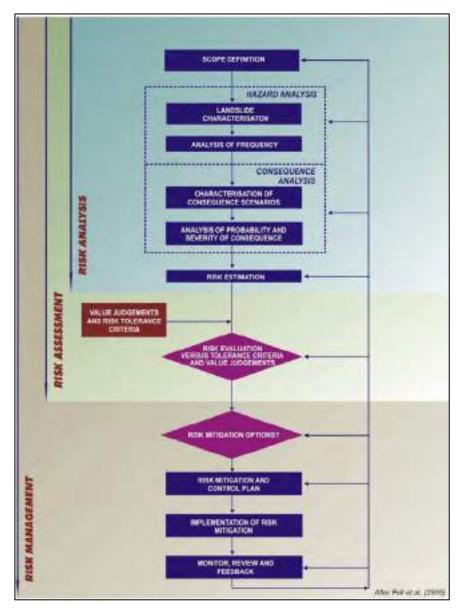


Figure A1 Framework for landslide risk management.

# 2.2 Risk Estimation Methodology

AGS (2007c) requires risks to loss of life to be estimated quantitatively for the person-most-at-risk. The person-most-at-risk will often but not always be the person with the greatest spatial temporal probability (i.e. the person most exposed to the risk). The Individual Risk-to-Life is defined as the risk of fatality or injury to any identifiable (named) individual who lives within the zone impacted by the landslide; or who follows a particular pattern of life that might subject him or her to the consequences of the landslide. The risk of 'loss-of-life' to an individual is calculated from:

$$\mathbf{R}_{(LoL)} = \mathbf{P}_{(H)} \times \mathbf{P}_{(S:H)} \times \mathbf{P}_{(T:S)} \times \mathbf{V}_{(D:T)}$$

Where:

**R**(LoL) is the risk (annual probability of death of an individual).

 $\mathbf{P}_{(H)}$  is the annual probability of the landslide (event).

 $\mathbf{P}_{(S:H)}$  is the probability of spatial impact of the event impacting an individual taking into account the travel distance and travel direction given the event. For example, the probability of an individual in a building or in the open being impacted by a rockfall / landslide at a given location.

 $\mathbf{P}_{(T:S)}$  is the temporal spatial probability (e.g. of the building or location being occupied by the individual at the time of impact) given the spatial impact and allowing for the possibility of evacuation given there is warning of the event occurrence.

 $\mathbf{V}_{(D:T)}$  is the vulnerability of the individual (probability of loss of life of the individual given the impact).

# 2.3 Landslide Risk Assessment Uncertainty

The process of risk assessment involves estimation of likelihood, consequence and risks based on available information for the study site. By its very nature, much of the data, including historical and current inventories may be incomplete whilst an understanding of the triggering events has a degree of uncertainty attached to it. Judgement is required to estimate the nature and size of potential hazards, their frequency of occurrence and their impact on a variety of elements at risk. As these judgements are based on the knowledge, experience and understanding of the assessor, it is not unusual for different assessors to make different judgements about the level of risk.

The thought process used in establishing likelihoods, consequences and determining spatial and temporal factors for properties has been documented for transparency. The structure of the risk assessment process is well defined and values for some input parameters have been tabulated to guide standard approaches by different assessors. However, this should not be mistaken for precision given the limitations of the inputs outlined above. Generally, the levels of likelihoods and risks should be thought of as being within a range of typically +/- half an order of magnitude.

While the basis for the judgements contained in this report are well documented, and the levels of risk considered to be good representations of reality, the accuracy and precision of the process should not be overestimated and should always be used in an appropriate manner in combination with risk management including mitigation and treatment options.

# 3. Hazard Characterisation

AGS (2007c) generally states that all credible hazards originating on, above and below the sites should be assessed. This is generally a predictive exercise based on knowledge and understanding of the geological and geomorphological setting with a view to assembling historical evidence for past hazard events.

### 3.1 Defining the Most Likely Significant Landslide

Following Cyclone Gabrielle, small landslides within the Muriwai area were often noted to be shallow translational slides developed in the upper residual profile of the Awhitu Sand Formation which, under saturation, transition into debris flows. Detailed analysis by GHD of the mapped landslides within the Karekare and Piha areas, which included size, estimated volume, travel distance and travel angle, was undertaken to characterise the nature and distribution of landslides following the rainfall events that occurred in early 2023, particularly the Cyclone Gabrielle rainfall event, has been used as a basis for defining the magnitude of the 'most significant landslide' for the site.

A total of 80 landslides were mapped throughout Karekare and Piha following the storm events in Jan and Feb 2023. These landslides were then grouped into categories of volume in 50 m³ increments. Results for an assessment of "frequency as categorised by volume" is shown in Figure 1 below.

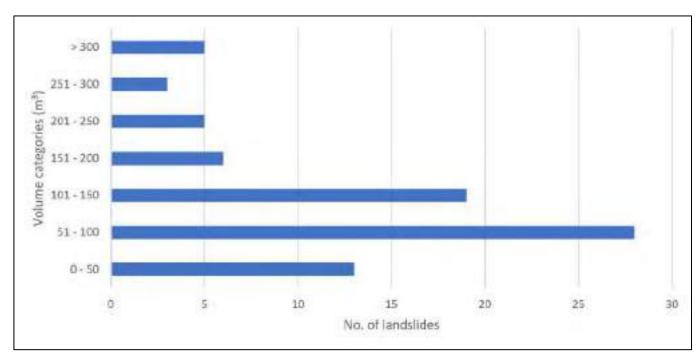


Figure A2 The number or frequency of mapped debris flows (on the x axis) as categorised by volume increments for mapped source areas of debris flows (on the y axis in  $m^3$ ) in Karekare and Piha.

In addition, detailed information regarding volume size, travel angle, travel distance, confinement (either unconfined or channelized) and the degree of damage caused by slides impacting dwellings and building was also collated and a number of additional graphs were developed as below:

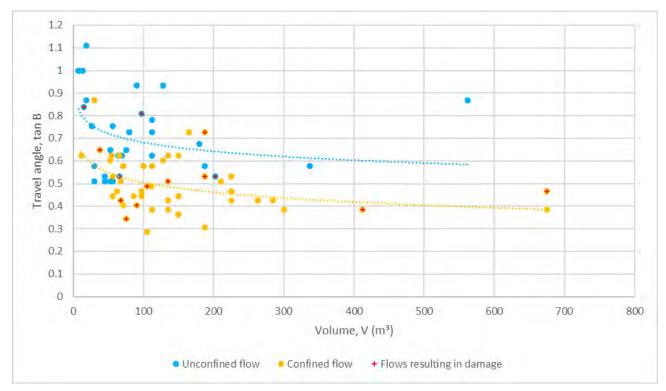


Figure A3 Travel angle vs volume of source area for the Karekare and Piha debris flows

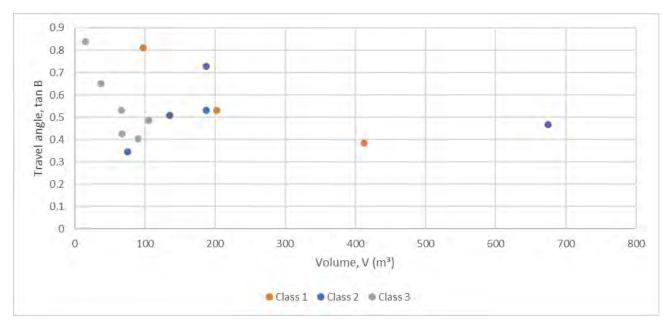


Figure A4 Plot of only those debris flows known to have caused some degree of damage to dwellings and buildings. Note Class 1 = Complete destruction/collapse of building, Class 2 = Partial destruction/collapse of building, significant inundation and Class 3 = Limited damage to building but no collapse or inundation, damage is other property infrastructure e.g., access stairs.

This assessment highlights a number of important points relating the nature of these hazards including:

- Whilst a range of volumes of source areas for debris flow was noted, the most common or likely sized event
  was of the order of 50-100 m<sup>3</sup> as determined by the frequency plot.
- Many smaller volume source areas for debris flows (less than 75 m³) typically only caused some lesser damage to buildings but once the volume increased above 100 m³, then the vast majority of debris flows were noted to have caused partial or full collapse of dwellings and buildings.
- The greater the volume of the source area, the lower the travel angle and the greater the runout or travel distance.
- Unconfined debris flows generally have a higher travel angle compared to confined or channelized debris flows of the same volume. This means that confined or channelised debris flows have a longer runout or travel distance and hence have more potential to impact elements at risk further down the slope.

Based on this site-specific data and analysis, GHD has adopted a working definition for these risk assessments of what is termed the **most likely significant landslide** as follows:

- The volume of most likely significant landslides is assumed to be 100 m<sup>3</sup>.
- This volume has been shown to cause significant building damage resulting in partial to full dwelling and building collapse.
- As a result, this hazard is considered to have a high probability for causing loss of life.
- Where this hazard is unconfined, the adopted travel angle based on Figure 3 has been taken as Tan (B) = 0.69 or approx. = 35°
- Where this hazard is confined or channelised the adopted travel angle based on Figure 3 has been taken as Tan (B) = 0.50 or approx. = 26.5°
- Comparison with Figure 6 from Hunter and Fell (2002) suggests the site derived travel angles are generally consistent with other data presented in that plot.

The definition of the **most likely significant landslide** is considered to be a reasonably conservative but not overly cautious estimate of the potential hazard that may affect the site. This is based on an assessment of an overview of landslides that GHD has observed in Muriwai, Karekare and Piha in 2023.

It is noted however that in some specific circumstances, larger recent debris flows may have occurred in close proximity to the site under investigation. As such, where there is evidence for a larger hazard, the assessor may

choose to adopt a larger volume event based on judgement and knowledge of that particular site. In this case other values for travel angle can be read from Figure 3.

IMPORTANT NOTE: It is duly acknowledged that volume alone does not necessarily account for the full potential of a debris flow to cause significant damage and other factors such as the degree of channelization, the additional entrainment of volume within a channel, the degree of saturation of the debris materials, the location of the source area on the hillslope, the direction of travel, the distance of travel and the velocity of the hazard at the point of impact all play important roles in the destructive capacity of any debris flow. Some of these factors are considered within the risk assessment process as conditional probabilities in spatial considerations.

# 3.2 Description of Other Landslide Types

As discussed in the scope of the covering report, other landslide hazards may exist at the site under assessment. These may include existing geohazards that have resulted from recent failures with the potential to pose risk to life in the immediate short-term (i.e. within the next few years) such as regression of translational failures to occur downslope of dwelling, failure of over-steepened fill and cut slopes, rockfall hazards associated with exposed rock faces/headscarps and/or loose debris remaining upslope of dwellings.

In addition, other possible geotechnical slope instability hazards relating to modified slopes (i.e. human made) may also exist and have potential to pose a risk to life - such as failures of fills, cuttings and failed retaining walls. This represents hazards that may have a range of likelihood from almost certain to possible.

Where appropriate, descriptions and definitions for each of these hazards are provided in the covering report on a case-by-case basis and will be specific to the observed hazard and actual conditions at this site.

# 3.3 General Descriptors for Size Classification of Landslides.

Generalized or relative descriptions of size classification systems for landslides vary significantly depending on the country of origin and the nature of the landslide hazards typically encountered. For the purposes of these assessments, GHD proposes to use the following size classification descriptions adopted from the Transport for New South Wales (TfNSW) Guide to Slope Risk Analysis Version 4 (TfNSW 2014) (see Table 3.1 below).

Relative size term	Volume range	Typical mid-range dimensions (width x length x depth in metres)
Very small	<20 m3	4 x 4 x 0.5
Small	20 to 200 m3	10 x 10 x1
Medium	200 to 2000 m3	20 x 20 x 2.5
Large	2000 to 20000 m3	40 x 40 x 5
Verv large	>20.000 m3	60 x 60 x 8

Table A3.1 Landslide size classification

# 4. Likelihood P<sub>(H)</sub>

Likelihood or annual probability of occurrence of the landslide,  $P_{(H)}$ , is one of the most critical but difficult to estimate factors as part of the risk assessment process.

# 4.1 The Most Likely Significant Landslide

The recent flood / storm events, the estimation of recurrence intervals for that event and the occurrence of the observed hazards form the basis for the current estimated probability of occurrence for the most likely significant landslide hazard. However, observations of the recent events noted that not all similar slopes failed as a result of

the initiating storm event and as such, an additional consideration for probability of occurrence has been included within the analysis by using conditional probabilities as follows:

$$P_{(H)} = P_{(H'1)} \times P_{(H'2)}$$

Where:

 $P_{(H^1)}$  = Probability that the rainfall threshold for the most credible significant landslide is exceeded which is taken as a proxy for landslide initiation. This is assumed to be 1 in 100 or 0.01 (see analysis and discussion by Auckland Council below) or 1 in 50 or 0.02 under the influence of future climate change.

 $P_{(H'2)}$  =Probability that the slope for the specific assessment fails, which relates to how many of the actual slopes failed out of the total number of all slopes present. This probability is typically based a on spatial analysis of the total area of failed landslides slopes compared to the total area of all slopes for the geomorphic setting in which the site is located.

# 4.2 Auckland Council Guidance on Frequency for Most Likely Significant Landslide

Council provided GHD with an assessment of available rainfall data associated with Cyclone Gabrielle (Auckland Council 2023) (AC memo). During Cyclone Gabrielle, the tipping bucket rain gauge at Muriwai failed and was inundated by flood waters. The AC memo also provided rainfall analysis using AC's Quantitative Precipitation Estimate (QPE) Rain Radar System, which is a real-time rainfall product that utilises the MetService radar. The rainfall data presented by AC indicates a peak rainfall total for Muriwai during the event of 146.9mm, occurring over 12-hour period. This total is >100-year event at a 12-hour duration. The data suggests that for the 12-hour duration rainfall, the Annual Recurrence Interval (ARI) is >100 years and may be in the order of 250 years. However, we understand that the calculation above the 100-year assessment becomes increasingly unreliable, primarily as a result of the relatively short statistical rainfall records available in New Zealand. For the other durations modelled, the rainfall was below the 100-year event.

The AC memo recommended that an envelope of "risk" is estimated as the ARI figures will change over time and as these events are incorporated into the statistical record. The AC memo states that in general, it is considered reasonable to consider the Cyclone Gabrielle event to be in the range of 100-250 year ARI. For this assessment we have assumed that the annual likelihood of a landslide event occurring that is similar in magnitude to the February 2023 event, is about 1 in 100 (i.e., 0.01). This is considered to have a *likely* probability of occurrence.

The assumption of 1 in 100 based on rainfall frequency is a simplifying and possibly conservative assumption that we consider reasonable. It does not consider other factors that could potentially affect stability (antecedent conditions, geology, groundwater conditions, slope height and angle, vegetation, surface water management-overland flow path, overflow from water storage tanks, effect of effluent disposal field), all of which are difficult to quantify.

The AC memo further recommended that risk assessment reports consider the potential for climate change to increase the frequency of high intensity rainfall. We understand that the National Institute of Water and Atmospheric Research (NIWA) has projected a 20% increase in rainfall intensity over the next 100 years which suggests that a 250-year ARI event could increase to a 50-year ARI event. Consequently, we have also included a sensitivity check based on a 50-year ARI event.

We draw the reader's attention to Section 3 of this report and reiterate that AGS (2007c) generally states that all credible hazards originating on, above and below the sites should be assessed. This report has conformed to this requirement and assessed landslide hazards that were observable during the site mapping and/or able to be interpreted via other means such as readily available aerial photographs, lidar data etc. It should be recognised that specific hazards such as rockfalls, failed retaining walls, over-steepened cuts/fill batters may have likelihoods in the *Certain to Almost Certain* range and are more likely to occur in the short term.

#### 4.3 Other Landslide Hazards

Where other slope failures and instabilities as described in Section 3.2 are considered, individual assessments of  $P_{(H)}$ , the probability of occurrence, are made on the basis of expert judgment, performance of similar landslides in the area and recent site observations.

When considering hazards that may pose immediate or short-term risks to life it is probable that such hazards will have high likelihoods of occurrence that could be triggered by relatively frequent events. As a result, such hazard may have likelihoods in the *Certain to Almost Certain* range as per the ASGS2007 qualitative descriptors for likelihood.

# 5. Probability of Spatial Impact P<sub>(S:H)</sub>

The AGS definition of spatial probability is represented by single term  $P_{(S:H)}$  and is described as the probability of spatial impact by the landslide on the element at risk, given the landslide occurs and taking into account the travel distance and travel direction.

# 5.1 The Most Likely Significant Landslide - Upslope of Site

A number of conditional factors may be involved in the spatial distribution for the most likely significant landslide, and for further transparency, the following methodology has been adopted:

$$P_{(S:H)} = P_{(S':H'1)} \times P_{(S':H'2)}$$

#### Where:

- P(s::H'1) = The probability that if the landslide occurs it travels in the direction of the site under assessment. If the slopes above are consistent, and planar then probability is assumed to be 0.8 to 1.0 depending on the topography; if the originating landslide enters a channel that is directed onto the property then probability is assumed to be 1.0, or if the landslide enters a channel that is directed away from the sites then the probability is assumed to be 0.05 taking account of a small probability that the landslide may super elevate and leave the channel.
- P<sub>(S':H'2)</sub> = The Probability that if the landslide occurs it will travel to at least the site under assessment and will impact the property. This is to be based on two considerations as follows:
  - Modelled Behaviour based on travel distance analysis undertaken by GHD for 80 observed landslides slides in the Karekare and Piha areas (see Figure A3). Either probability = 1.0 if the travel angle projects past the dwelling, = 0.5 if the travel angle projects to the rear of the dwelling or = 0.0 if the travel angle falls short of the dwelling.

#### And/or

- 2. Observational behaviour: based on site observations of whether the previous landslides within close proximity to the study site, travelled sufficient distance to reach the site under assessment; if yes Probability = 1.0, if no, then probability = 0
- NOTE 1: The GHD analysis of travel distance highlights the effect of channelisation which shows confined debris flows travel further (i.e., they have a lower travel angle) than those which are unconfined on consistent or planar slopes. Such considerations are included on a site-by-site basis. Interestingly, this event-specific analysis also generally agrees with findings presented in Hunter and Fell (2002).
- NOTE 2: Where significant debris flows have occurred in close proximity to the site under assessment, and
  the observed travel distance is greater than that estimated using the modelled approach, the preferred GHD
  approach is to use the greater of the two travel distances to assess spatial impact.

# 5.2 The Most Likely Significant Landslide – Under the Dwelling/Building and/or Downslope Below the Dwelling/Building

Based on the possible failure area:

- If the failure area is > ~5 m from the dwelling then the value for P<sub>(S:H)</sub> will be 0 as a landslide occurring at that location will not impact dwelling. (The general assumption is that the landslide headscarp would have a length of 5m based on size of most likely significant landslide).
- If the failure area is within ~5m from the dwelling (like above) then the value for P<sub>(S:H)</sub> will be 0.5 to account for uncertainty of it encroaching within the footprint of the dwelling.
- If the failure area encompasses a significant portion of the dwelling then the value for P<sub>(S:H)</sub> will be 1.0 as there is a certain probability it will impact the dwelling.

Estimates of how far back the most significant landslide will regress are difficult to model without a detailed slope stability analysis and sufficiently accurate soil and rock inputs. This would require an intrusive geotechnical investigation which is outside the scope of this study.

GHD has adopted a more empirical approach that assesses the spatial extent of lateral downslope movement of the most likely significant landslide based on direct observations of existing landslides in close proximity to the site under assessment. In the absence of other information, a similar extent of regression has been applied to any future slides. An estimate of P<sub>(S:H)</sub> can then be made as to the potential interaction with the element at risk.

# 5.3 Other landslides – Upslope of the study site

Other types of potential landslides situated above dwellings and buildings on the site under assessment, should be assessed in a similar manner to the most likely significant landslide. Estimates of travel distance are taken from Hunter and Fell (2002) and/or previous local knowledge and/or observation of similar landslides in the area.

When undertaking short term assessments, hazards involving reactivation of existing landslides that are located upslope of the study site that didn't previously reach the site must be taken account. In addition, remobilisation of debris from any upslope landslides must also be assessed for their potential of runout or travel distance using Hunter and Fell (2002).

Similarly potential failures of modified slopes such as cuttings or fills located above or directly adjacent to dwellings and buildings must also be assessed for their spatial impact and the methods of assessment follow the same approach.

# 5.4 Other landslides – under buildings and downslope of the building

A similar approach to that taken for other landslides upslope has been adopted. Observation of existing failures and how much lateral downslope movement can be used as a proxy for what may occur in the future under a regression type scenario.

# 5.5 Temporal Spatial Probability P<sub>(T:H)</sub>

These risk assessments have not considered specific occupancy scenarios for each individual residence. We acknowledge that the occupancy of each residence could vary significantly depending on the demographics of the residents and the usage of the residence. For example, some residences may be predominantly used as holiday accommodation, occupied mainly on weekends, whereas other residences could be permanently occupied by working families.

This assessment has assumed the following occupancies:

- Residences are typically occupied for 15 hours each day during weekdays;
- On weekends, residences are occupied for about 20 hours each day;

The percentage of time a residence is occupied is therefore about 68%.

Any further delineation of the spatial variations in occupancy (i.e. if a bedroom is at the front or the rear of the house etc) are not considered feasible or warranted within the context of the precision of this assessment.

# 6. Vulnerability $V_{(D:T)}$

## 6.1 Most likely significant Landslide

AGS (2007c) includes a table of vulnerability values for various inundation and building damage scenarios as adapted by Finlay et al (1999). It is important to note that the AGS (2007c) vulnerability table doesn't adequately cater for all the building damage scenarios GHD has observed in Muriwai, Karekare and Piha. GHD has therefore further adapted this table and combined it with information from the TfNSW Guide to Slope Risk Analysis (2014) as well as observations of damage to buildings and structures resulting from the recent landslides in Muriwai, Karekare and Piha.

The table of vulnerability values used in this assessment is presented in Table A6.1. These values have been used as a guide and expert judgement has been applied to select a value within the range of values where appropriate on a site-specific basis.

Table A6.1 Summary of Vulnerability Values adopted

Case	Range	Typical value to be used in	Comments
	- rungo	this assessment	
Person in a building that collapses under impact from debris flow	0.8 -1.0	0.9	Death is almost certain. Evacuation unlikely to occur
If building is inundated with debris and the person is buried	0.8 -1.0	0.8	Very high potential for death Evacuation unlikely to occur
If building is inundated with debris but no collapse occurs and the person is not buried	0.01 -0.1	0.1	High chance of survival Evacuation unlikely to occur
If the debris strikes the building only	0.001-0.05	0.01	Very high chance of survival
If failure occurs below the building and results in significant collapse	0.5-0.8	0.6	Moderate to high potential for death. No forewarning signs with evacuation unlikely to occur.
If failure occurs below the building and results in partial collapse	0.01 -0.1	0.05	High chance of survival. Signs of building distress should provide occupants with opportunity to take evasive action.
If failure occurs below the building and results in damage. No collapse occurs.	0.001-0.05	0.005	Very high chance of survival. Evacuation almost certain.

# 7. Risk Evaluation

The main objectives of risk evaluation are usually to compare the assessed risk to risk levels that are acceptable or tolerable to the community, and therefore to decide whether to accept, tolerate or treat the risks and to set

priorities for remediation. The Tolerable Risk Criteria are usually imposed by the regulator, unless agreed otherwise with the owner/client. AGS (2007d) provides discussion and gives the AGS recommendations in relation to tolerable risk for loss of life. These are summarized in the table below.

Table A7.1 AGS Suggested Tolerable loss of life individual risk.

Situation	Suggested Tolerable Loss of Life Risk for the person most at risk
Existing Slope / Existing Development	10 <sup>-4</sup> per annum (1E-4 pa) or 1 in 10,000 pa
New Constructed Slope / New Development / Existing Landslide	10 <sup>-5</sup> per annum (1E-5 pa) or 1 in 100,000 pa

It is important to distinguish between "acceptable risks" and "tolerable risks". AGS (2007c) states that tolerable risks are risks within a range that society can live with so as to secure certain benefits. It is a range of risk regarded as non-negligible and needing to be kept under review and reduced further if practicable. Acceptable risks are risks which everyone affected is prepared to accept. Acceptable risks are usually considered to be one order of magnitude lower than the Tolerable risks.

# 8. References

Auckland Council (2023). 'Guidelines on the use of AGS (2007) for landslide risk assessment in Auckland following the 2023 flooding and cyclone'. Memorandum dated 20 September 2023.

Australian Geomechanics Vol 42 No 1 March 2007 Extract "Practice Note Guidelines for Landslide Risk Management 200" AGS (2007c)

P J Finlay, G R Mostyn & R Fell (1999). 'Landslides: Prediction of Travel Distance and Guidelines for Vulnerability of Persons'. Proc 8th. Australia New Zealand Conference on Geomechanics, Hobart. Australian Geomechanics Society, ISBN 1 86445 0029, Vol 1, pp.105-113.

Hunter. G., & Fell. R. (2002).' Estimation of Travel Distance for Landslides in Soil Slopes'. Australian Geomechanics, Vol 37, No2.

New South Wales Government, Transport for New South Wales 'Guide to Slope Risk Analysis' Version 4, April 2014.

# Appendix B

**Glossary of Terms** 

#### **DEFINITION OF TERMS**

**Acceptable Risk** – A risk which, for the purposes of life or work, society is prepared to accept as it is with no regard to its management. Society does not generally consider expenditure in further reducing such risks iustifiable.

**Authority** or **Council** having statutory responsibility for community activities, community safety and development approval or management of development within its defined area/region

**Consequence** – The outcomes or potential outcomes arising from the occurrence of a landslide expressed qualitatively or quantitatively, in terms of loss, disadvantage or gain, damage, injury or loss of life.

**Creep Failure** – A time-dependant deformation mechanism where constant stress is applied to a material. Creep failure can be identified by ridges the ground surface and curved tree trunks.

**Dropout –** A landslide feature occurring along the length of the road-side on the downslope edge. Drop outs can result in the undermining the road carriageway.

**Elements at Risk** – The population, buildings and engineering works, economic activities, public services utilities, infrastructure and environmental features in the area potentially affected by landslides.

Entrainment - The process of surface sediment transportation through water and mass movement.

**Frequency** – A measure of likelihood expressed as the number of occurrences of an event in a given time. See also Likelihood and Probability of Occurrence.

**Hazard** – A condition with the potential for causing an undesirable consequence. The description of landslide hazard should include the location, volume (or area), classification and velocity of the potential landslides and any resultant detached material, and the probability of their occurrence within a given period of time.

**Individual Risk to Life –** The risk of fatality or injury to any identifiable (named) individual who lives within the zone impacted by the landslide or who follows a particular pattern of life that might subject him or her to the consequences of the landslide.

**Landslide** - A landslide is defined as the movement of a mass of rock, debris, or earth down a slope. The most widely used landslide classification system is that proposed by Cruden and Varnes in 1996 (after Varnes 1954 and Varnes 1978). This has been updated by Hungr, et al., 2014. In its most simple form two nouns are used to describe, firstly the type of material involved and secondly, the mechanism of failure, i.e., rock fall, debris flow.

**Landslide inventory** – An inventory of the location, classification, volume, activity and date of occurrence of landsliding

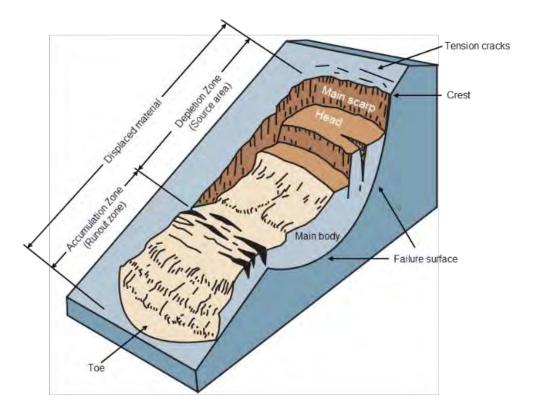
**Landslide Risk -** Landslide risk is defined herein as the likelihood that a particular landslide will occur and the possible consequences to a specific element at risk (property or human life) taking account of both spatial and temporal considerations.

**Landslide Susceptibility –** A quantitative or qualitative assessment of the classification, volume (or area) and spatial distribution of landslides which exist or poten**t**ially may occur in an area. Susceptibility may also include a description of the velocity and intensity of the existing or potential landsliding.

#### **Landslide Classification** – Referenced from Varnes, 1978.

Landslide Type	Landslide Description	Illustration
Rotational sliding	The landslide failure surface is curved concavely upward and the movement of mass is mainly rotational. Rotational movement causes back tilting of the displaced material near the headscarp.	
Translational sliding	The landslide mass moves along a planar failure surface with minor rotational movement.	
Earth flow	The movement of saturated fine- grained materials or clay bearing rocks. The displaced material forms a characteristic hourglass shape with an elongated flow path.	None and
Debris flow	The rapid movement of saturated, loose material caused by heavy precipitation and surface water flow. Commonly occurring on steep slopes.	
Debris avalanche	A type of debris flow that is extremely rapid.	
Rock fall	The separation of rocks and boulders along fractures, joints and bedding planes on steep slopes or cliffs. The movement is heavily influenced by mechanical weathering of the rock mass and gravity.	

Landslide characteristics – Modified after Varnes, 1978.



**Likelihood** – Used as a qualitative description of probability or frequency of the event/landslide.

**Overland Flow Path** – The predicated flow path of stormwater over the topography.

**Permeability** – The capacity of a material to allow water to pass through it. Clay materials are impermeable whereas gravels and sands are porous and therefore permeable.

**Probability** – A measure of the degree of certainty. This measure has a value between zero (impossibility) and 1.0 (certainty). It is an estimate of the likelihood of the magnitude of the uncertain quantity or the likelihood of the occurrence of the uncertain future event. There are two main interpretations:

(i) Statistical – frequency or fraction – The outcome of a repetitive experiment of some kind like flipping coins. It also includes the idea of population variability. Such a number is called an "objective" or relative frequentist probability because it exists in the real world and is in principle measurable by doing the experiment.

(ii) Subjective probability (degree of belief) – Quantified measure of belief, judgement, or confidence in the likelihood of a outcome, obtained by considering all available information honestly, fairly and with a minimum of bias. Subjective probability is affected by the state of understanding of a process, judgement regarding an evaluation or the quality and quantity of information. It may change over time as the state of knowledge changes.

Probability of Occurrence – used interchangeably with Likelihood.

**Quantitative Risk Analysis** – an analysis based on numerical values of the probability, vulnerability and consequences, and resulting in a numerical value of the risk.

**Recurrence Interval (repeat period)** – An estimated value of how often an event occurs based on the average time between passed events.

**Regression** – The continual movement of a landslide downslope and or widening/retreat of the headscarp.

The **Regulator** will be the responsible body/authority for setting Acceptable/Tolerable Risk Criteria to be adopted for the community/region/activity, which will be the basis for setting levels for Acceptable and Tolerable Risk in the application of the risk assessment guidelines.

**Risk** – A measure of the probability and severity of an adverse effect to health, property or the environment. Risk is often estimated by the product of probability x consequences. However, a more general interpretation of risk involves a comparison of the probability and consequences in a non-product form.

**Risk Analysis –** The use of available information to estimate the risk to individuals, population, property or the environment from hazards. Risk analyses generally contain the following steps: scope definition, hazard identification and risk estimation.

Risk Assessment – The process of risk analysis and risk evaluation.

**Risk Control or Risk Treatment** – The process of decision making for managing risk and the implementation or enforcement of risk mitigation measures and the re-evaluation of its effectiveness from time to time, using the results of risk assessment as one input.

**Risk Estimation** – The process used to produce a measure of the level of health, property or environmental risks being analysed. Risk estimation contains the following steps: frequency analysis, consequence analysis and their integration.

**Risk Evaluation** – The stage at which values and judgements enter the decision process, explicitly or implicitly, by including consideration of the importance of the estimated risks and the associated social, environmental, and economic consequences, in order to identify a range of alternatives for managing the risks.

**Risk Management** – The complete process of risk assessment and risk control (or risk treatment).

Runout Distance – The horizontal distance from the source area to the distal toe.

Susceptibility - see Landslide Susceptibility

**Temporal-Spatial Probability** – The probability that the element at risk is in the affected area at the time of the landslide.

**Tolerable Risk** – A risk within a range that society can live with so as to secure certain net benefits. It is a range of risk regarded as non-negligible and needing to be kept under review and reduced further if possible.

Transgression-regression cycles – Sedimentary deposits formed from cycles of sea level rise and fall.

**Travel Angle –** The angle from the crest of the source area to the distal toe of the debris (run out zone)

**Vulnerability** – The degree of loss to a given element or set of elements within the area affected by the landslide hazard. It is expressed on a scale of 0 (no loss) to 1 (total loss). For property, the loss will be the value of the damage relative to the value of the property; for persons, it will be the probability that a particular life (the element at risk) will be lost, given the person(s) is affected by the landslide.





# Appendix F

**Geotechnical Investigations Report** 



# Waitakere Coastal Communities Landslide Risk Assessment

**Appendix F – Geotechnical Investigations Report - Muriwai** 

Auckland Council
15 May 2024

→ The Power of Commitment



Project n	ame	Waitakere Coastal Communities Landslide Risk Assessment					
Docume	Waitakere Coastal Communities Landslide Risk Assessment   Appendix F – Geotech Investigations Report - Muriwai						nical
Project n	umber	12612462					
File name	е	12612462_Append	ix F GIR_FINAL	Rev2.docx			
Status	Revision	Author	Reviewer		Approved for	issue	
Code			Name	Signature	Name	Signature	Date
S4	0	Johan Mendonca / Mi-Nu Kang / Johnie Xu	Don Macfarlane	Meluforen	Roy Pearson	Roy Pearson	03/11/2023
S4	1	Luke Agnew	Don Macfarlane	Dringolen	Roy Pearson	Roy Pearson	30/04/2024
S4	2	Luke Agnew	Don Macfarlane	Delugation	Roy Pearson	Roy Prarson	15/04/2024
[Status code]							
[Status code]							

#### **GHD Limited**

Contact: Matt Howard, Technical Director - Engineering Geologist | GHD

27 Napier Street, GHD Centre Level 3

Freemans Bay, Auckland 1010, New Zealand

T +64 9 370 8000 | F +64 9 370 8001 | E aklmail@ghd.com | ghd.com

#### © GHD 2024

This document is and shall remain the property of GHD. The document may only be used for the purpose for which it was commissioned and in accordance with the Terms of Engagement for the commission. Unauthorised use of this document in any form whatsoever is prohibited.

# **Contents**

F1.	Introd	uction	•
	F1.1	Purpose of this report	•
	F1.2	Background	•
	F1.3	Scope	•
	F1.4	Report structure	2
F2.	Site in	vestigation overview	3
	F2.1	General	3
	F2.2	Subcontractor management	3
F3.	Site in	vestigation methodology	4
	F3.1	Boreholes	4
	F3.2	In-situ strength testing	4
		F3.2.1 Standard penetration testing (SPT)	4
	<b>50.0</b>	F3.2.2 Handheld shear vane	7
	F3.3	Groundwater level monitoring F3.3.1 Piezometer construction and static readings	-
		F3.3.2 Variable head permeability (slug) testing	-
		F3.3.3 Telemetry	ç
	F3.4	Investigation locations	10
F4.	Geote	chnical laboratory testing	10
	F4.1	General	10
	F4.2	Atterberg Limit	11
	F4.3	Particle Size Distribution	12
	F4.4	Detection of Presence of Allophane in Soils:	13
	F4.5	Pinhole and Crumb Testing	13
	F4.6	Uniaxial Compressive Strength (UCS)	13
F5.	Refere	ences	14
F6.	Limita	tions	15
Tal	ble in	dex	
Tabl	e F1	Summary of accompanying Muriwai landslide risk assessment reports	2
Tabl	e F2	Borehole investigations summary (all holes to target depth)	4
Tabl	e F3	Overview of the SPT hammer efficiency of the drilling rig	5
	e F4	Shear vane testing summary	7
	e F5	Groundwater levels following piezometer installation and bore development.	8
ſabl	e F6	Results from the hydraulic conductivity tests (data from BH-M09 was not credible	,
Tahl	e F7	and is not presented) Hydrostatic Level Sensor install depth summary.	Č
	e F8	General summary of geotechnical laboratory testing scheduled.	10
	e F9	Summary of Pinhole and Crumb Testing	13
		•	

# Figure index

Figure F1	Muriwai location showing the February 2023 landslides mapped by GHD (blued lines)	3
Figure F2	Uncorrected SPT 'N' value graphs against depth (m bgl) for all boreholes (left graph), with the same information separated into borehole groupings for clarity	6
Figure F3	Plasticity Index chart	11
Figure F4	Particle Size Distribution chart	12
Figure F5	Uniaxial Compressive Strength (UCS) versus depth	13

# **Appendices**

Appendix F1	Site Plan
Appendix F2	Borehole Logs and Photographs
Appendix F3	Laboratory Test Results
Appendix F4	Calibration certificates for shear vane and SPT hammer

# F1. Introduction

# F1.1 Purpose of this report

GHD has been engaged by Auckland Council (AC)<sup>1</sup> to carry out landslide risk assessments and to provide associated landslide risk management advice and geotechnical investigations in the Waitakere area, specifically for the residential areas of Muriwai, Piha and Karekare.

One of the project work items is to conduct a geotechnical borehole investigation to understand the subsurface conditions in the vicinity of the 80 m-high escarpment to the east of Muriwai township that experienced damaging landslides in February 2023. This report is a factual account of the work undertaken, the materials that were encountered and their geotechnical characterisation from laboratory testing. These results are used to inform the engineering geological characterisation in Overall Report Appendix B.

Groundwater monitoring was installed in some boreholes for future groundwater monitoring by AC and some of this data is presented.

This report is an appendix to the overall GHD landslide risk report and should be read in conjunction with it, as well as associated appendices. The overall report contains additional information and synthesises the results of other appended assessments carried out by GHD.

# F1.2 Background

Two significant rainfall events affected the Waitakere area in late January and early February 2023, resulting from the impacts of ex-tropical cyclones Hale and Gabrielle, respectively.

The Cyclone Gabrielle weather event of 14 February 2023 resulted in widespread catastrophic flooding and slope instability in the settlement of Muriwai where several debris avalanches (which included rocks and trees) occurred, some of which developed into saturated debris flows that resulted in damage to buildings and infrastructure. Two fatalities occurred due to impact of landslides on private dwellings. This tragic event was similar to a 1965 storm event that also claimed two lives.

Following the event, rapid building assessment of residential properties was undertaken in Muriwai, with some houses having access by owners restricted (a yellow placard – e.g. access in daylight hours only) and some for which no access was permitted (a red placard). Dwellings that retained unrestricted access were white placarded.

### F1.3 Scope

The intention of the geotechnical investigation and groundwater monitoring installation was to:

- Support the development of the ground model of the site
- Provide an of understanding of geotechnical properties of previously failed landslide material
- Understand the presence of significant geological boundaries that may be influencing slope failure
- Identify groundwater profiles within the slope and their response to rain events, and to provide ongoing, telemetered data for use by AC.

<sup>&</sup>lt;sup>1</sup> As part of contract CW198379, Master Services Agreement CCCS: CW74240 dated 7/09/2019, subsequent work item 'Waitakere Coastal Communities Landslide Risk Assessment', dated 26/04/2023

The scope for this investigation is as follows:

#### **Boreholes**

- Drill nine boreholes advanced to a depth of between 11 m and 80 m below ground level (bgl) at Muriwai in locations at the top and below the escarpment where landslides occurred in February 2023, with the following distribution:
  - Three approximately 80 m deep boreholes at Oaia Road, east of (above) the Muriwai escarpment
  - Three boreholes below the Muriwai escarpment on Domain Crescent (two to approximately 11 m bgl and one to approximately 41 m bgl)
  - Three boreholes below the Muriwai escarpment on Motutara Road (two to approximately 11 m bgl and one to approximately 41 m bgl)
- Log the recovered material using NZGS (2005) guidelines
- Conduct Standard Penetration Tests (SPTs) at 1.5 m intervals
- Record data in AGS4 format and upload borehole logs to the New Zealand Geotechnical Database

#### Groundwater monitoring

- Install standpipe piezometer screens in some of the boreholes
- Measure initial water levels during drilling and following screen installation
- Supervise installation of water level data recorders and AC monitoring-compatible telemetry hardware to allow ongoing data collection (by AC)

#### Laboratory testing

- Testing of recovered soils and rocks including:
  - Atterberg Limit testing
  - Particle size distribution (wet sieve) tests
  - Unconfined Compressive Strength tests
  - Pinhole and Crumb dispersibility

This report may be updated in the future to include ongoing data.

## F1.4 Report structure

This report is a factual account of the Muriwai geotechnical investigation and is one of six appendices that are part of assessing the risk-to-life from landslides at Muriwai. A list of report appendices is presented in Table F1.

Table F1 Summary of accompanying Muriwai landslide risk assessment reports

Report Section	Description
Overall Report	Waitakere Coastal Communities Landslide Risk Assessment (Muriwai) Overall Report
Appendix A	Figures
Appendix B	Engineering Geological Report
Appendix C	Slope Stability Assessment
Appendix D	RAMMS debris flow analysis
Appendix E	Landslide Risk Assessment
Appendix F	Geotechnical Investigations Report (this report)

# F2. Site investigation overview

#### F2.1 General

Intrusive site investigations commenced on the 29<sup>th</sup> of June 2023 and were completed on the 18<sup>th</sup> of August 2023. The location of Muriwai is shown in Figure F1 below and a plan showing the borehole locations is presented in Figure F1-1 in Appendix F1.

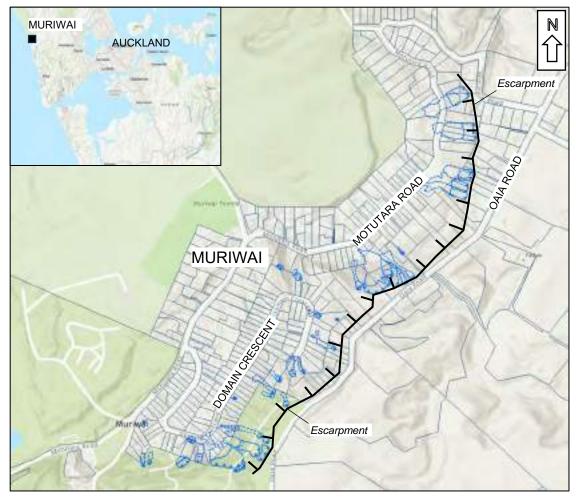


Figure F1 Muriwai location showing the February 2023 landslides mapped by GHD (blued lines)

All nine boreholes were drilled within the road reserve, with three holes along each of Oaia Road, Domain Crescent and Motutara Road. Six groundwater dataloggers with telemetry hardware were installed in the boreholes with piezometer screens. The location, depth and installation summary of these holes are presented in Table F2 below.

# **F2.2** Subcontractor management

GHD engaged DCN Drilling Limited (DCN) to undertake the site investigation physical works. DCN directly engaged and managed additional subcontractors required to complete the physical works on site, including traffic management and buried services clearance.

Babbage Geotechnical Laboratory (BGL) and Geotechnics Ltd were engaged to carry out geotechnical laboratory testing. ConnectM2M Limited installed piezometer dataloggers and telemetry.

Table F2 Borehole investigations summary (all holes to target depth)

Location ID	Street location	Easting	Northing	Reduced level (m)	Termination depth (m bgl)	Screen interval (m bgl)
BH-M01		1728691	5923873	138.0	79.60	73 – 79
BH-M02	Oaia Road	1728387	5923493	144.5	79.57	60 – 66
BH-M03	-	1728010	5923112	150.0	79.64	73 – 79
BH-M04	Domain Crescent	1727699	5923031	53.0	10.95	No installation
BH-M05		1727856	5923234	63.5	10.95	No installation
BH-M06		1728033	5923293	90.0	40.95	21 – 27
BH-M07		1728235	5923652	52.0	40.64	33 – 39
BH-M08	Motutara Road	1728392	5923798	63.0	10.95	No installation
BH-M09		1728448	5923911	72.5	10.95	7.2 – 10.2

# F3. Site investigation methodology

#### F3.1 Boreholes

Boreholes were completed as follows:

- Hand auger or hydro-excavation to 1.5 m bgl to avoid striking buried services.
- Conventional ('Open Barrel') coring to recover nominal 83 mm diameter core in low strength near surface material.
- Wireline triple tube (HQTT) coring to recover nominal 61mm diameter core at greater depths.

Boreholes without piezometers installed were backfilled with bentonite and the surface reinstated. All well covers were capped with plastic lockable lids and rubber gaskets ('toby box'), flush to ground level. All receiver/transmitter units that house the telemetry equipment were installed in an adjacent service box, which itself is covered with a lockable plastic lid flush to ground level.

For BH-M06 & 07 wells are within the road, with the service boxes being offset less than 1 m away (outside of carriageway).

A short length of connecting wire is buried at shallow depth (less than 1 m bgl) between the well head and the service box. For BH-M06 and BH-M07, this is encased in a PVC plastic sleeve. Wire connections are not marked at ground level.

Borehole logs, core photographs and piezometer installation details are presented in Appendix F2.

# F3.2 In-situ strength testing

The following in-situ strength testing was performed during the drilling of boreholes.

#### F3.2.1 Standard penetration testing (SPT)

Standard Penetration Testing (SPTs) were performed at 1.5 m intervals in accordance with NZS 4402: 1988 Test 6.5.1 "Determination of the penetration resistance of a soil". SPT results are recorded on the borehole logs in Appendix F2 with the associated hammer calibration sheets. SPT results plotted against reduced level are presented in Figure F2.

Values given on the attached borehole logs are uncorrected N values. Table F3 gives the hammer efficiency value for each SPT hammer used during the site investigations. The associated drilling rig is reported on the corresponding borehole log. SPT calibration documentation is presented in Appendix F4.

Table F3 Overview of the SPT hammer efficiency of the drilling rig

Drilling Rig	SPT Trip Hammer Reference	SPT Hammer Efficiency	Boreholes Drilled	
TR 200	3	68.5 %	All boreholes except BH-M04	
MOR 700 1		68.1 %	BH-M04	

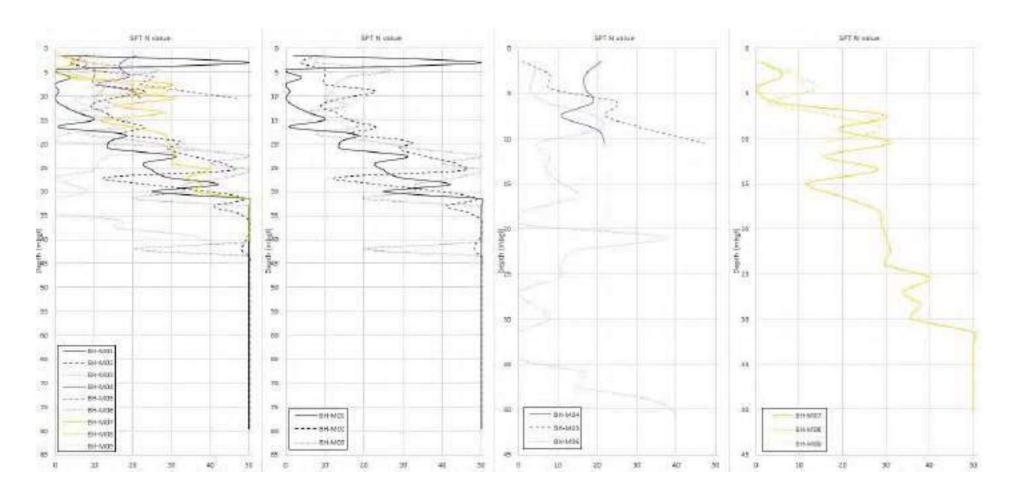


Figure F2 Uncorrected SPT 'N' value graphs against depth (m bgl) for all boreholes (left graph), with the same information separated into borehole groupings for clarity

#### F3.2.2 Handheld shear vane

Shear vane testing was performed during drilling of machine boreholes where cohesive soils were encountered. Measurements were typically taken every 1.5 m depth from core prior to extrusion from the core barrel.

All shear strengths shown on the appended logs are corrected vane shear strengths derived in accordance with the NZGS "Guideline for Hand Held Shear Vanes Test" (2001). The peak and remoulded vane readings represent hand-held dial readings from a 19 mm vane, adjusted using the calibration sheets attached in Appendix F4. These are reported on the logs as undrained shear strength and are summarised in Table F4.

Table F4 Shear vane testing summary

Borehole	Test Depth (m bgl)	Vane Serial Number	Corrected Peak Undrained Shear Strength (kPa)	Corrected Residual Undrained Shear Strength (kPa)	Note
BH-M01	3.0	GEO902	>211	n/a	Vane unable to penetrate
BH-M02	0.5	GEO1060	155	87	
BH-M02	1.0	GEO1060	142	74	
BH-M02	1.5	GEO1060	111	59	
BH-M02	3.0	GEO1060	>211	n/a	Vane unable to penetrate
BH-M06	3.0	GEO902	>211	n/a	Vane unable to penetrate
BH-M06	4.5	GEO902	>211	n/a	Vane unable to penetrate
BH-M08	3.0	GEO902	>211	n/a	Vane unable to penetrate

# F3.3 Groundwater level monitoring

#### F3.3.1 Piezometer construction and static readings

Groundwater readings were periodically taken during the drilling programme (see Table F5). Groundwater levels measured in piezometers following bore development are summarised in Table F5.

## F3.3.2 Variable head permeability (slug) testing

Slug testing was carried out between the 28<sup>th</sup> and 30<sup>th</sup> of August 2023 to estimate the permeability of the materials in the screened range of the piezometers. Rising and falling head tests were carried out in all six piezometers installed.

The data obtained from the rising and falling head tests were analysed using Aqtesolv Software (v 4.51), and the hydraulic conductivity values were obtained using the Bower and Rice (1976) and Hvorslev (1951) solutions. The results are provided in Table F6.

Table F5 Groundwater levels following piezometer installation and bore development.

Bore ID	Ground	Screen Interval	Groundwater level											
	Elevation		28 Au	g 2023	29 Au	ıg 2023	30 Au	g 2023	9 <sup>th</sup> Ap	or 2024	17 <sup>th</sup> A	pr 2024	19 <sup>th</sup> Ap	or 2024
	(m RL)	(m bgl)	(m bgl)	(m RL)	(m bgl)	(m RL)	(m bgl)	(m RL)	(m bgl)	(m RL)	(m bgl)	(m RL)	(m bgl)	(m RL)
BH-M01	138.0	73 – 79	59.38	78.62	Not read			51.51	86.49	Not	read	Not	read	
BH-M02	144.5	60 – 66	84.79	59.73	84.76	59.74	Not	read	Not read		59.75	84.75	59.74	84.76
BH-M03	150.0	73 – 79	Dry	-	Dry	-	Dry	-	Not read		Dry	-	Dry	-
BH-M06	90.0	21 – 27	19.97	70.02	19.82	70.17	19.86	70.14	Not	read	19.65	70.35	18.51	71.49
BH-M07	52.0	33 – 39	Not read	-	7.32	44.68	Not	read	Not	read	7.36	44.64	7.52	44.48
BH-M09	72.5	7.2 – 10.2	6.83	65.67	6.83	65.67	Not	read	Not read		7.22	65.28	7.23	65.27

Tah	

Bore ID	Hydraulic conductivity (m/s)						
Dole 1D	Bouwer-Rice	Hvorslev	Mean				
BH-M01	8.8E-08	1.0E-07	9.5E-08				
BH-M02	5.5E-09	6.5E-09	5.9E-09				
BH-M06	1.7E-08	2.3E-08	2.0E-08				
BH-M07	3.4E-08	4.1E-08	7.45.00				
DH-IVIU7	1.4E-07	1.3E-07	7.1E-08				

#### F3.3.3 Telemetry

To allow long-term remote monitoring of water levels in piezometers by AC each piezometer was fitted with a pressure transducer data logger and cellular telemetry unit. Data loggers and telemetry are self-contained, vented and battery powered.

The telemetered groundwater monitoring equipment includes:

- Hydrostatic Level Sensor (PTX-002) and associated cable,
- Site Sentinel (X1-001 4G),
- Road Marker Antenna (XANT-007),
- Analogue Junction Box 1 input with vent (XIO-004)
- Marley 250 mm x 250 mm sealed cable management pit.

Each hydrostatic level sensor records and reports the level of water above the sensor. Each telemetered unit is configured to record this water level at 15-minute intervals. The data is transmitted daily at 2 pm. Once transmitted, the data is pushed directly to Auckland Councils Hydrotel system. A summary of the installation depths of the hydrostatic level sensors in meters below ground level (m bgl), and an approximated<sup>2</sup> value in m RL, is provided in Table F7.

Groundwater plots from the telemetered data, between the period of 19th October 2023 and 22nd March 2024 are presented in Appendix F5. Rainfall data taken from the Muriwai Golf Course (available on Auckland Council's Environmental Data Portal) for the same date range has been plotted on the graphs also. The groundwater data trace presented in Appendix F5 for BH-M01 represents a signal that is unverifiable and as such has been assumed to be erroneous.

Table F7 Hydrostatic Level Sensor install depth summary.

Bore ID	Hydrostatic Level Sensor Installation Depth					
	Measured value in m bgl	Approximate value in m RL <sup>2</sup>				
BH-M01	66.2	71.8				
BH-M02	65.85	78.7				
BH-M03	79.0	71.0				
BH-M06	27.0	63.0				
BH-M07	39.0	13.0				
BH-M09	10.3	62.2				

<sup>&</sup>lt;sup>2</sup> Hydrostatic Level Sensor installation depth presented in m RL is calculated using the estimated collar height of the bore. This collar height has been estimated from a local GIS viewer and has not been measured using GNSS techniques.

# F3.4 Investigation locations

The location of each borehole was recorded using handheld GPS, which has a metre-scale accuracy. This was compared with Auckland Council's online GIS viewer using measurements of investigation locations relative to known features.

Latitude and longitude are presented in terms of the New Zealand Transverse Mercator (NZTM 2000), the internationally recognised type of projection formally defined as the LINZS25002 standard (standard for New Zealand Geodetic Datum 2000 Projections), with elevation shown in the Auckland 1946 local mean sea level (MSL), one of thirteen local MSL circuits used in New Zealand.

# F4. Geotechnical laboratory testing

#### F4.1 General

The following tests were scheduled for selected samples by BGL:

- Atterberg Limit, (NZS 4402:1986, Test 2.2, 2.3 & 2.4)
- Particle Size Distribution (Wet Sieve), (NZS 4402:1986, Test 2.8.1)
- Particle Size Distribution (Hydrometer), (NZS 4402:1986, Test 2.8.4)
- Detection of Presence of Allophane in Soils: (NZS4402:1986, Test 3.4)
- Unconfined Compressive Strength (UCS). (NZS4402:1986,Test 6.3.1)

The following tests were scheduled for selected samples by Geotechnics Ltd:

- Pinhole, (ASTM D4647-13 2020)
- Dispersibility by the Crumb Method (BS 1377: Part 5: 1990 Clause 6.3, not IANZ accredited)
- Water Content, (NZS 4402: 1986, Test 2.1)

The number and type of tests are presented in Table F8. Testing results are presented in Appendix F3.

Table F8 General summary of geotechnical laboratory testing scheduled.

Investig ation ID	Water content	Atterberg limits (PL, LL, PI)	Particle size distribution (wet sieve)	Particle size distribution (hydrometer)	Crumb test	Uniaxial compressive strength (UCS)	Pinhole	Allophane Presence
BH-M01	1	1	2	1	1		1	
BH-M02	1		1			13	1	
BH-M03			1			9		
BH-M05			1					
Bh-M06			1					
BH-M07			3					
BH-M08			2					1
BH-M09			2					

# F4.2 Atterberg Limit

One sample was tested for Atterberg Limits, (NZS 4402:1986, Test 2.2, 2.3 & 2.4); the result is plotted on the plasticity index chart in Figure F3.

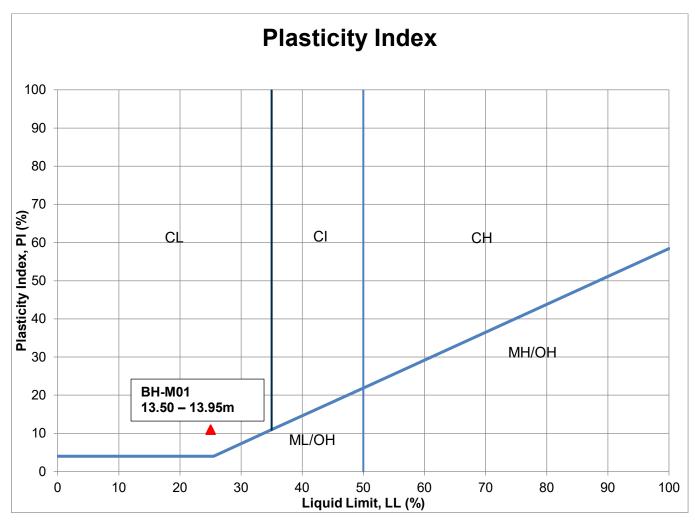


Figure F3 Plasticity Index chart

### **F4.3** Particle Size Distribution

Thirteen samples were taken from BH-M01 to BH-M09 and tested for Particle Size Distribution (PSD - wet sieve). One PSD sample from BH-M01 was tested for PSD - hydrometer (NZS 4402:1986 Test 2.8.4). The results are presented in Figure F4.

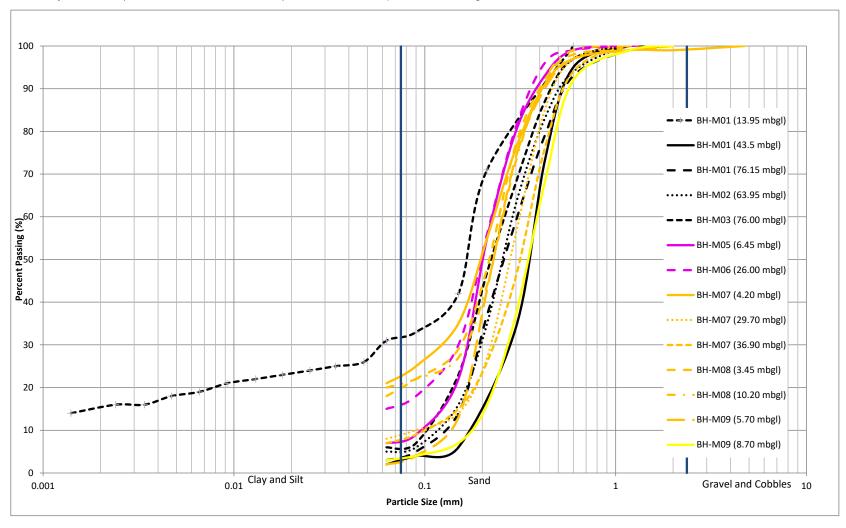


Figure F4 Particle Size Distribution chart

## F4.4 Detection of Presence of Allophane in Soils:

One sample (BH-M08, 10.00-10.10m) was tested for presence of allophane (NZS4402:1986, Test 3.4). The result indicates an allophane content of less than 5%.

## F4.5 Pinhole and Crumb Testing

Two samples were tested for dispersibility using Pinhole (ASTM D4647-13) and Crumb (BS 1377: Part 5: 1990 Clause 6.3) methods. The results are outlined in Table F9.

Table F9 Summary of Pinhole and Crumb Testing

Sample (BH & Depth)	Lab Description	Pinhole Method Classification	Crumb Method Classification
BH-M01 - 2.02 -2.06 m	Clayey SILT, dark brown; very soft, wet, high plasticity.	D1 (dispersive)	Grade 4 - Strong reaction (dispersive)
BH-M02 – 1.96 – 2.00 m	Silty CLAY, orange brown; very soft, wet, high plasticity	ND1 (non-dispersive)	Grade 4 - Strong reaction (dispersive)

## F4.6 Uniaxial Compressive Strength (UCS)

UCS testing was undertaken by BGL on Awhiti Group core samples from BH-M02 and BH-M03 (NZS4402:1986, Test 6.3.1). The results are presented against depth in Figure F5.

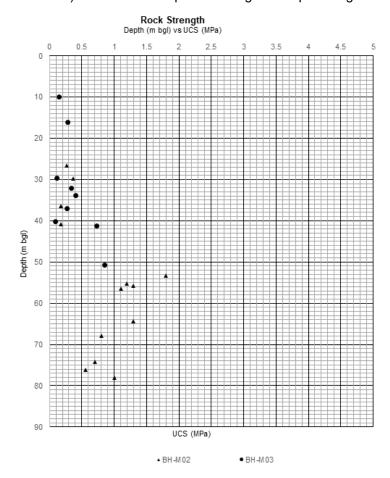


Figure F5 Uniaxial Compressive Strength (UCS) versus depth

## F5. References

Auckland Council GIS Viewer, Retrieved March 2020, <a href="https://geomapspublic.aucklandcouncil.govt.nz/viewer/index.html">https://geomapspublic.aucklandcouncil.govt.nz/viewer/index.html</a>

Auckland Council (2019), "Professional Services Term Contract – Geotechnical Works Professional Services Scope"

Bouwer & Rice, 1976. A slug test method for determining hydraulic conductivity of unconfined aquifers with completely or partially penetrating wells, Water Resources Research, vol. 12, no. 3, pp. 423-428.

Hvorslev, 1951. Time Lag and Soil Permeability in Ground-Water Observations, Bul. no. 26, Waterways Experiment Station, Corps of Engineers, U.S. Army, Vicksburg, Mississippi

New Zealand Geotechnical Society (2005) "Guideline for the Field Classification and Description of Soil and Rock for Engineering Purposes"

New Zealand Geotechnical Society (2001) "Guideline for Hand Held Shear Vane Test"

New Zealand Standard 4402 (1986) "Methods of testing soils for civil engineering purposes"

### F6. Limitations

This report has been prepared by GHD Limited (GHD) for Auckland Council and may only be used and relied on by Auckland Council for the purpose agreed between GHD and Auckland Council as set out in Section 1 of this report.

GHD otherwise disclaims responsibility to any person other than Auckland Council arising in connection with this report. GHD also excludes implied warranties and conditions, to the extent legally permissible.

The services undertaken by GHD in connection with preparing this report were limited to those specifically detailed in the report and are subject to the scope limitations set out in the report.

The opinions, conclusions and any recommendations in this report are based on conditions encountered and information reviewed at the date of preparation of the report. GHD has no responsibility or obligation to update this report to account for events or changes occurring subsequent to the date that the report was prepared.

The opinions, conclusions and any recommendations in this report are based on assumptions made by GHD described in this report (refer Section 1 of this report). GHD disclaims liability arising from any of the assumptions being incorrect.

GHD does not accept responsibility arising from, or in connection with, varied conditions and any change in conditions. GHD is also not responsible for updating this report if the conditions change.

This report should not be altered, amended, abbreviated, or issued in part in any way without prior written approval by GHD. GHD does not accept liability in connection with the issuing of an unapproved or modified version of this report.

This report presents information obtained from, and testing undertaken at or in connection with, specific sample points, investigation locations and test points. Conditions at other parts of the site may be different from conditions found at the specific sample points. The actual characteristics of materials may vary significantly.

Sampling, investigations and testing were undertaken at a specific point in time. Ground conditions, including groundwater levels and contaminant concentrations can change over time. Therefore, the information from the sampling, investigations and testing may not represent the conditions that may be encountered across the site at any future point in time.

Investigations undertaken in respect of this report are constrained by the particular site conditions, such as physical access and the location of buildings, services and vegetation. As a result, not all relevant site features and conditions may have been identified in this report.

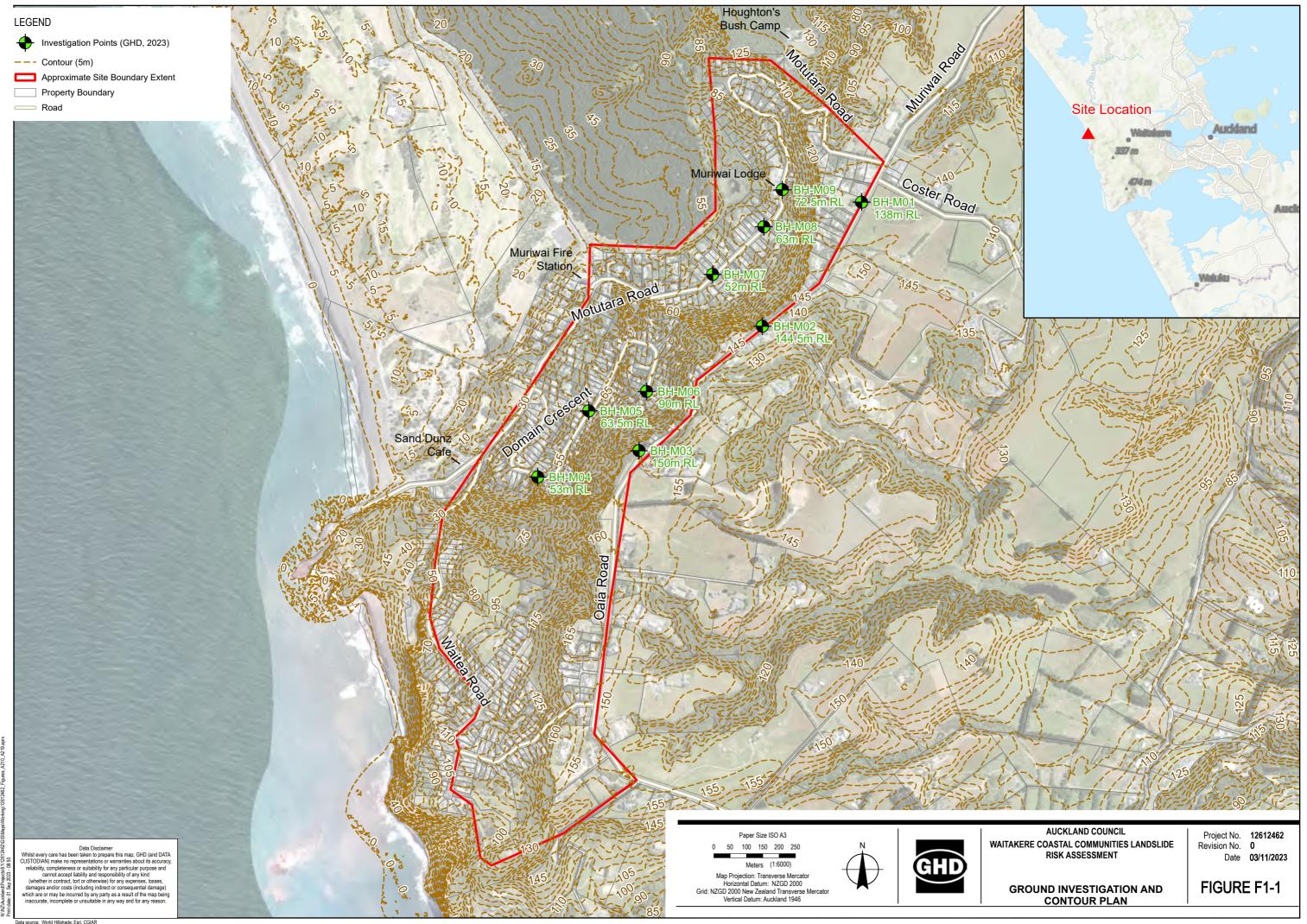
An understanding of the geotechnical site conditions depends on the integration of many pieces of information, some regional, some site specific, some structure specific and some experienced based. Hence this report should not be altered, amended, abbreviated, or issued in part in any way without prior written approval by GHD. GHD does not accept liability in connection with the issuing of an unapproved or modified version of this report.

Verification of the geotechnical assumptions and/or model is an integral part of the design process - investigation, construction verification, and performance monitoring. If the revealed ground or groundwater conditions vary from those assumed or described in this report the matter should be referred back to GHD.

## Appendices

# Appendix F1

Site Plan



## Appendix F2

## **Borehole Logs and Photographs**

- Glossary of symbols
- Borehole logs and photoboards

#### **GLOSSARY OF SYMBOLS**



This standard sheet should be read in conjunction with all test hole log sheets and any idealised geological sections prepared for the investigation report.

#### **GENERAL ABBREVIATIONS**

Activity type / drilling method

DT Dual tube OP Observation pit/trench
CA Casing advancement PM Pressuremeter test hole
EXP Logged exposure PQTT PQ triple tube coring
GCOP GCO probe RC Rotary cored

HA Hand Auger RCG Rotary drilling in common ground

HV Hydro Vacuum excavation RO Rotary open hole
HQTT HQ triple tube coring SCP Static cone penetrometer

ICBR In situ CBR test SH Shaft

IDENIn situ density testSNCSonic core drillingINSTInstrumentSPTStandard penetration test

**IVAN** In situ vane test TP Trial pit/trench MHA Machine Hollow auger Triple tube coring TT MSA Machine Solid auger VC Vibrocore NQ triple tube coring W Wash boring **NQTT** 

OB Open barrel

#### Sampling type

AMAL Amalgamated sample LB Large bulk disturbed sample (for earthworks testing)
B Bulk disturbed sample LDS Large Disturbed Sample

B Bulk disturbed sample LDS Large Disturbed Sample BLK Block sample M Mazier type sample C Core sample P Piston sample

**CBR** CBR mould sample TW Thin walled push in sample D Small disturbed sample U Undisturbed sample - open drive ES Soil sample for environmental testing U100 U110 Undisturbed Sample EW Water sample for environmental testing U76 U76 Undisturbed Sample

G Gas sample UT Thin wall open drive tube sampler

J Jar W Water sample

#### Other testing

F Falling Head Permeability Test
N Total blows - SPT Value

PK Packer Test

PP Pocket Penetrometer (suffixed by value in kPa)

PT Pressuremeter Test

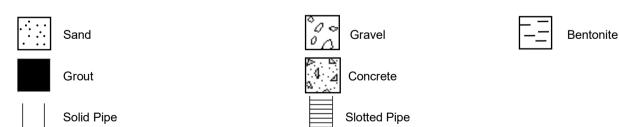
R Rising Head Permeability Test

SV Shear Vane Test (suffixed by value in kPa, peak/residual values)

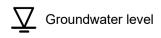
UTP Unable to penetrate (shear vane testing)

TD Target depth HCL Hydrochloric acid

#### **WELL SYMBOLS**

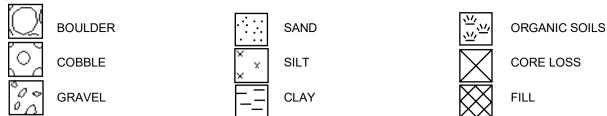


#### **GROUNDWATER SYMBOLS**



#### **SOIL SYMBOLS**

#### **Main Components**



Note: Composite soil types will be signified by combined symbols, e.g.

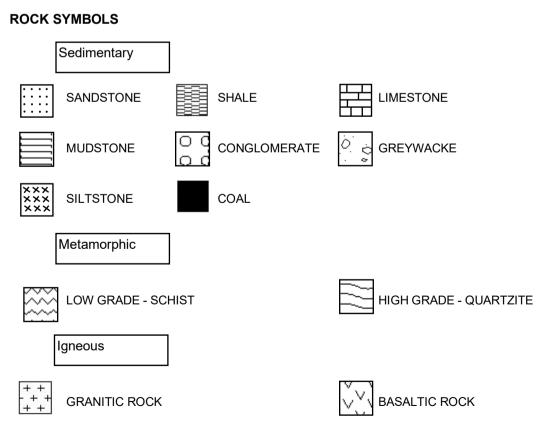


#### **SOIL DESCRIPTION ABBREVIATIONS**

Consiste	ency	S-F	Soft to firm
D	Dense	St	Stiff
D-VD	Dense to very dense	St-VSt	Stiff to very stiff
F	Firm	VD	Very dense
F-St	Firm to stiff	VL	Very loose
Н	Hard	VL-L	Very loose to loose
L	Loose	VS	Very soft
L-MD	Loose to medium dense	VS-S	Very soft to soft
MD	Medium dense	VSt	Very stiff
MD-D	Medium dense to dense	VSt-H	Very Stiff to hard
S	Soft		-

#### **Moisture Condition**

ט	Dry
D-M	Dry to moist
M	Moist
M-W	Moist to wet
S	Saturated
W	Wet



Note: Additional rock symbols may be allocated for a particular project. Interbedded rock will be represented using alternatively the above symbols

#### **ROCK DESCRIPTION ABBREVIATIONS**

**Rock Strength** 

Extremely weak EW EW - VW Extremely to very weak

VW Very weak VW - W Very weak to weak

W Weak

W-MS Weak to moderately strong

MS Moderately strong

MS - S Moderately strong to strong

S Strona

S - VSStrong to very strong

Very strong VS

VS - ES Very strong to extremely strong

ES Extremely strong

#### Weathering

RS Residual soil

CW-RS Completely weathered to residual soil

CW Completely weathered

Highly weathered to completely weathered HW-CW

HW Highly weathered

Moderately weathered to highly weathered MW-HW

Moderated weathering MW

SW-MW Slightly weathered to moderately weathered

Slightly Weathered SW

UW-SW Unweathered to slightly weathered

UW Unweathered (fresh)

#### **DEFECT DESCRIPTION ABBREVIATIONS**

**Fracture Type** 

Bedding Plane JΤ Joint СВ

SF **Sheared Surface** Cross Bed CI Cleavage SM Seam

Crushed Seam CS SS

**Sheared Seam** 

CZ Crush zone SZ Sheared Zone (>250 mm) FΙ

Foliation VN Vein Fractured Zone (>250 mm)

JS Joint set

#### Inclination

FΖ

Sub-horizontal SB G Gently inclined Μ Moderately inclined S Steeply inclined VS Very steeply inclined

SV Sub-vertical

Roughness

Slickensided sl Rough Smooth sm

#### **Texture**

Ы Planar St Stepped U Undulating

#### **Joint Set Counts**

X 2 2 joints

X 3 3 joints

X 4 4 joints X 5 5 joints

X 6 6 joints

X 7 7 joints

8 joints 8 X

9 joints X 9

> 10 joints

#### **Core Recovery Parameters**

100

TCR - Total Core Recovery % SCR - Solid Core Recovery %

RQD - Rock Quality Designation %

#### **Aperture**

Т Tight VN

Very Narrow Narrow Ν

Moderately Narrow MN MW Moderately Wide

Wide W VW Very Wide

#### Infilling or Coating

CN Clean

Carbonaceous Χ

CLAY Clay Chlorite KT Calcite CA Iron Oxide Fe MΙ Micaceous Quartz Ω7

Veneer

#### Spacing

VΕ

EC Extremely closely spaced VC Very closely spaced С Closely spaced

MWModerately widely spaced

W Widely spaced VW Very widely spaced

#### **Visual Defects**

Visual representation of defect angle from horizontal (example shown is 45°)



Client : Auckland Council

Site : 17 Oaia Road, Muriwai 0881

Job Number: 12612462

Commenced: 29/06/2023 Completed: 5/07/2023

Hole No. : BH-M01

Sheet : 1 of 10 Hole Length : 79.60m Scale @ A4 : 1:40

Logged : JM

Material Description    To graph   Sample   Samp	ting: 1 138	17286	891.45 Northing: 5923873.69 Datum: AUCKHT1946	Syste	em:	NZTN	<b>Л</b> 200	0			roces			: JN : JH				
Clayey SILT with some organics; brown, mottled crange and grey. Self to firm, moist, low plasticity. Organics, nodets and roots. [TOPSOIL]  Clayey SILT with name roots; brown, mottled crange and grey. Soft to firm, moist, low plasticity. Organics, nodets.  FILL].  Clayey SILT with name roots; brown, speckled grey. Soft, moist, low plasticity. Organics, nodets.  FILL].  Clayey SILT with name roots; brown, speckled grey. Soft, moist, low plasticity.  The soft is less of the soft of t		Graphic			Geological Unit	Moisture condition	Consistancy / Relative density			-			Weathering		TCR SCR RQD	Defect Spacing (mm)	instrumentation Installation	Water level
Clayery Slrt with minor organics: brown, motelled orange and grey. Soft to firm', moiest, low plasticity. Organics, rooflets.    Clayery Slrt with some roots; brown, speckled grey. Soft to firm', moist, low plasticity. Organics, rooflets.   Clayery Slrt with some roots; brown, speckled grey. Soft to firm', moist, low plasticity. Roots, 3 to 25 mm in diameter. [AWHITU W. M. J. 1.55. 1.50 Wet. 100   1	10 /1	174.5	grey. 'Soft to firm', moist, low plasticity. Organics, rootle	e and ets and	TOPSOIL		'S-F'	2.5	<u> </u>		_	25 50 75		5 > 2 > 1	(70)	20 60 200	370	
moist, low plasticity. Roots, 3 to 25 mm in diameter. [AWHITU M M M No. 2	22 0.55		grey. 'Soft to firm', moist, low plasticity. Organics, rootle [FILL].	ets.							НА				100			-
Silty fine SAND; dark brown, speckled black-grey. Very dense, moist.  CORE LOSS  Silty fine SAND; dark brown, speckled black and grey. Very dense, moist.  Silty fine SAND; dark brown, speckled black and grey. Very dense, moist.  To be a contracting of the second of th	0   X   X   X   X   X   X   X   X   X	× ;	moist, low plasticity. Roots, 3 to 25 mm in diameter. [A' SAND FORMATION].	oft', WHITU		_	'S'		0/1 0/1		SPT				100	-		-
Silty fine SAND; dark brown, speckled black-grey. Very dense, moist.  CORE LOSS  Silty fine SAND; dark brown, speckled black and grey. Very dense, moist.  Silty fine SAND; dark brown, speckled black and grey. Very dense, moist.  CORE LOSS  Silty fine SAND; dark brown, speckled black and grey. Very dense, moist.  Silty fine SAND; dark brown, speckled black and grey. Very dense, moist.  Silty fine SAND; dark brown, speckled black and grey. Very dense, moist.  Silty fine SAND; grey, speckled black and grey. Very dense, moist.  M VD  Silty fine SAND; grey, speckled black. Loose, moist.  M VL  Silty fine SAND; grey, speckled black. Loose, moist.  M VL  Silty fine SAND; grey, speckled black. Loose, moist.  Inclination: Vertical Orientation: Ground Water Level  Contractor: DCN  Date Time Reading 18			Silty CLAY; brown, speckled grey. 'Soft', moist, high pla	asticity.							OB				100	-		
CORE LOSS  Sitty fine SAND; dark brown, speckled black and grey. Very dense, moist.  CORE LOSS  Sitty fine SAND; grey, speckled black. Loose, moist.  Sitty fine SAND; grey, speckled black. Loose, moist.  M L SPT ST		. · .×	moist.	dense,	†		VD		SPT 15/17 21/29		SPT				100	-		, , , , , ,
CORE LOSS  CORE LOSS  Silty fine SAND; grey, speckled black. Loose, moist.  CORE LOSS  Silty fine SAND; grey, speckled black. Loose, moist.  M L SPT 1713 1714 1717 1717 1717 1717 1717 1717	<u> </u>	. : .×	Silty fine SAND; dark brown, speckled black and grey.	Very					for 70mm N > 50		нотт				71			
Silty fine SAND; grey, speckled black. Loose, moist.    Silty fine SAND; grey, speckled black. Loose, moist.   M   L   SPT   I/I   I	7 1	· · · · · · · · · · · · · · · · · · ·	CORFLOSS		ND FORMATION		_		17/33		SPT				0	- -		<u> </u>
Silty fine SAND; grey, speckled black. Loose, moist.  M L 1/1/1 L 2/1/1 N=4  CORE LOSS  Silty fine SAND; grey, speckled black. Loose, moist.  M VL SPT 000 000 000 000 000 000 000 000 000 0					AWHITU SA						НОТТ				0			
CORE LOSS  Silty fine SAND; grey, speckled black. Loose, moist.  Silty fine SAND; grey, speckled black. Loose, moist.  Silty fine SAND; grey, speckled black. Loose, moist.  SPT  ON  ON  ON  ON  Notes and Comments:  End of Hole @ 79.60m, Target Depth.  Coordinates and RLs are approximated from the local GIS viewer. Locations are	445 X	×				М	L		1/1 1/1 1/1		SPT				38			,, ,, ,,
Notes and Comments:  End of Hole @ 79.60m, Target Depth. Coordinates and RLs are approximated from the local GIS viewer. Locations are	× × × × × × × × × × × × × × × × × × ×	×			1			-			НОТТ				82			3 / ) 3
End of Hole @ 79.60m, Target Depth.  Coordinates and RLs are approximated from the local GIS viewer. Locations are		×							0/0 0/0 0/0		SPT				0	-		
Coordinates and RLs are approximated from the local GIS viewer. Locations are				Inclinati	ion: \	/ertica	al		Or	ientat	ion:			Gr	ound W			
Shear Vane Id: GEO902  Refer to explanation sheets for abbreviation and symbols	dinates ect to fu	and F uture s	RLs are approximated from the local GIS viewer. Locations are urvey.	Equipm	ent:	TR 20		2						Dat	te Time	Readir (mbg	ng Hole de (mbgl)	epth



Client : Auckland Council

Site : 17 Oaia Road, Muriwai 0881

Job Number: 12612462

Commenced: 29/06/2023

Completed: 5/07/2023

Hole No. : BH-M01

Sheet : 2 of 10 Hole Length : 79.60m : 1:40

Scale @ A4 : JM Logged

			Datum: AUCKHT1946		Unit	tion	_		mple	C				: JH			_
RL (m)	Depth (m)	Graphic	Material Description		Geological Unit	Moisture condition	Consistancy / Relative density	Number / Type	Result	Casing	Method	Flush Return (%)	Weathering	***Estimated ***Strength (MPa)	TCR SCR RQD (%)	Defect Defect Spacing (mm)	Instrumentation Installation
	9-	X     X     X	Clayey silty fine SAND; grey, speckled black. Very loose moist. (continued from layer starting at 8.0m)	Э,					SPT		НОТТ	25 50 75			78	0 0 0	
-	1.6	× ·- × ·: × ·: × .:	Sandy SILT with some clay; grey with minor brown stre 'Very soft', saturated, non-plastic. Sand, fine.	aks.		S	'VS'	_	0/0 0/0 0/0 0/1 N = 1		SPT				100	_	-   -
- 87 - 1	0 1 2	× · · · · × · · · · · · · · · · · · · ·	Silty fine SAND; grey with minor light brown streaks. W	et.		W	-				НОТТ				100	-	
1	95 1 1 1 1 1 9	X	Clayey silty fine SAND; grey with some light brown stre Very loose, moist.			М	VL		SPT 0/0 0/0 0/0 0/0 N = 0		SPT				0		
— 1 - -	1 - 00	× · · · · · · · · · · · · · · · · · · ·	Sandy SILT with minor clay; grey, streaked light brown. soft', wet, non-plastic. Sand, fine to medium.	'Very	NOIL	W	'VS'				натт				100	-	
- 97 - 1	2-	× × × × × × × × × × × × × × × × × × ×	Silty fine SAND; light grey, streaked brown, speckled bl Very loose, wet.	ack.	AWHITU SAND FORMATION		VL	•	SPT 0/0 0/0 0/0 1/1 N = 2		SPT				0	1111111	
- - - 1729 -	3-	× × · · · · · · · · · · · · · · · · · ·	12.45 - 18.00 Very loose to loose.		AWHI		VL-L	-			нотт				100	-	
- - - 1	4-	× × × × × × × × × × × × × × × × × × ×						P3.95 13.95DS 13.50	SPT 0/0 0/0 1/5 N = 6		SPT				100	- - - -	
- - -		×						14.30 B			натт				100	,	
- 1 	5 -	× × × × × × × × × × × × × × × × × × ×							SPT 1/1 1/2 2/5 N = 10		SPT				0		\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\
122	-	×		T <sub>10-22</sub>	4:	/- · · · ·					HQTT				100		
Enc	of Ho	ole @ 79	nments: .60m, Target Depth. RLs are approximated from the local GIS viewer. Locations are	Inclinat			dI		Or	ientat	ion:			Da	ound W	- In ::	Hole dept
sub	ject to	tes and i future s	urvey.	Equipn				2									



Client : Auckland Council

Site : 17 Oaia Road, Muriwai 0881

Job Number: 12612462

Commenced: 29/06/2023 Completed: 5/07/2023

: BH-M01 Hole No.

Sheet : 3 of 10 : 79.60m Hole Length : 1:40 Scale @ A4

Logged : JM

	: 138		Datum: AUCKHT1946		z	_		Sar	nple		heck			: J <del>I</del>				Γ
RL (m)	Depth (m)	Graphic	Material Description		Geological Unit	Moisture condition	Consistancy / Relative density	Number / Type	Result	Casing	Method	Flush Return (%)	Weathering	Estimated Strength (MPa)	TCR SCR RQD (%)	Defect Spacing (mm)	Instrumentation Installation	Motor Ional
<del></del>	-	× ·: × ·: × .:	Silty fine SAND; light grey, streaked brown, speckled bl Very loose, wet. (continued from layer starting at 11.7r	lack. m )							HQTT	25 50 75		3 > 3 2 >	100	000	7000	
- 1121 -	-	× × × × × × × × × × × × × × × × × × ×	16.40 - 16.50 Brown streaks.						SPT 0/0 0/1 0/0 N = 1		SPT				0			
- 1 - -	17	×									нотт				100			-
- - - -	18-	× × × × × × × × × × × × × × × × × × ×	18.00 - 18.50 Medium dense.				MD		SPT 2/2 3/3 4/8 N = 18		SPT				100	-		-
- 110 -	18.5	×	Fine SAND, trace silt; grey. Medium dense, moist.			М					натт				100			-
- - -					DRMATION				SPT 1/1 2/3 4/5 N = 14		SPT				0			
- 118	20.4	× .	Silty fine to medium SAND with trace clay; light brown, streaked light orange. Medium dense, moist.		AWHITU SAND FORMATION						натт				100	-		- - - -
- 117	21 -	×	Streamed light Grange. Wediann across, moles.						SPT 2/2 2/3 4/5 N = 14		SPT				0	<u>.</u>		-
116 -	21.45	×	Fine to medium SAND, trace silt; grey, mottled orange; indistinctly, very thinly bedded at 5-10°. Medium dense dense, moist.	to			MD-D				НОТТ				100	-		-
- - -	-								SPT 3/5 8/8							-		Σ
- 115	23 -								7/8 N = 31		SPT				0	-	10,000	
- 4											НОТТ				100			
	es ar	d Con	ments:	Inclination	on: \	ertica	al	I	Ori	entat	ion:			Gr	ound W	ater Le	vel	<u></u>
End	d of Ho		60m, Target Depth. RLs are approximated from the local GIS viewer. Locations are	Contrac			00							Da	te Time	Reading (mbgl)	g Hole dep (mbgl)	pth
Def			on sheets for abbreviation and symbols	Shear V	ane/	ld: Gl	EO902	2										

RL: 138 Depth ( 26

Project : AC Geo Panel - Waitakere

Client : Auckland Council

Site : 17 Oaia Road, Muriwai 0881

Job Number: 12612462

Hole No. : BH-M01 Sheet : 4 of 10 : 79.60m Hole Length

Scale @ A4 : 1:40 Logged : JM

Commenced: 29/06/2023 Completed: 5/07/2023 Processed : JM Easting: 1728691.45 Northing: 5923873.69 System: NZTM2000 Checked : JHS Datum: AUCKHT1946 Sample **Geological Unit** Moisture condition 8 Consistancy / Relative density Strength (MPa) Defect Spacing (mm) Flush Return **Material Description** Water level Estimated Number / Method Casing Result SCR RQD Fine to medium SAND, trace silt; grey, mottled orange; indistinctly, very thinly bedded at 5-10°. Medium dense to SPT 100 dense, moist. (continued from layer starting at 21.5m) HØH 100 Highly weathered, dark grey-green, speckled light grey and black, fine to medium grained SANDSTONE; extremely weak SPT 100 HÖH 100 SPT 4/4 4/6 8/11 N = 29 SPT 100 AWHITU SAND FORMATION 27.65 Grey-green. Highly weathered, orange brown, speckled grey and dark brown, fine to medium grained SANDSTONE; extremely weak. HØH 100 SPT 0 HQT 100 SPT 0 Highly weathered, orange brown, streaked black, dark grey and dark red, distinctly bedded, fine to medium grained SANDSTONE; extremely weak; very thinly bedded at 10-20°. 보 100 Moderately weathered, dark grey, fine to medium grained SANDSTONE; extremely weak. SPT 8/13 15/17 18 for 65mm N > 50 SPT 82 100 **Ground Water Level** Inclination: Vertical Orientation: Notes and Comments: End of Hole @ 79.60m, Target Depth.

25 August 2023

GHD - NZGD.GLB || Date:

REV3.GPJ || Library:

GENERAL LOG | Project: BH-M01

≘

Report I

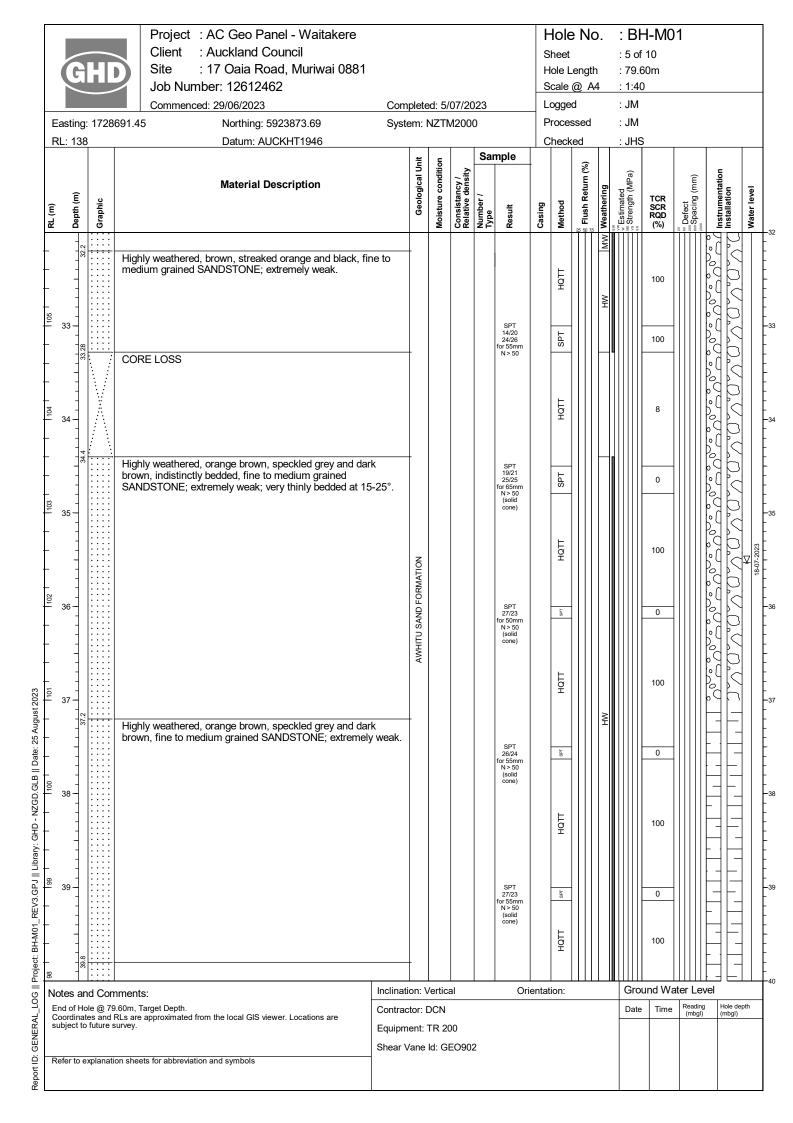
Coordinates and RLs are approximated from the local GIS viewer. Locations are subject to future survey.

Refer to explanation sheets for abbreviation and symbols

Contractor: DCN

Equipment: TR 200 Shear Vane Id: GEO902

Reading (mbgl) Date Time





Client : Auckland Council

Site : 17 Oaia Road, Muriwai 0881

Job Number: 12612462

 Hole No. : BH-M01

Sheet : 6 of 10 Hole Length : 79.60m Scale @ A4 : 1:40

Logged : JM

RL: 138		Datum: AUCKHT1946					Sai	nple	C	heck	ed		: JHS	S 		
RL (m) Depth (m)	Graphic	Material Description		Geological Unit	Moisture condition	Consistancy / Relative density			Casing	Method	Flush Return (%)	Weathering	***Estimated ***Strength (MPa)	TCR SCR RQD (%)	Defect Spacing (mm)	Instrumentation Installation
		Highly weathered, brown, speckled grey and dark brown distinctly bedded, fine to medium grained SANDSTONE extremely weak; very thinly bedded at 0-20°. (continued layer starting at 39.8m)	Ξ;					SPT 28/22 for 50mm N > 50 (solid cone)		SPT	25 50 75		7. 7. 7. 7. 7. 7. 7. 7. 7. 7. 7. 7. 7. 7	100	00	
		Highly weathered, brown, speckled dark orange brown, medium grained SANDSTONE; extremely weak.	fine to					SPT 25/25 for 60mm N > 50 (solid cone)		SPT HQTT				0		\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\
56 43				AWHITU SAND FORMATION			43.80 B 43.50	SPT 29/21 for 45mm N > 50 (solid cone)		. HQTT		HW		0		
		45.00 - 45.03 Extremely weak, dark brown LIGNITE.		AWHITUS				SPT 28/22 for 50mm N > 50 (solid cone)		TT SPT HQTT				0		
76 46		Highly weathered, brown, speckled grey and dark orang brown, distinctly bedded, fine to medium grained SANDSTONE; extremely weak; very thinly bedded at 10						SPT 35/15 for 20mm N > 50 (solid cone)		T HQTT				0		
Notes an	le @ 79 es and I	.60m, Target Depth. RLs are approximated from the local GIS viewer. Locations are	Inclinat Contrac Equipm	ctor: I	DCN			Ori	entat	ion:			Gro	ound Wa	- In ::	



Client : Auckland Council

Site : 17 Oaia Road, Muriwai 0881

Job Number: 12612462

: BH-M01 Hole No.

Sheet : 7 of 10 Hole Length : 79.60m Scale @ A4 : 1:40

	_: 1:	-		691.45 Northing: 5923873.69  Datum: AUCKHT1946	Oyst	CIII.	INZ 11	И200	U			roces			: JM : JH				
IXI		30		Datum. ACCN 11 1340		=	_		Sai	nple		IIECK			. 01 K				Π
RL (m)	Denth (m)	ceptiii (iii)	Graphic	Material Description		Geological Unit	Moisture condition	Consistancy / Relative density	Number / Type	Result	Casing	Method	g Flush Return (%)	Weathering	***Estimated ***Strength (MPa)	TCR SCR RQD (%)	Defect	Instrumentation Installation	Water level
	-	99		Highly weathered, brown, speckled grey and dark orang brown, distinctly bedded, fine to medium grained SANDSTONE; extremely weak; very thinly bedded at 10 (continued from layer starting at 46.8m) 48.00 - 48.65 Trace organic fragments to 5 mm.						SPI 32/18 for 25mm N > 50 (solid cone)						0	-		
80	- - 49 <del>-</del> - -	48.6		Highly weathered, orange brown, distinctly bedded, fine medium grained SANDSTONE; trace organics to 5 mm extremely weak; very thinly bedded at 10-30°.	to ;							НОТТ		/		100			- - - - -
	-	49.5		Highly weathered, orange brown, fine to medium graine SANDSTONE; extremely weak.	;d					SPT 20/30 for 45mm N > 50 (solid cone)		8		H		0	-		-
1	50 <del></del> - - - - -											НОТТ				100			- - - -
. /01	- - 51 <del>-</del>	1 "	× × × × × ×	Completely weathered, brown, mottled light yellowish brown, siltsone; extremely weak.  Moderately weathered, grey, speckled light brown, fine medium grained SANDSTONE; extremely weak.		†				SPT 39/11 for 15mm		1-8		CW		0	- -		-
	- - - - - - 52 – -	-		medium grained SANDSTONE; extremely weak. 51.20 - 51.35 20-40 mm shell fragments.		 AWHITU SAND FORMATION				N > 50 (solid cone)		нотт				100			
	53 <del>-</del>	52.5		Moderately weathered, dark grey-green, distinctly bedde to medium grained SANDSTONE; extremely weak; very bedded at 10-30° with very closely spaced irregular laminations of silty sandstone.	ed, fine thinly	AWHIT				SPT 42/18 for 5mm N > 50 (solid cone)		ТТОН				100			
<u> </u>	- - - - 54 <del>-</del>	2								SPT 38/12 for 35mm		SPT		M		0	-	10,00	
	-	54.8 54		Moderately weathered, brown, mixed grey and light yello distinctly bedded, fine to medium grained SANDSTONE extremely weak; very thinly laminated at 15-25°.	<u>:</u> ;					N > 50 (solid cone)		НОТТ				100			
	- 55 <del>-</del> - - - -	2		Moderately weathered, dark grey-brown, distinctly bedd to medium grained SANDSTONE; extremely weak; very bedded at 15-35°.	ed, fine thinly					SPT									
70	-	-			1					33/17 for 35mm N > 50 (solid cone)		HQTT				100			
				nments:	Inclinat			al		Ori	entat	ion:			+		ater Lev	-	epth
Su	ordii	nate t to	es and I future s	.60m, Target Depth.  RLs are approximated from the local GIS viewer. Locations are urvey.  on sheets for abbreviation and symbols	Equipm Shear	nent:	TR 20		2						04/07/		(mbgl)	(mbgl)	5.63

: BH-M01 Project : AC Geo Panel - Waitakere Hole No. Client : Auckland Council : 8 of 10 Sheet Site : 17 Oaia Road, Muriwai 0881 : 79.60m Hole Length Job Number: 12612462 Scale @ A4 : 1:40 Commenced: 29/06/2023 Completed: 5/07/2023 Logged : JM Processed : JM Easting: 1728691.45 Northing: 5923873.69 System: NZTM2000 RL: 138 Checked Datum: AUCKHT1946 : JHS Sample **Geological Unit** Moisture condition 8 Consistancy / Relative density Strength (MPa) Defect Spacing (mm) Flush Return **Material Description** Estimated Number / Method Casing Depth ( SCR RQD Moderately weathered, dark grey-brown, distinctly bedded, fine to medium grained SANDSTONE; extremely weak; very thinly bedded at 15-35°. (continued from layer starting at 54.8m) HOT 100 SPT 24/26 for 55mn N > 50 (solid cone) SPT 0 ĦÖĦ 100 58 0 SPT HQT 88 Moderately weathered, dark grey, mixed brown and orange, fine to medium grained SANDSTONE; extremely weak. AWHITU SAND FORMATION SPT n CORE LOSS Highly to moderately weathered, dark grey, mottled brown-orange, fine to medium grained SANDSTONE; extremely weak. HÖT 81 25 August 2023 SPT 25/25 for 55mm N > 50 (solid cone) GHD - NZGD.GLB || Date: SPT 0 **CORE LOSS** Moderately weathered, grey, mottled orange, fine to medium grained SANDSTONE; extremely weak. HØH 84 Moderately weathered, dark grey, fine to medium grained REV3.GPJ || Library: SANDSTONE; extremely weak. SPT 31/19 for 55mr N > 50 (solid cone) SPT 0 CORE LOSS HØH 22 **Ground Water Level** Inclination: Vertical Orientation: Notes and Comments:

|| Project: BH-M01 GENERAL LOG ≘

Report I

End of Hole @ 79.60m, Target Depth. Coordinates and RLs are approximated from the local GIS viewer. Locations are subject to future survey.

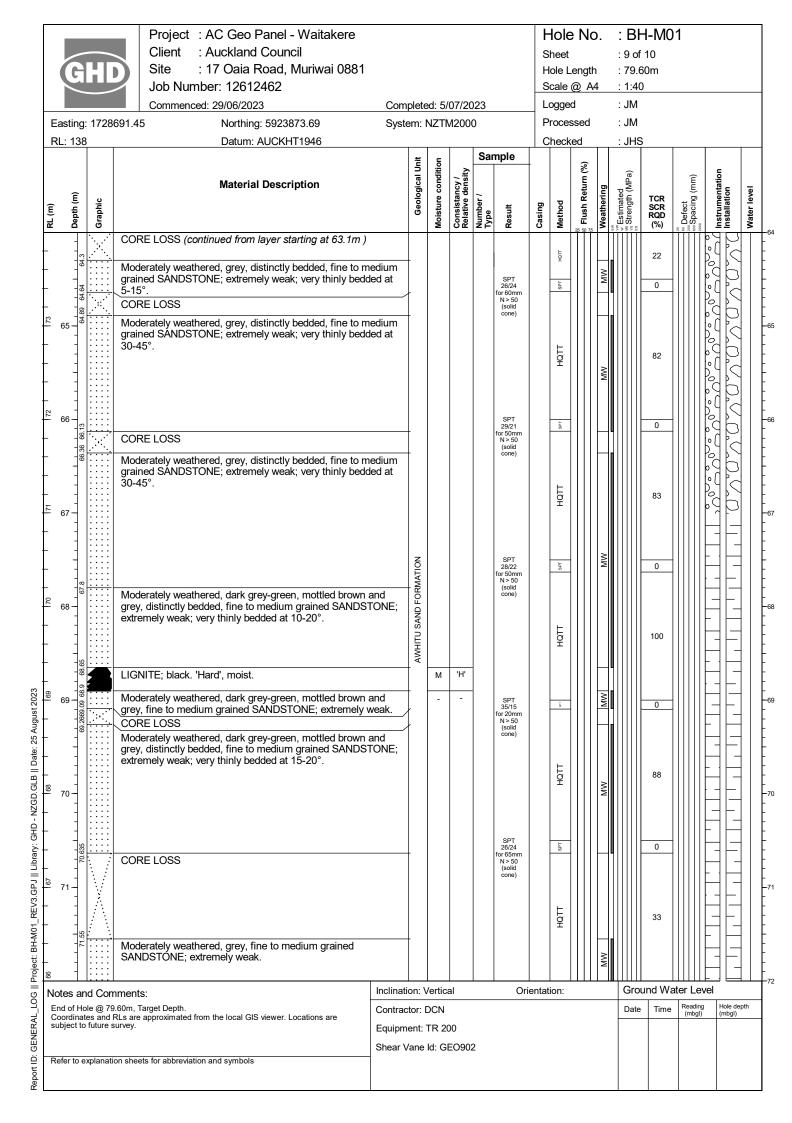
Refer to explanation sheets for abbreviation and symbols

Contractor: DCN Equipment: TR 200

Reading (mbgl) Date Time

Water level

Shear Vane Id: GEO902



Easting: 1728691.45

Project : AC Geo Panel - Waitakere

Client : Auckland Council

Site : 17 Oaia Road, Muriwai 0881

Job Number: 12612462

Commenced: 29/06/2023 Completed: 5/07/2023 Northing: 5923873.69

System: NZTM2000

Sheet : 10 of 10 Hole Length : 79.60m Scale @ A4 : 1:40

Hole No.

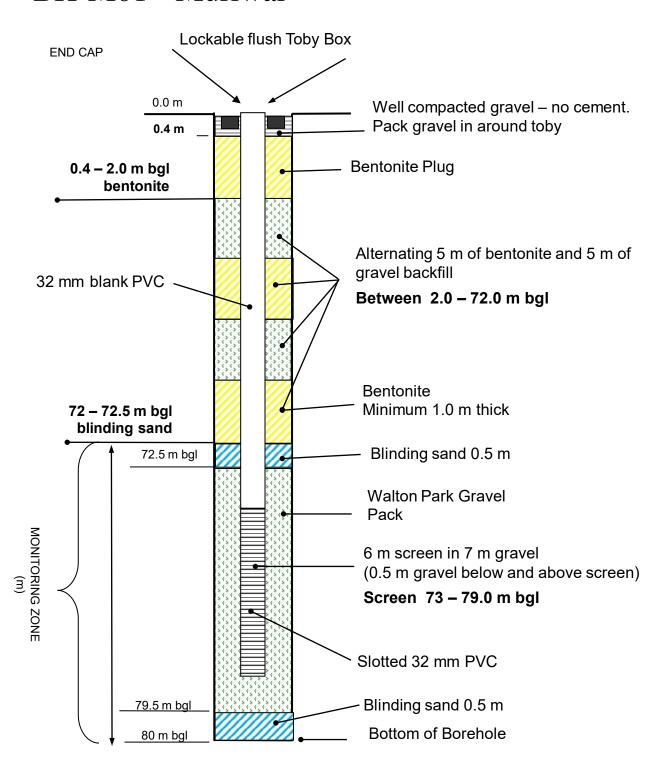
Logged : JM

: BH-M01

Processed : JM

					¥	Ĕ		Sai	mple			•						
RL (m)	Depth (m)	Graphic	Material Description		Geological Unit	Moisture condition	Consistancy / Relative density	Number / Type	Result	Casing	Method	કુ Flush Return (%)	Weathering	Estimated  Strength (MPa)	TCR SCR RQD (%)	be Defect (mm)	Instrumentation Installation	Water level
	-		Moderately weathered, grey, fine to medium grained SANDSTONE; extremely weak. (continued from layer s	starting					SPI 34/16 for 20mm N > 50 (solid cone)		å	25 50 7	2		0	-		Π
	-		at 71.6m )						(solid cone)									
3 -											НФТТ				100			
: 7	73 − ₽ - -	: : : :	Moderately weathered, dark grey, distinctly bedded, fine medium grained SANDSTONE; extremely weak; thinly at 25-35°.	e to bedded														
			at 25-35°.						SPT 40/10						0			
									for 10mm N > 50 (solid cone)									
7	74 -										   				400			
											НОТТ				100			
! <del>,</del>	-																	
7	75 -				z				SPT 33/17 for 30mm N > 50 (solid		SPT				0	-		
	-				RMATIO				cone)									
<u> </u>	-				AWHITU SAND FORMATION						НОТТ		WW		100			
- /	76 -				WHITU S													
	-				Ā				SPT 26/24 for 55mm N > 50		SPT				0			
	77 –								N > 50 (solid cone)									
,	' - - - -										натт				100			
	-										I							
3 7	78 -								SPT		F							
	-								29/21 for 50mm N > 50 (solid cone)		SPT				0	-		
									·		L							
3 7	79 –										HQTT				100			
	-	::::	End of Hole @ 79.60m, Target Depth.					_	SPT 35/15 for 20mm N > 50 (solid		1 de 1				0	<u> </u>		H
1	-			1		, t' .			cone)					Cre	und M	latar La	) val	
End	d of Ho	ole @ 79	nments: L60m, Target Depth.	Contract			al		Ori	entat	ion:			Date	und W	T	na Hole der	pth
Coo	ordinat ject to	es and future :	RLs are approximated from the local GIS viewer. Locations are urvey.	Equipme			00							05/07 18/07	/23 08:09 /23 16:19	5 26	.9 72	2.095 9.59
			on sheets for abbreviation and symbols	Shear Va	ane	ld: Gl	EO90	2										

## BH-M01 - Muriwai



NOT TO SCALE





Project	AC Geo Panel – Waitākere	Coordinates	1728691.45 E
Job Number	12612462	(NZTM 2000)	5923873.69 N
Client	Auckland Council	Location	17 Oaia Rd, Muriwai
Date	29 June to 5 July 2023	Location	







Project	AC Geo Panel – Waitākere	Coo	rdinates	1728691.45 E
Job Number	12612462	(NZ	TM 2000)	5923873.69 N
Client	Auckland Council	Loo	ation	17 Oaia Rd, Muriwai
Date	29 June to 5 July 2023	LOC	ation	







Project	AC Geo Panel – Waitākere	Coordinates	1728691.45 E
Job Number	12612462	(NZTM 2000)	5923873.69 N
Client	Auckland Council	Location	17 Oaia Rd, Muriwai
Date	29 June to 5 July 2023	Location	





Project	AC Geo Panel – Waitākere	Coordinates	1728691.45 E
Job Number	12612462	(NZTM 2000)	5923873.69 N
Client	Auckland Council	Location	17 Oaia Rd, Muriwai
Date	29 June to 5 July 2023	Location	





Project	AC Geo Panel – Waitākere	Coordinates	1728691.45 E
Job Number	12612462	(NZTM 2000)	5923873.69 N
Client	Auckland Council	Location	17 Oaia Rd, Muriwai
Date	29 June to 5 July 2023	Location	







Project	AC Geo Panel – Waitākere	Coordinates	1728691.45 E
Job Number	12612462	(NZTM 2000)	5923873.69 N
Client	Auckland Council	Location	17 Oaia Rd, Muriwai
Date	29 June to 5 July 2023	Location	





Project	AC Geo Panel – Waitākere	Coordinates	1728691.45 E
Job Number	12612462	(NZTM 2000)	5923873.69 N
Client	Auckland Council	Location	17 Oaia Rd, Muriwai
Date	29 June to 5 July 2023	Location	







Project	AC Geo Panel – Waitākere	Coordinates	1728691.45 E
Job Number	12612462	(NZTM 2000)	5923873.69 N
Client	Auckland Council	Location	17 Oaia Rd, Muriwai
Date	29 June to 5 July 2023	Location	





Project	AC Geo Panel – Waitākere	Coordinates	1728691.45 E
Job Number	12612462	(NZTM 2000)	5923873.69 N
Client	Auckland Council	Location	17 Oaia Rd, Muriwai
Date	29 June to 5 July 2023	Location	





Project	AC Geo Panel – Waitākere	Coordinates	1728691.45 E
Job Number	12612462	(NZTM 2000)	5923873.69 N
Client	Auckland Council	Location	17 Oaia Rd, Muriwai
Date	29 June to 5 July 2023	Location	







Project	AC Geo Panel – Waitākere	Coordinates	1728691.45 E
Job Number	12612462	(NZTM 2000)	5923873.69 N
Client	Auckland Council	Location	17 Oaia Rd, Muriwai
Date	29 June to 5 July 2023	Location	





Project	AC Geo Panel – Waitākere	Coordinates	1728691.45 E
Job Number	12612462	(NZTM 2000)	5923873.69 N
Client	Auckland Council	Location	17 Oaia Rd, Muriwai
Date	29 June to 5 July 2023	Location	





Project	AC Geo Panel – Waitākere	Coordinates	1728691.45 E
Job Number	12612462	(NZTM 2000)	5923873.69 N
Client	Auckland Council	Location	17 Oaia Rd, Muriwai
Date	29 June to 5 July 2023	Location	





Project	AC Geo Panel – Waitākere	Coordinates	1728691.45 E
Job Number	12612462	(NZTM 2000)	5923873.69 N
Client	Auckland Council	Location	17 Oaia Rd, Muriwai
Date	29 June to 5 July 2023	Location	





Project	AC Geo Panel – Waitākere	Coordinates	1728691.45 E
Job Number	12612462	(NZTM 2000)	5923873.69 N
Client	Auckland Council	Location	17 Oaia Rd, Muriwai
Date	29 June to 5 July 2023	Location	





Project	AC Geo Panel – Waitākere	Coordinates	1728691.45 E
Job Number	12612462	(NZTM 2000)	5923873.69 N
Client	Auckland Council	Location	17 Oaia Rd, Muriwai
Date	29 June to 5 July 2023	Location	







Project	AC Geo Panel – Waitākere	Coordinates	1728691.45 E
Job Number	12612462	(NZTM 2000)	5923873.69 N
Client	Auckland Council	Location	17 Oaia Rd, Muriwai
Date	29 June to 5 July 2023	Location	





Project	AC Geo Panel – Waitākere	Coordinates	1728691.45 E
Job Number	12612462	(NZTM 2000)	5923873.69 N
Client	Auckland Council	Location	17 Oaia Rd, Muriwai
Date	29 June to 5 July 2023	Location	





Project	AC Geo Panel – Waitākere	Coordinates	1728691.45 E
Job Number	12612462	(NZTM 2000)	5923873.69 N
Client	Auckland Council	Location	17 Oaia Rd, Muriwai
Date	29 June to 5 July 2023	Location	





Project	AC Geo Panel – Waitākere	Coordinates	1728691.45 E
Job Number	12612462	(NZTM 2000)	5923873.69 N
Client	Auckland Council	Location	17 Oaia Rd, Muriwai
Date	29 June to 5 July 2023	Location	





Project	AC Geo Panel – Waitākere	Coordinates	1728691.45 E
Job Number	12612462	(NZTM 2000)	5923873.69 N
Client	Auckland Council	Location	17 Oaia Rd, Muriwai
Date	29 June to 5 July 2023	Location	







Project	AC Geo Panel – Waitākere	Coordinates	1728691.45 E
Job Number	12612462	(NZTM 2000)	5923873.69 N
Client	Auckland Council	Location	17 Oaia Rd, Muriwai
Date	29 June to 5 July 2023	Location	





Photograph @ 6.0 m not recovered.





Project	AC Geo Panel – Waitākere	Coordinates	1728691.45 E
Job Number	12612462	(NZTM 2000)	5923873.69 N
Client	Auckland Council	Location	17 Oaia Rd, Muriwai
Date	29 June to 5 July 2023	Location	



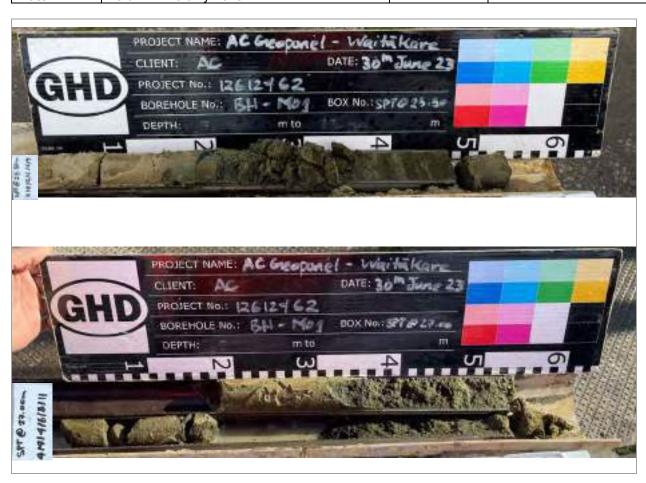


Project	AC Geo Panel – Waitākere	Coordinates	1728691.45 E
Job Number	12612462	(NZTM 2000)	5923873.69 N
Client	Auckland Council	Location	17 Oaia Rd, Muriwai
Date	29 June to 5 July 2023	Location	





Project	AC Geo Panel – Waitākere	Coordinates	1728691.45 E
Job Number	12612462	(NZTM 2000)	5923873.69 N
Client	Auckland Council	Location	17 Oaia Rd, Muriwai
Date	29 June to 5 July 2023	Location	





Project	AC Geo Panel – Waitākere	Coordinates	1728691.45 E
Job Number	12612462	(NZTM 2000)	5923873.69 N
Client	Auckland Council	Location	17 Oaia Rd, Muriwai
Date	29 June to 5 July 2023	Location	





Client : Auckland Council

Site : 150 Oaia Rd, Muriwai 0881

Job Number: 12612462

Scale @ A4 : 1:40

Hole No.

Hole Length

Sheet

: BH-M02

: 1 of 10

: 79.57m

	: 144		387.63 Northing: 5923493.52  Datum: AUCKHT1946	Syste	2111. I	4 <b>4</b>	00	•			roces			: JN : JH	IS 23/08	/2023	
			Batanii Ale Stanii 10 10		Unit	tion	_		mple								_
RL (m)	Depth (m)	Graphic	Material Description		Geological Unit	Moisture condition	Consistancy / Relative density	Number / Type	Result	Casing	Method	ଞ୍ଚ ଞ୍ଚ Flush Return (%)	Weathering	*** Estimated *** Strength (MPa)	TCR SCR RQD (%)	60 Defect 800 Spacing (mm)	Instrumentation Installation
-		\(\bar{\chi}\cdot\) \(\bar{\gamma}\cdot\) \(	Clayey SILT; dark brown, mottled orange-brown. 'Very moist, low plasticity. [TOPSOIL].	stiff',	OPSOIL	M	'VSt'										
- 144 4	10.0		Clayey SILT; brown, speckled orange-dark brown. Very moist, low plasticity. [FILL].	y stiff,	FILL		VSt		SV@0.5m 155/87 kPa		HA					<u>-</u>	
-	1-	× × · · · · · · · · · · · · · · · · · ·	Clayey SILT with trace sand; brown, mottled and streat orange. Very stiff, moist, low plasticity. Sand, fine. [AW SAND FORMATION].	ked /HITU					SV@1m 142/74 kPa							- - - -	
1143	1 1 7:	×	Clayey SILT; brown, mottled and streaked orange. 'Ver	av otiff'	_		'VSt'		SV@1.5m 111/59 kPa SPT 1/1		SPT				100		
-	2-	× × ; × × ;	moist, low plasticity.	y suii,			VSt		1/1 2/2 2/2 N = 8		0)						
. 741	-	* -* ; × -* ; × -× ;									90 8				100	- - -	
	3-	× × ; × × ; × × ;	3.00 - 3.20 Hard.				Н		SV@3m UTP SPT		F				100		
1 141		× - : × - : × - :	Clayey SILT with minor sand; brown streaked yellow-o 'Stiff', moist, low plasticity. Sand, fine. [AWHITU SAND FORMATION]	range. )			'St'		1/0 1/1 1/1 1/1 N = 4		SPT				100		
	4 - 868	×	3.80 - 3.95 Speckled black.  Clayey fine SAND; grey speckled black. Moist.		ATION		-				OB				100	-	
- 140	4.3	× . × . · . · .×	Silty fine SAND; light grey speckled black, streaked or Loose, moist.	ange.	SAND FORMATION		L		SPT 1/1								
- -	5 -	× × ×			AWHITU 8				1/2 3/4 N = 10		SPT				100		
- 139		× · · · × · · · × · · · · · · · · · · ·									08				100	-	
- -	6-	×							SPT 1/1							- -	
- 138	-	×							1/3 3/3 N = 10		SPT				0	- -	-   -
	7-	× · . · · × · · · · · · · · · · · · · ·	6.80 With trace clay.								0B				100		
		×							SPT							-	
-	7.957.8	× .	Amorphous PEAT; brown-black, streaked red-orange.	'Very	-		'VSt'		1/0 1/3 3/3 N = 10		SPT				100	<u> </u>	<u> </u>
			nments:	Inclination			al		Ori	ientat	ion:				ound Wa	Reading	Hole depth
Coc	rdina	es and I future s	.57m, Target Depth. RLs are approximated from the local GIS viewer. Locations are urvey.	Contrac			00							Da	te Time	(mbgl)	(mbgl)
				Shear V				60									

Client : Auckland Council

Site : 150 Oaia Rd, Muriwai 0881

Job Number: 12612462

Commenced: 4/08/2023

Completed: 17/08/2023

Scale @ A4 : 1:40 Logged : JM

Sheet

Hole Length

Hole No. : BH-M02

: 2 of 10

: 79.57m

171	.: 144	1.5	Datum: AUCKHT1946		T			Sa	nple	1	heck	lea	П	. J⊓	S 23/08	12023	Т	Т
RL (m)	Depth (m)	Graphic	Material Description		Geological Unit	Moisture condition	Consistancy / Relative density			Casing	Method	Flush Return (%)	Weathering	Estimated Strength (MPa)	TCR SCR RQD (%)	o Defect Spacing (mm)	Instrumentation Installation	1
<del>-</del>	-12	::::	stiff, moist.			-	-				-	25 50 7	5	33388	81	20 800 200 200 200 200 200 200 200 200 2	<del>                                     </del>	Ť
136		<u> </u>	CORE LOSS (continued from layer starting at 8.0m) Amorphous PEAT; brown-black, streaked red-orange. 'stiff', moist.	Very		М	'VSt'				OB				81			-
-	9	× . × . × .	Silty fine to medium SAND; grey-brown, streaked orange-yellow. Medium dense, moist.				MD	-	SPT 1/2									}
135	9.45	× · · · · × · · · · · · · · · · · · · ·	CORE LOSS			-	-		4/6 6/7 N = 23		SPT				100			}
-	10 <del>-</del> 2										НОТТ				52			}
- 134	-	×	Silty fine to medium SAND; light grey, streaked dark gr Medium dense, moist; indistinctly, closely bedded at 0-	ey. 5°.		М	MD		SPT									}
-	-	× . × . · . · ×							SPT 1/1 2/3 4/5 N = 14		SPT				0			,
133 -	11 -	×									E				75		0,00	}
<u>-</u> -	11.74	× · · · · · · · · · · · · · · · · · · ·	CORE LOSS	-	ORMATION		-	-			HQTT				/5			}
28	12 - 2	× ×	Silty fine to medium SAND; light grey, streaked dark gr Loose, moist.	ey.	AWHITU SAND FORMATION	М	L	-	SPT 3/0 1/1 3/4 N = 9		SPT				0			<u>'</u> }
<del>-</del> -	13 -	× · · · × · · · × · · · · · × · · · · ·	Clayey SILT; grey. 'Stiff', moist.  Silty fine to medium SAND; light grey, speckled black; indistinctly very thinly bedded at 0-5°. Medium dense, r	noist.	AWF		'St' / MD	,			НОТТ				100			
- 131	-	×							SPT 2/2 2/2 4/5 N = 13		SPT				0		0000	} }∑
-	14 -   85	×	CORE LOSS		Ť	-	-									-		}
1130	14.3	× . × . × .	Silty fine to medium SAND; grey-orange, speckled light grey-black. Medium dense, moist.	:		М	MD	-			HQTT				67			-
129	15 -	× . × × ×							SPT 2/1 2/3 5/6 N = 16		SPT				0			- - - -
<u>-</u>	15.4		CORE LOSS			-	-				HQTT				0			
Not	es ar	nd Con	ments:	Inclinati	ion: \	/ertic	al		Or	ientat	ion:	шШ 	<u> </u>	Gr	ound W	ater Le	vel	
Co	ordinat	tes and I	.57m, Target Depth. RLs are approximated from the local GIS viewer. Locations are	Contrac										Dat	e Time	Reading (mbgl)	g Hole de (mbgl)	epth
sul	oject to	future s	urvey.	Equipm				60										
Re	for to c	volonoti	on sheets for abbreviation and symbols	Shear \	rane	ıu. G	EU 10	UU										



Client : Auckland Council

: 150 Oaia Rd, Muriwai 0881 Site

Job Number: 12612462

: BH-M02 Hole No.

Sheet : 3 of 10 : 79.57m Hole Length Scale @ A4 : 1:40

RI	_: 144		387.63 Northing: 5923493.52 Datum: AUCKHT1946	System							heck	ed		: JH	S 23/08	/2023		
- 1 11			Balam. AGGRATI 1040		<u>≡</u> T	<u>_</u>			nple					. 011	20,00	2020		Τ
RL (m)	Depth (m)	Graphic	Material Description		Geological Unit	Moisture condition	Consistancy / Relative density	Number / Type	Result	Casing	Method	Flush Return (%)	Weathering	Estimated	TCR SCR RQD (%)	Defect Spacing (mm)	Instrumentation Installation	
-	<u>-</u>		CORE LOSS (continued from layer starting at 15.5m	)			<u> </u>				натт	25 50 75			0	20 60 200 200 200 200 200 200 200 200 20		ľ
- 1128	16.5	× . × . × .	Silty fine to medium SAND; light brownish grey. Mediudense, moist.	um		M	MD		SPT 2/1 2/4 7/10 N = 23		SPT				100			-
-	17 - 9	×	CORE LOSS			-	-											
	17.6	× .	Silty fine to medium SAND; light brownish grey. Mediudense, moist.	um		M	MD				НОТТ				38			
-	18 - 18	× · · · × · · · × · · · · · · · · · · ·	Clayey SILT with minor sand; grey, speckled black. 'F stiff, moist, low plasticity. Sand, fine to coarse.	irm to			'F-St'		SPT 4/4 4/4 4/5 N = 17		SPT				100			Ī Ā
1126	18.7	×	18.20 - 18.35 Grey, speckled black.  Silty fine to medium SAND; light grey-light brown, streand mottled orange; indistinctly bedded very thinly bed	eaked dded at			MD				ш				100			-
. 671	19 -	× · . · . × · . · × · . · × · . · × · . · ×	40°. Medium dense, moist.					<b>\</b>			НОТТ				100			
-	1 1 1 93.6	× · · · × · · · · · · · · · · · · · · ·			FORMAIION				SPT 5/5 6/8 8/10 N = 32		SPT				0			,
	20		CORE LOSS		AWHILD SAND	-	-				натт				38			,
	21 -	× . · . · .× ×	Silty fine to medium SAND; light grey-light brown, strelight orange, mottled orange. Medium dense, moist.		∢ _	М	MD		SPT 4/6									
. 571.	21.45	×	Silty fine to medium SAND; orange brown, speckled b	olack,					6/7 8/8 N = 29		SPT				0			,
	22 -	× · . × · . × · . × · . × · . × · . × · . ×	streaked yellow-orange. Medium dense, moist. 21.85 - 21.90 Dark orange-red.								НДТТ				100			
- 22		· · · × · · · · × · · · · ×	22.50 - 23.60 Dense.				D		SPT 4/6									
	23 –	× · · · × · · · × · · · × · · · ×	22.60 - 23.60 Orange-brown, streaked orange.						7/8 9/11 N = 35		SPT				100		0,000	
1721	- - - - - - - - - -	× · . · . · .× × · .									натт				100			
	32		Fine to medium SAND; orange brown, speckled black distinctly very thinly bedded at 5-15°. Dense, moist. 23.60 Carbonaceous fragments up to 10mm.	; Inclination	). \/-	rtic	al .		0-	ientat				Gra	ound Wa	ater! ^		
En	d of Ho	le @ 79	nments: .57m, Target Depth.	Contracto			11		Or	ientat	IUII.			Date		Reading	g Hole de	epth
Co	ordinat	es and f future s	RLs are approximated from the local GIS viewer. Locations are	Equipmer Shear Var	t: T	₹ 20		30						08/08		(mbgi)		9.9



Client : Auckland Council

Site : 150 Oaia Rd, Muriwai 0881

Job Number: 12612462

Commenced: 4/08/2023

: BH-M02 Hole No.

: 1:40

Sheet : 4 of 10 Hole Length : 79.57m

Scale @ A4 Logged : JM

_		887.63 Northing: 5923493.52	Syste	m: N	IZTN	1200	)			roces			: JM		/2022		
RL (m) Depth (m)	Graphic	Datum: AUCKHT1946  Material Description		Geological Unit	Moisture condition	Consistancy / Relative density		Result	Casing	Method	E Flush Return (%)	Weathering	Strength (MPa)	TCR SCR RQD (%)	Defect (mm) Spacing (mm)	Instrumentation Installation	Water level
120 -		Fine to medium SAND; orange brown, speckled black; distinctly very thinly bedded at 5-15°. Dense, moist. (cor from layer starting at 23.6m)	ntinued					SPI 3/3 7/11 12/13 N = 43		SPT	25075			44			
25 -										НОТТ				100			-
26 —								SPT 4/8 10/12 12/12 N = 46		SPT				44			-
27 —							26.75 C 26.50	SPT		НОТТ				100			-
		27.00 - 29.40 Medium dense.	4	MATION		MD		SPT 2/2 2/3 3/5 N = 13		SPT				0	-		-
28 -		28.00 - 28.25 With patches of carbonaceous material.		AWHITU SAND FORMATION				SPT		НОТТ				100			-
29 -			•	∢				SPT 3/2 4/5 6/9 N = 24		SPT				100			
30 -		· ·				D	29.92 C 29.69	SPT 6/7		HQTT				100			
- - - - - - -								8/9 10/13 N = 40		SPT				100			
31 -								SDT		HQTT				100			
			Inclinati-	n: \/	ortio	N.		SPT 9/10 12/14 14/9 N = 49 (solid cone)	onto:	SPT			Gra	0			
subject to	ole @ 79 tes and F o future s	57m, Target Depth. LLs are approximated from the local GIS viewer. Locations are	Contract Equipme	or: C ent: 1	CN R 20	00	60	Ori	entat	ion:			Date		T	Hole de (mbgl)	pth

Completed: 17/08/2023

Client : Auckland Council

Site : 150 Oaia Rd, Muriwai 0881

Job Number: 12612462

Commenced: 4/08/2023

Completed: 17/08/2023

: BH-M02 Hole No. Sheet : 5 of 10 Hole Length : 79.57m Scale @ A4 : 1:40

Logged : JM

Easting: RL: 144		887.63 Northing: 5923493.52  Datum: AUCKHT1946	Syste							roces heck			: JM : JH	3 23/08	/2023
RL (m) Depth (m)	Graphic	Material Description		Geological Unit	Moisture condition	Consistancy / Relative density		Result	Casing	Method	Flush Return (%)	Weathering	***Estimated	TCR SCR RQD (%)	** Defect *** Defect *** Spacing (mm) *** Instrumentation Instrumentation
		Fine to medium SAND; orange brown, speckled black; distinctly very thinly bedded at 5-15°. Dense, moist. (confrom layer starting at 23.6m)	ontinued							HQTT	25 50 75		5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5	100	
33 -								SPT 12/12 8/9 12/12 N = 41 (solid cone)		SPT				0	
34-										HQTT				100	
35 —						<		SPT 9/11 10/12 12/13 N = 47 (solid cone)		SPT				0	
36 —				AWHITU SAND FORMATION				SPT		HQTT				100	
		36.00 - 40.50 Very dense.		AWHITU SAN		VD	36.65 C 36.35	SPT 14/16 18/18 14 for 55mm N > 50 (solid cone)		T SPT				0	
37 -			*					SPT 15/16 19		SPT HQTT				0	
38 -		37.90 - 38.00 Very thinly bedded at 20-30°.						for 75mm N > 50 (solid cone)		нотт				100	
39 —								SPT 11/11 12/16 for 75mm		Has I				0	
								N > 50 (solid cone)		HQTT				100	\0,\0,\0,\0,\0,\0,\0,\0,\0,\0,\0,\0,\0,\
Notes an End of Ho Coordinate subject to	le @ 79 es and F	57m, Target Depth. RLs are approximated from the local GIS viewer. Locations are	Contrac Equipme	tor: [ ent: <sup>-</sup>	DCN FR 20	00	60	Ori	entati	ion:			Gro		Reading (mbgl) Hole dep (mbgl)



Client : Auckland Council

Site : 150 Oaia Rd, Muriwai 0881

Job Number: 12612462

Commenced: 4/08/2023

Completed: 17/08/2023

: BH-M02 Hole No. Sheet : 6 of 10 Hole Length : 79.57m

Scale @ A4 : 1:40

: JM Logged

	.: 144		Datum: AUCKHT1946					60.	mnle	Γ' ັ	heck	<u> </u>	П		S 23/08.		
RL (m)	Depth (m)	Graphic	Material Description		Geological Unit	Moisture condition	Consistancy / Relative density		Result aldu	Casing	Method	Flush Return (%)	Weathering	*** Estimated *** Strength (MPa)	TCR SCR RQD (%)	Defect Spacing (mm)	Instrumentation Installation
-			Fine to medium SAND; orange brown, speckled black; distinctly very thinly bedded at 5-15°. Dense, moist. (co from layer starting at 23.6m)	ntinued							НОТТ	25 50 75	5	<u> </u>	100	0	
104	41 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1		Highly weathered, orange brown, streaked orange, special black, fine to medium grained, indistinctly bedded SANDSTONE; extremely weak; very thinly bedded at 20	ckled 0-30°.		-	-	41.00 C 40.80			НОТТ		MW		100	0	
102	42   1   41.8		Highly weathered, greenish grey, streaked brown-orang speckled black, fine to medium grained SANDSTONE; extremely weak.						SPT 9/10 12/12 12/12 N = 48 (solid cone)		SPT				0	0	
- - -	43 42.8 42.642	× × × × × × × × × × × × × × × × × × ×	Silty CLAY; ligh grey, streaked dark grey-orange. 'Stiff', low plasticity.  Highly weathered, light grey, speckled dark grey-black, SILTSTONE; extremely weak.  Highly weathered, brown, streaked and speckled orang frine to medium grained SANDSTONE; extremely weak.  Highly weathered, light orange brown, streaked orange,	e-black,	, , ,	- M	'St'		,		НОТТ				100	0	
1101	44 —		speckled black, indistinctly bedded, fine to medium grai SANDSTONE; extremely weak; very thinly bedded at 19	ned	AWHITU SAND FORMATION				SPT 8/11 14/15 15/6 for 25mm N > 50 (solid cone)		SPT				0		
- 100	45 —				AWHITUS				SPT		НОТТ				100	- - - -	
- - 66									11/14 26/24 for 55mm N > 50 (solid cone)		T SPT		HW		0	-	
- 86	46 -								SPT 12/15		т натт				100	_	
- - -	- - - 47 <del>-</del> - -								25/25 for 65mm N > 50 (solid cone)		т				100	-	
161	1			Inclination	on: \	/ortic			0	entat	HØH			Gr	100	ater Leve	
			ments: 57m, Target Depth.	Contract			~1		011	Jinal	.011.			Dat		Reading	Hole dept
Co	ordinate	es and F future s	Ls are approximated from the local GIS viewer. Locations are	Equipme			00							09/08		(mbgl)	(mbgl) 40.9
	,	- 0	•	Shear V				60									
				Juleal V	ane	ıu. Ul		UU						1	- 1	1	1



Client : Auckland Council

: 150 Oaia Rd, Muriwai 0881 Site

Job Number: 12612462

Hole No. : BH-M02 Sheet : 7 of 10 : 79.57m Hole Length Scale @ A4 : 1:40

	Commenced: 4/08/2023	Comp	lete	d· 17	7/08/2	023		L	ogge	d		: JM				
Easting: 172	·	Syster							roces			: JM				
RL: 144.5	Datum: AUCKHT1946				ı			c	heck	ed		: JH	<u>\$ 23/08</u>	/2023		
			pi t	io		Saı	nple	1		(%						
Depth (m) Graphic	Material Description		Geological Unit	Moisture condition	Consistancy / Relative density	Number / Type		Casing	Method	ह ह Flush Return (%)	Weathering	***Estimated	TCR SCR RQD (%)	<sup>20</sup> <sup>80</sup> Defect <sup>800</sup> Spacing (mm)	Instrumentation Installation	Water level
	Highly weathered, light orange brown, streaked orange, speckled black, indistinctly bedded, fine to medium grail SANDSTONE; extremely weak; very thinly bedded at 15 (continued from layer starting at 43.0m)	ned 5-25°.					SPI 14/14 18/18 14 for 50mm N > 50		SPT				0			
49-	(continued from layer starting at 40.0m)						(solid cone)		нат				100			
-							SPT 13/16 22/28 for 75mm N > 50		SPT				0			
50 -							(solid cone)									
									HQTT				100			
51							SPT 16/18 24/26 for 50mm N > 50		SPT		HW		0			
			AATION				(solid cone)									
52 —	:   52.00 - 52.63 Light orange brown, streaked orange.	7	AWHITU SAND FORMATION						HQTT				100			
52.635	Highly weathered, brown, speckled black, fine to mediul		AWHITU				SPT 21/29 for 60mm N > 50		SPT				0			
53	grained SANDSTONE; extremely weak.					53.30	(solid cone)		натт				100			
54 - 25	53.90 - 54.13 Dark greyish brown.					53.90	SPT 23/27 for 60mm N > 50		SPT				0			
	Highly weathered, dark brown-grey, speckled black, fine medium grained SANDSTONE; extremely weak.	e to					(solid cone)		TI				73			
55 —						55.20			오		HW		/3			
55.625	grained SANDSTONE: extremely weak	m				55.86.50 C	SPT 25/25 for 50mm N > 50 (solid cone)		HQTT ser				0			
:::	:  -	In ali4	n: \ ′	laut: -		١	·	iont-			Ш		ound Wa	otor Lo		
otes and Co and of Hole @	omments: 79.57m, Target Depth.	Inclinatio			<b>1</b> 1		Or	ientat	иоп:			Dat		Reading	Hole dep	pth
	d RLs are approximated from the local GIS viewer. Locations are	Equipme			00							14/08		(mbgl)	(mbgl)	
-		Shear Va				30										
Defer to explan	ation sheets for abbreviation and symbols	- Cilcui Va		J. UI												



Client : Auckland Council

Site : 150 Oaia Rd, Muriwai 0881

Job Number: 12612462

Commenced: 4/08/2023

Completed: 17/08/2023

: BH-M02 Hole No.

Sheet : 8 of 10 Hole Length : 79.57m Scale @ A4 : 1:40

Logged : JM

	144.		Datum: AUCKHT1946					000	mple	Γ' ັ	hecke		П		S 23/08			
(III)	Depth (m)	Graphic	Material Description		Geological Unit	Moisture condition	Sonsistancy / Relative density	Number / Type		Casing	Method	Flush Return (%)	Weathering	***Estimated	TCR SCR RQD (%)	o Defect co Spacing (mm)	Instrumentation Installation	Water level
	-		Highly weathered, brown, speckled black, fine to mediul grained SANDSTONE; extremely weak. (continued from starting at 55.6m)	m n layer			O.E.	56.50 56.11 C			натт	25 50 75	, ,	\$ \$ \$ \$ \$ \$ \$ \$ \$ \$ \$ \$	100	20 60 200 800 800		
57	-							26.90 C	SPT 24/26		ъ				0	-		
	-								for 55mm N > 50 (solid cone)		0)					•		
58	-										HQT		HW		100			
3	- - - - -								SPT 23/27 for 65mm N > 50 (solid		Fas.				0	- -		
59				•	AATION				cone)		HQTT				100			
60	60.13		CORE LOSS		AWHITU SAND FORMATION				SPT 24/26 for 55mm N > 50 (solid cone)		PdS				0	- -		
61	-				AWF						HQTT				4			
3	1.8 61.45		Highly weathered, brown, speckled black, fine to mediugrained SANDSTONE; extremely weak.						SPT 21/29 for 70mm N > 50 (solid		SPT				0	-		
62	19		Highly weathered, dark brown, speckled black, medium coarse grained SANDSTONE; weak.	to					cone)		HQTT		MH		100			
63	62.9		Moderately weathered, greyish green, speckled black-greater to medium grained SANDSTONE; extremely weak.	rey,	-				SPT 21/29 for 65mm N > 50 (solid		SPT		MW		0	-		
	63.5		Highly weathered, orange brown, speckled black-grey, f medium grained SANDSTONE; extremely weak.	ine to	-				cone)		HQTT		HW		100			
lotes	an	d Con	nments:	Inclination	on: \	/ertic	al	1	Ori	entat	ion:	ш	1 1	Gro	und W	ater Lev	vel	
End o	f Hol	le @ 79	.57m, Target Depth. RLs are approximated from the local GIS viewer. Locations are	Contract Equipme	tor: [	DCN TR 20	00	60						Date	e Time	Reading (mbgl)	g Hole der (mbgl)	pth

Project : AC Geo Panel - Waitakere Client : Auckland Council

: 150 Oaia Rd, Muriwai 0881 Site

Job Number: 12612462

Commenced: 4/08/2023

Completed: 17/08/2023

Scale @ A4 Logged

: JM

Hole No.

Hole Length

Sheet

: BH-M02

: 9 of 10

: 79.57m

: 1:40

RL: 144.	5	Datum: AUCKHT1946					0-		<u> </u>	heck	ed	П	: JHS	3 23/08 I	/2023		Т
RL (m) Depth (m)	Graphic	Material Description		Geological Unit	Moisture condition	Consistancy / Relative density		Result ald m	Casing	Method	Flush Return (%)	Weathering	***Estimated ***Strength (MPa)	TCR SCR RQD (%)	© Defect Spacing (mm)	Instrumentation Installation	Motor lovel
8 -		Highly weathered, orange brown, speckled black-grey, medium grained SANDSTONE; extremely weak. (conti from layer starting at 63.5m)	fine to nued				64.72 C 64.44	SPT 26/24 for 55mm N > 50 (solid cone)		SPT HQTT	2 2 7	HW		0	N 0 N 0 N		
99   79   79		Moderately weathered, greyish green, speckled black-g fine to medium grained SANDSTONE; extremely weak	irey,					SPT 25/25 for 65mm N > 50		вы				0			
67 —						<		(solid cone)		нотт		MW		100			
68 -	×	Silty fine to medium SAND; greyish green, speckled	2	AWHITU SAND FORMATION		<b>&gt;</b>	68.33 C 67.93	SPT 50 for 65mm bouncing @ 65 mm		HQTT				100			
69 75 69	× .× × .×	black-grey. Very dense, moist.  CORE LOSS  Moderately weathered, greenish grey, speckled black-c	rey,					SPT 50 for 70mm bouncing @ 70 mm		2				0			-
70 -		fine to medium grained SANDSTONE; extremely weak						SPT		НОТТ		MW		69			-
71 - 71 - 71 - 71 - 71 - 71 - 71 - 71 -		CORE LOSS  Moderately weathered, grey, speckled black-dark grey, distinctly bedded, fine to medium grained SANDSTONE extremely weak; very thinly bedded at 0-15°.	Ξ;	_				23/27 for 65mm N > 50 (solid cone)		нотт		MW		86			-
Notes and End of Hol Coordinate subject to	e @ 79 s and f	.57m, Target Depth. RLs are approximated from the local GIS viewer. Locations are	Inclinati Contract Equipm Shear V	tor: [	DCN			Ori	entat	ion:			Gro Date 16/08/		Reading (mbgl)	g Hole der (mbgl)	epth



Client : Auckland Council

: 150 Oaia Rd, Muriwai 0881 Site

Job Number: 12612462

Commenced: 4/08/2023

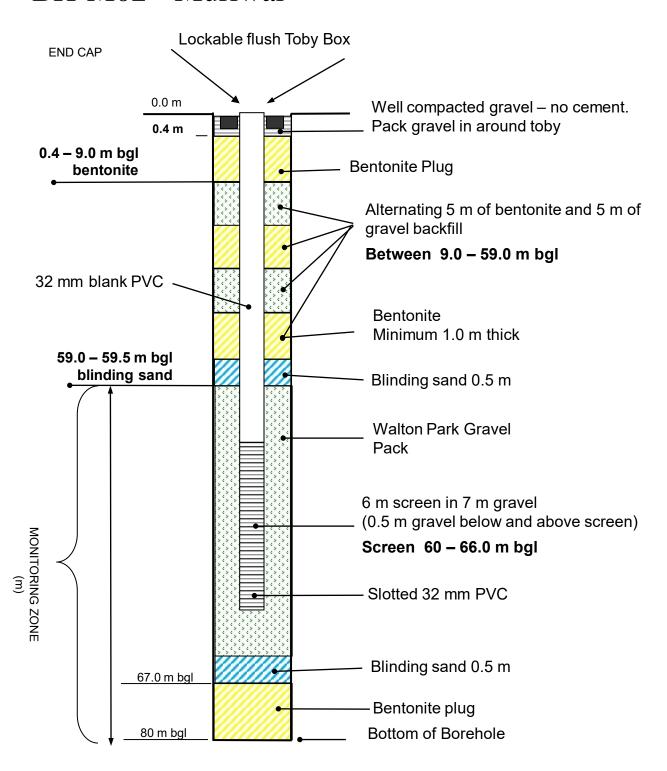
Completed: 17/08/2023

: BH-M02 Hole No. Sheet : 10 of 10 : 79.57m Hole Length Scale @ A4 : 1:40

Logged : JM

	-				_		Sar	nple		heck	eu	$\Box$	. JII	3 23/08	72025		Г
RL (m) Depth (m)	Graphic	Material Description		Geological Unit	Moisture condition	Consistancy / Relative density			Casing	Method	Flush Return (%)	Weathering	***Estimated ***Strength (MPa)	TCR SCR RQD (%)	Defect Spacing (mm)	Instrumentation Installation	
		Moderately weathered, grey, speckled black-dark grey, distinctly bedded, fine to medium grained SANDSTON extremely weak; very thinly bedded at 0-15°. (continue layer starting at 70.8m)	IE;			<u> </u>	2.5	SPI 35/15 for 15mm N > 50 (solid cone)		HQTT	25 50 7	MW N	S S S S S S S S S S S S S S S S S S S	100	200		
		CORE LOSS		-				SPT 31/19 for 20mm N > 50 (solid cone)		1.69				0			
. 0/1		Moderately weathered, grey, speckled black-dark grey, distinctly bedded, fine to medium grained SANDSTON extremely weak; very thinly bedded at 0-15°. 74.50 - 75.12 Distinctly bedded, very closely spaced, withinly bedded, dark grey, sandstone beds at sub-horizon angles.	IE; /ery				74.50 C 74.20			НОТТ		MW		59			
		CORE LOSS  Moderately weathered, grey, distinctly bedded, fine to a grained SANDSTONE; extremely weak; very closely be 0-10°.	medium edded at	FORMATION				SPT 30/20 for 45mm N > 50 (solid cone)		SPT				0			
				AWHITU SAND FORMATION			76.40 C 76.13	SPT 31/19 for 25mm N > 50 (solid cone)		натт натт		MW		0 /	*		
38.6				-			78.47 C 78.14	SPT 50 for 75mm bouncing @ 75 mm		š				0			
79-		Highly weathered, dark grey, fine to medium grained SANDSTONE, trace carbonaceous material; extremely	y weak.					SPT 50 (		HQTT		HW		100			
		End of Hole @ 79.57m,Target Depth.						for 70mm bouncing @ 70 mm									
	le @ 79. es and F	57m, Target Depth. RLs are approximated from the local GIS viewer. Locations are	Contraction Equipment Shear V	tor: [ ent: <sup>-</sup>	DCN FR 20	00	60	Ori	ientat	ion:			Date	Time	T	Hole de	pth

# BH-M02 - Muriwai



NOT TO SCALE



Project	AC Geo Panel – Waitākere	Coordinates	1728387.63 E
Job Number	12612462	(NZTM 2000)	5923493.52 N
Client	Auckland Council	Location	150 Oaia Rd, Muriwai
Date	7 August to 17 July 2023	Location	





Project	AC Geo Panel – Waitākere	Coordinates	1728387.63 E
Job Number	12612462	(NZTM 2000)	5923493.52 N
Client	Auckland Council	Location	150 Oaia Rd, Muriwai
Date	7 August to 17 July 2023	Location	





Project	AC Geo Panel – Waitākere	Coordinates	1728387.63 E
Job Number	12612462	(NZTM 2000)	5923493.52 N
Client	Auckland Council	Location	150 Oaia Rd, Muriwai
Date	7 August to 17 July 2023	Location	





Project	AC Geo Panel – Waitākere	Coordinates	1728387.63 E
Job Number	12612462	(NZTM 2000)	5923493.52 N
Client	Auckland Council	Location	150 Oaia Rd, Muriwai
Date	7 August to 17 July 2023	Location	





Project	AC Geo Panel – Waitākere	Coordinates	1728387.63 E
Job Number	12612462	(NZTM 2000)	5923493.52 N
Client	Auckland Council	Location	150 Oaia Rd, Muriwai
Date	7 August to 17 July 2023	Location	





Project	AC Geo Panel – Waitākere	Coordinates	1728387.63 E
Job Number	12612462	(NZTM 2000)	5923493.52 N
Client	Auckland Council	Location	150 Oaia Rd, Muriwai
Date	7 August to 17 July 2023	Location	





Project	AC Geo Panel – Waitākere	Coordinates	1728387.63 E
Job Number	12612462	(NZTM 2000)	5923493.52 N
Client	Auckland Council	Location	150 Oaia Rd, Muriwai
Date	7 August to 17 July 2023	Location	







Project	AC Geo Panel – Waitākere	Coordinates	1728387.63 E
Job Number	12612462	(NZTM 2000)	5923493.52 N
Client	Auckland Council	Location	150 Oaia Rd, Muriwai
Date	7 August to 17 July 2023	Location	







Project	AC Geo Panel – Waitākere	Coordinates	1728387.63 E
Job Number	12612462	(NZTM 2000)	5923493.52 N
Client	Auckland Council	Location	150 Oaia Rd, Muriwai
Date	7 August to 17 July 2023	Location	





Project	AC Geo Panel – Waitākere	Coordinates	1728387.63 E
Job Number	12612462	(NZTM 2000)	5923493.52 N
Client	Auckland Council	Location	150 Oaia Rd, Muriwai
Date	7 August to 17 July 2023	Location	







Project	AC Geo Panel – Waitākere	Coordinates	1728387.63 E
Job Number	12612462	(NZTM 2000)	5923493.52 N
Client	Auckland Council	Location	150 Oaia Rd, Muriwai
Date	7 August to 17 July 2023	Location	





Project	AC Geo Panel – Waitākere	Coordinates	1728387.63 E
Job Number	12612462	(NZTM 2000)	5923493.52 N
Client	Auckland Council	Location	150 Oaia Rd, Muriwai
Date	7 August to 17 July 2023	Location	





Project	AC Geo Panel – Waitākere	Coordinates	1728387.63 E
Job Number	12612462	(NZTM 2000)	5923493.52 N
Client	Auckland Council	Location	150 Oaia Rd, Muriwai
Date	7 August to 17 July 2023	Location	





Project	AC Geo Panel – Waitākere	Coordinates	1728387.63 E
Job Number	12612462	(NZTM 2000)	5923493.52 N
Client	Auckland Council	Location	150 Oaia Rd, Muriwai
Date	7 August to 17 July 2023	Location	





Project	AC Geo Panel – Waitākere	Coordinates	1728387.63 E
Job Number	12612462	(NZTM 2000)	5923493.52 N
Client	Auckland Council	Location	150 Oaia Rd, Muriwai
Date	7 August to 17 July 2023	Location	





Project	AC Geo Panel – Waitākere	Coordinates	1728387.63 E
Job Number	12612462	(NZTM 2000)	5923493.52 N
Client	Auckland Council	Location	150 Oaia Rd, Muriwai
Date	7 August to 17 July 2023	Location	





Project	AC Geo Panel – Waitākere	Coordinates	1728387.63 E
Job Number	12612462	(NZTM 2000)	5923493.52 N
Client	Auckland Council	Location	150 Oaia Rd, Muriwai
Date	7 August to 17 July 2023	Location	





Project	AC Geo Panel – Waitākere	Coordinates	1728387.63 E
Job Number	12612462	(NZTM 2000)	5923493.52 N
Client	Auckland Council	Location	150 Oaia Rd, Muriwai
Date	7 August to 17 July 2023	Location	





Project	AC Geo Panel – Waitākere	Coordinates	1728387.63 E
Job Number	12612462	(NZTM 2000)	5923493.52 N
Client	Auckland Council	Location	150 Oaia Rd, Muriwai
Date	7 August to 17 July 2023	Location	





Project	AC Geo Panel – Waitākere	Coordinates	1728387.63 E
Job Number	12612462	(NZTM 2000)	5923493.52 N
Client	Auckland Council	Location	150 Oaia Rd, Muriwai
Date	7 August to 17 July 2023	Location	





Project	AC Geo Panel – Waitākere	Coordinates	1728387.63 E
Job Number	12612462	(NZTM 2000)	5923493.52 N
Client	Auckland Council	Location	150 Oaia Rd, Muriwai
Date	7 August to 17 July 2023	Location	





Project	AC Geo Panel – Waitākere	Coordinates	1728387.63 E
Job Number	12612462	(NZTM 2000)	5923493.52 N
Client	Auckland Council	Location	150 Oaia Rd, Muriwai
Date	7 August to 17 July 2023	Location	





Project	AC Geo Panel – Waitākere	Coordinates	1728387.63 E
Job Number	12612462	(NZTM 2000)	5923493.52 N
Client	Auckland Council	Location	150 Oaia Rd, Muriwai
Date	7 August to 17 July 2023	Location	





Project	AC Geo Panel – Waitākere	Coordinates	1728387.63 E
Job Number	12612462	(NZTM 2000)	5923493.52 N
Client	Auckland Council	Location	150 Oaia Rd, Muriwai
Date	7 August to 17 July 2023	Location	





Project	AC Geo Panel – Waitākere	Coordinates	1728387.63 E
Job Number	12612462	(NZTM 2000)	5923493.52 N
Client	Auckland Council	Location	150 Oaia Rd, Muriwai
Date	7 August to 17 July 2023	Location	





Project	AC Geo Panel – Waitākere	Coordinates	1728387.63 E
Job Number	12612462	(NZTM 2000)	5923493.52 N
Client	Auckland Council	Location	150 Oaia Rd, Muriwai
Date	7 August to 17 July 2023	Location	





Project	AC Geo Panel – Waitākere	Coordinates	1728387.63 E
Job Number	12612462	(NZTM 2000)	5923493.52 N
Client	Auckland Council	Location	150 Oaia Rd, Muriwai
Date	7 August to 17 July 2023	Location	





Project	AC Geo Panel – Waitākere	Coordinates	1728387.63 E
Job Number	12612462	(NZTM 2000)	5923493.52 N
Client	Auckland Council	Location	150 Oaia Rd, Muriwai
Date	7 August to 17 July 2023	Location	





Project	AC Geo Panel – Waitākere	Coordinates	1728387.63 E
Job Number	12612462	(NZTM 2000)	5923493.52 N
Client	Auckland Council	Location	150 Oaia Rd, Muriwai
Date	7 August to 17 July 2023	Location	



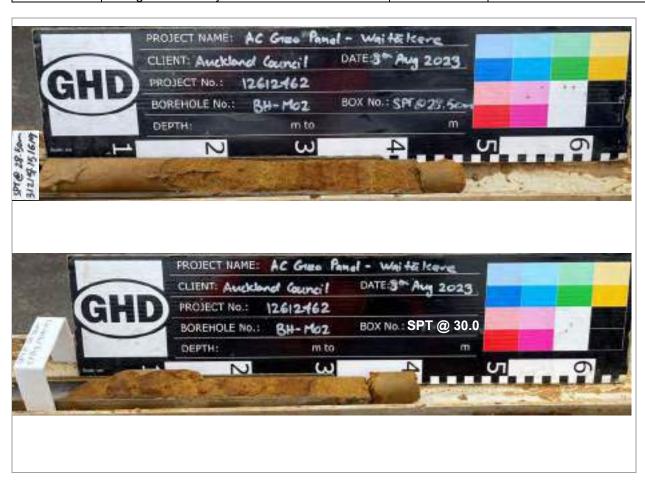


Project	AC Geo Panel – Waitākere	Coordinates	1728387.63 E
Job Number	12612462	(NZTM 2000)	5923493.52 N
Client	Auckland Council	Location	150 Oaia Rd, Muriwai
Date	7 August to 17 July 2023	Location	





Project	AC Geo Panel – Waitākere	Coordinates	1728387.63 E
Job Number	12612462	(NZTM 2000)	5923493.52 N
Client	Auckland Council	Location	150 Oaia Rd, Muriwai
Date	7 August to 17 July 2023	Location	





Project : AC Geo Panel - Waitakere

Client : Auckland Council

Site : 250 Oaia Road, Muriwai 0881

Job Number: 12612462

Commenced: 25/07/2023 Completed: 3/08/2023

Hole No. : BH-M03
Sheet : 1 of 10

Hole Length : 79.64m Scale @ A4 : 1:40

Logged : JM, MK

RL	.: 150	)	Datum: AUCKHT1946		T_	_		Sar	nple	C	heck	ed		: JH	IS 23/08	/2023	
RL (m)	Depth (m)	Graphic	Material Description		Geological Unit	Moisture condition	Consistancy / Relative density	umber /	Result	Casing	Method	Flush Return (%)	Weathering	***Estimated ***Strength (MPa)	TCR SCR RQD	Defect Spacing (mm)	Instrumentation Installation
œ	<u> </u>	9	HAND AUGERED. NOT LOGGED			-	-	ZF	<u> </u>	8	2	25 50 75	>	3 3 2 5 6	(%)	200	
149	1 —										НА				0		
- 148	2-	×	Silty fine to medium SAND; orange-brown, speckled be Loose, moist. [AWHITU SAND FORMATION]	olack.		М	L		SPT 2/2 2/2 2/3 N = 9		SPT				100		
147	3	× ·	2.55 - 2.73 Light brown. 2.73 - 4.30 Orange brown.						<b>SPT</b>		OB				100		
- -	3	× · · · · × · · · · · · · · · · · · · ·							SPT 1/1 1/2 2/3 N = 8		SPT				100		
- 146	4-	× .	Silty fine to medium SAND; light grey streaked orange Medium dense, moist.		MATION		MD		SPT 5/5		OB				100		
1145	5 -	×	4.65 - 4.70 Orange brown.		AWHITU SAND FORMATION				5/5 5/6 7/9 N = 27		SPT				100		
	9	×	5.30 Grey. Silty CLAY, some sand; grey. 'Hard', moist, high plast Sand: fine, orange. Silty fine to medium SAND; light grey. Medium dense 5.60 - 6.00 Grey-orange brown.	/	\[ \frac{4}{\chi} \]		'H' MD		SPT 3/3		HQTT				100		
	6.45	× .	CORE LOSS			-	-		3/3 4/4 4/4 N = 16		SPT				100		
- 143	7-	×	Silty fine to medium SAND; light grey mottled orange Medium dense, moist.	brown.		М	MD				HQTT				67		
. 741	Notes and Comments:    SPT   1/2   2/3   3/5   N=13   0/9   1/9											100					
			nments: 9.64m, Target Depth.	Contra			dl		Or	ientati	on:			Dat	ound Wa	Reading	Hole de
Co	ordina		RLs are approximated from the local GIS viewer. Locations are	Equipn Shear	nent:	TR 20	00							Sat		(mbgl)	(mbgl)
Re	fer to e	explanat	ion sheets for abbreviation and symbols														

Hole No. : BH-M03 Project : AC Geo Panel - Waitakere Client : Auckland Council Sheet : 2 of 10 Site : 250 Oaia Road, Muriwai 0881 Hole Length : 79.64m Job Number: 12612462 Scale @ A4 : 1:40 Commenced: 25/07/2023 Completed: 3/08/2023 Logged : JM, MK Processed : MK Easting: 1728010.05 Northing: 5923112.26 System: NZTM2000 RL: 150 Checked : JHS 23/08/2023 Datum: AUCKHT1946 Sample **Geological Unit** Moisture condition 8 Consistancy / Relative density Strength (MPa) Flush Return Spacing (mm) **Material Description** Neathering Water level Estimated TCR SCR RQD Depth (m) Number / Graphic Method Casing Defect CORE LOSS (continued from layer starting at 8.0m) 보 n SPT 2/2 2/3 3/4 N = 12 9 Silty fine to medium SAND; light grey. Medium dense, moist. MD SPT 9.00 - 9.05 Orange. 100 9.70 - 10.50 Grey locally mottle orange brown. HOT O 100 10 9.95 Gently inclined, orange brown, 15 mm bed. Silty fine to medium SAND, some carbonaceous inclusions; grey. Medium dense, moist. SPT 0 Completely to highly weathered, grey, fine to medium grained SANDSTONE; extremely weak. 보 100 AWHITU SAND FORMATION SPT 1/1 2/3 4/7 N = 16 SPT 0 12.50 - 12.52 Sub-horizontal carbonaceous bed. Highly weathered, grey, fine to medium grained SANDSTONE; very weak with carbonaceous fragments to 5mm. REV4.GPJ | Library: GHD - NZGD.GLB | Date: 25 August 2023 보연 ⋛ 100 13.20 - 13.33 Orange-grey. 'VSt' Silty CLAY, minor sand; grey. 'Very stiff', moist, high plasticity. SPT 0/1 0/1 1/3 N = 5 Sand: fine. SPT 0 14.03 - 14.13 Mottled orange. MD Silty fine to medium SAND; light grey, mottled orange. Medium dense, moist, Ę 100 135 SPT 3/3 4/4 4/6 N = 18 SPT 0 ₹ GENERAL LOG | Project: BH-M03 Highly weathered, light grey, fine to medium grained SANDSTONE; extremely weak. HØH 100 00.9 Ground Water Level Inclination: Vertical Orientation: Notes and Comments: Reading (mbgl) End of Hole @ 79.64m, Target Depth. Contractor: DCN Date Time Coordinates and RLs are approximated from the local GIS viewer. Locations are subject to future survey. Equipment: TR 200 Shear Vane Id: ≘ Refer to explanation sheets for abbreviation and symbols Report I



Project : AC Geo Panel - Waitakere

Client : Auckland Council

Site : 250 Oaia Road, Muriwai 0881

Job Number: 12612462

Hole Length : 79.64m Scale @ A4 : 1:40

: BH-M03

: 3 of 10

Hole No.

Sheet

	150		010.05 Northing: 5923112.26 Datum: AUCKHT1946	Syster		<b>1</b> 2   1	VIZOU	O			roces			: Mł	s 23/08	3/2023		
TKE.			Material Description		Geological Unit	condition	ncy / density		nple		TICON.	Flush Return (%)	ng				ntation on	le le
RL (m)	Depth (m)	Graphic			Geolo	Moisture	Consistancy / Relative density	Number / Type	Result	Casing	Method	E Flush R	ਲ Weathering	Estimated Strength (MPa)	TCR SCR RQD (%)	Defect Spacing (mm)	Instrumentation Installation	Water level
	16.27 16	× .,	Highly weathered, light grey, fine to medium grained SANDSTONE; very weak. 16.21 - 16.27 Stained orange.			M	MD	16.27 C			HQTT		H		100			¥
2		^ 	Silty fine to medium SAND; light grey, mottled orange. dense, moist.	Medium				_	SPT 2/3 4/4 4/6 N = 18		SPT				100	-		
- 17	17.15 17	×	Silty fine to medium SAND; light grey, mottled orange. dense, moist.	Medium		_	-									†		
2 15	-		Highly weathered, orange, fine to medium grained SANDSTONE; extremely weak.								НОТТ		MH		100			
- 18	55 1 1 1 8	× . × . × .	Silty fine to medium SAND; orange brown. Loose to medium, moist.	edium		М	L-MD		SPT 1/1 1/2 2/3 N = 8		SPT				100	-		
<u>-</u> 19	15 1 1 1 18		Highly weathered, brown, fine to medium grained SANDSTONE; extremely weak.  19.00 - 19.15 Orange.			-					натт		MH		100			
	19.35 19	× .	Completely weathered, orange, fine to medium grained SANDSTONE; extremely weak			M	MD						S					
2		× · . × . × . × . × . × . × . × . × . ×	Silty fine to medium SAND; orange. Medium dense, me	oist.	FORMATION	M	MID		SPT 2/3 4/6 6/7 N = 23		SPT				0	1		
- 20	- 1 - 1 - 2 - 2 - 2 - 2 - 3 - 4		CORE LOSS	N	AWHITU SAND F	-	-	-								†		
	1 -	× . × . × . × .	Silty fine to medium SAND; orange. Dense, moist.		AWHI	М	D		SPT		НОТТ				57			
_	45	×							3/5 7/8 9/9 N = 33		SPT				100			
2	12		CORE LOSS			-	-				F							
22	22.3	× × × × ×	Sandy SILT; brownish grey. 'Stiff', moist, low plasticity. fine.  Silty fine to medium SAND; orange. Moist.	Sand:		M	'St'				HQTT				48			
. 23	22.45		Highly weathered, orange, fine to medium grained SANDSTONE; extremely weak.			-			SPT 6/10 15/15 15/5 for 25mm N > 50		SPT		^		100	-		
	1 1 1 1 1										НДТТ		MH		100		70,00	
	33.	× .	Silty fine to medium SAND; orange. Dense, moist.			М	D											
End	of Ho	le @ 79	ments: 64m, Target Depth.	Inclinatio			al		Ori	entat	ion:			Gre		Reading (mbgl)		pth
Cooi	rdinat ect to	es and F future s	tLs are approximated from the local GIS viewer. Locations are urvey.	Equipme Shear Va			00									(bgi)	(,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,	

Project : AC Geo Panel - Waitakere

Client : Auckland Council

Site : 250 Oaia Road, Muriwai 0881

Job Number: 12612462

Commenced: 25/07/2023 Completed: 3/08/2023

Scale @ A4 : 1:40

Hole Length

Hole No.

Sheet

Logged : JM, MK

: BH-M03

: 4 of 10

: 79.64m

	_: 150		010.05 Northing: 5923112.26 Datum: AUCKHT1946	Syste	em: l	NZTN	/1200	0			roces heck			: MK	: S 23/08	/2023		
1 11	100				I Unit	dition	ity		nple		, ICON				20/00		uo	
RL (m)	Depth (m)	Graphic	Material Description		Geological Unit	Moisture condition	Consistancy /	Number / Type	Result	Casing	Method	Flush Return (%)	Weathering	***Estimated ***Strength (MPa)	TCR SCR RQD (%)	<sup>20</sup> <sup>80</sup> Defect <sup>800</sup> Spacing (mm)	Instrumentation Installation	
		× . : :	Silty fine to medium SAND; orange. Dense, moist. (co from layer starting at 23.7m)	ntinued			011	2 -	SPI 6/8 8/9 11/12 N = 40		SPT	25 50 75		5 3 5 9 6	0	20 60 200 800 800		<u> </u>
	24.4		CORE LOSS		-	-	-	-										
C71 -	25 - 25	× . · . · .× · . · .	Silty fine to medium SAND; orange. Moist.			М					HQTT				57			
	1 1 1 25		Highly weathered, orange, fine to medium grained SANDSTONE; extremely weak.			-			SPT 7/11 16/18 16		SPT		HW		100			
. 47	26 – 95	:::: :::::	CORE LOSS		-				for 35mm N > 50									
			Highly weathered, light brown, fine to medium grained SANDSTONE; extremely weak.  26.35 - 26.92 Grades to dark orange.								НОТТ		,		82			
. 5711	27 -								SPT 6/7 10/11 11/12 N = 44		SPT		HW		0		00°	
-	27.45		Completely weathered, orange, fine to medium grained SANDSTONE; extremely weak.	d	RMATION													
- 1122	28 -				AWHITU SAND FORMATION						HQTT		CW		100			-
	28.4		Highly weathered, orange brown, fine to medium grain SANDSTONE; extremely weak.	ied	AWH				SPT 6/7 8/8 8/9 N = 33		SPT				0			
	29 -							29.55			НОТТ				100			
1120	30 -							29.75 C	SPT				HW					-
									4/4 6/8 9/10 N = 33		SPT				100			
	31 -										НОТТ				100			
	31.55	×—: ×—: ×—:	31.45 - 31.55 Completely weathered.  Clayey SILT, some sand; grey. 'Hard', moist, low plast Sand: fine.	-		М	'H'	31.95	SPT 3/4 5/5 5/5 N = 20		SPT		¢w		100			
<sup>≈</sup> No	tes ar	× —∃ nd Com	31.55 - 32.50 Grades to underlying geology with depth ments:	n. Inclinati	on: \	ertica	al	E	Or	ientat	ion:			Gro	ound Wa	ater Lev	∟ ∟ vel	_
En	d of Ho	ole @ 79 es and I	.64m, Target Depth. RLs are approximated from the local GIS viewer. Locations are	Contrac										Date	e Time	Reading (mbgl)	Hole de (mbgl)	pth
		future s	on sheets for abbreviation and symbols	Equipm Shear V			00											

Hole No. : BH-M03 Project : AC Geo Panel - Waitakere Client : Auckland Council Sheet : 5 of 10 Site : 250 Oaia Road, Muriwai 0881 Hole Length : 79.64m Job Number: 12612462 Scale @ A4 : 1:40 Commenced: 25/07/2023 Completed: 3/08/2023 Logged : JM, MK Processed : MK Easting: 1728010.05 Northing: 5923112.26 System: NZTM2000 RL: 150 Checked : JHS 23/08/2023 Datum: AUCKHT1946 Sample **Geological Unit** Moisture condition 8 \*\*\*Estimated \*\*\*Strength (MPa) Consistancy / Relative density Defect Spacing (mm) Flush Return **Material Description** Weathering TCR SCR RQD Number Method Casing Depth ( Clayey SILT, some sand; grey. 'Hard', moist, low plasticity. Sand: fine. (continued from layer starting at 31.6m) × 32.23 × 보 100 Silty fine to medium SAND with some clay; grey. Very dense, VD SPT 100 Highly weathered, orange-brown, fine to medium grained SANDSTONE; extremely weak. HQTT 100 34 100 SPT HÖH 100 AWHITU SAND FORMATION 36 SPT 100 REV4.GPJ || Library: GHD - NZGD.GLB || Date: 25 August 2023 HØH 100 SPT 19/31 SPT 100 or 65mm N > 50 CORE LOSS 보 15 Highly weathered, orange brown, fine to medium grained SANDSTONE; extremely weak. SPT 100 Highly weathered, dark brown-orange, fine to medium grained SANDSTONE; very weak. HØT 100 **Ground Water Level** Inclination: Vertical Orientation: Notes and Comments: Reading (mbgl) Date

₹ GENERAL LOG | Project: BH-M03 ≘ Report I

End of Hole @ 79.64m, Target Depth. Coordinates and RLs are approximated from the local GIS viewer. Locations are subject to future survey.

Refer to explanation sheets for abbreviation and symbols

Contractor: DCN

Time

Water level

Equipment: TR 200 Shear Vane Id:

Project : AC Geo Panel - Waitakere

Client : Auckland Council

Site : 250 Oaia Road, Muriwai 0881

Job Number: 12612462

Commenced: 25/07/2023 Completed: 3/08/2023

: BH-M03 Hole No. Sheet : 6 of 10

Hole Length : 79.64m Scale @ A4 : 1:40

Logged : JM. MK

Easting: 1728	040 0F N						7	oggeo				MK			
	_	System	n: NZT	M200	0			roces			: MK				
RL: 150	Datum: AUCKHT1946				Sor	mnla	C	hecke	ed	П	: JHS	3 23/08 	/2023		
RL (m) Depth (m) Graphic	Material Description	1	Geological Unit	Consistancy / Relative density		Result aldu	Casing	Method	ಜ್ಞ Flush Return (%)	Weathering	***Estimated ***Strength (MPa)	TCR SCR RQD (%)	20 90 Defect 90 Spacing (mm)	Instrumentation Installation	Water level
	Highly weathered, dark brown-orange, fine to medium gr SANDSTONE; very weak. (continued from layer starting 39.5m)	rained g at			41.15 40.43 C 40.14	SPT 8/10 12/12 13/13 N > 50		SPT HQTT		HW		0			
	Highly weathered, grey SILTSTONE; very weak.  Highly weathered, grey-brown, indistinctly bedded SILTSTONE; very weak; very thinly bedded at 0-5°.  Completely weathered, greyish brown MUDSTONE; extr weak.	remely			41.43 C	SPT 3/3 5/5 5/5 5/5 for 75mm N > 50 (solid		SPT HQTT		CW		100			
43 - 701 43 - 77	Highly weathered, grey-orange, indistinctly bedded, fine medium grained SANDSTONE; very weak.  Highly weathered, orange, fine to medium grained SANDSTONE; extremely weak.  43.00 - 43.03 Dark brown layer.  43.02 - 43.03 Moderately strongly cemented layer.		OKWALION			SPT 12/16 18/20 12 for 35mm N > 50		SPT HQTT				0			
44	Highly weathered, red streaked brown, distinctly bedded		AWHILD SAND FORMALION			(solid cone)  SPT 23/27 for 65mm N > 50 (solid cone)		HQTT		HW		0			
46 -	to medium grained SANDSTONE; extremely weak; very closely spaced, thin iron oxide laminations, inclined 10-3	0°.				SPT 21/29 for 70mm N > 50 (solid cone)		ТДН				0			
Highly weathered, red streaked brown, distinctly bedded, fine to medium grained SANDSTONE; extremely weak; very closely spaced, thin iron oxide laminations, inclined 10-30°.  Notes and Comments:  End of Hole @ 79.94m, Target Depth. Coordinates and Rts are approximated from the local GIS viewer. Locations are subject to future survey.  Inclination: Vertical Orientation: Ground Water Contractor: DCN Equipment: TR 200 Shear Vane Id:								Reading (mbgl)	Hole de (mbgl)	epth					

Project : AC Geo Panel - Waitakere

Client : Auckland Council

Site : 250 Oaia Road, Muriwai 0881

Job Number: 12612462

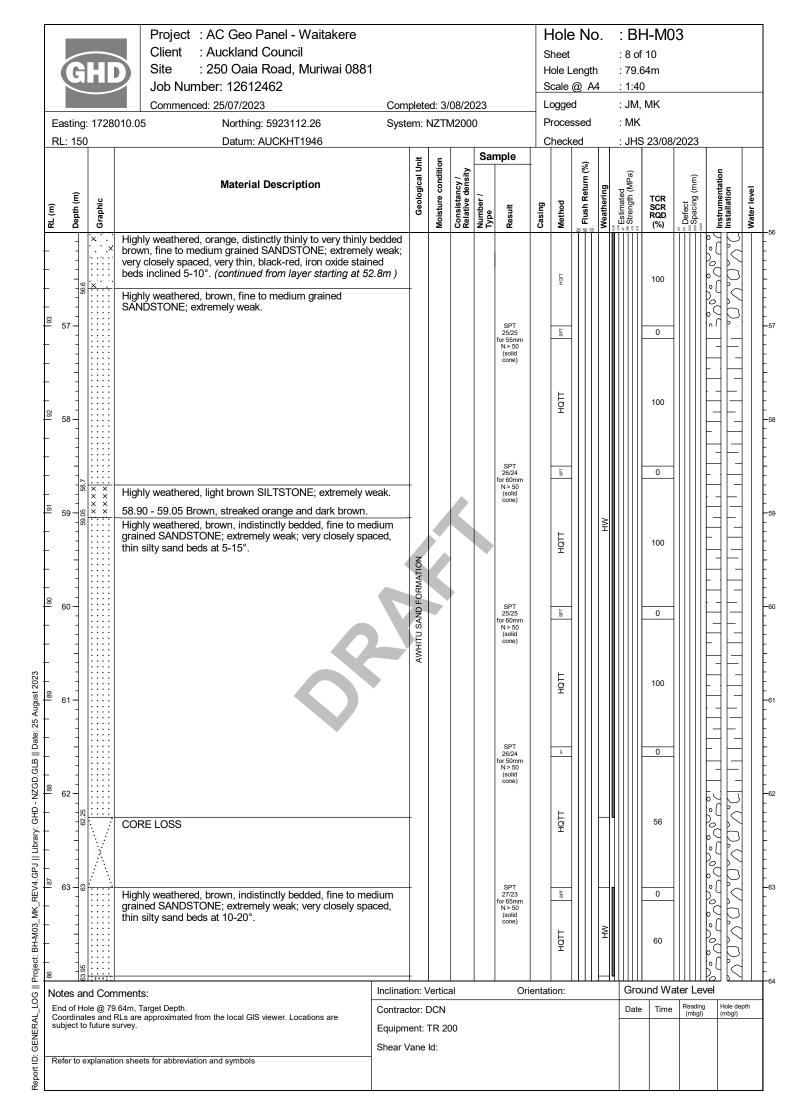
Commenced: 25/07/2023 Completed: 3/08/2023

: BH-M03 Hole No.

Sheet : 7 of 10 Hole Length : 79.64m Scale @ A4 : 1:40

Logged : JM, MK

															Sa	mple										i T
												I Unit	dition	ry ,			1		(%) ر		a)		-	,	5	
RL (m)	Depth (m)	Graphic				N	Material	Descr	ription			Geological Unit	Moisture condition	Consistancy / Relative dens.	Number / Type	Result	Casing	Method	Flush Return	Weathering	***Estimated ***Strength (MPa)	TCR SCR RQD (%)	© Defect	000	Instrumentation Installation	Water level
- 4	19		:  t	o mediu :losely s	m grain paced,	ed SAI thin iro	NDSTON	NE; ext laminat	remely w ions, inc	tly bedded veak; very slined 10-3						SPI 21/29 for 60mm N > 50 (solid cone)		НОТТ	\$ 917	5		100	0 2 0 2	-		
	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1		:  ç	rained S	SANDS	TONE;	extreme	ely wea	edded, fi k; very c clined 5-	ne to med closely spa 10°.	lium aced,					SPT 20/30 for 65mm N > 50		SPT				0				
- 5	50 -		: 5	19.74 Re 50.00 - 5 50.00 - 5	60.03 B	ack, m		ly stron	gly ceme	ented.					73	(solid cone)		НОТТ		MH		92		-		
<u> </u>	51 —			50.73 - 5 51.12 Da											51.00 C 50.73	SPT 28/22 for 45mm N > 50 (solid cone)		SPT				0		-		
<u> </u>	52 —		5	51.42 Br	own.						7	AWHITU SAND FORMATION		·				HQTT				100				
	52 7652 58		<u>.</u> (	52.50 - 5 CORE L	OSS eathere	d, oran	ige, disti	nctly th	ninly to ve	ery thinly be	pedded	AWHITU 8				SPT 26/24 for 50mm N > 50 (solid cone)		ž				0		000000	10,V0,	
	,~	×	\	ery clos peds incl	elv spa	ced. ve	gramed ry thin, b	black-re	ed, iron o	oxide stain	ed .							НОТТ				89		00000		
96 (	54 -	× .	×													SPT 21/29 for 55mm N > 50 (solid cone)		₽.		HW		0		0000000	\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\	
	55 —	×	× : : :															HQTT				100				
\$	-	× .			66.60 D	ark bro	wn, spe	ckled b	lack.							SPT 22/28 for 55mm N > 50 (solid cone)		HQTT				100		00000	), V, O, V	
End of Hole @ 79.64m, Target Depth. Coordinates and RLs are approximated from the local GIS viewer. Locations are						Date 31/07		Read (mbg	ina	Hole del (mbgl)	pth 1.13															



Hole No. : BH-M03 Project : AC Geo Panel - Waitakere Client : Auckland Council Sheet : 9 of 10 Site : 250 Oaia Road, Muriwai 0881 Hole Length : 79.64m Job Number: 12612462 Scale @ A4 : 1:40 Commenced: 25/07/2023 Completed: 3/08/2023 Logged : JM, MK Easting: 1728010.05 Processed : MK Northing: 5923112.26 System: NZTM2000 RL: 150 Checked : JHS 23/08/2023 Datum: AUCKHT1946 Sample **Geological Unit** Moisture condition 8 Consistancy / Relative density Strength (MPa) Flush Return **Material Description** Weathering Estimated TCR SCR RQD Depth (m) Number / Graphic Method Casing CORE LOSS (continued from layer starting at 64.0m) HOT 60 0 SPT VD Silty fine to medium SAND; brown, streaked and speckled М HØH 62 orange; indistinctly very thinly bedded at 10-25°. Very dense, 66 SPT 0 CORE LOSS HQT 33 AWHITU SAND FORMATION Silty fine to medium SAND; brown, streaked orange, speckled SPT 0 black. Very dense, moist. 68 HØH 100 REV4.GPJ || Library: GHD - NZGD.GLB || Date: 25 August 2023 SPT 11/12 14/17 19 for 75mm N > 50 (solid cone) SPT 0 HØH 100 8/11 13/16 18/3 for 10mr N > 50 (solid cone) SPT 0 ₹ HØH || Project: BH-M03 100 Inclination: Vertical Orientation: GENERAL\_LOG

Notes and Comments:

≘

Report I

End of Hole @ 79.64m, Target Depth. Coordinates and RLs are approximated from the local GIS viewer. Locations are subject to future survey.

Refer to explanation sheets for abbreviation and symbols

Contractor: DCN Equipment: TR 200

Shear Vane Id:

**Ground Water Level** 

Reading (mbgl) Date Time

Defect Spacing (mm)

Water level



Project : AC Geo Panel - Waitakere

Client : Auckland Council

Site : 250 Oaia Road, Muriwai 0881

Job Number: 12612462

Commenced: 25/07/2023 Completed: 3/08/2023

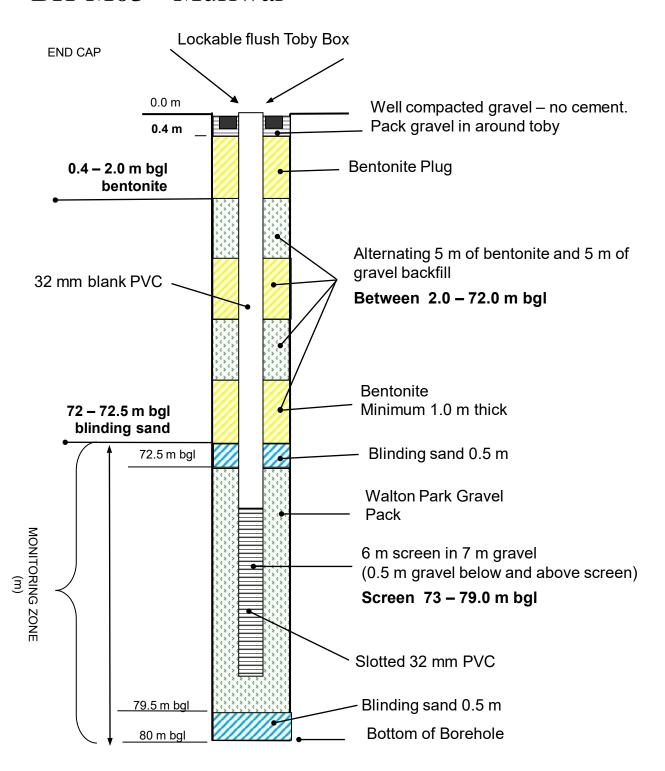
: BH-M03 Hole No.

Sheet : 10 of 10 : 79.64m Hole Length Scale @ A4 : 1:40

Logged : JM, MK

East RL:	_		010.05 Northing: 5923112.26  Datum: AUCKHT1946	Syste	m: N	NZTN	/1200	0			roces heck			: M <sup>k</sup> : JH	( S 23/08	3/2023		
	Depth (m)	Graphic	Material Description		Geological Unit	Moisture condition	Consistancy / Relative density		Result	Casing	Method	Flush Return (%)	Weathering	*** Estimated	TCR SCR RQD (%)	"Defect "Spacing (mm)	Instrumentation Installation	Water level
	72.29	×	Silty fine to medium SAND; brown, streaked orange, sp black. Very dense, moist. (continued from layer starting 67.5m)  CORE LOSS	peckled g at	-	-	-		SP1 14/17 22/28 for 65mm N > 50 (solid		SPT	25 50 7	5	<u> </u>	0	- 20		
- - <u> </u> 73	72.97	×	Silty fine to medium SAND; brown, streaked orange, sp	neckled	-	М	VD	-	cone)		натт				43			
- -		· . · .× · . · .× · . · .×	black. Very dense, moist.	Jeckied		IVI	VD		SPT 12/14							-		
- <u>9</u> 74	74.06	· · · · · · · · · · · · · · · · · · ·	CORE LOSS		_			-	16/16 18 for 65mm N > 50 (solid cone)		SPT				0	-		
- - -			CONE LOSS			-					НОТТ				18			
- <u>92</u> 75 - -	75.365	×	Silty fine to medium SAND; greyish brown, streaked red	ddish	NOI	M	VD		SPT 10/12 15/16 7 for 65mm N > 50 (solid		SPT				0	-		
- - <del>*</del> 76	, , , , , ,	· · · · × · · · · · · × · · · · · × · · · · ×	brown. Very dense, moist.  75.90 - 76.00 Very weakly cemented iron oxide bed.	udisii	AWHITU SAND FORMATION	M	<b>V</b>		cone)		НОТТ				100			
- -	-	×	76.30 - 76.40 Very weakly cemented iron oxide bed.		AWHITU				SPT 14/23 26/24		SPT				0	-		
- <del>2</del> 77 -	76.98 76.78		CORE LOSS  Highly weathered, greyish brown, distinctly bedded, fine medium grained SANDSTONE; extremely weak; very claspaced, very thinly bedded, brown sandstone beds at 5-	losely	-	-	-	_	for 55mm N > 50 (solid cone)				нм см			_		
-			76.98 - 77.08 Completely weathered, recovered as san 77.50 - 77.60 Completely weathered, recovered as san	d.							НОТТ		¢w		81			
78 - -	78.43	: ::	CORE LOSS						SPT 27/23 for 50mm N > 50 (solid cone)		SPT		HW		0	-		
- - - 79											НОТТ				21			
- - 	-	;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;	End of Hole @ 79.64m,Target Depth.						SPT 25/25 for 60mm N > 50 (solid		TdS				0	-		
R Note:	-	4 0	amouto:	Inclinatio	ın: \/	ertica	al .		cone)	ientat	ion:			Gr	ound W	ater Le	vel	Ц
Notes and Comments:  End of Hole @ 79.64m, Target Depth. Coordinates and RLs are approximated from the local GIS viewer. Locations are subject to future survey.  Refer to explanation sheets for abbreviation and symbols  Inclination: V Contractor: Equipment: Shear Vane									Oli	ioiiidl	1011.			Dat 02/08	e Time	Reading (mbgl)	Hole de (mbgl)	epth 2.29

# BH-M03 - Muriwai



NOT TO SCALE





Project	AC Geo Panel – Waitākere	Coordinates	1728010.05 E
Job Number	12612462	(NZTM 2000)	5923112.26 N
Client	Auckland Council	Location	250 Oaia Rd, Muriwai
Date	25 July to 3 August 2023	Location	





Project	AC Geo Panel – Waitākere	Coordinates	1728010.05 E
Job Number	12612462	(NZTM 2000)	5923112.26 N
Client	Auckland Council	Location	250 Oaia Rd, Muriwai
Date	25 July to 3 August 2023	Location	







Project	AC Geo Panel – Waitākere	Coordinates	1728010.05 E
Job Number	12612462	(NZTM 2000)	5923112.26 N
Client	Auckland Council	Location	250 Oaia Rd, Muriwai
Date	25 July to 3 August 2023	Location	







Project	AC Geo Panel – Waitākere	Coordinates	1728010.05 E
Job Number	12612462	(NZTM 2000)	5923112.26 N
Client	Auckland Council	Location	250 Oaia Rd, Muriwai
Date	25 July to 3 August 2023	Location	







Project	AC Geo Panel – Waitākere	Coordinates	1728010.05 E
Job Number	12612462	(NZTM 2000)	5923112.26 N
Client	Auckland Council	Location	250 Oaia Rd, Muriwai
Date	25 July to 3 August 2023	Location	







Project	AC Geo Panel – Waitākere	Coordinates	1728010.05 E
Job Number	12612462	(NZTM 2000)	5923112.26 N
Client	Auckland Council	Location	250 Oaia Rd, Muriwai
Date	25 July to 3 August 2023	Location	







Project	AC Geo Panel – Waitākere	Coordinates	1728010.05 E
Job Number	12612462	(NZTM 2000)	5923112.26 N
Client	Auckland Council	Location	250 Oaia Rd, Muriwai
Date	25 July to 3 August 2023	Location	







Project	AC Geo Panel – Waitākere	Coordinates	1728010.05 E
Job Number	12612462	(NZTM 2000)	5923112.26 N
Client	Auckland Council	Location	250 Oaia Rd, Muriwai
Date	25 July to 3 August 2023	Location	







Project	AC Geo Panel – Waitākere	Coordinates	1728010.05 E
Job Number	12612462	(NZTM 2000)	5923112.26 N
Client	Auckland Council	Location	250 Oaia Rd, Muriwai
Date	25 July to 3 August 2023	Location	





Project	AC Geo Panel – Waitākere	Coordinates	1728010.05 E
Job Number	12612462	(NZTM 2000)	5923112.26 N
Client	Auckland Council	Location	250 Oaia Rd, Muriwai
Date	25 July to 3 August 2023	Location	





Project	AC Geo Panel – Waitākere	Coordinates	1728010.05 E
Job Number	12612462	(NZTM 2000)	5923112.26 N
Client	Auckland Council	Location	250 Oaia Rd, Muriwai
Date	25 July to 3 August 2023	Location	





Project	AC Geo Panel – Waitākere	Coordinates	1728010.05 E
Job Number	12612462	(NZTM 2000)	5923112.26 N
Client	Auckland Council	Location	250 Oaia Rd, Muriwai
Date	25 July to 3 August 2023	Location	







Project	AC Geo Panel – Waitākere	Coordinates	1728010.05 E
Job Number	12612462	(NZTM 2000)	5923112.26 N
Client	Auckland Council	Location	250 Oaia Rd, Muriwai
Date	25 July to 3 August 2023	Location	







Project	AC Geo Panel – Waitākere	Coordinates	1728010.05 E
Job Number	12612462	(NZTM 2000)	5923112.26 N
Client	Auckland Council	Location	250 Oaia Rd, Muriwai
Date	25 July to 3 August 2023	Location	







Project	AC Geo Panel – Waitākere	Coordinates	1728010.05 E
Job Number	12612462	(NZTM 2000)	5923112.26 N
Client	Auckland Council	Location	250 Oaia Rd, Muriwai
Date	25 July to 3 August 2023	Location	







Project	AC Geo Panel – Waitākere	Coordinates	1728010.05 E
Job Number	12612462	(NZTM 2000)	5923112.26 N
Client	Auckland Council	Location	250 Oaia Rd, Muriwai
Date	25 July to 3 August 2023	Location	





Project	AC Geo Panel – Waitākere	Coordinates	1728010.05 E
Job Number	12612462	(NZTM 2000)	5923112.26 N
Client	Auckland Council	Location	250 Oaia Rd, Muriwai
Date	25 July to 3 August 2023	Location	







Project	AC Geo Panel – Waitākere	Coordinates	1728010.05 E
Job Number	12612462	(NZTM 2000)	5923112.26 N
Client	Auckland Council	Location	250 Oaia Rd, Muriwai
Date	25 July to 3 August 2023	Location	







Project	AC Geo Panel – Waitākere	Coordinates	1728010.05 E
Job Number	12612462	(NZTM 2000)	5923112.26 N
Client	Auckland Council	Location	250 Oaia Rd, Muriwai
Date	25 July to 3 August 2023	Location	





Project	AC Geo Panel – Waitākere	Coordinates	1728010.05 E
Job Number	12612462	(NZTM 2000)	5923112.26 N
Client	Auckland Council	Location	250 Oaia Rd, Muriwai
Date	25 July to 3 August 2023	Location	





Project	AC Geo Panel – Waitākere	Coordinates	1728010.05 E
Job Number	12612462	(NZTM 2000)	5923112.26 N
Client	Auckland Council	Location	250 Oaia Rd, Muriwai
Date	25 July to 3 August 2023	Location	





Project	AC Geo Panel – Waitākere	Coordinates	1728010.05 E
Job Number	12612462	(NZTM 2000)	5923112.26 N
Client	Auckland Council	Location	250 Oaia Rd, Muriwai
Date	25 July to 3 August 2023	Location	







Project	AC Geo Panel – Waitākere	Coordinates	1728010.05 E
Job Number	12612462	(NZTM 2000)	5923112.26 N
Client	Auckland Council	Location	250 Oaia Rd, Muriwai
Date	25 July to 3 August 2023	Location	







Project	AC Geo Panel – Waitākere	Coordinates	1728010.05 E
Job Number	12612462	(NZTM 2000)	5923112.26 N
Client	Auckland Council	Location	250 Oaia Rd, Muriwai
Date	25 July to 3 August 2023	Location	







Project	AC Geo Panel – Waitākere	Coordinates	1728010.05 E
Job Number	12612462	(NZTM 2000)	5923112.26 N
Client	Auckland Council	Location	250 Oaia Rd, Muriwai
Date	25 July to 3 August 2023	Location	







Project	AC Geo Panel – Waitākere	Coordinates	1728010.05 E
Job Number	12612462	(NZTM 2000)	5923112.26 N
Client	Auckland Council	Location	250 Oaia Rd, Muriwai
Date	25 July to 3 August 2023	Location	







Project	AC Geo Panel – Waitākere	Coordinates	1728010.05 E
Job Number	12612462	(NZTM 2000)	5923112.26 N
Client	Auckland Council	Location	250 Oaia Rd, Muriwai
Date	25 July to 3 August 2023	Location	







Project	AC Geo Panel – Waitākere	Coordinates	1728010.05 E
Job Number	12612462	(NZTM 2000)	5923112.26 N
Client	Auckland Council	Location	250 Oaia Rd, Muriwai
Date	25 July to 3 August 2023	Location	







Project	AC Geo Panel – Waitākere	Coordinates	1728010.05 E
Job Number	12612462	(NZTM 2000)	5923112.26 N
Client	Auckland Council	Location	250 Oaia Rd, Muriwai
Date	25 July to 3 August 2023	Location	





Project	AC Geo Panel – Waitākere	Coordinates	1728010.05 E
Job Number	12612462	(NZTM 2000)	5923112.26 N
Client	Auckland Council	Location	250 Oaia Rd, Muriwai
Date	25 July to 3 August 2023	Location	





Project	AC Geo Panel – Waitākere	Coordinates	1728010.05 E
Job Number	12612462	(NZTM 2000)	5923112.26 N
Client	Auckland Council	Location	250 Oaia Rd, Muriwai
Date	25 July to 3 August 2023	Location	





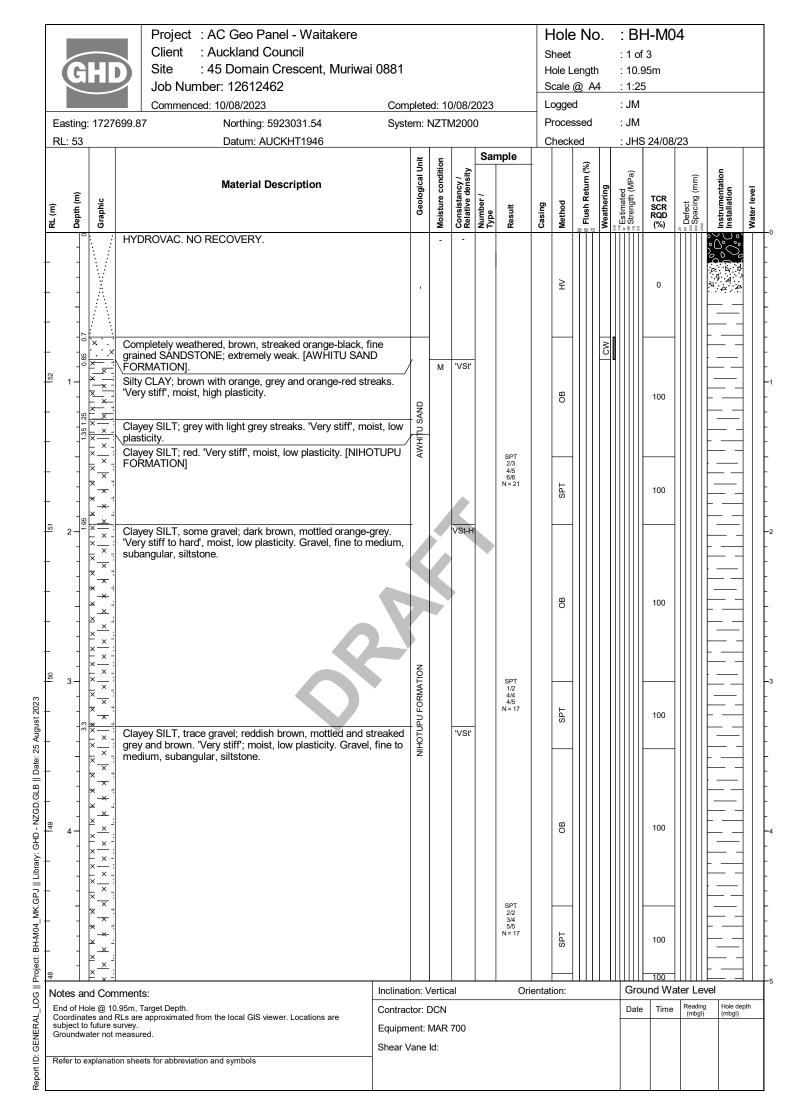
Project	AC Geo Panel – Waitākere	Coordinates	1728010.05 E
Job Number	12612462	(NZTM 2000)	5923112.26 N
Client	Auckland Council	Location	250 Oaia Rd, Muriwai
Date	25 July to 3 August 2023	Location	





Project	AC Geo Panel – Waitākere	Coordinates	1728010.05 E
Job Number	12612462	(NZTM 2000)	5923112.26 N
Client	Auckland Council	Location	250 Oaia Rd, Muriwai
Date	25 July to 3 August 2023	Location	





Project : AC Geo Panel - Waitakere Hole No. : BH-M04 Client : Auckland Council Sheet : 2 of 3 Site : 45 Domain Crescent, Muriwai 0881 : 10.95m Hole Length Job Number: 12612462 Scale @ A4 : 1:25 Commenced: 10/08/2023 Completed: 10/08/2023 Logged : JM Processed : JM Easting: 1727699.87 Northing: 5923031.54 System: NZTM2000 RL: 53 Datum: AUCKHT1946 Checked : JHS 24/08/23 Sample **Geological Unit** Moisture condition 8 Consistancy / Relative density Strength (MPa) Flush Return **Material Description** Estimated Depth (m) Number / Method Casing RL (m) SCR RQD Clayey SILT, trace gravel; reddish brown, mottled and streaked grey and brown. 'Very stiff'; moist, low plasticity. Gravel, fine to medium, subangular, siltstone. (continued from layer starting at 3.3m ) OB 100 SPT 100 × 6.65 - 7.20 Contains minor subangular siltstone gravel. × 6.80 - 8.95 Trace fine sand. × OB 100 × 'VSt NIHOTUPU FORMATION SPT 2/2 2/3 3/3 N = 11 × × SPT 51 × × 25 August 2023 8.10 30mm interbed of very stiff red clay. OB 62 × GHD - NZGD.GLB || Date: CORE LOSS Clayey SILT with trace gravel; reddish brown, mottled and 'VSt' streaked orange-brown-black. 'Very stiff', moist, low plasticity. MK.GPJ || Library: Sand, fine. Gravel, fine, subangular, siltstone. SPT 100 GENERAL\_LOG || Project: BH-M04\_ OB 100 Inclination: Vertical **Ground Water Level** 

Notes and Comments:

≘

Report I

End of Hole @ 10.95m, Target Depth. Coordinates and RLs are approximated from the local GIS viewer. Locations are subject to future survey.

Groundwater not measured.

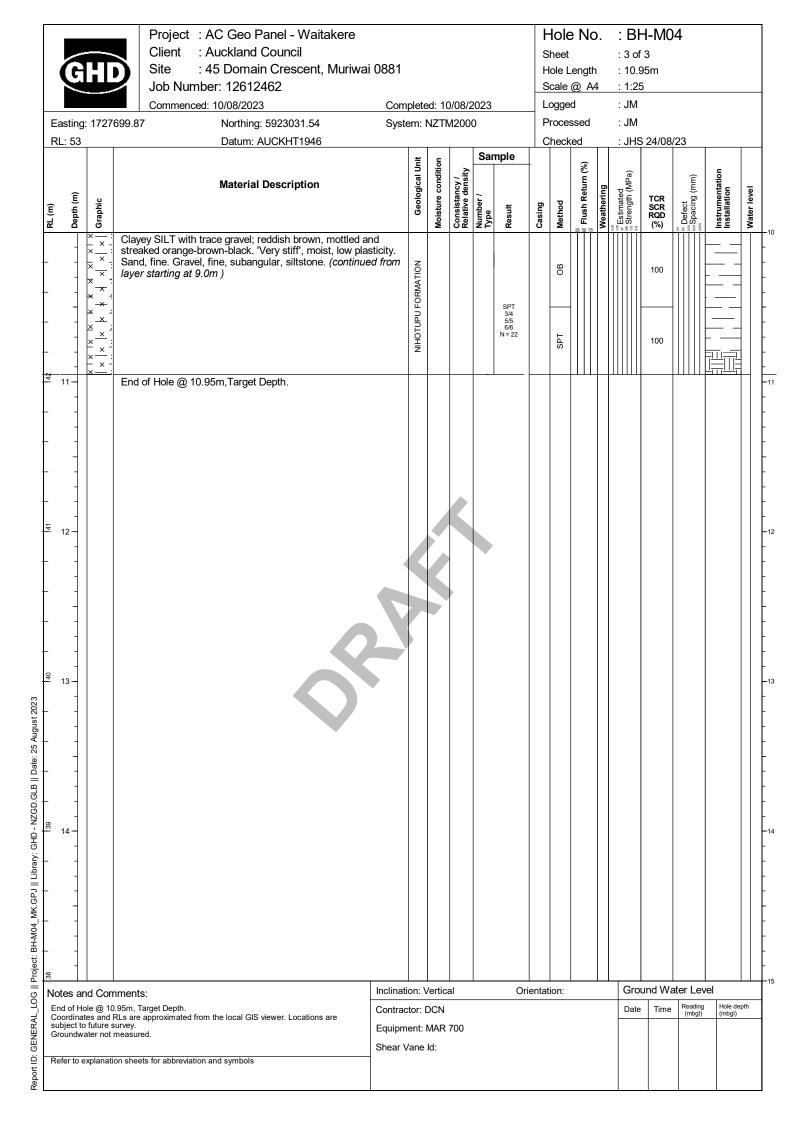
Refer to explanation sheets for abbreviation and symbols

Contractor: DCN Equipment: MAR 700 Shear Vane Id:

Orientation:

Reading (mbgl) Date Time

Water level





Project	AC Geo Panel – Waitākere	Coordinates	1727699.87 E
Job Number	12612462	(NZTM 2000)	5923031.54 N
Client	Auckland Council	Location	45 Domain Crescent,
Date	10 August 2023	Location	Muriwai





Project	AC Geo Panel – Waitākere	Coordinates	1727699.87 E
Job Number	12612462	(NZTM 2000)	5923031.54 N
Client	Auckland Council	Location	45 Domain Crescent,
Date	10 August 2023	Location	Muriwai





Project	AC Geo Panel – Waitākere	Coordinates	1727699.87 E
Job Number	12612462	(NZTM 2000)	5923031.54 N
Client	Auckland Council	Location	45 Domain Crescent,
Date	10 August 2023	Location	Muriwai





Project	AC Geo Panel – Waitākere	Coordinates	1727699.87 E
Job Number	12612462	(NZTM 2000)	5923031.54 N
Client	Auckland Council	Location	45 Domain Crescent,
Date	10 August 2023	Location	Muriwai





Project	AC Geo Panel – Waitākere	Coordinates	1727699.87 E
Job Number	12612462	(NZTM 2000)	5923031.54 N
Client	Auckland Council	Location	45 Domain Crescent,
Date	10 August 2023	Location	Muriwai





Project	AC Geo Panel – Waitākere	Coordinates	1727699.87 E
Job Number	12612462	(NZTM 2000)	5923031.54 N
Client	Auckland Council	Location	45 Domain Crescent,
Date	10 August 2023	Location	Muriwai





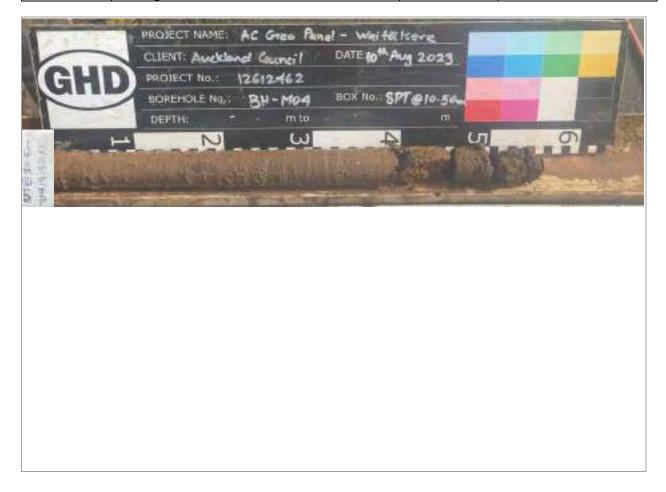
Project	AC Geo Panel – Waitākere	Coordinates	1727699.87 E
Job Number	12612462	(NZTM 2000)	5923031.54 N
Client	Auckland Council	Location	45 Domain Crescent,
Date	10 August 2023	Location	Muriwai







Project	AC Geo Panel – Waitākere	Coordinates	1727699.87 E
Job Number	12612462	(NZTM 2000)	5923031.54 N
Client	Auckland Council	Location	45 Domain Crescent,
Date	10 August 2023	Location	Muriwai



: BH-M05 Project : AC Geo Panel - Waitakere Hole No. Client : Auckland Council Sheet : 1 of 2 Site : 58 Domain Crescent, Muriwai 0881 : 10.95m Hole Length Job Number: 12612462 Scale @ A4 : 1:40 Commenced: 18/07/2023 Completed: 18/07/2023 Logged : MK Processed : MK Easting: 1727856.03 Northing: 5923234.43 System: NZTM2000 RL: 63.5 Checked : JHS 22/08/2023 Datum: AUCKHT1946 Sample **Geological Unit** Moisture condition 8 Consistancy / Relative density Strength (MPa) Flush Return **Material Description** Neathering Estimated Number / Method Casing Depth ( SCR RQD  $^{\circ}$ ASPHALT Sandy SILT with some clay; dark grey-black. 'Firm', moist, low М plasticity. Sand, fine. [FILL] Silty fine to coarse GRAVEL; dark grey. Moist. Gravel, 'St' ·× sub-rounded to sub-angular, greywacke. Sandy SILT with some clay; brown-grey-orange. 'Stiff', moist, low plasticity. Sand: fine to medium. [PALAEO-COLLUVIUM] ₹ .× 1.10 Wood fragments up to 50 mm. × SPT 100 Sandy organic SILT; black. 'Stiff', moist, low plasticity. Sand, 2 fine to medium. PALAEO-COLLUVIUM **CORE LOSS** ОВ Sandy organic SILT; black. 'Stiff', moist, low plasticity. Sand, М 'St' 57 fine to medium. 7/4/ Silty fine to medium SAND; grey. Loose, moist. L SPT 0/0 2/2 2/2 N = 8 SPT 100 Sandy organic SILT; grey-brown. 'Stiff', moist, low plasticity. Sand, fine to medium. 'St' ٠x 74/ Sandy SILT, some clay, minor organics; dark greyish brown. 'VSt' ·× OB 100 'Very stiff', moist, low plasticity. Sand, fine to medium. .× Organics, fibrous. ×. Fine to medium SAND with some silt; grey. Loose, moist. L 0/1 2/2 2/2 N = 8 [AWHITU SAND FORMATION] SPT 100 4.50 - 4.65 Light brown. CORE LOSS ОВ 25 August 2023 n 보 44 MK.GPJ | Library: GHD - NZGD.GLB | Date: Fine to medium SAND with some silt; grey. Medium dense, М MD AWHITU SAND FORMATION SPT 3/4 5/6 7/7 N = 25 SPT 100 보 100 || Project: BH-M05 SPT 3/4 4/5 6/7 N = 22 SPT

Notes and Comments:

GENERAL LOG

≘

Report I

End of Hole @ 10.95m, Target Depth. Coordinates and RLs are approximated from the local GIS viewer. Locations are subject to future survey.

Groundwater not measured.

Refer to explanation sheets for abbreviation and symbols

Inclination: Vertical

Orientation:

**Ground Water Level** 

Date

Contractor: DCN Equipment: TR 200 Shear Vane Id:

Reading (mbgl) Time

Defect Spacing (mm)

Water level

Easting: 1727856.03

Project : AC Geo Panel - Waitakere

Client : Auckland Council

Site : 58 Domain Crescent, Muriwai 0881

Job Number: 12612462

Commenced: 18/07/2023 Completed: 18/07/2023

: BH-M05 Hole No.

Sheet : 2 of 2 : 10.95m Hole Length

Scale @ A4 : 1:40 Logged : MK

	.: 63.: Depth (m)	Graphic	Datum: AUCKHT1946  Material Description		Geological Unit	Moisture condition	Consistancy / Relative density		mple	_	hecke	Flush Return (%)	Weathering	Estimated		TCR SCR RQD (%)	E Defect Spacing (mm)	Instrumentation Installation	
R (E)	Dept	Grag	Fine to medium SAND with some silt; grey. Medium de	ense		Mois	Con	M A	Result	Casing	Method	25 50 7 	Wea	Est		RQD (%) 100	Spa Spa	Instr	- 3
	-		moist. (continued from layer starting at 5.6m)	,															
3	-		8.40 - 9.25 Greenish grey.								HØTT					100			
	-																		
	9-				VIOIT				SPT 3/4 6/7										
	5 9.25	×	Silty fine SAND; grey. Medium dense, moist.		AWHITU SAND FORMATION				6/7 9/11 N = 33		SPT					100			
5	9.6 9.4	.::: <u>^</u>	CORE LOSS		AND F	- M	-												
	9.6	. · . · .	Fine to medium SAND with some silt; grey. Moist.  Moderately weathered, grey SILTSTONE; very weak.		SOLI	- M													
•	10 -	× × × × × × × × × ×			A						HQTT					86			
2	10.3	××	Moderately weathered, greenish grey, fine to medium of	grained									WW	ď					
3	+	::::	SANDSTÓNE; extremely weak.						SPT 6/8 9/11		-								
									12/15 N = 47		SPT					100			
•	11 -		End of Hole @ 10.95m,Target Depth.																
.,	}																		
2	1																		
	1																		
	12																		
	-																		
0	-																		
	-																		
	13																		
	]																		
8	-																		
	14 -																		
2	4																		
	15 –																		
	†																		
9	]																		
	+																		
	-																		
			nments:	Inclination			al		Or	ientat	ion:			-		und Wa	1		den#
Co	d of Ho ordinat	le @ 10 es and l future s	.95m, Target Depth. RLs are approximated from the local GIS viewer. Locations are uurvev.	Contract			20							_	Date	Time	Readin (mbgl	) Hole ( mbgl	depth I)
Sur	oundwa	ater not	measured.	Equipme	51 IL.	ır. Zl	<i>,</i>												
Gro				Shear Va	ane	ld:													





Project	AC Geo Panel – Waitākere	Coordinates	1727856.03 E
Job Number	12612462	(NZTM 2000)	5923234.43 N
Client	Auckland Council	Location	58 Domain Crescent,
Date	18 July 2023	Location	Muriwai





Project	AC Geo Panel – Waitākere	Coordinates	1727856.03 E
Job Number	12612462	(NZTM 2000)	5923234.43 N
Client	Auckland Council	Location	58 Domain Crescent,
Date	18 July 2023	Location	Muriwai





Project	AC Geo Panel – Waitākere	Coordinates	1727856.03 E
Job Number	12612462	(NZTM 2000)	5923234.43 N
Client	Auckland Council	Location	58 Domain Crescent,
Date	18 July 2023	Location	Muriwai





Project	AC Geo Panel – Waitākere	Coordinates	1727856.03 E
Job Number	12612462	(NZTM 2000)	5923234.43 N
Client	Auckland Council	Location	58 Domain Crescent,
Date	18 July 2023	Location	Muriwai





Project	AC Geo Panel – Waitākere	Coordinates	1727856.03 E
Job Number	12612462	(NZTM 2000)	5923234.43 N
Client	Auckland Council	Location	58 Domain Crescent,
Date	18 July 2023	Location	Muriwai





Project	AC Geo Panel – Waitākere	Coordinates	1727856.03 E
Job Number	12612462	(NZTM 2000)	5923234.43 N
Client	Auckland Council	Location	58 Domain Crescent,
Date	18 July 2023	Location	Muriwai







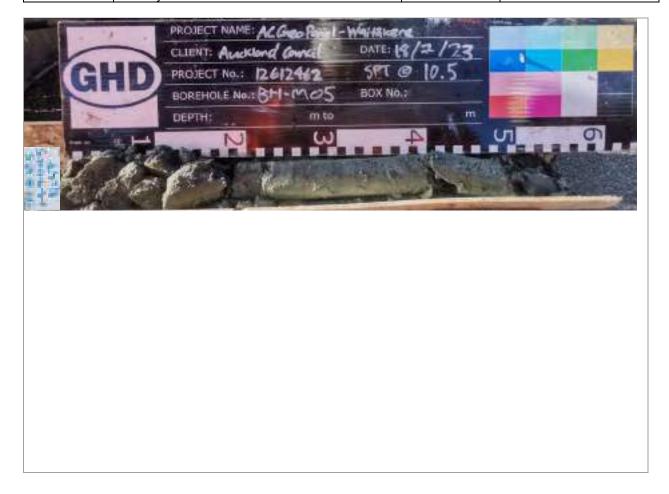
Project	AC Geo Panel – Waitākere	Coordinates	1727856.03 E
Job Number	12612462	(NZTM 2000)	5923234.43 N
Client	Auckland Council	Location	58 Domain Crescent,
Date	18 July 2023	Location	Muriwai

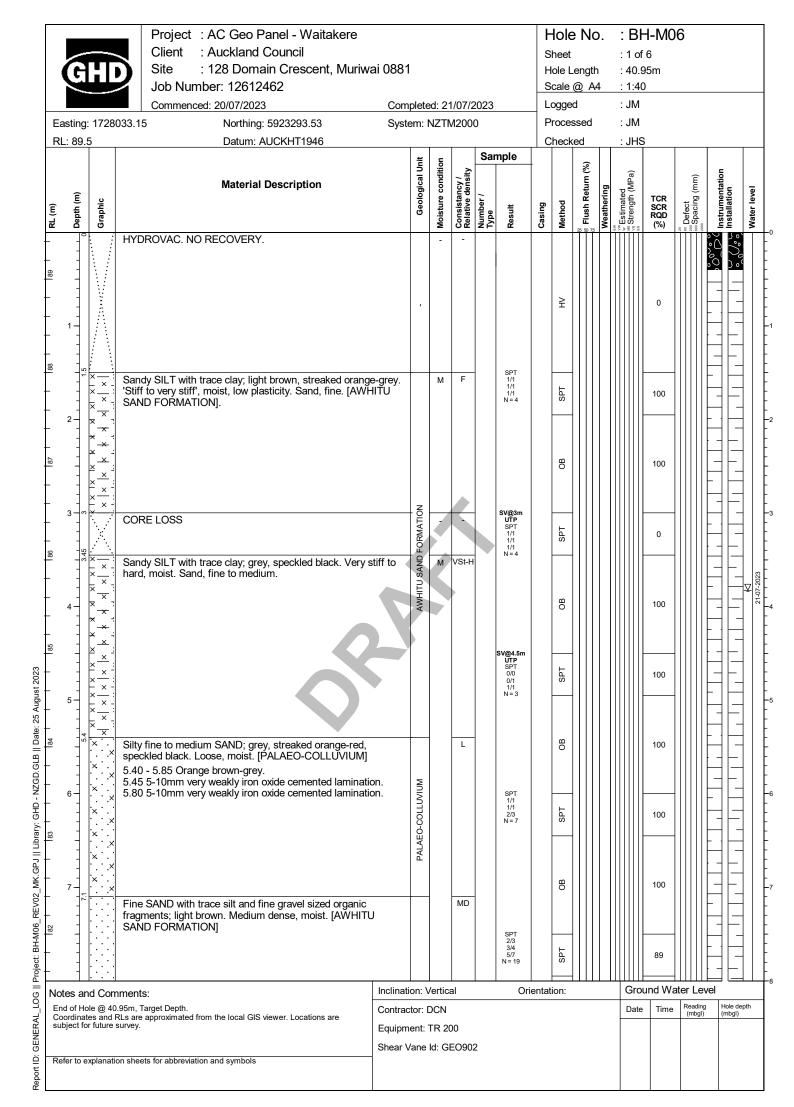


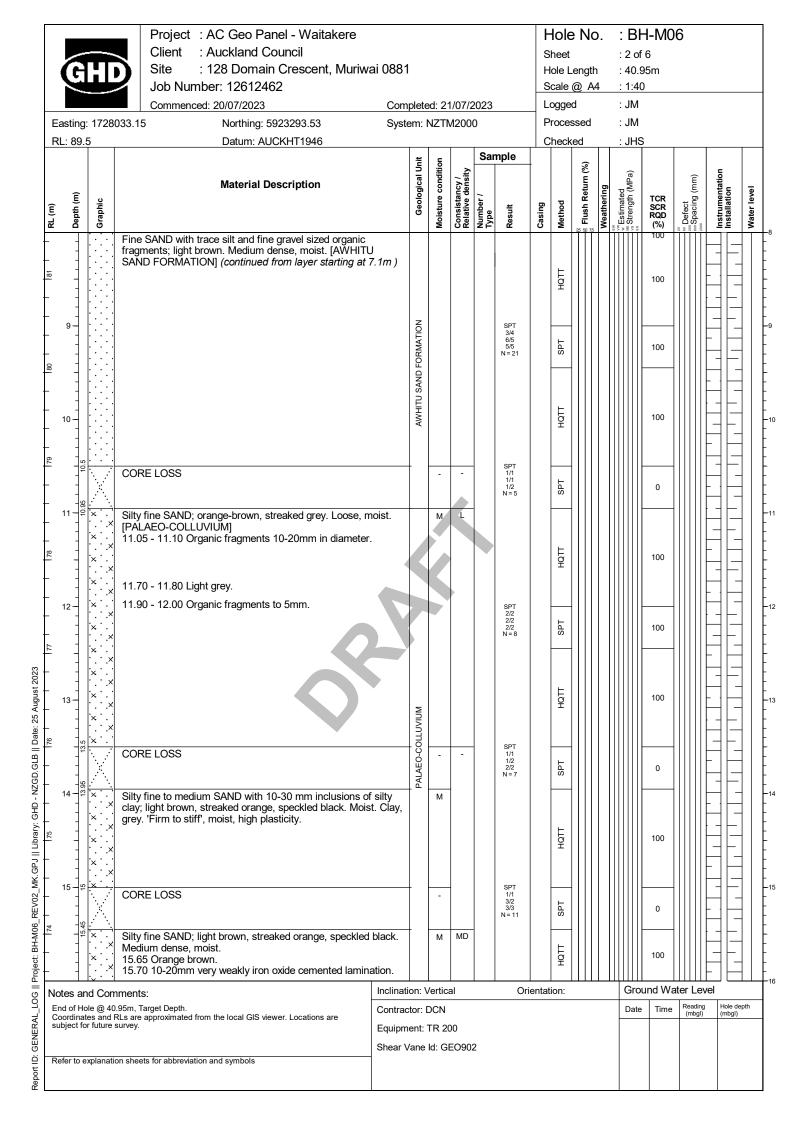




Project	AC Geo Panel – Waitākere	Coordinates	1727856.03 E
Job Number	12612462	(NZTM 2000)	5923234.43 N
Client	Auckland Council	Location	58 Domain Crescent,
Date	18 July 2023	Location	Muriwai







: BH-M06 Project : AC Geo Panel - Waitakere Hole No. Client : Auckland Council Sheet : 3 of 6 Site : 128 Domain Crescent, Muriwai 0881 : 40.95m Hole Length Job Number: 12612462 Scale @ A4 : 1:40 Commenced: 20/07/2023 Completed: 21/07/2023 Logged : JM Processed : JM Easting: 1728033.15 Northing: 5923293.53 System: NZTM2000 RL: 89.5 Checked Datum: AUCKHT1946 : JHS Sample **Geological Unit** Moisture condition 8 Consistancy / Relative density Strength (MPa) Flush Return **Material Description** Estimated Number / Method Casing Depth ( SCR RQD Silty fine SAND; light brown, streaked orange, speckled black. Medium dense, moist. (continued from layer starting at 15.5m 얼 100 Silty CLAY; grey, speckled and streaked orange-red speckles. 'F' SPT 'Firm', moist, high plasticity. MD Silty fine SAND with closely spaced thin interbeds of silty clay; light grey mottled orange. Medium dense, moist. Clay, firm, moist, high plasticity. PALAEO-COLLUVIUM HØH 100 SPT 1/1 0/0 1/1 N = 2 **CORE LOSS** SPT Clayey SILT with minor sand with very closely spaced very thin interbeds of sandy silt and trace fine gravel sized organic fragments; light grey, mottled orange. Firm, moist, low plasticity. Sand, fine. [AWHITU SAND FORMATION] × × HØT 100 CORE LOSS SPT 20 HQTT Silty CLAY; grey-brown. 'Firm', moist, high plasticity. М 'F' 25 August 2023 AWHITU SAND FORMATION Silty fine SAND; light grey, streaked orange. Dense, moist. SPT 100 GHD - NZGD.GLB || Date: **CORE LOSS** 보 Silty fine SAND; light grey. Medium dense, moist. М MD .GPJ || Library: CORE LOSS SPT ₹ Silty fine SAND; light grey. Loose to medium dense, wet. W L-MD REV02 보연 || Project: BH-M06 100

Notes and Comments: End of Hole @ 40.95m, Target Depth.

GENERAL\_LOG

≘

Report I

Coordinates and RLs are approximated from the local GIS viewer. Locations are subject for future survey.

Refer to explanation sheets for abbreviation and symbols

Orientation:

Contractor: DCN Date

Equipment: TR 200 Shear Vane Id: GEO902

Inclination: Vertical

20/07/23 21/07/23 15:45 08:30

Ground Water Level

Defect Spacing (mm)

93

0

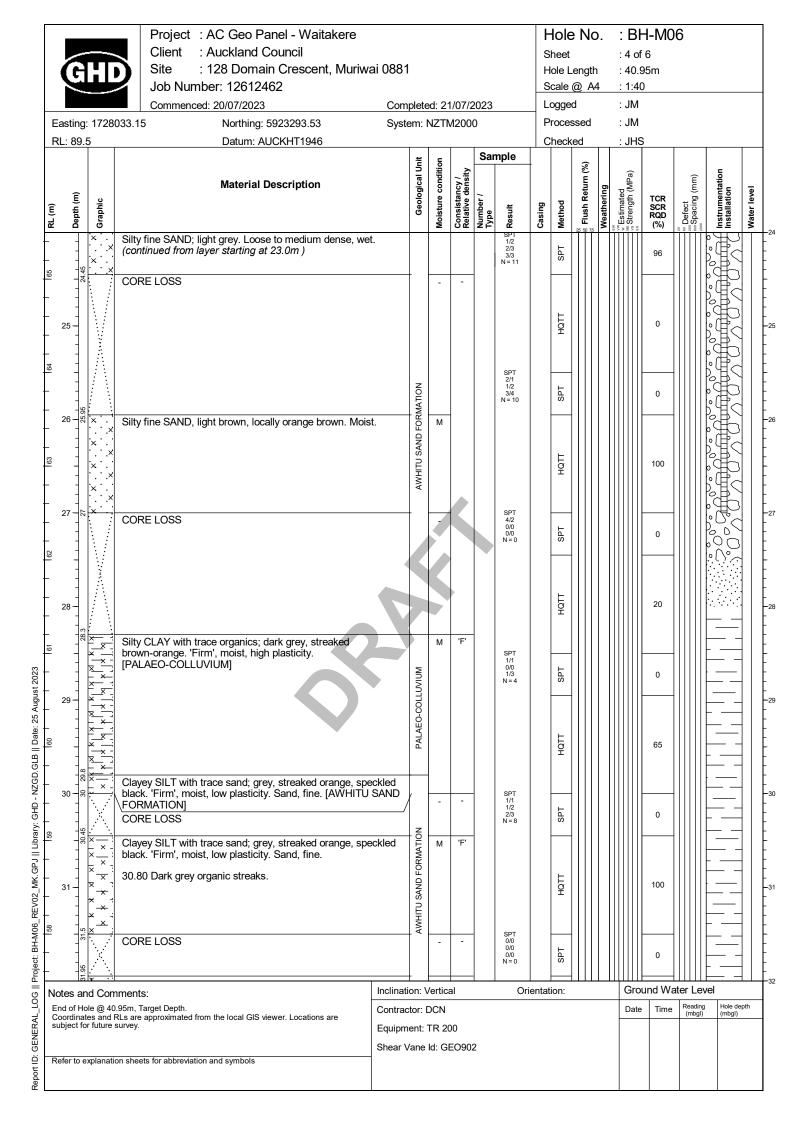
0

29

48

0

Water level





Project : AC Geo Panel - Waitakere

Client : Auckland Council

Site : 128 Domain Crescent, Muriwai 0881

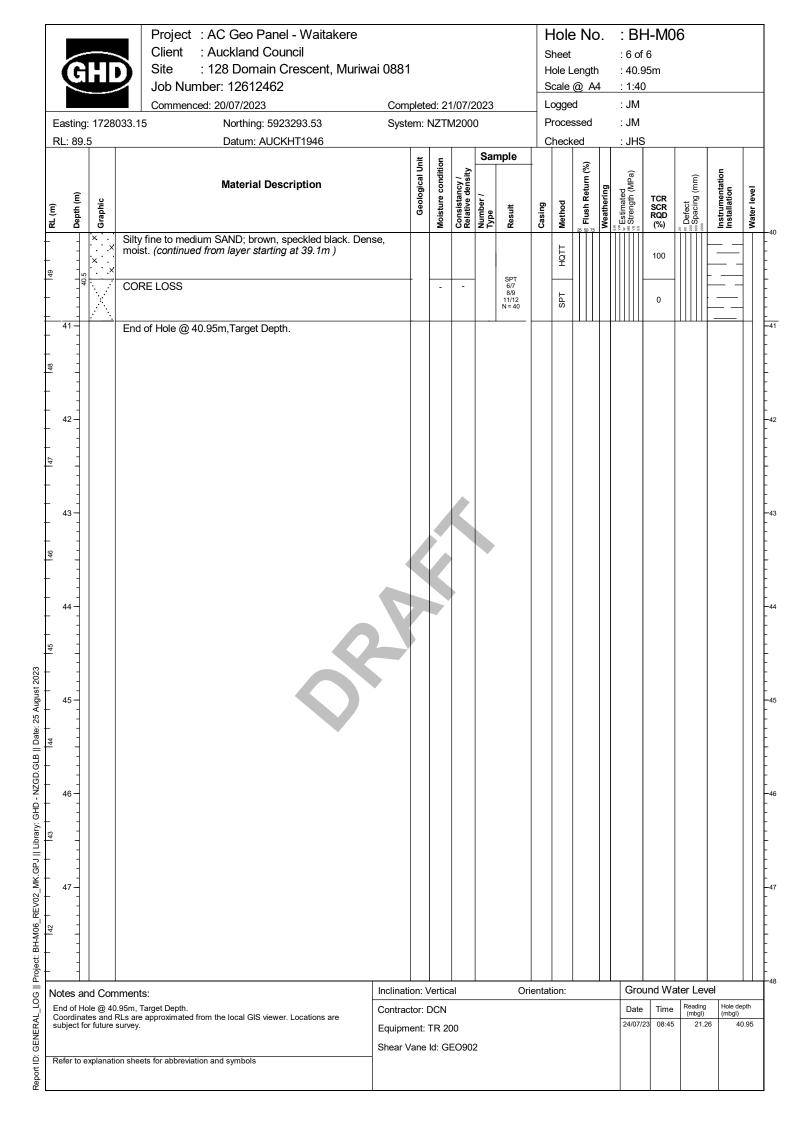
Job Number: 12612462

Commenced: 20/07/2023 Completed: 21/07/2023 Hole No. : BH-M06

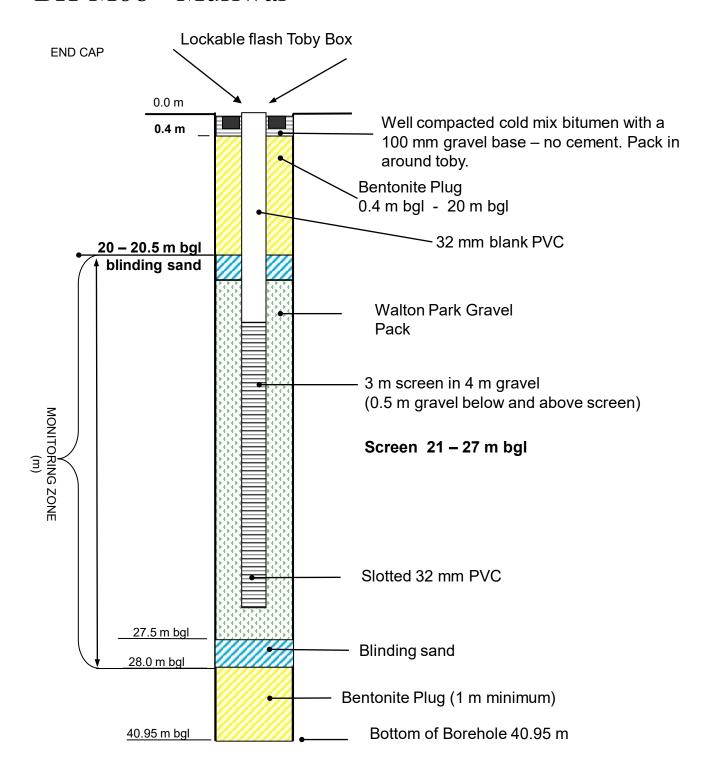
Sheet : 5 of 6 Hole Length : 40.95m

Scale @ A4 : 1:40 Logged : JM

33 - X · · · · · · · · · · · · · · · · · ·	Sandy SILT; light grey, streaked light grey-brown. 'Firm', low plasticity. Sand, fine. (continued from layer starting 32.0m)  x  x  x  x  x  x  x	at NOLLEWING GIVES LITHWA	Moi Mi	بَ Consistancy / Relative density		SPT 0/0 0/0 0/0	Casing	HQTT Method	rn (%)		.: "Estimated .: Strength (MPa)	TCR SCR RQD (%)	Defect	instrumentation installation
33 - × × × × × × × × × × × × × × × × × ×	Sandy SILT; light grey, streaked light grey-brown. 'Firm', low plasticity. Sand, fine. (continued from layer starting 32.0m)  Silty CLAY with trace organics; dark grey-brown. 'Firm to be seen as a series of the same and the same as a series of th	moist, at	Moi Mi		Number / Type	SPT 0/0 0/0 0/0		2	% Flush Return (%)	Weathering	** Strength (MPa)	100		instrumentation
33 - × × × × × × × × × × × × × × × × × ×	Sandy SILT; light grey, streaked light grey-brown. 'Firm', low plasticity. Sand, fine. (continued from layer starting 32.0m)  Silty CLAY with trace organics; dark grey-brown. 'Firm to be seen as a second series of the second second series of the second series of the second second series of the second s	at NOLLEWING GIVES LITHWA	M			SPT 0/0 0/0 0/0			5 50 75		- W W S S S S S S S S S S S S S S S S S	100	20 60 70 70 80 80 80	
34	× : × : × Silty CLAY with trace organics; dark grey-brown. 'Firm to					N = 0		SPT				0		
	<ul> <li>Clayey SILT with minor organics; grey, mottled brown. 'S wet, low plasticity.</li> </ul>	Soft',	W	'F-St'		SPT 0/0 0/0 0/0 0/0 N = 0	_	SPT HQTT				100		
	Silty CLAY; dark grey-brown. 'Firm', moist, high plasticity [AWHITU SAND FORMATION]  Clayey SILT with trace sand; light grey, streaked dark grey-brown. 'Firm', moist, low plasticity. Sand, fine.  CORE LOSS	y.	M	'F'		SPT 2/3 3/4 4/6 N=17		SPT HQTT				0		
37 - ×	Silty fine SAND; light grey, streaked orange brown. Med dense, moist.  36.80 - 38.20 Orange streaks inclined 50-60°.	ium	M	MD		SPT 1/1 3/4 4/4 N = 15	_	SPT HQTT				0		
39 - 58 ×	38.80 Orange brown and grey.  Silty fine to medium SAND; brown, speckled black. Dense moist.			D		SPT 2/3 5/7 11/11 N = 34	_	HQTT SPT HQTT				96		
	ற 40.95m, Target Depth. and RLs are approximated from the local GIS viewer. Locations are	Inclination Contractor Equipment	: DCN t: TR 2	00	2	Ori	ientatio				Gro	ound Wa	Readi (mbg	ng Hole dept



# BH-M06 - Muriwai



NOT TO SCALE



Project	AC Geo Panel – Waitākere	Coordinates	1728033.15 E
Job Number	12612462	(NZTM 2000)	5923293.53 N
Client	Auckland Council	Location	128 Domain Crescent,
Date	20 to 21 July 2023	Location	Muriwai





Project	AC Geo Panel – Waitākere	Coordinates	1728033.15 E
Job Number	12612462	(NZTM 2000)	5923293.53 N
Client	Auckland Council	Location	128 Domain Crescent,
Date	20 to 21 July 2023	Location	Muriwai





Project	AC Geo Panel – Waitākere	Coordinates	1728033.15 E
Job Number	12612462	(NZTM 2000)	5923293.53 N
Client	Auckland Council	Location	128 Domain Crescent,
Date	20 to 21 July 2023	Location	Muriwai





Project	AC Geo Panel – Waitākere	Coordinates	1728033.15 E
Job Number	12612462	(NZTM 2000)	5923293.53 N
Client	Auckland Council	Location	128 Domain Crescent,
Date	20 to 21 July 2023	Location	Muriwai







Project	AC Geo Panel – Waitākere	Coordinates	1728033.15 E
Job Number	12612462	(NZTM 2000)	5923293.53 N
Client	Auckland Council	Location	128 Domain Crescent,
Date	20 to 21 July 2023	Location	Muriwai





Project	AC Geo Panel – Waitākere	Coordinates	1728033.15 E
Job Number	12612462	(NZTM 2000)	5923293.53 N
Client	Auckland Council	Location	128 Domain Crescent,
Date	20 to 21 July 2023	Location	Muriwai





Project	AC Geo Panel – Waitākere	Coordinates	1728033.15 E
Job Number	12612462	(NZTM 2000)	5923293.53 N
Client	Auckland Council	Location	128 Domain Crescent,
Date	20 to 21 July 2023	Location	Muriwai





Project	AC Geo Panel – Waitākere	Coordinates	1728033.15 E
Job Number	12612462	(NZTM 2000)	5923293.53 N
Client	Auckland Council	Location	128 Domain Crescent,
Date	20 to 21 July 2023	Location	Muriwai





Project	AC Geo Panel – Waitākere	Coordinates	1728033.15 E
Job Number	12612462	(NZTM 2000)	5923293.53 N
Client	Auckland Council	Location	128 Domain Crescent,
Date	20 to 21 July 2023	Location	Muriwai





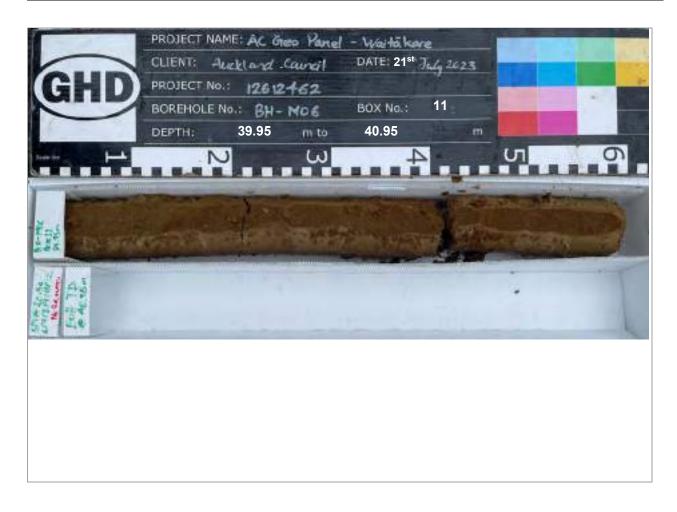
Project	AC Geo Panel – Waitākere	Coordinates	1728033.15 E
Job Number	12612462	(NZTM 2000)	5923293.53 N
Client	Auckland Council	Location	128 Domain Crescent,
Date	20 to 21 July 2023	Location	Muriwai







Project	AC Geo Panel – Waitākere	Coordinates	1728033.15 E
Job Number	12612462	(NZTM 2000)	5923293.53 N
Client	Auckland Council	Location	128 Domain Crescent,
Date	20 to 21 July 2023	Location	Muriwai





Project	AC Geo Panel – Waitākere	Coordinates	1728033.15 E
Job Number	12612462	(NZTM 2000)	5923293.53 N
Client	Auckland Council	Location	128 Domain Crescent,
Date	20 to 21 July 2023	Location	Muriwai





Project	AC Geo Panel – Waitākere	Coordinates	1728033.15 E
Job Number	12612462	(NZTM 2000)	5923293.53 N
Client	Auckland Council	Location	128 Domain Crescent,
Date	20 to 21 July 2023	Location	Muriwai





Project	AC Geo Panel – Waitākere	Coordinates	1728033.15 E
Job Number	12612462	(NZTM 2000)	5923293.53 N
Client	Auckland Council	Location	128 Domain Crescent,
Date	20 to 21 July 2023	Location	Muriwai







Project	AC Geo Panel – Waitākere	Coordinates	1728033.15 E
Job Number	12612462	(NZTM 2000)	5923293.53 N
Client	Auckland Council	Location	128 Domain Crescent,
Date	20 to 21 July 2023	Location	Muriwai

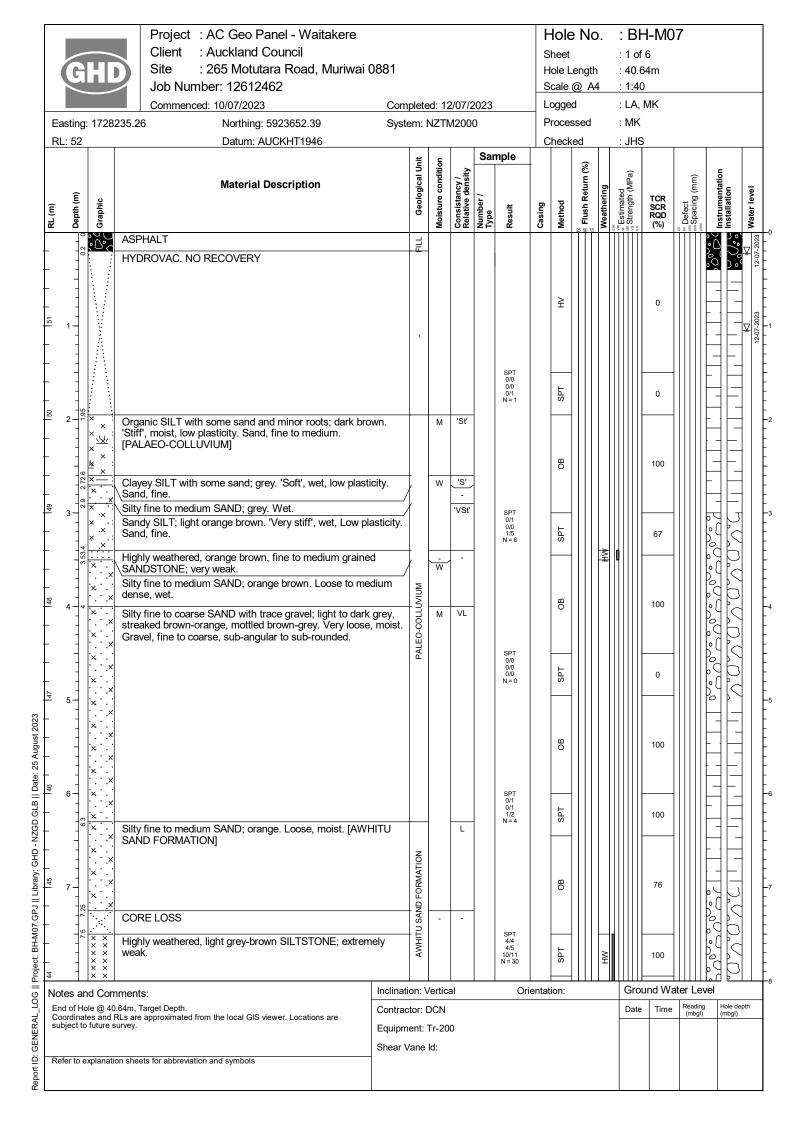






Project	AC Geo Panel – Waitākere	Coordinates	1728033.15 E
Job Number	12612462	(NZTM 2000)	5923293.53 N
Client	Auckland Council	Location	128 Domain Crescent,
Date	20 to 21 July 2023	Location	Muriwai





Hole No. : BH-M07 Project : AC Geo Panel - Waitakere Client : Auckland Council Sheet : 2 of 6 Site : 265 Motutara Road, Muriwai 0881 Hole Length : 40.64m Job Number: 12612462 Scale @ A4 : 1:40 Commenced: 10/07/2023 Completed: 12/07/2023 Logged : LA, MK Processed : MK Easting: 1728235.26 Northing: 5923652.39 System: NZTM2000 Checked RL: 52 Datum: AUCKHT1946 : JHS Sample **Geological Unit** Moisture condition 8 Consistancy / Relative density Strength (MPa) Defect Spacing (mm) Flush Return **Material Description** Water level Neathering Estimated TCR SCR RQD Depth (m) Number / Graphic Method Casing Highly weathered, orange brown, fine to medium grained SANDSTONE; extremely weak. 보 100 SPT 2/2 3/4 5/7 N = 19 9 SPT 100 CORE LOSS HQT 0 10 Silty fine SAND; dark greenish grey. Medium dense to dense, moist. MD-D М SPT 100 Silty fine to medium SAND; dark orange brown. Moist. 보연 **CORE LOSS** 33 AWHITU SAND FORMATION 120mm SPT 2/2 3/3 5/5 N = 16 Silty fine to medium SAND; dark orange brown. Medium М MD dense, moist. SPT 67 보연 100 || Project: BH-M07.GPJ || Library: GHD - NZGD.GLB || Date: 25 August 2023 SPT 5/5 6/6 7/9 N = 28 SPT 100 CORE LOSS Highly weathered, dark orange brown, fine to medium grained SANDSTONE; extremely weak. HQTT ≩ 62 М Fine to medium SAND with some silt; orange brown. Moist. **CORE LOSS** SPT 0 Silty fine to medium SAND; light grey. Medium dense, moist. MD М 보 100 **Ground Water Level** Inclination: Vertical Orientation: Notes and Comments: GENERAL LOG End of Hole @ 40.64m, Target Depth. Reading (mbgl) Contractor: DCN Date Time Coordinates and RLs are approximated from the local GIS viewer. Locations are subject to future survey. Equipment: Tr-200 Shear Vane Id:

≘

Report I

Refer to explanation sheets for abbreviation and symbols

: BH-M07 Project : AC Geo Panel - Waitakere Hole No. Client : Auckland Council Sheet : 3 of 6 Site : 265 Motutara Road, Muriwai 0881 : 40.64m Hole Length Job Number: 12612462 Scale @ A4 : 1:40 Commenced: 10/07/2023 Completed: 12/07/2023 Logged : LA, MK Processed : MK Easting: 1728235.26 Northing: 5923652.39 System: NZTM2000 RL: 52 Checked Datum: AUCKHT1946 : JHS Sample **Geological Unit** Moisture condition 8 Consistancy / Relative density Strength (MPa) Flush Return **Material Description** Estimated Number / Graphic Method Casing Depth ( Silty fine to medium SAND; orange brown. Medium dense, moist. (continued from layer starting at 15.9m) 덛 SPT 1/2 3/4 6/7 N = 20 SPT CORE LOSS ĦÖĦ Silty fine to medium SAND; orange brown. Medium dense, М MD SPT 3/3 5/6 8/9 N = 28 SPT CORE LOSS Silty fine to medium SAND; orange brown. Medium dense, М MD HÖT 18.90 - 19.40 Brownish grey. AWHITU SAND FORMATION 4/4 6/6 7/10 N = 29 SPT HQTT CORE LOSS Silty fine to medium SAND; orange brown. Medium dense, MD М SPT 4/4 6/7 8/9 N = 30 moist. || Project: BH-M07.GPJ || Library: GHD - NZGD.GLB || Date: 25 August 2023 SPT **CORE LOSS** Silty fine to medium SAND; orange brown. Medium dense to MD-D dense, moist. HØT SPT 23.20 - 24.50 Dark reddish brown. 보연

Defect Spacing (mm)

SCR RQD

100

100

38

0

76

100

48

100

76

100

100

Water level

Ground Water Level Inclination: Vertical Orientation: Notes and Comments: End of Hole @ 40.64m, Target Depth. Reading (mbgl) Date Contractor: DCN Time Coordinates and RLs are approximated from the local GIS viewer. Locations are subject to future survey. Equipment: Tr-200

Shear Vane Id:

Refer to explanation sheets for abbreviation and symbols

GENERAL LOG

≘

Report I

: BH-M07 Project : AC Geo Panel - Waitakere Hole No. Client : Auckland Council Sheet : 4 of 6 Site : 265 Motutara Road, Muriwai 0881 : 40.64m Hole Length Job Number: 12612462 Scale @ A4 : 1:40 Commenced: 10/07/2023 Completed: 12/07/2023 Logged : LA, MK Processed : MK Easting: 1728235.26 Northing: 5923652.39 System: NZTM2000 RL: 52 Checked Datum: AUCKHT1946 : JHS Sample Geological Unit Moisture condition 8 Consistancy / Relative density Strength (MPa) Flush Return **Material Description** Estimated Number / Graphic Method Casing Depth ( Result SCR RQD SP1 6/7 6/7 8/9 N = 30 Silty fine to medium SAND; orange brown. Medium dense to dense, moist. (continued from layer starting at 21.6m) SPT 100 24.50 - 24.70 Fine sand. CORE LOSS HØH 57 Silty fine to medium SAND; orange brown. Moist. М 25.20 - 25.30 Carbonaceous inclusions SPT 6/7 9/10 10/11 N = 40 Silty fine to medium SAND; reddish orange brown. Dense, D SPT 100 25.50 - 25.67 Carbonaceous fragments to 10 mm. 26 26.33 - 26.47 Very closely spaced iron oxide stained HÖH 100 laminations at 20-30°. SPT 100 AWHITU SAND FORMATION HOT 100 SPT 100 33 29.00 - 30.00 Very closely spaced, orange brown laminations || Project: BH-M07.GPJ || Library: GHD - NZGD.GLB || Date: 25 August 2023 at 15-30°. HÖT 100 SPT 100 보 100 Highly weathered, orange brown, fine to medium grained SANDSTONE; extremely weak. Recovered as:

Notes and Comments: End of Hole @ 40.64m, Target Depth.

GENERAL LOG

≘

Report I

Coordinates and RLs are approximated from the local GIS viewer. Locations are subject to future survey.

Silty SAND. Very dense, moist.

Refer to explanation sheets for abbreviation and symbols

Orientation:

SPT

**Ground Water Level** 

100

Contractor: DCN Equipment: Tr-200 Shear Vane Id:

Inclination: Vertical

Reading (mbgl) Date Time

Instrumentation Installation

Water level

Defect Spacing (mm)

: BH-M07 Project : AC Geo Panel - Waitakere Hole No. Client : Auckland Council Sheet : 5 of 6 Site : 265 Motutara Road, Muriwai 0881 : 40.64m Hole Length Job Number: 12612462 Scale @ A4 : 1:40 Commenced: 10/07/2023 Completed: 12/07/2023 Logged : LA, MK Processed : MK Easting: 1728235.26 Northing: 5923652.39 System: NZTM2000 RL: 52 Checked Datum: AUCKHT1946 : JHS Sample Geological Unit Moisture condition 8 Consistancy / Relative density Strength (MPa) Flush Return **Material Description** Estimated Number / Method Casing Depth ( SCR RQD Silty fine to medium SAND; dark reddish orange brown. Very VD М 보 dense, moist. 100 32.69 - 32.82 Carbonaceous fragments to 10 mm. SPT 10/12 13/14 12/12 N > 50 (solid cone) Completely weathered, dark orange brown, distinctly bedded, fine to coarse SANDSTONE; extremely weak; very thinly SPT 0 bedded at 40-45°. 33.35 - 33.40 Iron staining. CORE LOSS HQT 52 Completely weathered, brown, streaked red-orange, fine to medium grained SANDSTONE; extremely weak. SPT 0 (solid cone) HQT 100 AWHITU SAND FORMATION SPT 14/19 24/26 or 65mn N > 50 (solid cone) SPT 0 VD Fine to medium SAND with some silt; dark orange brown. Very М dense, moist. HØH 100 37 || Project: BH-M07.GPJ || Library: GHD - NZGD.GLB || Date: 25 August 2023 SPT 23/27 for 70mm N > 50 (solid cone) 37.50 ~20 mm layer of fine to medium, sub-angular, dark red SPT 0 iron stained, sandstone gravel. Highly weathered, dark reddish brown, mottled dark grey-orange brown, fine to medium grained SANDSTONE; HQT extremely weak. 100 SPT 9/14 24/26 for 65mm N > 50 (solid cone) SPT 0 HØH 100

Spacing (mm)

Defect

Water level

0

33.45

Time

08:30

0.2

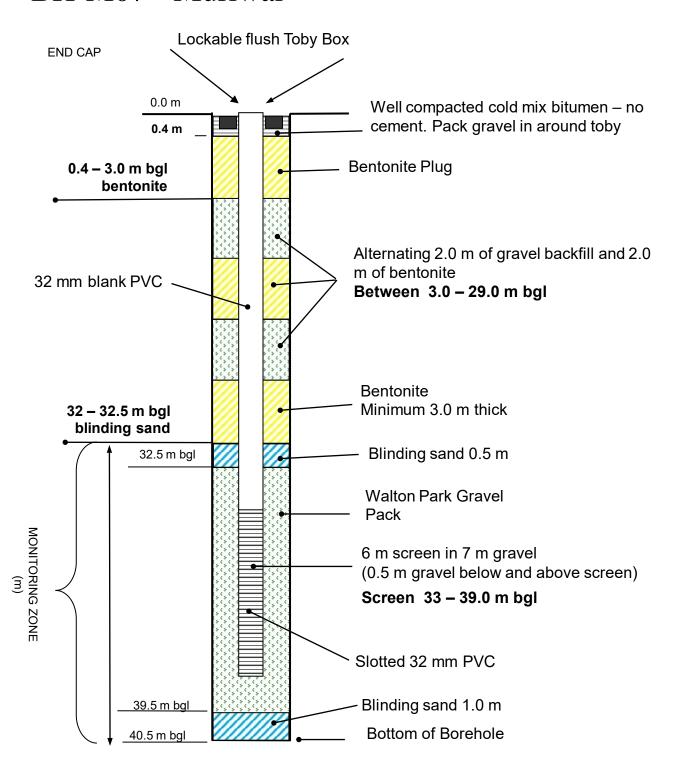
GENERAL LOG ≘ Report I

**Ground Water Level** Inclination: Vertical Orientation: Notes and Comments: End of Hole @ 40.64m, Target Depth. Contractor: DCN Date Coordinates and RLs are approximated from the local GIS viewer. Locations are subject to future survey. 12/07/23 Equipment: Tr-200 Shear Vane Id: Refer to explanation sheets for abbreviation and symbols

Project : AC Geo Panel - Waitakere : BH-M07 Hole No. Client : Auckland Council Sheet : 6 of 6 Site : 265 Motutara Road, Muriwai 0881 Hole Length : 40.64m Job Number: 12612462 Scale @ A4 : 1:40 Commenced: 10/07/2023 Completed: 12/07/2023 Logged : LA, MK Processed : MK Easting: 1728235.26 Northing: 5923652.39 System: NZTM2000 RL: 52 Datum: AUCKHT1946 Checked : JHS Sample Geological Unit Moisture condition 8 Consistancy / Relative density Strength (MPa) Flush Return **Material Description** Water level TCR SCR RQD Depth (m) Number / Method Casing Highly weathered, dark grey, fine to medium grained SANDSTONE; extremely weak. (continued from layer starting 100 at 39.8m) End of Hole @ 40.64m, Target Depth. GENERAL\_LOG || Project: BH-M07.GPJ || Library: GHD - NZGD.GLB || Date: 25 August 2023 Ground Water Level Inclination: Vertical Orientation: Notes and Comments: End of Hole @ 40.64m, Target Depth.

Coordinates and RLs are approximated from the local GIS viewer. Locations are subject to future survey. Date Contractor: DCN Time 12/07/23 14:00 1.02 40.635 Equipment: Tr-200 Shear Vane Id: Report ID: Refer to explanation sheets for abbreviation and symbols

# BH-M07 - Muriwai



NOT TO SCALE



Project	AC Geo Panel – Waitākere	Coordinates	1728235.26 E
Job Number	12612462	(NZTM 2000)	5923652.39 N
Client	Auckland Council	Location	265 Motutara Road,
Date	10 to 12 July 2023	Location	Muriwai





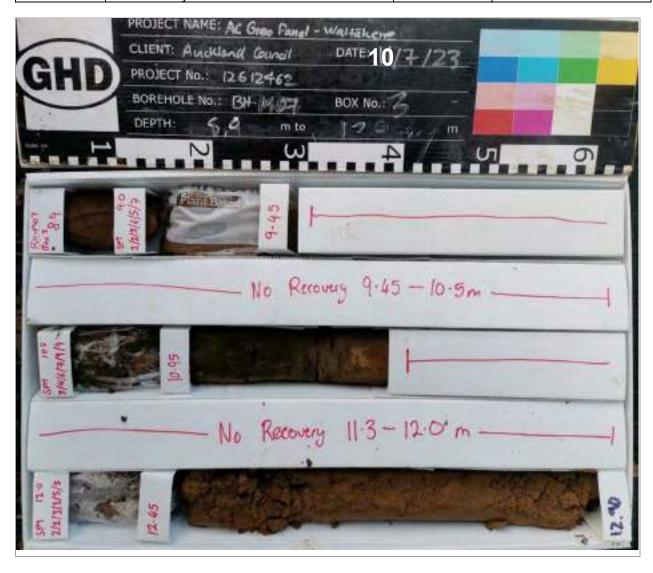
Project	AC Geo Panel – Waitākere	Coordinates	1728235.26 E
Job Number	12612462	(NZTM 2000)	5923652.39 N
Client	Auckland Council	Location	265 Motutara Road,
Date	10 to 12 July 2023	Location	Muriwai







Project	AC Geo Panel – Waitākere	Coordinates	1728235.26 E
Job Number	12612462	(NZTM 2000)	5923652.39 N
Client	Auckland Council	Location	265 Motutara Road,
Date	10 to 12 July 2023	Location	Muriwai





Project	AC Geo Panel – Waitākere	Coordinates	1728235.26 E
Job Number	12612462	(NZTM 2000)	5923652.39 N
Client	Auckland Council	Location	265 Motutara Road,
Date	10 to 12 July 2023	Location	Muriwai







Project	AC Geo Panel – Waitākere	Coordinates	1728235.26 E
Job Number	12612462	(NZTM 2000)	5923652.39 N
Client	Auckland Council	Location	265 Motutara Road,
Date	10 to 12 July 2023	Location	Muriwai







Project	AC Geo Panel – Waitākere	Coordinates	1728235.26 E
Job Number	12612462	(NZTM 2000)	5923652.39 N
Client	Auckland Council	Location	265 Motutara Road,
Date	10 to 12 July 2023	Location	Muriwai







Project	AC Geo Panel – Waitākere	Coordinates	1728235.26 E
Job Number	12612462	(NZTM 2000)	5923652.39 N
Client	Auckland Council	Location	265 Motutara Road,
Date	10 to 12 July 2023	Location	Muriwai







Project	AC Geo Panel – Waitākere	Coordinates	1728235.26 E
Job Number	12612462	(NZTM 2000)	5923652.39 N
Client	Auckland Council	Location	265 Motutara Road,
Date	10 to 12 July 2023	Location	Muriwai







Project	AC Geo Panel – Waitākere	Coordinates	1728235.26 E
Job Number	12612462	(NZTM 2000)	5923652.39 N
Client	Auckland Council	Location	265 Motutara Road,
Date	10 to 12 July 2023	Location	Muriwai







Project	AC Geo Panel – Waitākere	Coordinates	1728235.26 E
Job Number	12612462	(NZTM 2000)	5923652.39 N
Client	Auckland Council	Location	265 Motutara Road,
Date	10 to 12 July 2023	Location	Muriwai





Project	AC Geo Panel – Waitākere	Coordinates	1728235.26 E
Job Number	12612462	(NZTM 2000)	5923652.39 N
Client	Auckland Council	Location	265 Motutara Road,
Date	10 to 12 July 2023	Location	Muriwai





Project	AC Geo Panel – Waitākere	Coordinates	1728235.26 E
Job Number	12612462	(NZTM 2000)	5923652.39 N
Client	Auckland Council	Location	265 Motutara Road,
Date	10 to 12 July 2023	Location	Muriwai





Project	AC Geo Panel – Waitākere	Coordinates	1728235.26 E
Job Number	12612462	(NZTM 2000)	5923652.39 N
Client	Auckland Council	Location	265 Motutara Road,
Date	10 to 12 July 2023	Location	Muriwai





Project	AC Geo Panel – Waitākere	Coordinates	1728235.26 E		
Job Number	12612462	(NZTM 2000)	5923652.39 N		
Client	Auckland Council	Location	265 Motutara Road,		
Date	10 to 12 July 2023	Location	Muriwai		





Project	AC Geo Panel – Waitākere	Coordinates	1728235.26 E		
Job Number	12612462	(NZTM 2000)	5923652.39 N		
Client	Auckland Council	Location	265 Motutara Road,		
Date	10 to 12 July 2023	Location	Muriwai		





Project	AC Geo Panel – Waitākere	Coordinates	1728235.26 E
Job Number	12612462	(NZTM 2000)	5923652.39 N
Client	Auckland Council	Location	265 Motutara Road,
Date	10 to 12 July 2023	Location	Muriwai





Project	AC Geo Panel – Waitākere	Coordinates	1728235.26 E		
Job Number	12612462	(NZTM 2000)	5923652.39 N		
Client	Auckland Council	Location	265 Motutara Road,		
Date	10 to 12 July 2023	Location	Muriwai		





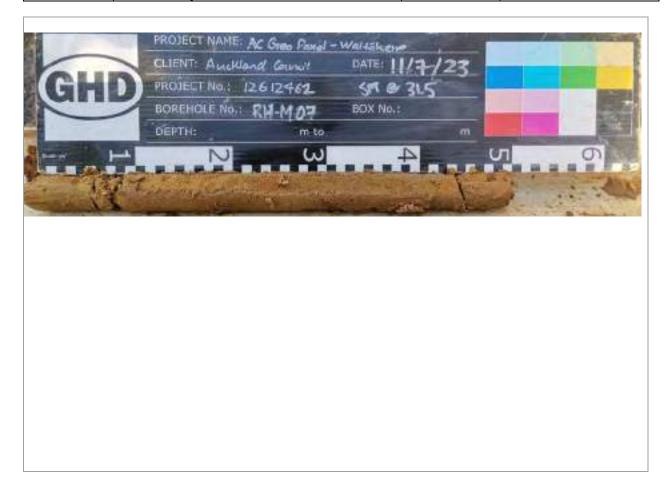
Project	AC Geo Panel – Waitākere	Coordinates	1728235.26 E		
Job Number	12612462	(NZTM 2000)	5923652.39 N		
Client	Auckland Council	Location	265 Motutara Road,		
Date	10 to 12 July 2023	Location	Muriwai		







Project	AC Geo Panel – Waitākere	Coordinates	1728235.26 E		
Job Number	12612462	(NZTM 2000)	5923652.39 N		
Client	Auckland Council	Location	265 Motutara Road,		
Date	10 to 12 July 2023	Location	Muriwai		





Project : AC Geo Panel - Waitakere

Client : Auckland Council

Site : 217 Motutara Rd, Muriwai 0881

Job Number: 12612462

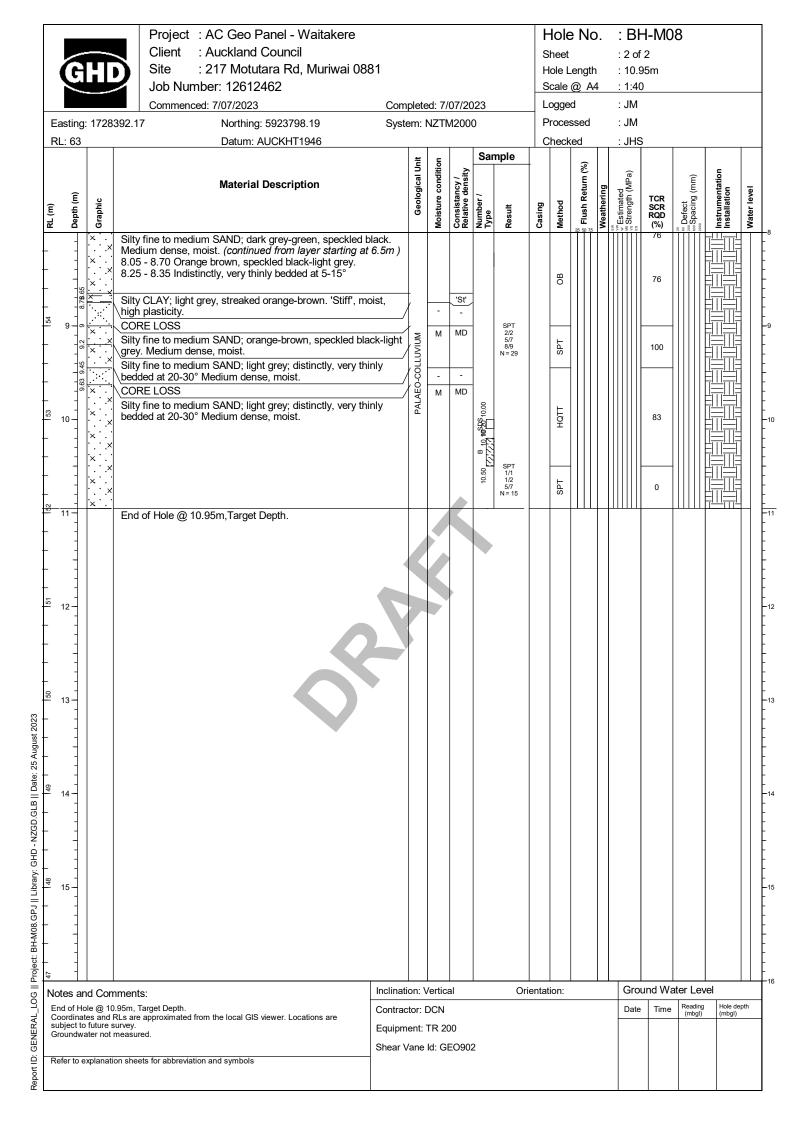
Commenced: 7/07/2023 Completed: 7/07/2023

: BH-M08 Hole No.

Sheet : 1 of 2 : 10.95m Hole Length

Scale @ A4 : 1:40 Logged : JM

Ea	asting	g: 172	283	92.17 Northing: 5923798.19	Syste				0		$\neg$	roce	ssed		: JN	l			
RL	_: 63			Datum: AUCKHT1946							c	heck	ed		: JH	s			
	(E)	J		Material Description		Geological Unit	Moisture condition	tancy / e density	Number / Type	nple	_	-	Flush Return (%)	əring	westimated Strength (MPa)	TCR	Defect Spacing (mm)	Instrumentation Installation	lovol
R E	Depth (m)	Graphic				Š	Moistu	Consis	Numbe	Result	Casing	Method	Flush	Weathering	Estim	TCR SCR RQD (%)	Defec Spaci	Instrur	Water level
	_	1	:	HYDROVAC - NO RECOVERY			-	-					25 50 75		1		3 6 5 6 5	000	1
	-																		
	1																	60°C	<u>'</u>
	]					'						₹				0		000	}
_	1-																	500	
	-																		\
		- ×	- ;	Silty fine to medium SAND with pockets of organics to grey, mottled light grey. Very loose, moist.	25 mm;		М	VS		SPT 0/0 0/0		F							
	-	× ×	-	[PALAEO-COLLUVIUM]						0/0 N = 0		SPT				0		600	
_	2-	× ×	7															600	}
		×_×	4									m							,
	1	×××										OB				100		600	,
3	-	××	- 1	2.85 - 3.15 Grey-green.														000	}
=	3 - 4	; × – ; × ×			Loono	<u> </u>		Ķ		SV@3m UTP SPT 1/1		SPT				100			,
	-	^`.   <sub>×</sub> :		Silty fine to medium SAND; light grey, mottled orange. moist.	Loose,				3.45	1/1 3/4		SF				100		000	}
			×		4	K			3.70 B										
n n	-		.×						3.70			OB				100		6000	,
_	4-		.×									0				100		000	}
			·×			Σ				0.0.7								000	
	]	×	·×	4.55 - 4.65 Medium dense.		OLLUV		MD		SPT 1/1 2/3 4/5 N = 14		SPT				100			\
8	5	×	·×			AEO-COLLUVIUM				N = 14		S							,
	Ĭ -	×	·^			PALA												500	
	]	× .	×	_								OB				100			}
		×	×																
	6	×	×							SPT									,
		×	. ×	6.10 - 7.20 Dark brown, speckled black.						1/0 1/0 1/1		SPT				0			
	6.45		:	Silty fine to medium SAND; dark grey-green, speckled	hlack	+		MD		N = 3									
	+	×.	.×	Medium dense, moist.	JIGON.			""											=
8	7-	×		6.85 - 7.05 Brown, speckled black-light grey, streaked green-orange.								0B				100			=
	1	×	Ĵ	7.20 - 7.30 Light grey, speckled black.															
	‡	×	$\hat{\cdot}$	7.30 - 8.05 Brown, speckled black-light grey, streaked green-orange.						SPT 1/1									1
		×	·^	7.55 - 7.65 Reddish orange, speckled black.															
8	<u>†</u>	es and Comments:    Inclination: Vertical   Orientation:   Ground Water Level																	
En	d of H	ole @	10.9	95m, Target Depth.	Contrac			aı		Or	ıcıııdl	ion.			Dat		T	g Hole de	epth
Coordinates and RLs are approximated from the local GIS viewer. Locations are subject to future survey.  Groundwater not measured.  Equipment: TR 200																			
Re	fer to	explan	atio	n sheets for abbreviation and symbols	Shear \	/ane	ld: G	EO90	2										
	10 6	onpiail	auUl	sssa for approvation and symbols															





Project	AC Geo Panel – Waitākere	Coordinates	1728367.96 E
Job Number	12612462	(NZTM 2000)	5923777.42 N
Client	Auckland Council	Location	217 Motutara Road,
Date	7 July 2023	Location	Muriwai





Project	AC Geo Panel – Waitākere	Coordinates	1728367.96 E		
Job Number	12612462	(NZTM 2000)	5923777.42 N		
Client	Auckland Council	Location	217 Motutara Road,		
Date	7 July 2023	Location	Muriwai		





Project	AC Geo Panel – Waitākere	Coordinates	1728367.96 E		
Job Number	12612462	(NZTM 2000)	5923777.42 N		
Client	Auckland Council	Location	217 Motutara Road,		
Date	7 July 2023	Location	Muriwai		





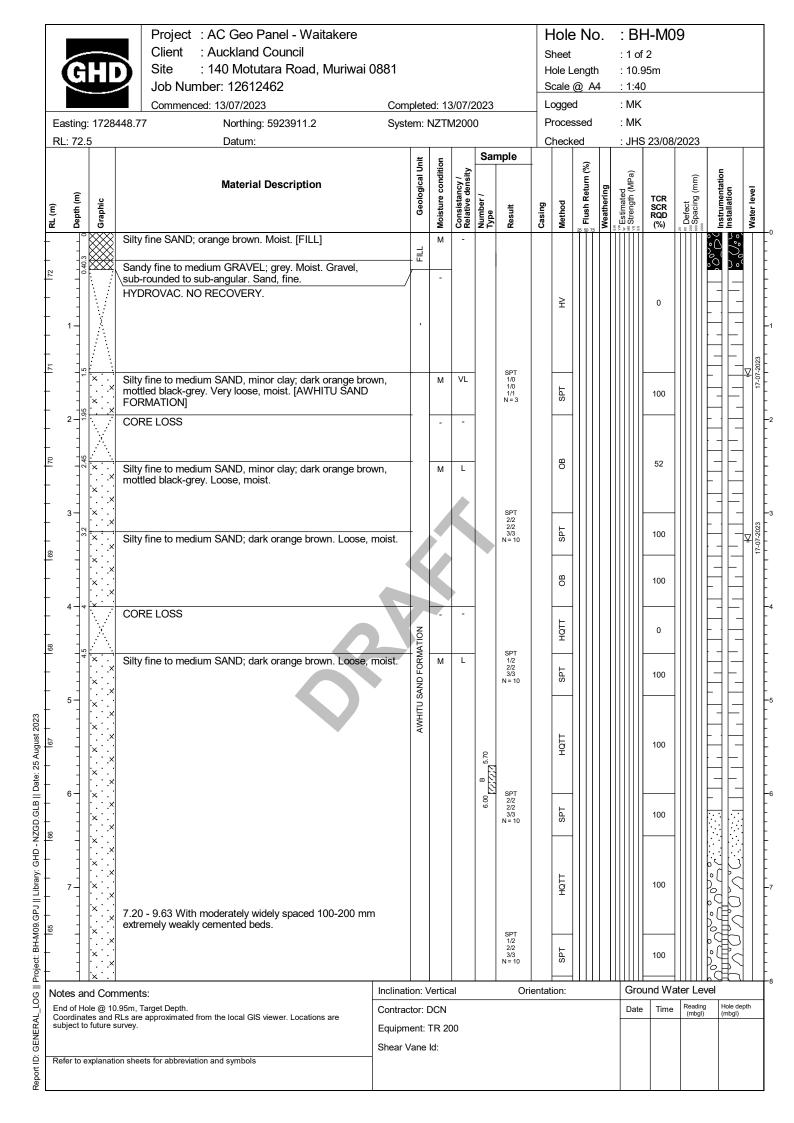
Project	AC Geo Panel – Waitākere	Coordinates	1728367.96 E		
Job Number	12612462	(NZTM 2000)	5923777.42 N		
Client	Auckland Council	Location	217 Motutara Road,		
Date	7 July 2023	Location	Muriwai		





Project	AC Geo Panel – Waitākere	Coordinates	1728367.96 E
Job Number	12612462	(NZTM 2000)	5923777.42 N
Client	Auckland Council	Location	217 Motutara Road,
Date	7 July 2023	Location	Muriwai





Project : AC Geo Panel - Waitakere Hole No. : BH-M09 Client : Auckland Council Sheet : 2 of 2 Site : 140 Motutara Road, Muriwai 0881 Hole Length : 10.95m Job Number: 12612462 Scale @ A4 : 1:40 Commenced: 13/07/2023 Completed: 13/07/2023 Logged : MK Processed : MK Easting: 1728448.77 Northing: 5923911.2 System: NZTM2000 RL: 72.5 Checked : JHS 23/08/2023 Datum: Sample Geological Unit Moisture condition 8 <sup>™</sup>Estimated
<sup>™</sup>Strength (MPa) Consistancy / Relative density Flush Return **Material Description** TCR SCR RQD Depth (m) Number / Graphic Method Casing Silty fine to medium SAND; dark orange brown. Loose, moist. (continued from layer starting at 4.5m) 보 100 SPT 1/2 2/2 3/3 N = 10 AWHITU SAND FORMATION SPT 78 Highly weathered, dark orange brown, fine to medium grained SANDSTONE; extremely weak. HQTT 100 10 Silty fine to coarse SAND; dark orange brown. Medium dense, MD moist. SPT 100 End of Hole @ 10.95m, Target Depth. 12 || Project: BH-M09.GPJ || Library: GHD - NZGD.GLB || Date: 25 August 2023 Inclination: Vertical **Ground Water Level** Orientation: Notes and Comments: GENERAL\_LOG End of Hole @ 10.95m, Target Depth.

Coordinates and RLs are approximated from the local GIS viewer. Locations are subject to future survey. Date Time Contractor: DCN 17/07/23 17/07/23 12:15 14:15 1.5 3.27 Equipment: TR 200

Shear Vane Id:

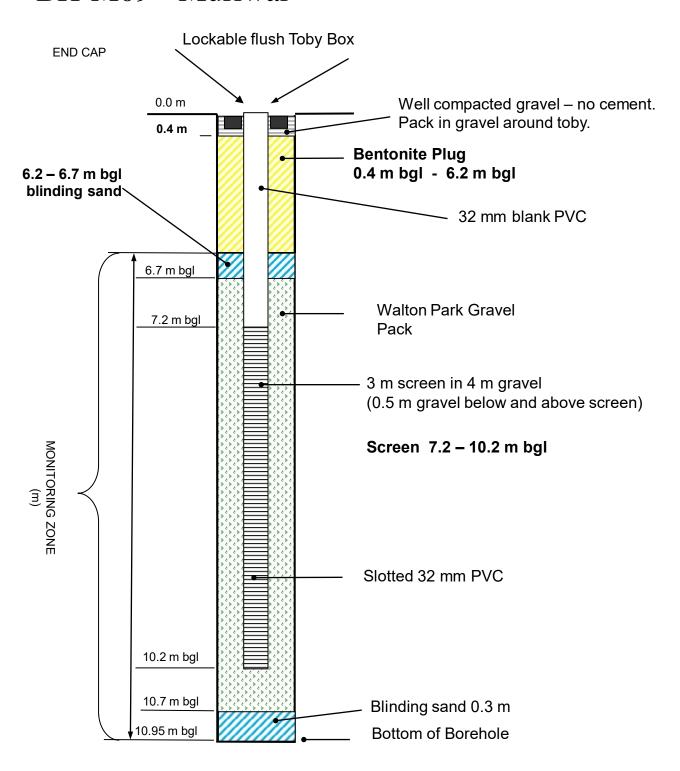
≘

Report I

Refer to explanation sheets for abbreviation and symbols

Water level

# BH-M09 - Muriwai

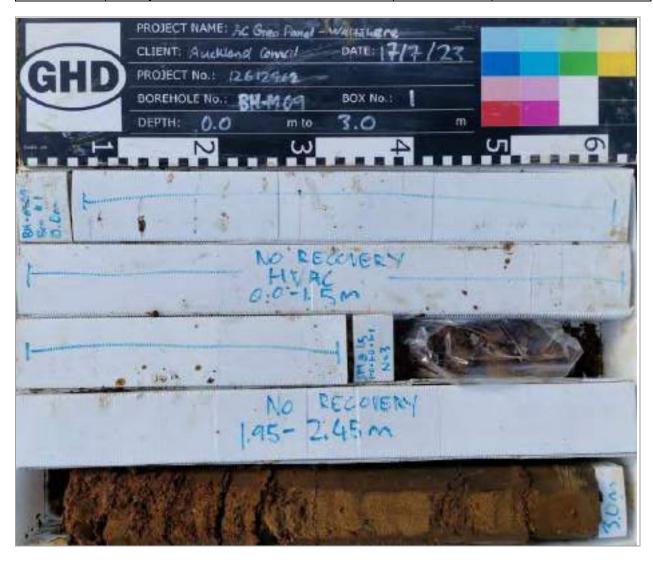


NOT TO SCALE





Project	AC Geo Panel – Waitākere	Coordinates	1728448.77 E
Job Number	12612462	(NZTM 2000)	5923911.20 N
Client	Auckland Council	Location	140 Motutara Road,
Date	17 July 2023		Muriwai







Project	AC Geo Panel – Waitākere	Coordinates	1728448.77 E
Job Number	12612462	(NZTM 2000)	5923911.20 N
Client	Auckland Council	Location	140 Motutara Road,
Date	17 July 2023		Muriwai







Project	AC Geo Panel – Waitākere	Coordinates	1728448.77 E
Job Number	12612462	(NZTM 2000)	5923911.20 N
Client	Auckland Council	Location	140 Motutara Road,
Date	17 July 2023	Location	Muriwai



### Report of photographs





Project	AC Geo Panel – Waitākere	Coordinates	1728448.77 E
Job Number	Job Number 12612462		5923911.20 N
Client	Auckland Council		140 Motutara Road,
Date	17 July 2023	Location	Muriwai



### Report of photographs

Site identification - BH-M09



Project	AC Geo Panel – Waitākere	Coordinates	1728448.77 E
Job Number	12612462	(NZTM 2000)	5923911.20 N
Client	Auckland Council	Location	140 Motutara Road,
Date	17 July 2023	Location	Muriwai



### Report of photographs

Site identification - BH-M09



Project	AC Geo Panel – Waitākere	Coordinates	1728448.77 E
Job Number	12612462	(NZTM 2000)	5923911.20 N
Client	Auckland Council	Location	140 Motutara Road,
Date	17 July 2023	Location	Muriwai



# Appendix F3

**Laboratory Test Results** 



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 Page 1 of 3

GHD Limited PO Box 6543 Wellesley Street Auckland 1141 Job Number: 63532#L BGL Registration Number: 2806

Checked by: WEC

22<sup>nd</sup> September 2023

Attention: METTE van LITH

### ATTERBERG LIMITS TESTING

Dear Mette,

Re: WAITAKERE LHRA – MURIWAI GROUND INVESTIGATION

Your Reference:

Report Number: 63532#L/AL Waitakere LHRA

The following report presents the results of Atterberg Limits testing at BGL of a soil sample delivered to this laboratory during August 2023. Test results are summarised below, with page 3 showing where the sample plots 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

Borehole	Sample	Depth (m)	Water	Liquid	Plastic	Plasticity
Number	Number		Content (%)	Limit	Limit	Index
BH-M01	<b>S</b> 1	13.50 – 13.95	29.0	25 ♦	14 ♦	11 ♦

The soil fraction passing a 425μm sieve was used for the liquid limit and plastic limit tests.

The whole soil was used for the water content test (the soil was in a natural state), and the soil fraction passing a 0.425mm sieve was used for the liquid limit and plastic limit tests. The soil was wet up and dried where required for the liquid limit and plastic limit 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 and test 2.3: plastic limit are reported to the nearest whole number.



Please note that the test results relate only to the sample as-received, and relate only to the sample 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



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.



Job Number:	63532#L	Sheet 1 of 1	Page 3 of 3
Reg. Number:	2806	Version No:	7
Report No:	63532#L/AL Waitakere LHRA	Version Date:	July 2022

WAITAKERE LHRA - MURIWAI GROUND INVESTIGATION

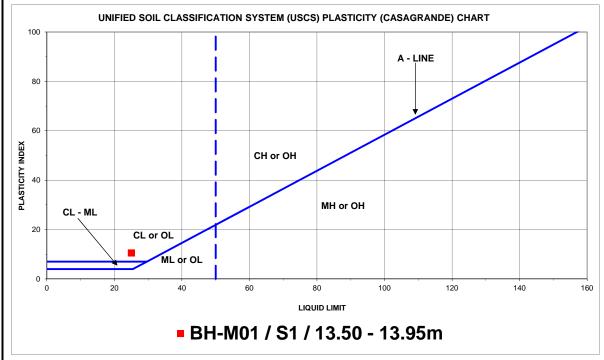
### DETERMINATION OF THE LIQUID LIMIT, PLASTIC LIMIT & THE PLASTICITY INDEX

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

Tested By:	JL	August 2023
Compiled By:	JF	10/08/2023
Checked By:	JF	10/08/2023

	SUMMARY OF TESTING					
Borehole Number	Sample Number	Depth (m)	Liquid Limit	Plastic Limit	Plasticity Index	Soil Classification Based on USCS Chart Below
BH-M01	S1	13.50 - 13.95	25	14	11	CL
						_

The chart below & soil classification terminology is taken from ASTM D2487-17<sup>e1</sup> "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)

CH = CLAY, high plasticity ('fat' clay)

OL = ORGANIC CLAY or ORGANIC SILT, low liquid limit

OH = ORGANIC CLAY or ORGANIC SILT, high liquid limit

ML = SILT, low liquid limit CL - ML = SILTY CLAY MH = SILT, high liquid limit ('elastic silt')



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

Page 1 of 16

BGL Registration Number: 2806

Checked by: WEC

25th September 2023

Job Number: 63532#L

GHD Limited PO Box 6543 Wellesley Street Auckland 1141

Attention: METTE van LITH

#### WET SIEVE PARTICLE-SIZE DISTRIBUTION TESTING

Dear Mette.

Re: WAITAKERE LHRA – MURIWAI GROUND INVESTIGATION

Your Reference:

Report Number: 63532#L/AL Waitakere LHRA

The following report presents the results of wet sieve particle-size distribution testing at BGL of soil samples delivered to this laboratory during August & September 2023. 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

			Fraction	of Sample (% of Dr	ry Mass)
Borehole Number	Sample Number	Depth (m)	GRAVEL (2 – 60mm)	<b>SAND</b> (0.06 – 2mm)	SILT & CLAY FRACTIONS (< 0.06mm)
BH-M01	S3	43.50 – 43.80	0	98	2
BH-M05	S1	6.45 - 6.65	0	93	7
BH-M07	S1	4.20 – 4.50	1	78	21
BH-M07	S2	29.70 – 30.00	0	92	8
BH-M08	S1	3.45 – 3.70	0	82	18
BH-M08	S3	10.20 – 10.50	0	80	20
ВН-М09	<b>S</b> 1	5.70 - 6.00	0	98	2

Please note that the results table immediately above with the various particle-size fractions is included for your information only, and is not included in the IANZ endorsement for this report.



			Fraction	of Sample (% of Di	y Mass)
Borehole Number	Sample Number	Depth (m)	GRAVEL (2 – 60mm)	<b>SAND</b> (0.06 – 2mm)	SILT & CLAY FRACTIONS (< 0.06mm)
BH-M01	D4	76.15 – 76.50	0	97	3
BH-M02	D14	63.95 – 64.25	0	95	5
BH-M03	D10	76.00 – 76.30	0	94	6
ВН-М06	D1	26.00 – 26.30	0	85	15
BH-M07	D3	36.90 – 37.20	0	93	7
ВН-М09	D2	8.70 – 9.00	0	97	3

Please note that the results table immediately above with the various particle-size fractions is included for your information only, and is not included in 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, the percentages passing the sieves are reported to nearest 1%.

The wet sieve method used by BGL is a slight variation of the 2.8.1 test standard. It is, in our opinion, a more accurate method as it does not rely on an assumed total dry mass determined from water content testing of sub-samples, but actually determines & uses the exact total dry mass (*opinion not IANZ endorsed*).

The following departures from the test standard occurred:

- The total dry mass of the entire sieved sample was determined, and was not calculated by using two
  water content sub-samples as in the standard.
- A detergent was used to deflocculate the sample rather than a sodium hexametaphosphate/sodium carbonate dispersing agent solution.
- The recovery of the wet fines (i.e. the silt & clay passing the 63μm wash sieve) for determining the percentage of silt & clay was omitted (as per 2.8.1 Note 7), therefore the percentage passing the 63μm was obtained by difference. A 10% hydrochloric acid flocculating agent was therefore not used.



Job Number: 63532#L 25<sup>th</sup> September 2023 Page 3 of 16

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



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.



Job Number:	63532#L	Sheet 1 of 1	Page 4 of 16
Reg. Number:	2806	Version No:	5
Report No:	63532#L/PSD Waitakere LHRA	Issue Date:	July 2022

# WAITAKERE LHRA - MURIWAI GROUND INVESTIGATION

### PARTICLE-SIZE DISTRIBUTION BY WET SIEVE

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

Tested By:	WEC/JL	11-Aug-23
Compiled By:	JL	11-Aug-23
Checked By:	JF	14-Aug-23

*вн:* **ВН-М01** 

Sample No:

Depth: 43.50 - 43.80m

Water Content: 22.1 % (material < 37.5mm)

**S3** 

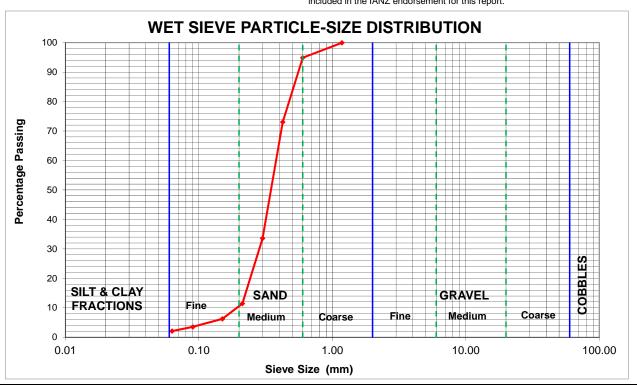
#### **TEST METHOD:**

Sample weighed wet, then oven-dried and re-weighed. Sample then washed over a  $63\mu m$  sieve. Sample then oven dried, weighed & sieved over a stack of test sieves. The percentage passing the  $63\mu m$  was obtained by difference.

#### SIEVE ANALYSIS (% of dry mass)

Sieve	Percentage
Size (mm)	Passing
1.18	100
0.600	95
0.425	73
0.300	34
0.212	11
0.150	6
0.090	4
0.063	2

				TOTAL	
COBBLES:		200 - 60mm		0	%
	(Coarse)	60 - 20mm	0		
GRAVEL:	(Medium)	20 - 6mm	0	0	%
	(Fine)	6 - 2mm	0		
	(Coarse)	2.0 - 0.6mm	5		
SAND:	(Medium)	0.6 - 0.2mm	84	98	%
	(Fine)	0.2 - 0.06mm	9		
SILT & CLAY	FRACTIONS:	< 0.06mm		2	%
				100%	





Report No.	03332#L/F3D Wallakele LITIKA	issue Date.	July 2022
Report No:	63532#L/PSD Waitakere LHRA	Issue Date:	July 2022
Reg. Number:	2806	Version No:	5
Job Number:	63532#L	Sheet 1 of 1	Page 5 of 16

# WAITAKERE LHRA - MURIWAI GROUND INVESTIGATION

### PARTICLE-SIZE DISTRIBUTION BY WET SIEVE

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

Tested By:	WEC / JL	11-Aug-23
Compiled By:	JL	11-Aug-23
Checked By:	JF	14-Aug-23

**BH: BH-M05** 

Sample No:

**S1** 

Depth: 6.45 - 6.65m

Water Content:

27.7 % (material < 37.5mm)

100%

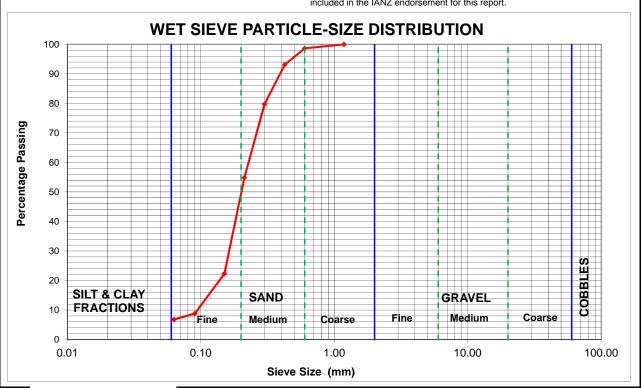
#### **TEST METHOD:**

Sample weighed wet, then oven-dried and re-weighed. Sample then washed over a  $63\mu m$  sieve. Sample then oven dried, weighed & sieved over a stack of test sieves. The percentage passing the  $63\mu m$  was obtained by difference.

#### SIEVE ANALYSIS (% of dry mass)

Sieve	Percentage
Size (mm)	Passing
1.18	100
0.600	99
0.425	93
0.300	80
0.212	55
0.150	22
0.090	9
0.063	7

				TOTAL	
COBBLES:		200 - 60mm		0	%
	(Coarse)	60 - 20mm	0		
GRAVEL:	(Medium)	20 - 6mm	0	0	%
	(Fine)	6 - 2mm	0		
	(Coarse)	2.0 - 0.6mm	1		
SAND:	(Medium)	0.6 - 0.2mm	50	93	%
	(Fine)	0.2 - 0.06mm	42		
	<u> </u>				
SILT & CLAY	FRACTIONS:	< 0.06mm		7	%





Job Number:	63532#L	Sheet 1 of 1	Page 6 of 16
Reg. Number:	2806	Version No:	5
Report No:	63532#L/PSD Waitakere LHRA	Issue Date:	July 2022

# WAITAKERE LHRA - MURIWAI GROUND INVESTIGATION

### PARTICLE-SIZE DISTRIBUTION BY WET SIEVE

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

Tested By:	WEC/JL	14-Aug-23
Compiled By:	JL	14-Aug-23
Checked By:	JF	14-Aug-23

*вн*: **ВН-М07** 

Sample No:

**S1** 

Depth: 4.20 - 4.50m

Water Content:

**31.0** % (material < 37.5mm)

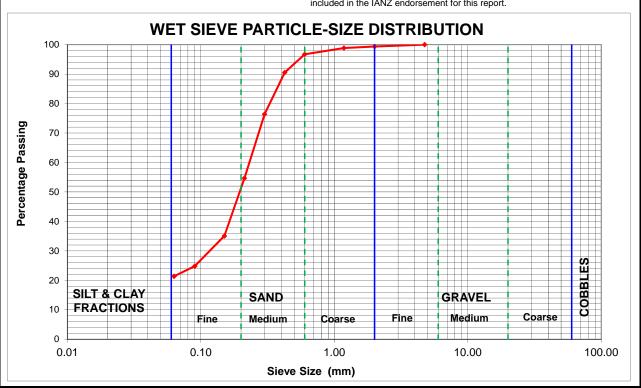
#### **TEST METHOD:**

Sample weighed wet, then oven-dried and re-weighed. Sample then washed over a  $63\mu m$  sieve. Sample then oven dried, weighed & sieved over a stack of test sieves. The percentage passing the  $63\mu m$  was obtained by difference.

#### SIEVE ANALYSIS (% of dry mass)

Sieve	Percentage
Size (mm)	Passing
4.75	100
2.00	99
1.18	99
0.600	97
0.425	91
0.300	76
0.212	55
0.150	35
0.090	25
0.063	21

	OIL 1 L / (11/ (L )	010 (70 01 GI)	mace		
				TOTAL	
COBBLES:		200 - 60mm		0	%
	(Coarse)	60 - 20mm	0		
GRAVEL:	(Medium)	20 - 6mm	0	1	%
	(Fine)	6 - 2mm	1		
	(Coarse)	2.0 - 0.6mm	2		
SAND:	(Medium)	0.6 - 0.2mm	46	78	%
	(Fine)	0.2 - 0.06mm	30		
		<u>.</u>			
SILT & CLAY	FRACTIONS:	< 0.06mm		21	%
				100%	





Job Number:	63532#L	Sheet 1 of 1	Page 7 of 16
Reg. Number:	2806	Version No:	5
Report No:	63532#L/PSD Waitakere LHRA	Issue Date:	July 2022
	14/4/5		

# WAITAKERE LHRA - MURIWAI GROUND INVESTIGATION

### PARTICLE-SIZE DISTRIBUTION BY WET SIEVE

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

Tested By:	WEC/JL	14-Aug-23
Compiled By:	JL	14-Aug-23
Checked By:	JF	14-Aug-23

*вн*: **ВН-М07** 

Sample No:

**S2** 

Depth: 29.70 - 30.00m

Water Content:

25.4 % (material < 37.5mm)

100%

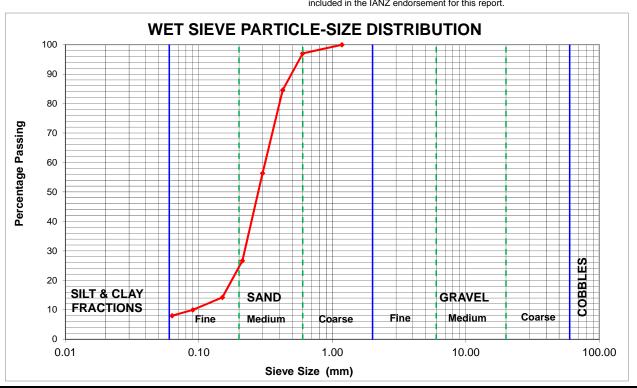
#### **TEST METHOD:**

Sample weighed wet, then oven-dried and re-weighed. Sample then washed over a  $63\mu m$  sieve. Sample then oven dried, weighed & sieved over a stack of test sieves. The percentage passing the  $63\mu m$  was obtained by difference.

#### SIEVE ANALYSIS (% of dry mass)

Sieve	Percentage
Size (mm)	Passing
1.18	100
0.600	97
0.425	85
0.300	56
0.212	27
0.150	14
0.090	10
0.063	8

				TOTAL	
COBBLES:		200 - 60mm		0	%
	(Coarse)	60 - 20mm	0		
GRAVEL:	(Medium)	20 - 6mm	0	0	%
	(Fine)	6 - 2mm	0		
	(Coarse)	2.0 - 0.6mm	3		
SAND:	(Medium)	0.6 - 0.2mm	72	92	%
	(Fine)	0.2 - 0.06mm	17		
				_	
SILT & CLAY	FRACTIONS:	< 0.06mm		8	%





Job Number:	63532#L	Sheet 1 of 1	Page 8 of 16
Reg. Number:	2806	Version No:	5
Report No:	63532#L/PSD Waitakere LHRA	Issue Date:	July 2022

# WAITAKERE LHRA - MURIWAI GROUND INVESTIGATION

### PARTICLE-SIZE DISTRIBUTION BY WET SIEVE

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

Tested By:	WEC/JL	11-Aug-23
Compiled By:	JL	11-Aug-23
Checked By:	JF	14-Aug-23

**BH-M08** 

Sample No:

**S1** 

Depth: 3.45 - 3.70m

Water Content:

**42.5** % (material < 37.5mm)

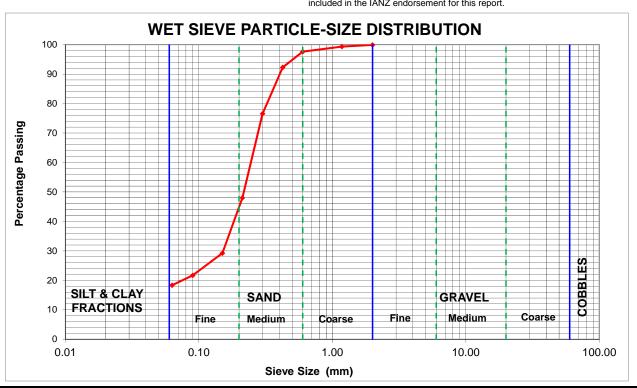
#### **TEST METHOD:**

Sample weighed wet, then oven-dried and re-weighed. Sample then washed over a  $63\mu m$  sieve. Sample then oven dried, weighed & sieved over a stack of test sieves. The percentage passing the  $63\mu m$  was obtained by difference.

#### SIEVE ANALYSIS (% of dry mass)

Sieve	Percentage
Size (mm)	Passing
2.00	100
1.18	99
0.600	98
0.425	92
0.300	77
0.212	48
0.150	29
0.090	22
0.063	18

				TOTAL	
COBBLES:		200 - 60mm		0	%
	(Coarse)	60 - 20mm	0		
GRAVEL:	(Medium)	20 - 6mm	0	0	%
	(Fine)	6 - 2mm	0		
	(Coarse)	2.0 - 0.6mm	2		
SAND:	(Medium)	0.6 - 0.2mm	53	82	%
	(Fine)	0.2 - 0.06mm	27		
				_	
SILT & CLAY	FRACTIONS:	< 0.06mm		18	%
			<u> </u>	100%	





Job Number:	63532#L	Sheet 1 of 1	Page 9 of 16
Reg. Number:	2806	Version No:	5
Report No:	63532#L/PSD Waitakere LHRA	Issue Date:	July 2022
Report No:	63532#L/PSD Waitakere LHRA	Issue Date:	July 2022

# WAITAKERE LHRA - MURIWAI GROUND INVESTIGATION

### PARTICLE-SIZE DISTRIBUTION BY WET SIEVE

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

Tested By:	WEC/JL	14-Aug-23
Compiled By:	JL	14-Aug-23
Checked By:	JF	14-Aug-23

**BH: BH-M08** 

Sample No:

**S3** 

Depth: 10.20 - 10.50m

Water Content:

26.2 % (material < 37.5mm)

100%

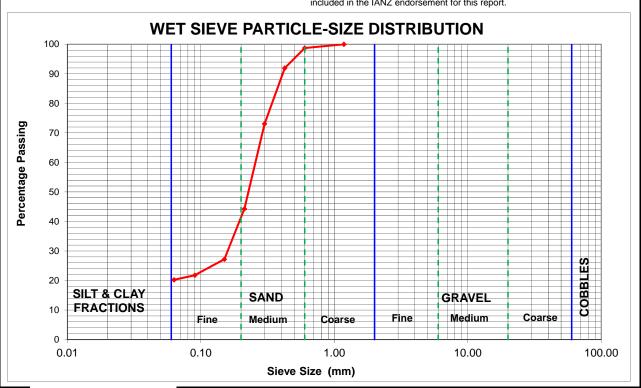
#### **TEST METHOD:**

Sample weighed wet, then oven-dried and re-weighed. Sample then washed over a  $63\mu m$  sieve. Sample then oven dried, weighed & sieved over a stack of test sieves. The percentage passing the  $63\mu m$  was obtained by difference.

#### SIEVE ANALYSIS (% of dry mass)

Sieve	Percentage
Size (mm)	Passing
1.18	100
0.600	99
0.425	92
0.300	73
0.212	44
0.150	27
0.090	22
0.063	20

				TOTAL	
COBBLES:		200 - 60mm		0	%
	(Coarse)	60 - 20mm	0		
GRAVEL:	(Medium)	20 - 6mm	0	0	%
	(Fine)	6 - 2mm	0		
•					
	(Coarse)	2.0 - 0.6mm	1		
SAND:	(Medium)	0.6 - 0.2mm	58	80	%
	(Fine)	0.2 - 0.06mm	21		
				_	
SILT & CLAY	FRACTIONS:	< 0.06mm		20	%





report No.	00002#Lif OD Waltakere LiffkA	issue pate.	oury LULL
Report No:	63532#L/PSD Waitakere LHRA	Issue Date:	July 2022
Reg. Number:	2806	Version No:	5
Job Number:	63532#L	Sheet 1 of 1	Page 10 of 16

# WAITAKERE LHRA - MURIWAI GROUND INVESTIGATION

### PARTICLE-SIZE DISTRIBUTION BY WET SIEVE

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

Tested By:	WEC/JL	14-Aug-23
Compiled By:	JL	14-Aug-23
Checked By:	JF	14-Aug-23

*вн*: **ВН-М09** 

Sample No:

**S1** 

Depth: 5.70 - 6.00m

Water Content: 26.2 % (material < 37.5mm)

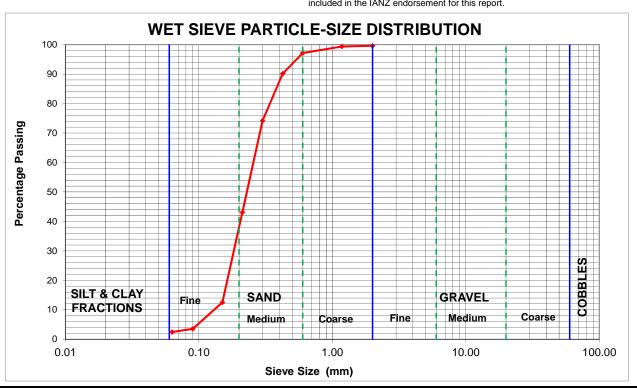
#### **TEST METHOD:**

Sample weighed wet, then oven-dried and re-weighed. Sample then washed over a  $63\mu m$  sieve. Sample then oven dried, weighed & sieved over a stack of test sieves. The percentage passing the  $63\mu m$  was obtained by difference.

#### SIEVE ANALYSIS (% of dry mass)

Sieve	Percentage
Size (mm)	Passing
2.00	100
1.18	99
0.600	97
0.425	90
0.300	74
0.212	43
0.150	13
0.090	4
0.063	2

				TOTAL	
COBBLES:		200 - 60mm		0	%
	(Coarse)	60 - 20mm	0		
GRAVEL:	(Medium)	20 - 6mm	0	0	%
	(Fine)	6 - 2mm	0		
	(Coarse)	2.0 - 0.6mm	3		
SAND:	(Medium)	0.6 - 0.2mm	59	98	%
	(Fine)	0.2 - 0.06mm	36		
				_	
SILT & CLAY	FRACTIONS:	< 0.06mm		2	%
				100%	





Job Number:	63532#L	Sheet 1 of 1	Page 11 of 16
Reg. Number:	2806	Version No:	5
Report No:	63532#L/PSD Waitakere LHRA	Issue Date:	July 2022

# WAITAKERE LHRA - MURIWAI GROUND INVESTIGATION

### PARTICLE-SIZE DISTRIBUTION BY WET SIEVE

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

Tested By:	JW / JL	21 & 25/09/23
Compiled By:	JL	25-Sep-23
Checked Bv:	JF	25-Sep-23

*вн*: **ВН-М01** 

Sample No:

**D4** 

Depth: 76.15 - 76.50m

Water Content:

**26.2** % (material < 37.5mm)

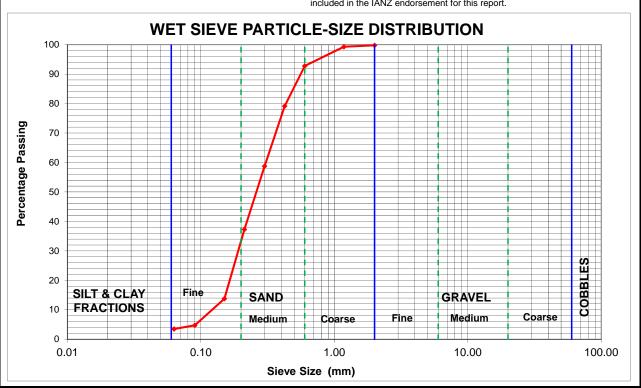
#### **TEST METHOD:**

Sample weighed wet, then oven-dried and re-weighed. Sample then washed over a  $63\mu m$  sieve. Sample then oven dried, weighed & sieved over a stack of test sieves. The percentage passing the  $63\mu m$  was obtained by difference.

#### SIEVE ANALYSIS (% of dry mass)

Sieve	Percentage
Size (mm)	Passing
2.00	100
1.18	99
0.600	93
0.425	79
0.300	59
0.212	37
0.150	14
0.090	5
0.063	3

				TOTAL	
COBBLES:		200 - 60mm		0	%
	(Coarse)	60 - 20mm	0		
GRAVEL:	(Medium)	20 - 6mm	0	0	%
	(Fine)	6 - 2mm	0		
	(Coarse)	2.0 - 0.6mm	7		
SAND:	(Medium)	0.6 - 0.2mm	60	97	%
	(Fine)	0.2 - 0.06mm	30		
SILT & CLAY	FRACTIONS:	< 0.06mm		3	%
				100%	





Job Number:	63532#L	Sheet 1 of 1	Page 12 of 16
Reg. Number:	2806	Version No:	5
Report No:	63532#L/PSD Waitakere LHRA	Issue Date:	July 2022

# WAITAKERE LHRA - MURIWAI GROUND INVESTIGATION

### PARTICLE-SIZE DISTRIBUTION BY WET SIEVE

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

Tested By:	JW	21-Sep-23
Compiled By:	JW	21-Sep-23
Checked By:	WEC	21-Sep-23

**BH-M02** 

Sample No:

**D14** 

Depth: 63.95 - 64.25m

Water Content:

**24.2** % (material < 37.5mm)

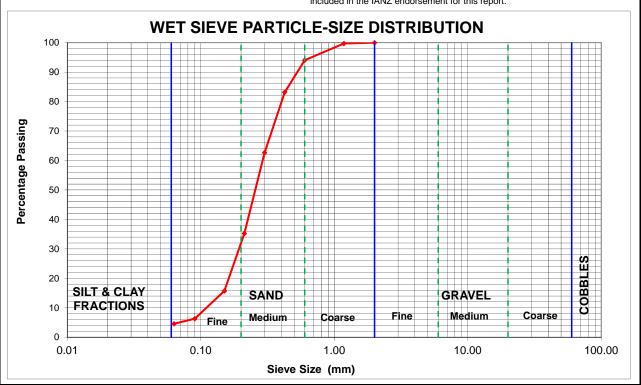
#### **TEST METHOD:**

Sample weighed wet, then oven-dried and re-weighed. Sample then washed over a  $63\mu m$  sieve. Sample then oven dried, weighed & sieved over a stack of test sieves. The percentage passing the  $63\mu m$  was obtained by difference.

#### SIEVE ANALYSIS (% of dry mass)

Sieve	Percentage
Size (mm)	Passing
2.00	100
1.18	100
0.600	94
0.425	83
0.300	63
0.212	35
0.150	16
0.090	6
0.063	5

				TOTAL	
COBBLES:		200 - 60mm		0	%
	(Coarse)	60 - 20mm	0		
GRAVEL:	(Medium)	20 - 6mm	0	0	%
	(Fine)	6 - 2mm	0		
	(Coarse)	2.0 - 0.6mm	6		
SAND:	(Medium)	0.6 - 0.2mm	62	95	%
	(Fine)	0.2 - 0.06mm	27		
				_	
SILT & CLAY	FRACTIONS:	< 0.06mm		5	%
			•	100%	





Job Number:	63532#L	Sheet 1 of 1	Page 13 of 16
Reg. Number:	2806	Version No:	5
Report No:	63532#L/PSD Waitakere LHRA	Issue Date:	July 2022

# WAITAKERE LHRA - MURIWAI GROUND INVESTIGATION

### PARTICLE-SIZE DISTRIBUTION BY WET SIEVE

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

Tested By:	JW	21-Sep-23
Compiled By:	JW	21-Sep-23
Checked By:	WEC	21-Sep-23

**BH-M03** 

Sample No:

**D10** 

Depth: 76.00 - 76.30m

Water Content:

25.2 % (material < 37.5mm)

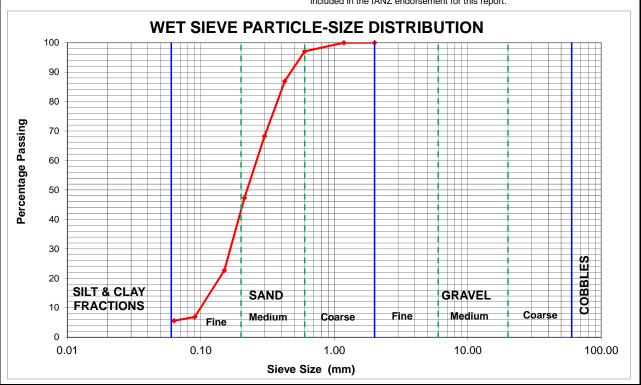
#### **TEST METHOD:**

Sample weighed wet, then oven-dried and re-weighed. Sample then washed over a  $63\mu m$  sieve. Sample then oven dried, weighed & sieved over a stack of test sieves. The percentage passing the  $63\mu m$  was obtained by difference.

#### SIEVE ANALYSIS (% of dry mass)

Sieve	Percentage
Size (mm)	Passing
2.00	100
1.18	100
0.600	97
0.425	87
0.300	68
0.212	47
0.150	23
0.090	7
0.063	6

				TOTAL	
COBBLES:		200 - 60mm		0	%
	(Coarse)	60 - 20mm	0		
GRAVEL:	(Medium)	20 - 6mm	0	0	%
	(Fine)	6 - 2mm	0		
	(Coarse)	2.0 - 0.6mm	3		
SAND:	(Medium)	0.6 - 0.2mm	54	94	%
	(Fine)	0.2 - 0.06mm	37		
SILT & CLAY	FRACTIONS:	< 0.06mm		6	%
				100%	





Job Number:	63532#L	Sheet 1 of 1	Page 14 of 16
Reg. Number:	2806	Version No:	5
Report No:	63532#L/PSD Waitakere LHRA	Issue Date:	July 2022

### WAITAKERE LHRA - MURIWAI GROUND INVESTIGATION

### PARTICLE-SIZE DISTRIBUTION BY WET SIEVE

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

Tested By:	JW	21-Sep-23
Compiled By:	JW	21-Sep-23
Checked By:	WEC	21-Sep-23

*вн*: **ВН-М06** 

Sample No:

**D1** 

Depth: 26.00 - 26.30m

Water Content:

**19.9** % (material < 37.5mm)

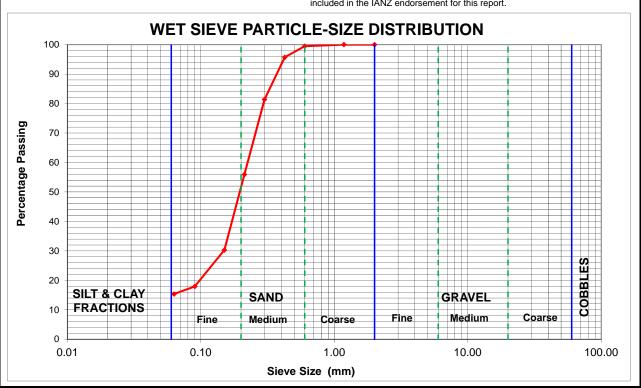
#### **TEST METHOD:**

Sample weighed wet, then oven-dried and re-weighed. Sample then washed over a  $63\mu m$  sieve. Sample then oven dried, weighed & sieved over a stack of test sieves. The percentage passing the  $63\mu m$  was obtained by difference.

#### SIEVE ANALYSIS (% of dry mass)

Sieve	Percentage
Size (mm)	Passing
2.00	100
1.18	100
0.600	99
0.425	96
0.300	81
0.212	56
0.150	30
0.090	18
0.063	15

				TOTAL	
COBBLES:		200 - 60mm		0	%
	(Coarse)	60 - 20mm	0		
GRAVEL:	(Medium)	20 - 6mm	0	0	%
	(Fine)	6 - 2mm	0		
	(Coarse)	2.0 - 0.6mm	1		
SAND:	(Medium)	0.6 - 0.2mm	47	85	%
	(Fine)	0.2 - 0.06mm	37		
SILT & CLAY	FRACTIONS:	< 0.06mm		15	%
				100%	





Job Number:	63532#L	Sheet 1 of 1	Page 15 of 16
Reg. Number:	2806	Version No:	5
Report No:	63532#L/PSD Waitakere LHRA	Issue Date:	July 2022

# WAITAKERE LHRA - MURIWAI GROUND INVESTIGATION

### PARTICLE-SIZE DISTRIBUTION BY WET SIEVE

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

Tested By:	JW	21-Sep-23
Compiled By:	JW	21-Sep-23
Checked Bv:	WEC	21-Sep-23

*вн*: **ВН-М07** 

Sample No:

**D3** 

Depth: 36.90 - 37.20m

Water Content:

25.8 % (material < 37.5mm)

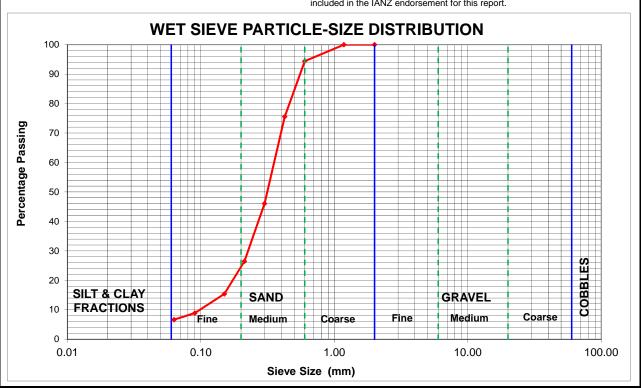
#### **TEST METHOD:**

Sample weighed wet, then oven-dried and re-weighed. Sample then washed over a  $63\mu m$  sieve. Sample then oven dried, weighed & sieved over a stack of test sieves. The percentage passing the  $63\mu m$  was obtained by difference.

#### SIEVE ANALYSIS (% of dry mass)

Sieve	Percentage
Size (mm)	Passing
2.00	100
1.18	100
0.600	94
0.425	76
0.300	46
0.212	26
0.150	15
0.090	9
0.063	7

				TOTAL	
COBBLES:		200 - 60mm		0	%
	(Coarse)	60 - 20mm	0		
GRAVEL:	(Medium)	20 - 6mm	0	0	%
	(Fine)	6 - 2mm	0		
	(Coarse)	2.0 - 0.6mm	6		
SAND:	(Medium)	0.6 - 0.2mm	70	93	%
	(Fine)	0.2 - 0.06mm	17		
SILT & CLAY	FRACTIONS:	< 0.06mm		7	%
				100%	





Job Number:	63532#L	Sheet 1 of 1	Page 16 of 16
Reg. Number:	2806	Version No:	5
Report No:	63532#L/PSD Waitakere LHRA	Issue Date:	July 2022

# WAITAKERE LHRA - MURIWAI GROUND INVESTIGATION

### PARTICLE-SIZE DISTRIBUTION BY WET SIEVE

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

Tested By:	JL	25-Sep-23
Compiled By:	JL	25-Sep-23
Checked By:	JF	25-Sep-23

*вн*: **ВН-М09** 

Sample No:

**D2** 

Depth: 8.70 - 9.00m

Water Content:

25.8 % (material < 37.5mm)

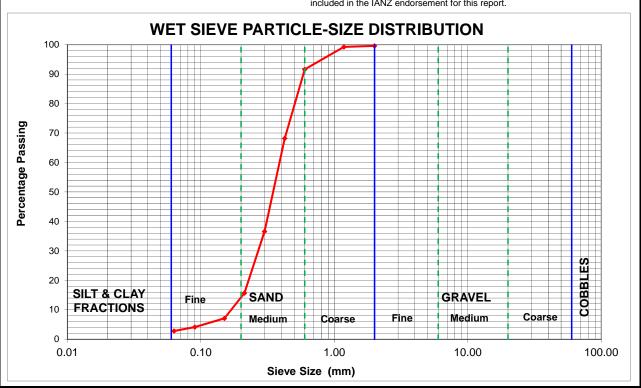
#### **TEST METHOD:**

Sample weighed wet, then oven-dried and re-weighed. Sample then washed over a  $63\mu m$  sieve. Sample then oven dried, weighed & sieved over a stack of test sieves. The percentage passing the  $63\mu m$  was obtained by difference.

#### SIEVE ANALYSIS (% of dry mass)

Sieve	Percentage
Size (mm)	Passing
2.00	100
1.18	99
0.600	92
0.425	68
0.300	37
0.212	16
0.150	7
0.090	4
0.063	3

				TOTAL	
COBBLES:		200 - 60mm		0	%
	(Coarse)	60 - 20mm	0		
GRAVEL:	(Medium)	20 - 6mm	0	0	%
	(Fine)	6 - 2mm	0		
	(Coarse)	2.0 - 0.6mm	8		
SAND:	(Medium)	0.6 - 0.2mm	78	97	%
	(Fine)	0.2 - 0.06mm	11		
SILT & CLAY	FRACTIONS:	< 0.06mm		3	%
				100%	





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 Page 1 of 3

GHD Limited PO Box 6543 Wellesley Street Auckland 1141

**BGL Registration Number: 2806** 

Checked by: WEC

22<sup>nd</sup> September 2023

Job Number: 63532#L

Attention: METTE van LITH

#### HYDROMETER PARTICLE-SIZE DISTRIBUTION TESTING

Dear Mette,

Re: WAITAKERE LHRA – MURIWAI GROUND INVESTIGATION

Your Reference:

Report Number: 63532#L/AL Waitakere LHRA

The following report presents the results of hydrometer particle-size distribution testing at BGL of a soil sample delivered to this laboratory during August 2023. Test results are summarised below, with page 3 showing a graph 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			Hydrometer Grading (% of Dry Mass)				
	Sample Number	Depth (m)	<b>GRAVEL</b> (2 – <9.50mm)	<b>SAND</b> (0.06 – 2mm)	SILT FRACTION (0.002 – 0.06mm)	CLAY FRACTION (< 0.002mm)	
BH-M01	S2	13.95 – 14.30	0	70	15	15	

The whole soil was used for this hydrometer test. As the organic content of the soil tested was very low, peroxide pretreatment was not carried out. A solid density of 2.65t/m³ was assumed for this hydrometer test, 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 sample as-received, and relate only to the sample 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



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.



Job Number:	63532#L	Sheet 1 of 1	Page 3 of 3
Reg. Number:	2806	Version No:	7
Report No:	63532#L/HYD Waitakere LHRA	Issue Date:	July 2022

# WAITAKERE LHRA - MURIWAI GROUND INVESTIGATION

### PARTICLE-SIZE DISTRIBUTION BY HYDROMETER

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

Tested By:	WEC	10-Aug-23
Compiled By:	WEC	11-Aug-23
Checked By:	JF	14-Aug-23

BH No: BH-M01 Sample No: S2 Depth: 13.95 - 14.30m

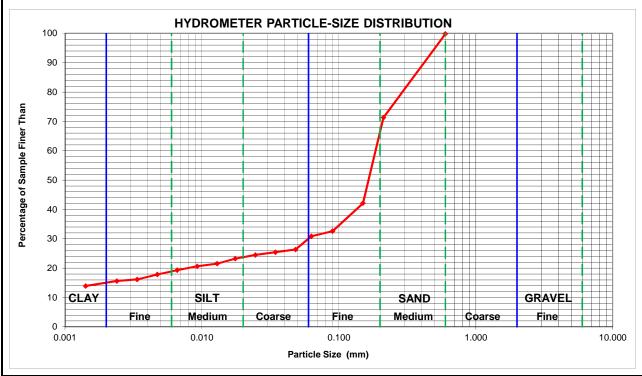
Water Content (%): 26.4

Sample History: Natural /-Air Dried / Oven Dried / Unknown pH of sedimentation suspension: 8.5

Particle Size (mm)	% Finer Than
0.600	100
0.212	71
0.150	42
0.090	33
0.063	31
0.048	26
0.034	25
0.025	24
0.018	23
0.013	22
0.0092	21
0.0066	19
0.0047	18
0.0034	16
0.0024	16
0.0014	14

<u>H\</u>	/DROMETER	TOTAL				
					i	
	GRAVEL:	(Medium)	< 9.5 - 6mm	0	0	%
		(Fine)	6 - 2mm	0		
					_	
		(Coarse)	2.0 - 0.6mm	0		
	SAND:	(Medium)	0.6 - 0.2mm	33	70	%
		(Fine)	0.2 - 0.06mm	37		
					•	
	CII T	(Coarse)	0.06 - 0.02mm	6		
	SILT FRACTION:	(Medium)	0.02 - 0.006mm	5	15	%
	TRACTION.	(Fine)	0.006 - 0.002mm	4		
,						
	CLAY F	RACTION:	< 0.002mm		15	%
	•		•		100%	

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





Babbage Geotechnical Laboratory Level 4

68 Beach Road P O Box 2027 Auckland 1010 Telephone E-mail

New Zealand 64-9-367 4954

wec@babbage.co.nz

Page 1 of 1

Please reply to: W.E. Campton

**GHD Limited** PO Box 6543 Wellesley Street Auckland 1141

Attention: **METTE van LITH**  Job Number: 63532#L

**BGL** Registration Number: 2806

Checked by: WEC

22<sup>nd</sup> September 2023

### **DETECTION OF THE PRESENCE OF ALLOPHANE**

Dear Mette,

WAITAKERE LHRA – MURIWAI GROUND INVESTIGATION Re:

Your Reference:

Report Number: 63532#L/AL Waitakere LHRA

The following table presents the results of 'Detection of the Presence of Allophane in Soils' testing at BGL of a soil sample delivered to this laboratory during August 2023. This sample was tested in accordance with the following standard:

**Detection of Presence of Allophane in Soils:** NZS4402:1986:Test 3.4

Borehole Number	Sample Number	Depth (m)	Allophane Content	
BH-M08	<b>S2</b>	10.00 – 10.10	< 5%	

Please note that the test results relate only to the sample as-received, and relate only to the sample 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** 



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

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

Page 1 of 69

GHD Limited PO Box 6543 Wellesley Street Auckland 1141 Job Number: 63532#L

BGL Registration Number: 2806

Checked by: WEC

2<sup>nd</sup> October 2023

Attention: METTE van LITH

### **UNCONFINED COMPRESSIVE STRENGTH (UCS) TESTING**

Dear Mette,

Re: WAITAKERE LHRA – MURIWAI GROUND INVESTIGATION

Your Reference:

Report Number: 63532#L/AL Waitakere LHRA

The following report presents the results of Uniaxial Unconfined Compressive Strength Testing at BGL of rock core samples delivered to this laboratory on the 18<sup>th</sup> of September 2023. These samples were tested in accordance with the following standards:

Water Content: NZS4402:1986:Test 2.1
Unconfined Compressive Strength Test: NZS4402:1986:Test 6.3.1

The table below summarises the test results, with the following pages presenting sample measurements and test data.

		FAILURE CONDITIONS					
Borehole Number	Sample Number	Depth (m)	Unconfined	Strain a	t Failure	Esilono Mada	
		, ,	Compressive Strength (kPa)	%	mm	Failure Mode	
BH-M02	<b>S</b> 1	26.50 – 26.75	270	0.74	0.89	planar	
BH-M02	<b>S</b> 2	29.69 – 29.92	370	0.75	0.86	planar	
BH-M02	<b>S</b> 3	36.35 – 36.65	180	0.50	0.61	planar	
BH-M02	<b>S</b> 4	40.80 – 41.00	180	0.46	0.55	planar	



			FAILURE CONDITIONS			s
Borehole Number	Sample Number	Depth (m)	Unconfined Compressive	Strain a	t Failure	Failure Mode
			Strength (kPa)	%	mm	i anure woue
BH-M02	S5	53.30 - 53.90	1,800	0.49	0.59	brittle
BH-M02	S6	55.20 - 55.50	1,200	0.52	0.63	planar
BH-M02	<b>S</b> 7	55.80 – 56.11	1,300	0.42	0.51	brittle
BH-M02	S8	56.50 - 56.90	1,100	0.50	0.60	brittle
BH-M02	S9	64.44 – 64.72	1,300	0.45	0.55	brittle
BH-M02	S10	67.93 – 68.33	800	0.48	0.58	brittle
BH-M02	S11	74.20 – 74.50	700	0.59	0.71	brittle
BH-M02	S12	76.13 – 76.40	560	0.43	0.51	brittle
BH-M02	S13	78.14 – 78.47	1,000	0.45	0.54	brittle
BH-M03*	UCS01	9.93 – 10.13	140	1.0	0.81	plastic / brittle
BH-M03	UCS02	16.00 – 16.27	280	1.0	1.2	brittle
BH-M03	UCS03	29.55 – 29.75	110	0.75	0.81	planar
BH-M03	UCS04	31.95 – 32.23	330	1.7	2.0	planar
BH-M03	UCS05	33.76 – 34.06	400	0.55	0.67	planar / brittle
BH-M03	UCS06	37.00 – 37.25	270	0.60	0.72	planar / brittle
BH-M03	UCS07	40.14 – 40.43	92	0.74	0.85	plastic
BH-M03	UCS08	41.15 – 41.43	720	0.81	0.94	planar
BH-M03	UCS09	50.73 – 51.00	850	0.62	0.74	brittle



Job Number: 63532#L 2<sup>nd</sup> October 2023 Page 3 of 69

\*Please note that the sample indicated with an asterisk (\*) was less than that required by the test standard i.e. "The test is limited to specimens in the form of right cylinders of height approximately equal to twice the diameter", therefore the results for this sample are not IANZ endorsed. In our experience the UCS value determined for this sample will be higher than if the sample had a length of twice the diameter (opinion not IANZ endorsed).

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. As per the reporting requirements of NZS4402: 1986: Test 6.3.1: UCS, dry density is reported to the nearest 0.05t/m³, the unconfined compressive strength is reported to two significant figures, and the strain & rate of axial compression at failure is reported to two significant figures.

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



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 BGI



Job No:	Reg. No:	Report No:	Page 4 of 69			
63532#L	2806	63532#L/UCS Waitakere LHRA	Version 3, July 2022			
PROJECT:		WAITAKERE LHRA - MURIWAI GROUND INVESTIGATION				

Unconfined Compressive Strength of Cohesive Soils

Test Methods: NZS4402: 1986: Test 2.1 / Test 6.3.1

		<u> </u>
Tested By:	WEC	27-Sep-23
Compiled By:	WEC	28-Sep-23
Checked By:	JF	2-Oct-23

Borehole: **BH-M02** Sample Number: **S1** Depth: **26.50 – 26.75m** 

Time (minutes)	Compression Gauge (mm)	Specimen Compression (mm)	Strain	Load Gauge (mm)	Axial Force (N)	Corrected Area (mm²)	Axial Stress (kPa)
0.00	9.799	0.000	0.000	7.776	0.0	2878.6	0
0.38	9.902	0.102	0.001	7.783	32.7	2881.0	11
0.75	9.996	0.197	0.002	7.793	83.7	2883.3	29
1.12	10.084	0.285	0.002	7.807	155.2	2885.4	54
1.50	10.166	0.367	0.003	7.823	236.7	2887.4	82
1.87	10.250	0.450	0.004	7.841	327.2	2889.4	113
2.23	10.331	0.531	0.004	7.862	428.8	2891.4	148
2.62	10.370	0.571	0.005	7.871	475.2	2892.3	164
2.98	10.445	0.645	0.005	7.892	582.1	2894.1	201
3.35	10.524	0.724	0.006	7.912	681.2	2896.1	235
3.73	10.602	0.803	0.007	7.928	763.6	2898.0	264
4.10	10.686	0.886	0.007	7.934	794.7	2900.0	274
4.37	10.737	0.938	0.008	7.913	688.2	2901.3	237
4.50	10.768	0.968	0.008	7.904	639.7	2902.0	220
4.65	10.792	0.993	0.008	7.897	604.7	2902.6	208
4.78	10.821	1.022	0.009	7.889	564.1	2903.3	194
4.92	10.865	1.066	0.009	7.884	539.4	2904.4	186
5.07	10.917	1.117	0.009	7.880	523.4	2905.6	180
5.20	10.999	1.199	0.010	7.877	504.1	2907.6	173
5.33	11.098	1.299	0.011	7.866	452.2	2910.1	155

**Unconfined Compressive Strength:** 

270

**kPa** 



Job No:	Reg. No:	Report No:	Page 5 of 69
63532#L	2806	63532#L/UCS Waitakere LHRA	Version 3, July 2022

# WAITAKERE LHRA - MURIWAI GROUND INVESTIGATION

Unconfined Compressive Strength of Cohesive Soils

Test Methods: NZS4402: 1986: Test 2.1 / Test 6.3.1

Tested By:	WEC	27-Sep-23
Compiled By:	WEC	28-Sep-23
Checked By:	JF	2-Oct-23

Borehole: **BH-M02** Sample Number: **S1** Depth: 26,50 - 26,75m

Test Performed on: rock / whole soil

Sample History: disturbed / undisturbed / remoulded / recompacted / unknown

Sample Method & Type: from core sample / from tube sample

Initial Diameter: 60.54 mm
Initial Length: 119.87 mm

Initial Mass: 663.65

Initial Bulk Density: 1.92 t/m<sup>3</sup>

Initial Dry Density: 1.50 t/m<sup>3</sup>

Water Content After Test: 29.0 %

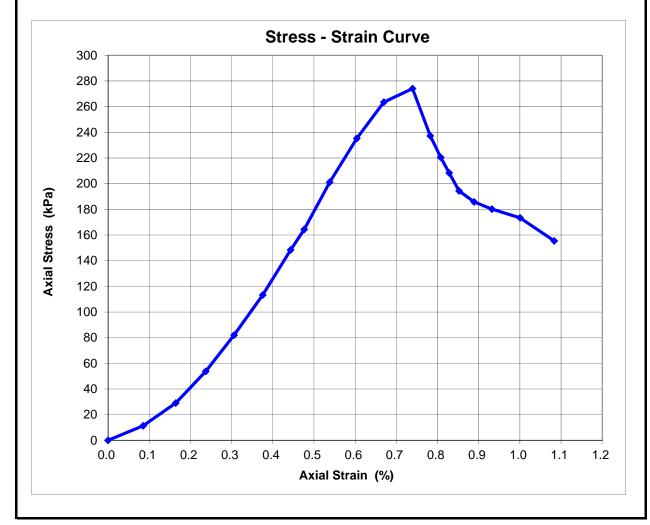
#### **Failure Conditions:**

Strain at failure: 0.74 %

Compression at failure: 0.89 mm

Rate of Compression: 0.22 mm / minute

Mode of Failure: planar





Job No:	Reg. No:	Report No:	Page 6 of 69
63532#L	2806	63532#L/UCS Waitakere LHRA	Version 3, July 2022

# WAITAKERE LHRA - MURIWAI GROUND INVESTIGATION

Unconfined Compressive Strength ofTested By:WEC27-Sep-23Cohesive SoilsCompiled By:WEC28-Sep-23Test Methods: NZS4402: 1986: Test 2.1 / Test 6.3.1Checked By:JF2-Oct-23

Borehole: BH-M02 Sample Number: S1 Depth: 26.50 - 26.75m

Sample Description (not part of BGL IANZ Accreditation):

SANDSTONE, fine to coarse, extremely weak, orange, weakly cemented.

### **SAMPLE BEFORE TEST**

### **SAMPLE AFTER TEST**







Job No:	Reg. No:	Report No:	Page 7 of 69
63532#L	2806	63532#L/UCS Waitakere LHRA	Version 3, July 2022
	WAITAKERE LHRA - MURIWAI		

### WAITAKERE LHRA - MURIWAI GROUND INVESTIGATION

Unconfined Compressive Strength of Cohesive Soils
Test Methods: NZS4402: 1986: Test 2.1 / Test 6.3.1

Tested By:	WEC	27-Sep-23
Compiled By:	WEC	28-Sep-23
Checked By:	JF	2-Oct-23

Borehole: **BH-M02** Sample Number: **\$2** Depth: **29.69 – 29.92m** 

	(mm²)	Axial Stress (kPa)
0.0	2908.8	0
74.5	2911.3	26
172.1	2913.5	59
285.5	2915.7	98
415.7	2917.6	142
477.3	2918.7	164
621.3	2920.5	213
744.9	2922.6	255
884.4	2923.3	303
979.3	2925.2	335
1045.2	2927.4	357
1065.9	2928.4	364
1083.5	2929.5	370
1094.3	2930.7	373
1093.6	2931.9	373
1076.2	2933.2	367
1010.3	2934.7	344
884.6	2936.5	301
800.0	2938.2	272
745.2	2939.7	254
698.7	2941.2	238
660.4	2942.5	224
625.5	2943.8	212
597.5	2945.0	203
569.7	2946.4	193
542.9	2947.8	184
454.1	2949.0	154

Unconfined Compressive Strength:

370 kPa



Job No:	Reg. No:	Report No:	Page 8 of 69
63532#L	2806	63532#L/UCS Waitakere LHRA	Version 3, July 2022

### WAITAKERE LHRA - MURIWAI GROUND **INVESTIGATION**

**Unconfined Compressive Strength of Cohesive Soils** 

Test Methods: NZS4402: 1986: Test 2.1 / Test 6.3.1

Tested By:	WEC	27-Sep-23
Compiled By:	WEC	28-Sep-23
Checked By:	JF	2-Oct-23

Depth: 29.69 - 29.92m Borehole: BH-M02 Sample Number: **S2** 

Test Performed on: rock / whole soil

Sample History: disturbed / remoulded / recompacted / unknown

Sample Method & Type: from core sample / from tube sample

> **Initial Diameter:** 60.86 mm **Initial Length:** 115.09 Initial Mass: 641.83

Initial Bulk Density: 1.92

1.45 t/m<sup>3</sup> Initial Dry Density:

Water Content After Test: 32.1

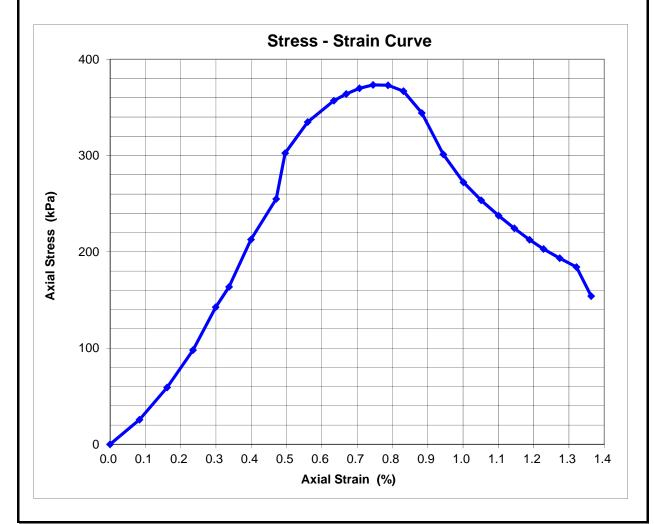
#### **Failure Conditions:**

0.75 Strain at failure:

Compression at failure: 0.86 mm

Rate of Compression: 0.21 mm / minute

Mode of Failure: planar





Job No:	Reg. No:	Report No:	Page 9 of 69
63532#L	2806	63532#L/UCS Waitakere LHRA	Version 3, July 2022

# WAITAKERE LHRA - MURIWAI GROUND INVESTIGATION

 Unconfined Compressive Strength of
 Tested By:
 WEC
 27-Sep-23

 Cohesive Soils
 Compiled By:
 WEC
 28-Sep-23

 Test Methods:
 NZS4402: 1986: Test 2.1 / Test 6.3.1
 Checked By:
 JF
 2-Oct-23

Borehole: BH-M02 Sample Number: S2 Depth: 29.69 - 29.92m

Sample Description (not part of BGL IANZ Accreditation):

SANDSTONE, fine to coarse, extremely weak, orange, weakly cemented.

### **SAMPLE BEFORE TEST**

### **SAMPLE AFTER TEST**





Job No:	Reg. No:	Report No:	Page 10 of 69
63532#L	2806	63532#L/UCS Waitakere LHRA	Version 3, July 2022
	10/0	TAILEDELLIDA	A ALLED IVA / A L

## WAITAKERE LHRA - MURIWAI GROUND INVESTIGATION

Unconfined Compressive Strength of Cohesive Soils
Test Methods: NZS4402: 1986: Test 2.1 / Test 6.3.1

Tested By:	WEC	27-Sep-23
Compiled By:	WEC	28-Sep-23
Checked By:	JF	2-Oct-23

Borehole: **BH-M02** Sample Number: **\$3** Depth: **36.35 – 36.65m** 

Time (minutes)	Compression Gauge (mm)	Specimen Compression (mm)	Strain	Load Gauge (mm)	Axial Force (N)	Corrected Area (mm²)	Axial Stress (kPa)
0.00	9.551	0.000	0.000	7.776	0.0	2738.6	0
0.38	9.641	0.090	0.001	7.784	41.7	2740.7	15
0.75	9.727	0.176	0.001	7.795	94.7	2742.6	35
1.13	9.811	0.260	0.002	7.808	160.2	2744.6	58
1.50	9.885	0.334	0.003	7.823	237.5	2746.2	86
1.87	9.964	0.413	0.003	7.841	327.3	2748.1	119
2.25	10.043	0.492	0.004	7.860	419.8	2749.9	153
2.62	10.105	0.554	0.005	7.870	472.9	2751.3	172
2.98	10.157	0.606	0.005	7.877	507.8	2752.5	185
3.37	10.268	0.717	0.006	7.875	497.8	2755.1	181
3.60	10.418	0.866	0.007	7.861	425.4	2758.5	154
3.83	10.491	0.939	0.008	7.853	384.4	2760.2	139
4.08	10.552	1.001	0.008	7.846	352.8	2761.6	128
4.32	10.614	1.063	0.009	7.839	317.4	2763.1	115
4.55	10.671	1.120	0.009	7.831	278.6	2764.4	101

**Unconfined Compressive Strength:** 180

**kPa** 



Job No:	Reg. No:	Report No:	Page 11 of 69
63532#L	2806	63532#L/UCS Waitakere LHRA	Version 3, July 2022

## WAITAKERE LHRA - MURIWAI GROUND INVESTIGATION

**Unconfined Compressive Strength of Cohesive Soils** 

Test Methods: NZS4402: 1986: Test 2.1 / Test 6.3.1

Tested By:	WEC	27-Sep-23
Compiled By:	WEC	28-Sep-23
Checked By:	JF	2-Oct-23

Borehole: **BH-M02** Sample Number: **\$3** Depth: 36.35 - 36.65m

Test Performed on: rock / whole soil

Sample History: disturbed / undisturbed / remoulded / recompacted / unknown

t/m<sup>3</sup>

1.65

Sample Method & Type: from core sample / from tube sample

Initial Diameter: 59.05 mm

Initial Length: 120.04 mm

Initial Mass: 662.61 g

Initial Bulk Density: 2.02 t/m<sup>3</sup>

Water Content After Test: 23.8 %

**Initial Dry Density:** 

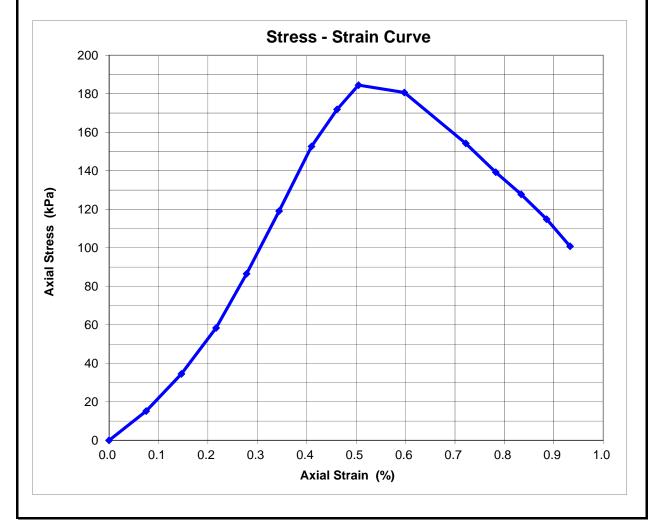
#### **Failure Conditions:**

Strain at failure: 0.50 %

Compression at failure: 0.61 mm

Rate of Compression: 0.20 mm / minute

Mode of Failure: planar





Job No:	Reg. No:	Report No:	Page 12 of 69
63532#L	2806	63532#L/UCS Waitakere LHRA	Version 3, July 2022

## WAITAKERE LHRA - MURIWAI GROUND INVESTIGATION

 Unconfined Compressive Strength of
 Tested By:
 WEC
 27-Sep-23

 Cohesive Soils
 Compiled By:
 WEC
 28-Sep-23

 Test Methods:
 NZS4402: 1986: Test 2.1 / Test 6.3.1
 Checked By:
 JF
 2-Oct-23

Borehole: BH-M02 Sample Number: \$3 Depth: 36.35 - 36.65m

Sample Description (not part of BGL IANZ Accreditation):

SANDSTONE, fine to coarse, extremely weak, orange, weakly cemented.

#### **SAMPLE BEFORE TEST**







Job No:	Reg. No:	Report No:	Page 13 of 69
63532#L	2806	63532#L/UCS Waitakere LHRA	Version 3, July 2022
	\A/ A	TAVEDELUDA	

# WAITAKERE LHRA - MURIWAI GROUND INVESTIGATION

Unconfined Compressive Strength of Cohesive Soils
Test Methods: NZS4402: 1986: Test 2.1 / Test 6.3.1

Tested By:	WEC	27-Sep-23
Compiled By:	WEC	28-Sep-23
Checked By:	JF	2-Oct-23

Borehole: **BH-M02** Sample Number: **\$4** Depth: **40.80 – 41.00m** 

Time (minutes)	Compression Gauge (mm)	Specimen Compression (mm)	Strain	Load Gauge (mm)	Axial Force (N)	Corrected Area (mm²)	Axial Stress (kPa)
0.00	4.440	0.000	0.000	7.773	0.0	2885.0	0
0.38	4.510	0.070	0.001	7.779	33.9	2886.7	12
0.75	4.581	0.141	0.001	7.788	74.8	2888.4	26
1.12	4.649	0.209	0.002	7.798	127.1	2890.0	44
1.50	4.711	0.271	0.002	7.811	194.2	2891.5	67
1.87	4.774	0.334	0.003	7.826	266.4	2893.0	92
2.23	4.838	0.398	0.003	7.842	347.4	2894.6	120
2.62	4.903	0.463	0.004	7.858	429.8	2896.2	148
2.98	4.940	0.500	0.004	7.865	463.9	2897.1	160
3.35	4.990	0.550	0.005	7.875	513.7	2898.3	177
3.73	5.157	0.716	0.006	7.825	263.1	2902.3	91
4.10	5.233	0.793	0.007	7.820	236.5	2904.2	81
4.48	5.325	0.884	0.007	7.810	185.6	2906.4	64
4.85	5.409	0.968	0.008	7.792	98.3	2908.5	34

**Unconfined Compressive Strength:** 

180 kPa



Job No:	Reg. No:	Report No:	Page 14 of 69
63532#L	2806	63532#L/UCS Waitakere LHRA	Version 3, July 2022

PROJECT: WA

### #L | 2806 | 63532#L/UCS Waitakere LHRA | Version 3, July 2022 WAITAKERE LHRA - MURIWAI GROUND

**INVESTIGATION** 

Unconfined Compressive Strength of Cohesive Soils

Test Methods: NZS4402: 1986: Test 2.1 / Test 6.3.1

Tested By:	WEC	27-Sep-23
Compiled By:	WEC	28-Sep-23
Checked By:	JF	2-Oct-23

Borehole: **BH-M02** Sample Number: **\$4** Depth: **40.80 - 41.00m** 

Test Performed on: rock / whole soil

Sample History: disturbed / undisturbed / remoulded / recompacted / unknown

Sample Method & Type: from core sample / from tube sample

Initial Diameter: 60.61 mm

Initial Length: 119.91 mm

Initial Mass: 690.28

Initial Bulk Density: 2.00 t/m<sup>3</sup>

Initial Dry Density: 1.60 t/m<sup>3</sup>

Water Content After Test: 24.6 %

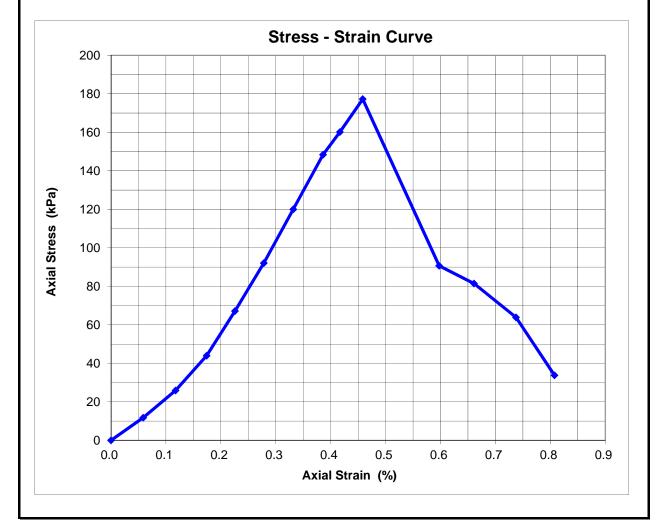
#### **Failure Conditions:**

Strain at failure: 0.46 %

Compression at failure: 0.55 mm

Rate of Compression: 0.16 mm / minute

Mode of Failure: planar





Job No:	Reg. No:	Report No:	Page 15 of 69
63532#L	2806	63532#L/UCS Waitakere LHRA	Version 3, July 2022

## WAITAKERE LHRA - MURIWAI GROUND INVESTIGATION

<b>Unconfined Compressive Strength o</b>	of Tested By:	WEC	27-Sep-23
Cohesive Soils	Compiled By:	WEC	28-Sep-23
Test Methods: NZS4402: 1986: Test 2.1 / Test 6.3.1	Checked By:	JF	2-Oct-23

Borehole: BH-M02 Sample Number: S4 Depth: 40.80 - 41.00m

Sample Description (not part of BGL IANZ Accreditation):

SANDSTONE, fine to coarse, extremely weak, orange, weakly cemented.

#### **SAMPLE BEFORE TEST**







Job No:	Reg. No:	Report No:	Page 16 of 69
63532#L	2806	63532#L/UCS Waitakere LHRA	Version 3, July 2022
	WA	TAKERE LHRA	- MURIWAI

### VAITAKERE LHRA - MURIWAI GROUND INVESTIGATION

Unconfined Compressive Strength of Cohesive Soils
Test Methods: NZS4402: 1986: Test 2.1 / Test 6.3.1

Tested By:	WEC	27-Sep-23
Compiled By:	WEC	28-Sep-23
Checked By:	JF	2-Oct-23

Borehole: BH-M02 Sample Number: \$5 Depth: 53.30 - 53.90m

Time (minutes)	Compression Gauge (mm)	Specimen Compression (mm)	Strain	Load Gauge (mm)	Axial Force (N)	Corrected Area (mm²)	Axial Stress (kPa)
0.00	4.685	0.000	0.000	7.784	0.0	2864.5	0
0.28	4.729	0.043	0.000	7.810	128.6	2865.6	45
0.57	4.757	0.072	0.001	7.843	295.4	2866.2	103
0.87	4.778	0.092	0.001	7.870	428.5	2866.7	149
1.15	4.809	0.123	0.001	7.893	547.1	2867.5	191
1.43	4.838	0.153	0.001	7.933	747.5	2868.2	261
1.73	4.865	0.180	0.001	7.977	965.0	2868.8	336
2.02	4.888	0.203	0.002	8.024	1205.3	2869.4	420
2.30	4.911	0.225	0.002	8.074	1452.0	2869.9	506
2.60	4.930	0.245	0.002	8.124	1706.6	2870.4	595
2.88	4.949	0.263	0.002	8.175	1959.1	2870.8	682
3.17	4.964	0.278	0.002	8.226	2219.3	2871.2	773
3.47	4.978	0.292	0.002	8.278	2478.8	2871.5	863
3.75	4.993	0.307	0.003	8.329	2735.5	2871.9	953
4.03	5.009	0.323	0.003	8.379	2986.8	2872.3	1040
4.33	5.026	0.341	0.003	8.429	3234.2	2872.7	1126
4.62	5.043	0.358	0.003	8.478	3483.5	2873.1	1212
4.92	5.062	0.377	0.003	8.526	3725.5	2873.5	1296
5.20	5.085	0.400	0.003	8.575	3967.8	2874.1	1381
5.48	5.107	0.421	0.003	8.623	4208.7	2874.6	1464
5.78	5.128	0.443	0.004	8.670	4444.2	2875.1	1546
6.07	5.151	0.465	0.004	8.716	4675.3	2875.7	1626
6.35	5.174	0.489	0.004	8.762	4906.3	2876.2	1706
6.50	5.187	0.501	0.004	8.783	5012.7	2876.5	1743
6.63	5.200	0.514	0.004	8.803	5114.3	2876.8	1778
6.77	5.218	0.532	0.004	8.821	5205.8	2877.3	1809
6.92	5.240	0.555	0.005	8.836	5282.4	2877.8	1836
7.05	5.279	0.594	0.005	8.838	5291.7	2878.7	1838
7.18	6.520	1.834	0.015	7.864	401.3	2908.8	138
7.33	6.537	1.852	0.015	7.858	372.1	2909.3	128
7.47	6.540	1.854	0.015	7.857	362.7	2909.3	125

Unconfined Compressive Strength: 1,800

**kPa** 



Job No:	Reg. No:	Report No:	Page 17 of 69
63532#L	2806	63532#L/UCS Waitakere LHRA	Version 3, July 2022

## WAITAKERE LHRA - MURIWAI GROUND INVESTIGATION

Unconfined Compressive Strength of Cohesive Soils

Test Methods: NZS4402: 1986: Test 2.1 / Test 6.3.1

Tested By:	WEC	27-Sep-23
Compiled By:	WEC	28-Sep-23
Checked By:	JF	2-Oct-23

Borehole: BH-M02 Sample Number: \$5 Depth: 53.30 - 53.90m

Test Performed on: rock / whole soil

Sample History: disturbed / undisturbed / remoulded / recompacted / unknown

Sample Method & Type: from core sample / from tube sample

Initial Diameter: 60.39 mm

Initial Length: 120.43 mm

Initial Mass: 662.48 g

Initial Bulk Density: 1.92 t/m<sup>3</sup>

Initial Dry Density: 1.55 t/m<sup>3</sup>

Water Content After Test: 24.7 %

#### **Failure Conditions:**

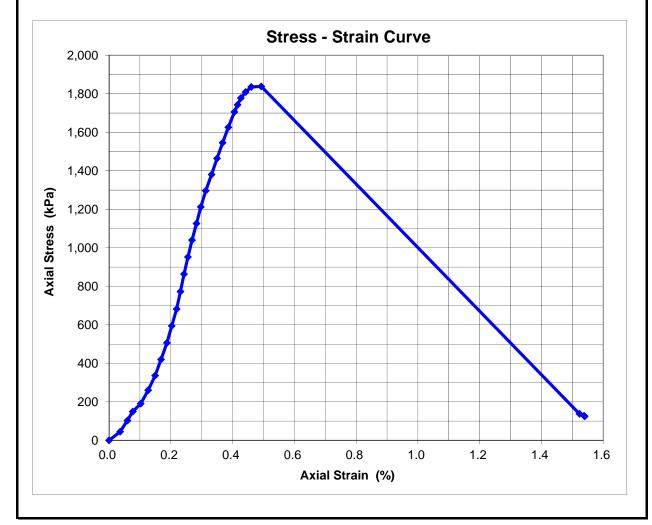
Strain at failure: 0.49 %

Compression at failure: 0.59 mm

0.084 mm / minute

Mode of Failure: brittle

Rate of Compression:





Job No:	Reg. No:	Report No:	Page 18 of 69
63532#L	2806	63532#L/UCS Waitakere LHRA	Version 3, July 2022

## WAITAKERE LHRA - MURIWAI GROUND INVESTIGATION

 Unconfined Compressive Strength of
 Tested By:
 WEC
 27-Sep-23

 Cohesive Soils
 Compiled By:
 WEC
 28-Sep-23

 Test Methods:
 NZS4402: 1986: Test 2.1 / Test 6.3.1
 Checked By:
 JF
 2-Oct-23

Borehole: BH-M02 Sample Number: S5 Depth: 53.30 - 53.90m

Sample Description (not part of BGL IANZ Accreditation):

SANDSTONE, fine to coarse, very weak, orange, weakly cemented.

#### **SAMPLE BEFORE TEST**







Job No:	Reg. No:	Report No:	Page 19 of 69
63532#L	2806	63532#L/UCS Waitakere LHRA	Version 3, July 2022
	WA	TAKERE LHRA	- MURIWAI

### VAITAKERE LHRA - MURIWAI GROUND INVESTIGATION

Unconfined Compressive Strength of Cohesive Soils
Test Methods: NZS4402: 1986: Test 2.1 / Test 6.3.1

Tested By:	WEC	27-Sep-23
Compiled By:	WEC	28-Sep-23
Checked By:	JF	2-Oct-23

Borehole: **BH-M02** Sample Number: **S6** Depth: **55.20 – 55.50m** 

Time (minutes)	Compression Gauge (mm)	Specimen Compression (mm)	Strain	Load Gauge (mm)	Axial Force (N)	Corrected Area (mm²)	Axial Stress (kPa)
0.00	1.892	0.000	0.000	6.499	0.0	2863.8	0
0.38	1.957	0.065	0.001	6.513	69.8	2865.4	24
0.75	2.010	0.118	0.001	6.534	177.4	2866.7	62
1.12	2.050	0.159	0.001	6.559	302.4	2867.6	105
1.50	2.085	0.194	0.002	6.585	432.2	2868.5	151
1.87	2.104	0.213	0.002	6.599	504.0	2868.9	176
2.23	2.143	0.251	0.002	6.632	669.0	2869.8	233
2.62	2.178	0.286	0.002	6.669	851.6	2870.7	297
2.98	2.213	0.321	0.003	6.709	1052.0	2871.5	366
3.37	2.245	0.354	0.003	6.752	1267.5	2872.3	441
3.73	2.278	0.387	0.003	6.796	1491.1	2873.1	519
4.10	2.308	0.417	0.003	6.843	1724.9	2873.8	600
4.48	2.338	0.447	0.004	6.890	1964.6	2874.5	683
4.85	2.368	0.476	0.004	6.939	2209.6	2875.3	768
5.22	2.396	0.505	0.004	6.989	2458.9	2875.9	855
5.60	2.425	0.534	0.004	7.038	2705.9	2876.6	941
5.97	2.453	0.561	0.005	7.088	2956.9	2877.3	1028
6.33	2.481	0.589	0.005	7.136	3196.5	2878.0	1111
6.72	2.518	0.626	0.005	7.177	3403.6	2878.9	1182
7.08	3.420	1.528	0.013	6.558	298.3	2900.8	103
7.30	3.476	1.584	0.013	6.556	285.6	2902.2	98

Unconfined Compressive Strength: 1,200

**kPa** 



Job No:	Reg. No:	Report No:	Page 20 of 69
63532#L	2806	63532#L/UCS Waitakere LHRA	Version 3, July 2022

### **WAITAKERE LHRA - MURIWAI GROUND INVESTIGATION**

**Unconfined Compressive Strength of Cohesive Soils** 

Test Methods: NZS4402: 1986: Test 2.1 / Test 6.3.1

Tested By: WEC 27-Sep-23 Compiled By: WEC 28-Sep-23 Checked By: 2-Oct-23

Depth: 55.20 - 55.50m Borehole: BH-M02 Sample Number: \$6

Test Performed on: rock / whole soil

Sample History: disturbed / remoulded / recompacted / unknown

Sample Method & Type: from core sample / from tube sample

> **Initial Diameter:** 60.39 mm **Initial Length:** 119.93 **Initial Mass:** 673.48

Initial Bulk Density: 1.96

**Initial Dry Density:** 1.65 t/m<sup>3</sup>

Water Content After Test: 19.5

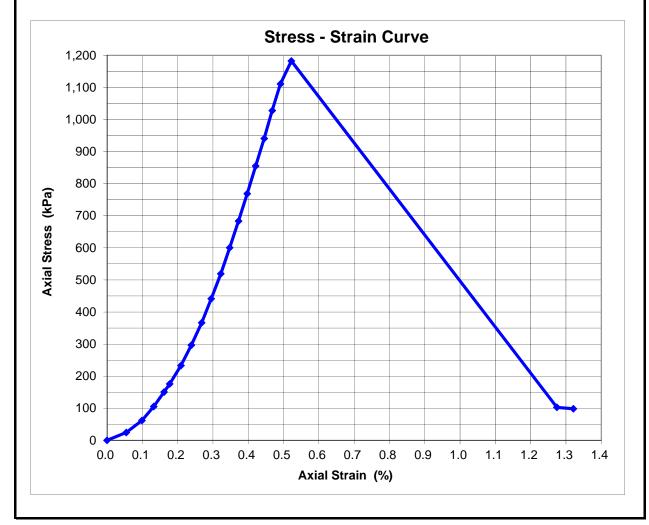
#### **Failure Conditions:**

Strain at failure: 0.52

Compression at failure: 0.63 mm

Rate of Compression: 0.093 mm / minute

Mode of Failure: planar





Job No:	Reg. No:	Report No:	Page 21 of 69
63532#L	2806	63532#L/UCS Waitakere LHRA	Version 3, July 2022

## WAITAKERE LHRA - MURIWAI GROUND INVESTIGATION

 Unconfined Compressive Strength of
 Tested By:
 WEC
 27-Sep-23

 Cohesive Soils
 Compiled By:
 WEC
 28-Sep-23

 Test Methods:
 NZS4402: 1986: Test 2.1 / Test 6.3.1
 Checked By:
 JF
 2-Oct-23

Borehole: BH-M02 Sample Number: S6 Depth: 55.20 - 55.50m

Sample Description (not part of BGL IANZ Accreditation):

SANDSTONE, fine to medium, very weak, dark orange, weakly cemented.

#### **SAMPLE BEFORE TEST**





Job No:	Reg. No:	Report No:	Page 22 of 69
63532#L	2806	63532#L/UCS Waitakere LHRA	Version 3, July 2022
	\ <b>\</b> \ \ \	TAVEDELUDA	MIIDIMAI

### WAITAKERE LHRA - MURIWAI GROUND INVESTIGATION

**Unconfined Compressive Strength of Cohesive Soils** 

Test Methods: NZS4402: 1986: Test 2.1 / Test 6.3.1

 Tested By:
 WEC
 27-Sep-23

 Compiled By:
 WEC
 28-Sep-23

 Checked By:
 JF
 2-Oct-23

Borehole: **BH-M02** Sample Number: **S7** Depth: **55.80** – **56.11m** 

Compression Gauge (mm)	Specimen Compression (mm)	Strain	Load Gauge (mm)	Axial Force (N)	Corrected Area (mm²)	Axial Stress (kPa)
1.386	0.000	0.000	6.505	0.0	2546.6	0
1.454	0.067	0.001	6.524	96.1	2548.0	38
1.513	0.127	0.001	6.549	220.5	2549.3	86
1.562	0.176	0.001	6.581	382.8	2550.3	150
1.575	0.189	0.002	6.601	483.1	2550.6	189
1.597	0.210	0.002	6.637	662.9	2551.1	260
1.622	0.235	0.002	6.678	870.6	2551.6	341
1.643	0.257	0.002	6.724	1099.3	2552.1	431
1.668	0.282	0.002	6.771	1338.4	2552.6	524
1.689	0.302	0.003	6.822	1590.9	2553.0	623
1.713	0.326	0.003	6.873	1846.5	2553.6	723
1.737	0.351	0.003	6.925	2109.3	2554.1	826
1.760	0.374	0.003	6.978	2373.9	2554.6	929
1.787	0.400	0.003	7.030	2635.4	2555.1	1031
1.813	0.426	0.004	7.080	2889.5	2555.7	1131
1.842	0.456	0.004	7.129	3134.5	2556.3	1226
1.893	0.507	0.004	7.164	3310.3	2557.4	1294
1.926	0.539	0.004	7.156	3266.8	2558.1	1277
2.475	1.088	0.009	6.759	1273.6	2569.9	496
			1			
	Gauge (mm)  1.386 1.454 1.513 1.562 1.575 1.597 1.622 1.643 1.668 1.689 1.713 1.737 1.760 1.787 1.813 1.842 1.893	Gauge (mm)         Compression (mm)           1.386         0.000           1.454         0.067           1.513         0.127           1.562         0.176           1.575         0.189           1.597         0.210           1.622         0.235           1.643         0.257           1.668         0.282           1.689         0.302           1.713         0.326           1.737         0.351           1.760         0.374           1.787         0.400           1.813         0.426           1.842         0.456           1.893         0.507           1.926         0.539	Gauge (mm)         Compression (mm)         Strain           1.386         0.000         0.000           1.454         0.067         0.001           1.513         0.127         0.001           1.562         0.176         0.001           1.575         0.189         0.002           1.597         0.210         0.002           1.622         0.235         0.002           1.643         0.257         0.002           1.668         0.282         0.002           1.689         0.302         0.003           1.713         0.326         0.003           1.737         0.351         0.003           1.760         0.374         0.003           1.813         0.426         0.004           1.842         0.456         0.004           1.893         0.507         0.004           1.926         0.539         0.004	Gauge (mm)         Compression (mm)         Strain         Load Gauge (mm)           1.386         0.000         0.000         6.505           1.454         0.067         0.001         6.524           1.513         0.127         0.001         6.549           1.562         0.176         0.001         6.581           1.575         0.189         0.002         6.601           1.597         0.210         0.002         6.637           1.622         0.235         0.002         6.678           1.643         0.257         0.002         6.724           1.688         0.282         0.002         6.771           1.689         0.302         0.003         6.822           1.713         0.326         0.003         6.873           1.737         0.351         0.003         6.925           1.760         0.374         0.003         7.030           1.813         0.426         0.004         7.080           1.842         0.456         0.004         7.164           1.926         0.539         0.004         7.156	Gauge (mm)         Compression (mm)         Strain (mm)         Load Gauge (mm)         Axial Force (N)           1.386         0.000         0.000         6.505         0.0           1.454         0.067         0.001         6.524         96.1           1.513         0.127         0.001         6.549         220.5           1.562         0.176         0.001         6.581         382.8           1.575         0.189         0.002         6.601         483.1           1.597         0.210         0.002         6.637         662.9           1.622         0.235         0.002         6.678         870.6           1.643         0.257         0.002         6.724         1099.3           1.668         0.282         0.002         6.771         1338.4           1.689         0.302         0.003         6.822         1590.9           1.713         0.326         0.003         6.873         1846.5           1.737         0.351         0.003         6.925         2109.3           1.760         0.374         0.003         7.030         2635.4           1.813         0.426         0.004         7.080         2889.5 <td>Gauge (mm)         Compression (mm)         Strain (mm)         Load Gauge (mm)         Axial Force (N)         Area (mm²)           1.386         0.000         0.000         6.505         0.0         2546.6           1.454         0.067         0.001         6.524         96.1         2548.0           1.513         0.127         0.001         6.549         220.5         2549.3           1.562         0.176         0.001         6.581         382.8         2550.3           1.575         0.189         0.002         6.601         483.1         2550.6           1.597         0.210         0.002         6.637         662.9         2551.1           1.622         0.235         0.002         6.678         870.6         2551.6           1.643         0.257         0.002         6.724         1099.3         2552.1           1.668         0.282         0.002         6.771         1338.4         2552.6           1.689         0.302         0.003         6.822         1590.9         2553.0           1.713         0.326         0.003         6.873         1846.5         2553.6           1.737         0.351         0.003         6.925</td>	Gauge (mm)         Compression (mm)         Strain (mm)         Load Gauge (mm)         Axial Force (N)         Area (mm²)           1.386         0.000         0.000         6.505         0.0         2546.6           1.454         0.067         0.001         6.524         96.1         2548.0           1.513         0.127         0.001         6.549         220.5         2549.3           1.562         0.176         0.001         6.581         382.8         2550.3           1.575         0.189         0.002         6.601         483.1         2550.6           1.597         0.210         0.002         6.637         662.9         2551.1           1.622         0.235         0.002         6.678         870.6         2551.6           1.643         0.257         0.002         6.724         1099.3         2552.1           1.668         0.282         0.002         6.771         1338.4         2552.6           1.689         0.302         0.003         6.822         1590.9         2553.0           1.713         0.326         0.003         6.873         1846.5         2553.6           1.737         0.351         0.003         6.925

Unconfined Compressive Strength: 1,300 kPa



Job No:	Reg. No:	Report No:	Page 23 of 69
63532#L	2806	63532#L/UCS Waitakere LHRA	Version 3, July 2022

## WAITAKERE LHRA - MURIWAI GROUND INVESTIGATION

**Unconfined Compressive Strength of Cohesive Soils** 

Test Methods: NZS4402: 1986: Test 2.1 / Test 6.3.1

Tested By:	WEC	27-Sep-23
Compiled By:	WEC	28-Sep-23
Checked By:	JF	2-Oct-23

Borehole: **BH-M02** Sample Number: **\$7** Depth: **55.80 – 56.11m** 

Test Performed on: rock / whole soil

Sample History: disturbed / undisturbed / remoulded / recompacted / unknown

Sample Method & Type: from core sample / from tube sample

Initial Diameter: 56.94 mm

Initial Length: 120.02 mm

Initial Mass: 586.43

Initial Bulk Density: 1.92 t/m<sup>3</sup>

Initial Dry Density: 1.60 t/m<sup>3</sup>

Water Content After Test: 20.6 %

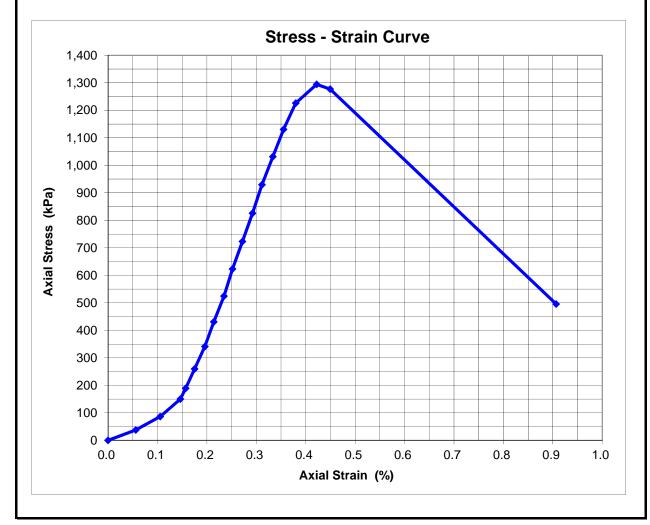
#### **Failure Conditions:**

Strain at failure: 0.42 %

Compression at failure: 0.51 mm

Rate of Compression: 0.085 mm / minute

Mode of Failure: brittle





Job No:	Reg. No:	Report No:	Page 24 of 69
63532#L	2806	63532#L/UCS Waitakere LHRA	Version 3, July 2022

## WAITAKERE LHRA - MURIWAI GROUND INVESTIGATION

 Unconfined Compressive Strength of
 Tested By:
 WEC
 27-Sep-23

 Cohesive Soils
 Compiled By:
 WEC
 28-Sep-23

 Test Methods:
 NZS4402: 1986: Test 2.1 / Test 6.3.1
 Checked By:
 JF
 2-Oct-23

Borehole: BH-M02 Sample Number: S7 Depth: 55.80 - 56.11m

Sample Description (not part of BGL IANZ Accreditation):

SANDSTONE, fine to coarse, very weak, dark orange, weakly to moderately cemented.

#### **SAMPLE BEFORE TEST**







Job No:	Reg. No:	Report No:	Page 25 of 69
63532#L	2806	63532#L/UCS Waitakere LHRA	Version 3, July 2022
	14/4		

### WAITAKERE LHRA - MURIWAI GROUND INVESTIGATION

Unconfined Compressive Strength of Cohesive Soils
Test Methods: NZS4402: 1986: Test 2.1 / Test 6.3.1

Tested By:	WEC	27-Sep-23
Compiled By:	WEC	28-Sep-23
Checked By:	JF	2-Oct-23

Borehole: **BH-M02** Sample Number: **\$8** Depth: **56.50 - 56.90m** 

Time (minutes)	Compression Gauge (mm)	Specimen Compression (mm)	Strain	Load Gauge (mm)	Axial Force (N)	Corrected Area (mm²)	Axial Stress (kPa)
0.00	6.645	0.000	0.000	6.499	0.0	2738.4	0
0.13	6.672	0.027	0.000	6.505	28.1	2739.0	10
0.27	6.700	0.055	0.000	6.510	57.2	2739.6	21
0.42	6.727	0.082	0.001	6.516	85.9	2740.2	31
0.55	6.758	0.113	0.001	6.522	116.8	2741.0	43
0.70	6.786	0.141	0.001	6.530	154.3	2741.6	56
0.83	6.815	0.170	0.001	6.536	187.3	2742.2	68
0.97	6.839	0.193	0.002	6.545	230.4	2742.8	84
1.12	6.854	0.209	0.002	6.554	276.7	2743.2	101
1.48	6.885	0.240	0.002	6.584	425.3	2743.9	155
1.85	6.901	0.256	0.002	6.595	481.1	2744.2	175
2.23	6.928	0.282	0.002	6.631	662.7	2744.8	241
2.60	6.959	0.313	0.003	6.670	858.5	2745.5	313
2.97	6.988	0.343	0.003	6.712	1070.9	2746.2	390
3.35	7.012	0.367	0.003	6.758	1298.5	2746.8	473
3.72	7.039	0.394	0.003	6.805	1533.7	2747.4	558
4.08	7.069	0.424	0.004	6.853	1778.0	2748.1	647
4.47	7.092	0.447	0.004	6.904	2035.1	2748.6	740
4.83	7.115	0.470	0.004	6.956	2294.8	2749.1	835
5.22	7.135	0.490	0.004	7.009	2560.3	2749.6	931
5.58	7.159	0.514	0.004	7.060	2818.1	2750.1	1025
5.93	7.223	0.577	0.005	7.078	2908.5	2751.6	1057
6.17	7.248	0.602	0.005	7,107	3050.2	2752.2	1108
6.42	7.997	1.352	0.011	6.548	246.9	2769.5	89

Unconfined Compressive Strength: 1,100 kPa



Job No:	Reg. No:	Report No:	Page 26 of 69
63532#L	2806	63532#L/UCS Waitakere LHRA	Version 3, July 2022

### **WAITAKERE LHRA - MURIWAI GROUND INVESTIGATION**

**Unconfined Compressive Strength of Cohesive Soils** 

Test Methods: NZS4402: 1986: Test 2.1 / Test 6.3.1

Tested By:	WEC	27-Sep-23
Compiled By:	WEC	28-Sep-23
Checked By:	JF	2-Oct-23

Depth: 56.50 - 56.90m Borehole: BH-M02 Sample Number: \$8

Test Performed on: rock / whole soil

Sample History: disturbed / remoulded / recompacted / unknown

Sample Method & Type: from core sample / from tube sample

**Initial Diameter:** 59.05 mm **Initial Length:** 120.11 **Initial Mass:** 636.25 Initial Bulk Density: 1.93

**Initial Dry Density:** 1.60 t/m<sup>3</sup>

Water Content After Test: 20.8

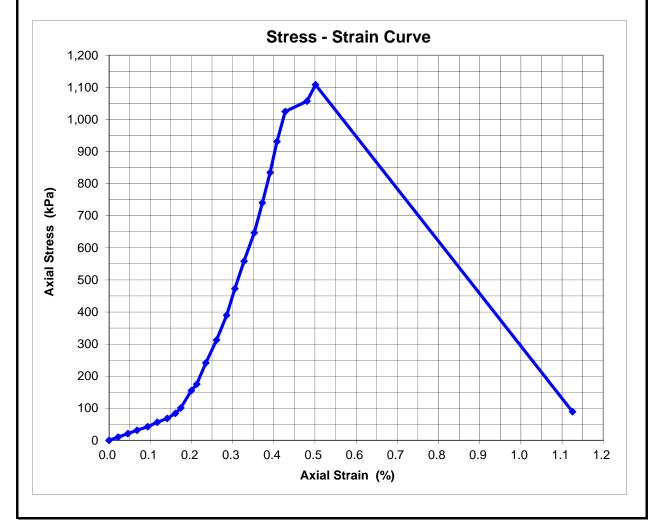
#### **Failure Conditions:**

0.50 Strain at failure:

0.60 Compression at failure: mm

Rate of Compression: 0.098 mm / minute

Mode of Failure: brittle





 Unconfined Compressive Strength of
 Tested By:
 WEC
 27-Sep-23

 Cohesive Soils
 Compiled By:
 WEC
 28-Sep-23

 Test Methods:
 NZS4402: 1986: Test 2.1 / Test 6.3.1
 Checked By:
 JF
 2-Oct-23

Borehole: **BH-M02** Sample Number: **S8** Depth: **56.50 – 56.90m** 

Sample Description (not part of BGL IANZ Accreditation):

SANDSTONE, fine to coarse, very weak, dark orange, weakly cemented.

#### **SAMPLE BEFORE TEST**





Job No:	Reg. No:	Report No:	Page 28 of 69
63532#L	2806	63532#L/UCS Waitakere LHRA	Version 3, July 2022
PROJECT:	WAI	TAKERE LHRA	- MURIWAI

GROUND INVESTIGATION

Unconfined Compressive Strength of Cohesive Soils
Test Methods: NZS4402: 1986: Test 2.1 / Test 6.3.1

Tested By:	WEC	27-Sep-23
Compiled By:	WEC	28-Sep-23
Checked By:	JF	2-Oct-23

Borehole: **BH-M02** Sample Number: **S9** Depth: **64.44** – **64.72m** 

Time (minutes)	Compression Gauge (mm)	Specimen Compression (mm)	Strain	Load Gauge (mm)	Axial Force (N)	Corrected Area (mm²)	Axial Stress (kPa)
0.00	2.253	0.000	0.000	5.246	0.0	2693.3	0
0.37	2.317	0.063	0.001	5.258	58.3	2694.8	22
0.73	2.372	0.119	0.001	5.274	138.6	2696.0	51
1.12	2.430	0.177	0.001	5.297	252.7	2697.3	94
1.48	2.484	0.230	0.002	5.327	404.7	2698.5	150
1.87	2.512	0.258	0.002	5.340	470.5	2699.1	174
2.23	2.525	0.272	0.002	5.380	670.0	2699.4	248
2.60	2.552	0.299	0.002	5.425	895.1	2700.0	332
2.98	2.576	0.323	0.003	5.472	1132.0	2700.5	419
3.35	2.599	0.346	0.003	5.521	1380.5	2701.0	511
3.72	2.622	0.369	0.003	5.574	1644.2	2701.6	609
4.10	2.645	0.391	0.003	5.627	1911.8	2702.1	708
4.47	2.666	0.413	0.003	5.682	2188.0	2702.6	810
4.83	2.688	0.435	0.004	5.737	2464.7	2703.1	912
5.22	2.712	0.458	0.004	5.790	2731.2	2703.6	1010
5.58	2.744	0.491	0.004	5.835	2956.3	2704.3	1093
5.83	2.765	0.512	0.004	5.865	3108.3	2704.8	1149
6.07	2.784	0.531	0.004	5.897	3265.6	2705.2	1207
6.30	2.804	0.551	0.005	5.922	3392.3	2705.7	1254
6.55	2.885	0.632	0.005	5.874	3150.0	2707.5	1163
6.78	3.639	1.385	0.011	5.351	524.6	2724.5	193

Unconfined Compressive Strength: 1,300 kPa



Job No:	Reg. No:	Report No:	Page 29 of 69
63532#L	2806	63532#L/UCS Waitakere LHRA	Version 3, July 2022

## WAITAKERE LHRA - MURIWAI GROUND INVESTIGATION

**Unconfined Compressive Strength of Cohesive Soils** 

Test Methods: NZS4402: 1986: Test 2.1 / Test 6.3.1

Tested By:	WEC	27-Sep-23
Compiled By:	WEC	28-Sep-23
Checked By:	JF	2-Oct-23

Borehole: **BH-M02** Sample Number: **S9** Depth: **64.44 – 64.72m** 

Test Performed on: rock / whole soil

Sample History: disturbed / undisturbed / remoulded / recompacted / unknown

Sample Method & Type: from core sample / from tube sample

Initial Diameter: 58.56 mm

Initial Length: 121.19 mm

Initial Mass: 667.98 g

Initial Bulk Density: 2.05 t/m<sup>3</sup>

Initial Dry Density: 1.65 t/m<sup>3</sup>

Water Content After Test: 22.9 %

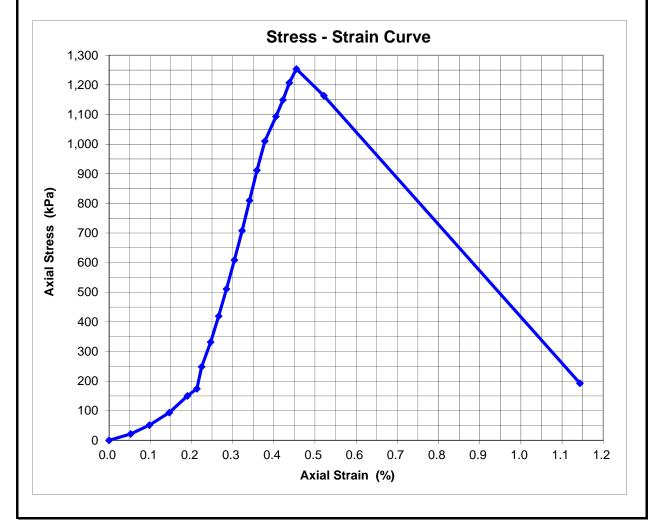
#### **Failure Conditions:**

Strain at failure: 0.45 %

Compression at failure: 0.55 mm

Rate of Compression: 0.088 mm / minute

Mode of Failure: brittle





Job No:	Reg. No:	Report No:	Page 30 of 69
63532#L	2806	63532#L/UCS Waitakere LHRA	Version 3, July 2022

## WAITAKERE LHRA - MURIWAI GROUND INVESTIGATION

 Unconfined Compressive Strength of
 Tested By:
 WEC
 27-Sep-23

 Cohesive Soils
 Compiled By:
 WEC
 28-Sep-23

 Test Methods:
 NZS4402: 1986: Test 2.1 / Test 6.3.1
 Checked By:
 JF
 2-Oct-23

Borehole: **BH-M02** Sample Number: **S9** Depth: **64.44** – **64.72**m

Sample Description (not part of BGL IANZ Accreditation):

SANDSTONE, fine to coarse, very weak, dark brownish orange, weakly to moderately cemented.

#### **SAMPLE BEFORE TEST**







Job No:	Reg. No:	Report No:	Page 31 of 69
63532#L	2806	63532#L/UCS Waitakere LHRA	Version 3, July 2022
	WA	<b>TAKERE LHRA</b>	- MURIWAI

### WAITAKERE LHRA - MURIWAI GROUND INVESTIGATION

Unconfined Compressive Strength of Cohesive Soils
Test Methods: NZS4402: 1986: Test 2.1 / Test 6.3.1

Tested By:	WEC	27-Sep-23	
Compiled By:	WEC	28-Sep-23	•
Checked By:	JF	2-Oct-23	•

Borehole: **BH-M02** Sample Number: **S10** Depth: **67.93 – 68.33m** 

Time (minutes)	Compression Gauge (mm)	Specimen Compression (mm)	Strain	Load Gauge (mm)	Axial Force (N)	Corrected Area (mm²)	Axial Stress (kPa)
0.00	8.820	0.000	0.000	5.246	0.0	2634.3	0
0.37	8.897	0.077	0.001	5.254	40.0	2636.0	15
0.73	8.972	0.152	0.001	5.267	104.8	2637.7	40
1.12	9.037	0.216	0.002	5.288	209.4	2639.1	79
1.48	9.085	0.265	0.002	5.316	348.3	2640.2	132
1.85	9.116	0.296	0.002	5.339	463.6	2640.8	176
2.23	9.129	0.309	0.003	5.365	595.9	2641.1	226
2.60	9.160	0.339	0.003	5.406	802.8	2641.8	304
2.97	9.192	0.371	0.003	5.448	1012.6	2642.5	383
3.35	9.226	0.406	0.003	5.491	1228.9	2643.3	465
3.72	9.273	0.453	0.004	5.526	1403.7	2644.3	531
4.00	9.299	0.479	0.004	5.557	1561.9	2644.9	591
4.13	9.312	0.492	0.004	5.573	1641.1	2645.2	620
4.27	9.325	0.505	0.004	5.589	1719.8	2645.5	650
4.42	9.339	0.519	0.004	5.606	1805.8	2645.8	683
4.55	9.352	0.532	0.004	5.623	1889.0	2646.0	714
4.70	9.366	0.546	0.005	5.638	1965.6	2646.4	743
4.83	9.380	0.560	0.005	5.653	2044.1	2646.7	772
4.97	9.397	0.577	0.005	5.666	2108.5	2647.0	797
5.12	9.804	0.984	0.008	5.347	505.4	2656.1	190

**Unconfined Compressive Strength:** 800



Job No:	Reg. No:	Report No:	Page 32 of 69
63532#L	2806	63532#L/UCS Waitakere LHRA	Version 3, July 2022

## WAITAKERE LHRA - MURIWAI GROUND INVESTIGATION

Unconfined Compressive Strength of Cohesive Soils

Test Methods: NZS4402: 1986: Test 2.1 / Test 6.3.1

Tested By:	WEC	27-Sep-23
Compiled By:	WEC	28-Sep-23
Checked By:	JF	2-Oct-23

Borehole: **BH-M02** Sample Number: **S10** Depth: **67.93** – **68.33m** 

Test Performed on: rock / whole soil

Sample History: disturbed / undisturbed / remoulded / recompacted / unknown

Sample Method & Type: from core sample / from tube sample

643.51

Initial Diameter: 57.92 mm

Initial Length: 120.24 mm

Initial Bulk Density: 2.03 t/m<sup>3</sup>

Initial Dry Density: 1.65 t/m<sup>3</sup>

Water Content After Test: 24.2 %

Initial Mass:

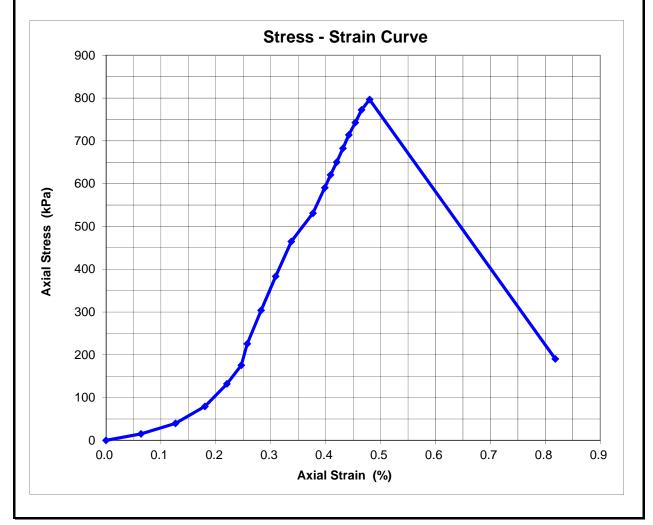
#### **Failure Conditions:**

Strain at failure: 0.48 %

Compression at failure: 0.58 mm

Rate of Compression: 0.12 mm / minute

Mode of Failure: brittle





Job No:	Reg. No:	Report No:	Page 33 of 69
63532#L	2806	63532#L/UCS Waitakere LHRA	Version 3, July 2022

## WAITAKERE LHRA - MURIWAI GROUND INVESTIGATION

 Unconfined Compressive Strength of
 Tested By:
 WEC
 27-Sep-23

 Cohesive Soils
 Compiled By:
 WEC
 28-Sep-23

 Test Methods:
 NZS4402: 1986: Test 2.1 / Test 6.3.1
 Checked By:
 JF
 2-Oct-23

Borehole: BH-M02 Sample Number: S10 Depth: 67.93 - 68.33m

Sample Description (not part of BGL IANZ Accreditation):

SANDSTONE, fine to coarse, extremely weak, dark orangish brown, weakly cemented.

#### **SAMPLE BEFORE TEST**





Job No:	Reg. No:	Report No:	Page 34 of 69
63532#L	2806	63532#L/UCS Waitakere LHRA	Version 3, July 2022
	\/\ \	TAKEDE I UDA	- MIIDIMAI

### WAITAKERE LHRA - MURIWAI GROUND INVESTIGATION

Unconfined Compressive Strength of Cohesive Soils
Test Methods: NZS4402: 1986: Test 2.1 / Test 6.3.1

Tested By:	WEC	27-Sep-23
Compiled By:	WEC	28-Sep-23
Checked By:	JF	2-Oct-23

Borehole: **BH-M02** Sample Number: **S11** Depth: **74.20 – 74.50m** 

Time (minutes)	Compression Gauge (mm)	Specimen Compression (mm)	Strain	Load Gauge (mm)	Axial Force (N)	Corrected Area (mm²)	Axial Stress (kPa)
0.00	3.600	0.000	0.000	5.246	0.0	2899.0	0
0.37	3.673	0.073	0.001	5.263	83.8	2900.8	29
0.75	3.740	0.140	0.001	5.282	179.9	2902.4	62
1.12	3.798	0.197	0.002	5.304	290.9	2903.8	100
1.48	3.855	0.255	0.002	5.328	410.3	2905.2	141
1.87	3.874	0.274	0.002	5.338	461.0	2905.7	159
2.23	3.910	0.309	0.003	5.368	609.8	2906.5	210
2.60	3.953	0.352	0.003	5.401	775.8	2907.6	267
2.98	3.995	0.394	0.003	5.435	945.6	2908.6	325
3.35	4.038	0.437	0.004	5.471	1125.5	2909.6	387
3.72	4.078	0.477	0.004	5.508	1312.2	2910.6	451
4.10	4.127	0.527	0.004	5.543	1491.9	2911.8	512
4.27	4.145	0.545	0.005	5.562	1583.8	2912.3	544
4.42	4.159	0.558	0.005	5.576	1654.8	2912.6	568
4.55	4.182	0.582	0.005	5.588	1715.0	2913.2	589
4.68	4.189	0.589	0.005	5.604	1796.5	2913.3	617
4.83	4.214	0.614	0.005	5.614	1847.5	2913.9	634
4.97	4.229	0.629	0.005	5.627	1908.9	2914.3	655
5.12	4.253	0.653	0.005	5.635	1953.2	2914.9	670
5.25	4.269	0.669	0.006	5.645	2001.3	2915.3	686
5.38	4.288	0.687	0.006	5.652	2037.2	2915.7	699
5.53	4.312	0.712	0.006	5.653	2043.1	2916.3	701
5.67	4.342	0.742	0.006	5.649	2019.4	2917.1	692
5.80	4.398	0.798	0.007	5.612	1835.0	2918.4	629
5.95	4.553	0.953	0.008	5.482	1181.8	2922.2	404
6.08	4.737	1.137	0.009	5.381	676.1	2926.8	231
6.22	4.798	1.197	0.010	5.358	559.8	2928.3	191
6.37	4.845	1.245	0.010	5.343	484.3	2929.4	165
6.50	4.897	1.296	0.011	5.331	426.3	2930.7	145

**Unconfined Compressive Strength:** 

700

**kPa** 



Job No:	Reg. No:	Report No:	Page 35 of 69
63532#L	2806	63532#L/UCS Waitakere LHRA	Version 3, July 2022

## WAITAKERE LHRA - MURIWAI GROUND INVESTIGATION

**Unconfined Compressive Strength of Cohesive Soils** 

Test Methods: NZS4402: 1986: Test 2.1 / Test 6.3.1

Tested By:	WEC	27-Sep-23
Compiled By:	WEC	28-Sep-23
Checked By:	JF	2-Oct-23

Borehole: **BH-M02** Sample Number: **S11** Depth: **74.20 – 74.50m** 

Test Performed on: rock / whole soil

Sample History: disturbed / undisturbed / remoulded / recompacted / unknown

Sample Method & Type: from core sample / from tube sample

655.99

Initial Diameter: 60.76 mm

Initial Length: 120.00 mm

Initial Bulk Density: 1.89 t/m³

Initial Dry Density: 1.45 t/m<sup>3</sup>

Water Content After Test: 31.8 %

Initial Mass:

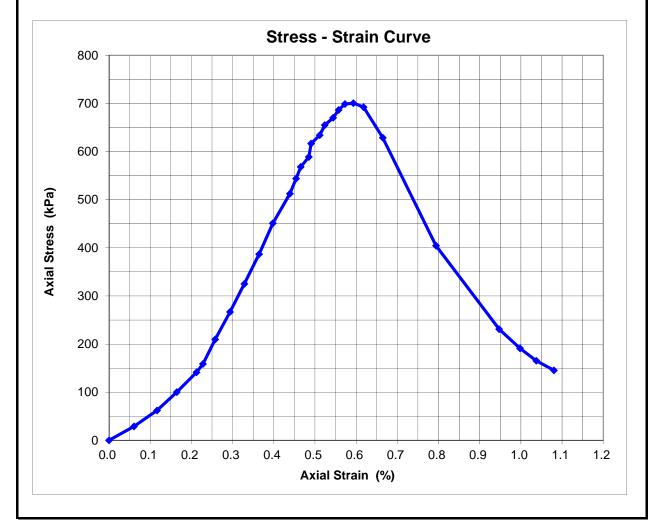
#### **Failure Conditions:**

Strain at failure: 0.59 %

Compression at failure: 0.71 mm

Rate of Compression: 0.13 mm / minute

Mode of Failure: brittle





Job No:	Reg. No:	Report No:	Page 36 of 69
63532#L	2806	63532#L/UCS Waitakere LHRA	Version 3, July 2022

## WAITAKERE LHRA - MURIWAI GROUND INVESTIGATION

 Unconfined Compressive Strength of
 Tested By:
 WEC
 27-Sep-23

 Cohesive Soils
 Compiled By:
 WEC
 28-Sep-23

 Test Methods:
 NZS4402: 1986: Test 2.1 / Test 6.3.1
 Checked By:
 JF
 2-Oct-23

Borehole: **BH-M02** Sample Number: **S11** Depth: **74.20 – 74.50m** 

Sample Description (not part of BGL IANZ Accreditation):

SANDSTONE, fine to coarse, extremely weak, brown, weakly cemented.

#### **SAMPLE BEFORE TEST**





Job No:	Reg. No:	Report No:	Page 37 of 69
63532#L	2806	63532#L/UCS Waitakere LHRA	Version 3, July 2022

## WAITAKERE LHRA - MURIWAI GROUND INVESTIGATION

Unconfined Compressive Strength of Cohesive Soils
Test Methods: NZS4402: 1986: Test 2.1 / Test 6.3.1

Tested By:	WEC	27-Sep-23
Compiled By:	WEC	28-Sep-23
Checked By:	JF	2-Oct-23

Borehole: **BH-M02** Sample Number: **S12** Depth: **76.13 – 76.40m** 

Time (minutes)	Compression Gauge (mm)	Specimen Compression (mm)	Strain	Load Gauge (mm)	Axial Force (N)	Corrected Area (mm²)	Axial Stress (kPa)
0.00	8.870	0.000	0.000	5.244	0.0	2887.4	0
0.37	8.944	0.075	0.001	5.255	53.6	2889.2	19
0.73	8.980	0.110	0.001	5.271	133.4	2890.0	46
1.12	9.034	0.164	0.001	5.290	229.3	2891.3	79
1.48	9.081	0.211	0.002	5.316	361.0	2892.5	125
1.87	9.117	0.247	0.002	5.336	457.5	2893.3	158
2.23	9.140	0.270	0.002	5.356	558.2	2893.9	193
2.60	9.181	0.312	0.003	5.388	720.3	2894.9	249
2.98	9.221	0.351	0.003	5.423	894.9	2895.8	309
3.35	9.257	0.388	0.003	5.461	1086.2	2896.7	375
3.72	9.294	0.424	0.004	5.500	1284.2	2897.6	443
4.10	9.331	0.462	0.004	5.538	1474.9	2898.5	509
4.47	9.380	0.511	0.004	5.566	1613.1	2899.7	556
4.73	9.432	0.562	0.005	5.555	1556.9	2901.0	537
4.88	9.482	0.612	0.005	5.523	1399.1	2902.2	482
5.02	9.534	0.665	0.006	5.520	1383.4	2903.5	476
5.15	9.581	0.711	0.006	5.518	1374.5	2904.6	473
5.30	9.625	0.756	0.006	5.514	1350.9	2905.7	465
5.43	9.699	0.829	0.007	5.487	1219.8	2907.5	420
5.57	9.754	0.885	0.007	5.470	1132.0	2908.8	389
5.72	9.814	0.944	0.008	5.443	996.2	2910.3	342
5.85	9.882	1.012	0.008	5.410	831.5	2911.9	286

**Unconfined Compressive Strength:** 

560 kPa



Job No:	Reg. No:	Report No:	Page 38 of 69
63532#L	2806	63532#L/UCS Waitakere LHRA	Version 3, July 2022

### WAITAKERE LHRA - MURIWAI GROUND INVESTIGATION

**Unconfined Compressive Strength of Cohesive Soils** 

Test Methods: NZS4402: 1986: Test 2.1 / Test 6.3.1

Tested By:	WEC	27-Sep-23
Compiled By:	WEC	28-Sep-23
Checked By:	JF	2-Oct-23

Borehole: **BH-M02** Sample Number: **S12** Depth: **76.13 – 76.40m** 

Test Performed on: rock / whole soil

Sample History: disturbed / undisturbed / remoulded / recompacted / unknown

Sample Method & Type: from core sample / from tube sample

Initial Diameter: 60.63 mm

Initial Length: 119.95 mm

Initial Mass: 647.59

Initial Bulk Density: 1.87 t/m<sup>3</sup>

Initial Dry Density: 1.40 t/m<sup>3</sup>

Water Content After Test: 31.8 %

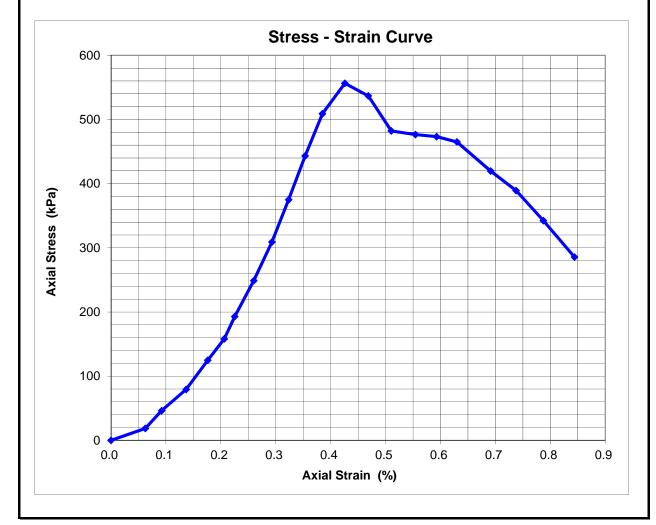
#### **Failure Conditions:**

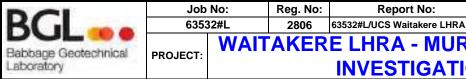
Strain at failure: 0.43 %

Compression at failure: 0.51 mm

Rate of Compression: 0.11 mm / minute

Mode of Failure: brittle





WAIT	AKER	E LHRA -	MURI	NAI	<b>GROUI</b>	ND
		INVESTI	GATIO	N		

Report No:

Tested By:	WEC	27-Sep-23
Compiled By:	WEC	28-Sep-23
Checked By:	IF	2-Oct-23

Page 39 of 69

Version 3, July 2022

**Unconfined Compressive Strength of Cohesive Soils** Test Methods: NZS4402: 1986: Test 2.1 / Test 6.3.1

Sample Number: \$12 Depth: 76.13 - 76.40m Borehole: BH-M02

Sample Description (not part of BGL IANZ Accreditation):

SANDSTONE, fine to coarse, extremely weak, grey with light brown oxidation around circumference, weakly cemented.

#### **SAMPLE BEFORE TEST**





Job No:	Reg. No:	Report No:	Page 40 of 69
63532#L	2806	63532#L/UCS Waitakere LHRA	Version 3, July 2022
	WA	TAKERE LHRA	- MURIWAI

### WAITAKERE LHRA - MURIWAI GROUND INVESTIGATION

Unconfined Compressive Strength of Cohesive Soils
Test Methods: NZS4402: 1986: Test 2.1 / Test 6.3.1

Tested By:	WEC	27-Sep-23
Compiled By:	WEC	28-Sep-23
Checked By:	JF	2-Oct-23

Borehole: **BH-M02** Sample Number: **\$13** Depth: **78.14 – 78.47m** 

Time (minutes)	Compression Gauge (mm)	Specimen Compression (mm)	Strain	Load Gauge (mm)	Axial Force (N)	Corrected Area (mm²)	Axial Stress (kPa)
0.00	8.668	0.000	0.000	5.243	0.0	2696.3	0
0.38	8.737	0.070	0.001	5.258	75.8	2697.9	28
0.75	8.800	0.132	0.001	5.279	181.6	2699.3	67
1.12	8.856	0.188	0.002	5.304	306.5	2700.6	113
1.50	8.895	0.228	0.002	5.332	449.3	2701.5	166
1.87	8.910	0.242	0.002	5.344	507.4	2701.8	188
2.23	8.948	0.281	0.002	5.377	674.4	2702.7	250
2.62	8.971	0.304	0.003	5.416	871.2	2703.2	322
2.98	9.006	0.338	0.003	5.454	1063.4	2704.0	393
3.23	9.025	0.357	0.003	5.482	1199.4	2704.4	443
3.47	9.046	0.379	0.003	5.509	1339.6	2704.9	495
3.72	9.067	0.399	0.003	5.537	1479.6	2705.3	547
3.95	9.086	0.418	0.003	5.567	1626.8	2705.8	601
4.18	9.102	0.434	0.004	5.596	1773.6	2706.1	655
4.43	9.119	0.451	0.004	5.625	1921.4	2706.5	710
4.67	9.131	0.463	0.004	5.657	2081.9	2706.8	769
4.90	9.145	0.477	0.004	5.688	2236.5	2707.1	826
5.15	9.162	0.494	0.004	5.718	2387.9	2707.5	882
5.38	9.176	0.508	0.004	5.749	2540.9	2707.8	938
5.62	9.191	0.524	0.004	5.779	2691.0	2708.1	994
5.87	9.209	0.541	0.005	5.805	2822.4	2708.5	1042
6.10	9.561	0.894	0.007	5.549	1536.5	2716.6	566
6.33	9.625	0.958	0.008	5.551	1549.6	2718.0	570
6.58	9.692	1.024	0.009	5.555	1569.4	2719.5	577
6.82	9.750	1.082	0.009	5.562	1605.5	2720.9	590
7.05	9.808	1.140	0.009	5.570	1641.4	2722.2	603

Unconfined Compressive Strength: 1,000 kPa



Job No:	Reg. No:	Report No:	Page 41 of 69
63532#L	2806	63532#L/UCS Waitakere LHRA	Version 3, July 2022

### **WAITAKERE LHRA - MURIWAI GROUND INVESTIGATION**

**Unconfined Compressive Strength of Cohesive Soils** 

Test Methods: NZS4402: 1986: Test 2.1 / Test 6.3.1

Tested By:	WEC	27-Sep-23
Compiled By:	WEC	28-Sep-23
Checked By:	JF	2-Oct-23

Depth: 78.14 - 78.47m Borehole: BH-M02 Sample Number: \$13

Test Performed on: rock / whole soil

Sample History: disturbed / remoulded / recompacted / unknown

Sample Method & Type: from core sample / from tube sample

> **Initial Diameter:** 58.59 mm **Initial Length:** 120.07 Initial Mass: 633.33

Initial Bulk Density: 1.96

1.55 **Initial Dry Density:** t/m<sup>3</sup>

Water Content After Test: 25.4

#### **Failure Conditions:**

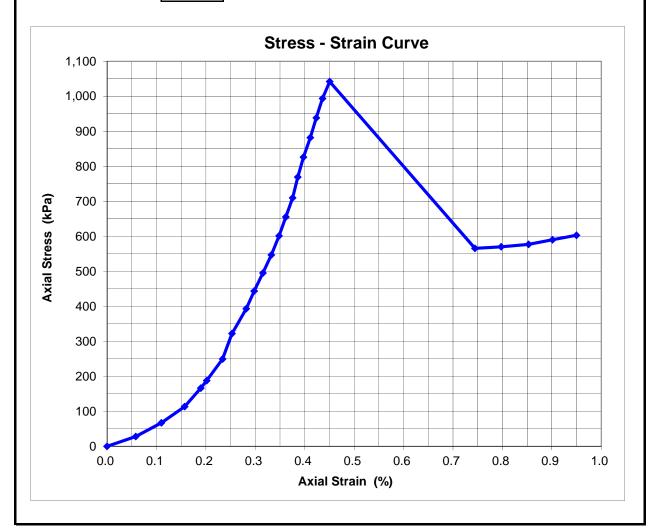
0.45 Strain at failure:

Compression at failure: 0.54 mm

Rate of Compression:

Mode of Failure: brittle

0.092 mm / minute





Job No:	Reg. No:	Report No:	Page 42 of 69
63532#L	2806	63532#L/UCS Waitakere LHRA	Version 3, July 2022

## WAITAKERE LHRA - MURIWAI GROUND INVESTIGATION

 Unconfined Compressive Strength of
 Tested By:
 WEC
 27-Sep-23

 Cohesive Soils
 Compiled By:
 WEC
 28-Sep-23

 Test Methods:
 NZS4402: 1986: Test 2.1 / Test 6.3.1
 Checked By:
 JF
 2-Oct-23

Borehole: **BH-M02** Sample Number: **S13** Depth: **78.14 – 78.47m** 

Sample Description (not part of BGL IANZ Accreditation):

SANDSTONE, fine to coarse, extremely weak to very weak, banded brown & dark brown, weakly cemented.

#### **SAMPLE BEFORE TEST**







Job No:	Reg. No:	Report No:	Page 43 of 69
63532#L	2806	63532#L/UCS Waitakere LHRA	Version 3, July 2022
	\A/ A	TAVEDELLIDA	NALIDIA/AI

### WAITAKERE LHRA - MURIWAI GROUND INVESTIGATION

Unconfined Compressive Strength of Cohesive Soils
Test Methods: NZS4402: 1986: Test 2.1 / Test 6.3.1

Tested By:	WEC	27-Sep-23	
Compiled By:	WEC	28-Sep-23	
Checked Bv:	JF	2-Oct-23	

Borehole: BH-M03 Sample Number: UCS01 Depth: 9.93 - 10.13m

Time (minutes)	Compression Gauge (mm)	Specimen Compression (mm)	Strain	Load Gauge (mm)	Axial Force (N)	Corrected Area (mm²)	Axial Stress (kPa)
0.00	3.399	0.000	0.000	5.243	0.0	2745.8	0
0.28	3.461	0.062	0.001	5.248	25.3	2747.9	9
0.58	3.521	0.122	0.002	5.253	53.3	2750.0	19
0.87	3.578	0.179	0.002	5.260	87.1	2752.0	32
1.15	3.630	0.232	0.003	5.268	126.3	2753.8	46
1.45	3.683	0.284	0.004	5.276	167.8	2755.6	61
1.73	3.738	0.340	0.004	5.284	206.2	2757.5	75
2.02	3.792	0.394	0.005	5.291	242.9	2759.4	88
2.32	3.847	0.449	0.006	5.298	278.5	2761.3	101
2.60	3.904	0.505	0.006	5.304	309.5	2763.3	112
2.88	3.962	0.563	0.007	5.309	335.4	2765.3	121
3.18	4.022	0.624	0.008	5.313	355.8	2767.4	129
3.47	4.083	0.684	0.009	5.317	373.0	2769.5	135
3.75	4.144	0.745	0.009	5.319	385.7	2771.6	139
4.05	4.207	0.808	0.010	5.320	390.7	2773.9	141
4.33	4.279	0.880	0.011	5.316	367.7	2776.4	132
4.62	4.344	0.946	0.012	5.315	363.3	2778.7	131
4.92	4.410	1.012	0.013	5.314	360.9	2781.0	130
5.20	4.478	1.079	0.014	5.314	360.2	2783.4	129
5.48	4.545	1.146	0.014	5.314	359.3	2785.7	129
5.78	4.609	1.210	0.015	5.314	359.6	2788.0	129
					1		
					1		
					1		
					1		
					1		
					1		İ

Unconfined Compressive Strength: 140 kPa



Job No:	Reg. No:	Report No:	Page 44 of 69
63532#L	2806	63532#L/UCS Waitakere LHRA	Version 3, July 2022

## WAITAKERE LHRA - MURIWAI GROUND INVESTIGATION

Unconfined Compressive Strength of Cohesive Soils

Test Methods: NZS4402: 1986: Test 2.1 / Test 6.3.1

Tested By:	WEC	27-Sep-23
Compiled By:	WEC	28-Sep-23
Checked By:	JF	2-Oct-23

Borehole: BH-M03 Sample Number: UCS01 Depth: 9.93 - 10.13m

Test Performed on: rock / whole soil

Sample History: disturbed / undisturbed / remoulded / recompacted / unknown

Sample Method & Type: from core sample / from tube sample

Initial Diameter: 59.13 mm

Initial Length: 79.91 mm

Initial Mass: 432.98 g

Initial Bulk Density: 1.97 t/m<sup>3</sup>

Initial Dry Density: 1.60 t/m<sup>3</sup>

Water Content After Test: 24.5 %

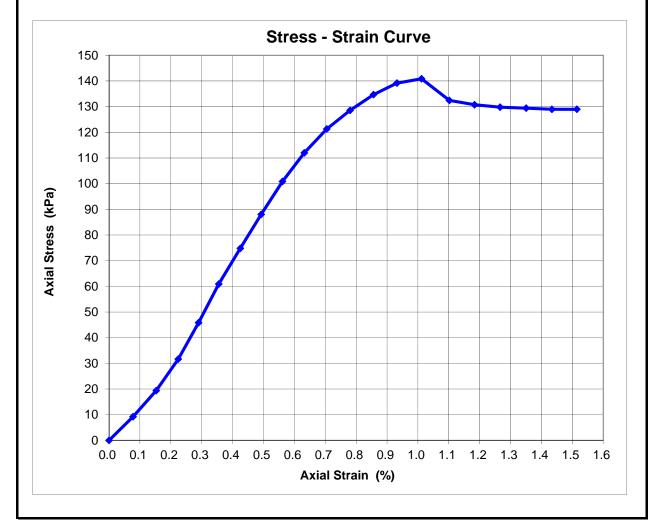
#### Failure Conditions:

Strain at failure: 1.0 %

Compression at failure: 0.81 mm

Rate of Compression: 0.20 mm / minute

Mode of Failure: plastic / brittle





Job No:	Reg. No:	Report No:	Page 45 of 69
63532#L	2806	63532#L/UCS Waitakere LHRA	Version 3, July 2022

## WAITAKERE LHRA - MURIWAI GROUND INVESTIGATION

 Unconfined Compressive Strength of
 Tested By:
 WEC

 Cohesive Soils
 Compiled By:
 WEC

 Test Methods:
 NZS4402: 1986: Test 2.1 / Test 6.3.1
 Checked By:
 JF

Borehole: BH-M03 Sample Number: UCS01 Depth: 9.93 - 10.13m

Sample Description (not part of BGL IANZ Accreditation):

SANDSTONE, fine, extremely weak, banded orange, dark orange & yellow, very weakly cemented.

**SAMPLE BEFORE TEST** 

**SAMPLE AFTER TEST** 

27-Sep-23

28-Sep-23 2-Oct-23







Job No:	Reg. No:	Report No:	Page 46 of 69
63532#L	2806	63532#L/UCS Waitakere LHRA	Version 3, July 2022
	۱۸/۸۱	TAVEDELUDA	

# WAITAKERE LHRA - MURIWAI GROUND INVESTIGATION

Unconfined Compressive Strength of Cohesive Soils
Test Methods: NZS4402: 1986: Test 2.1 / Test 6.3.1

Tested By:	WEC	27-Sep-23
Compiled By:	WEC	28-Sep-23
Checked By:	JF	2-Oct-23

Borehole: BH-M03 Sample Number: UCS02 Depth: 16.00 - 16.27m

Time (minutes)	Compression Gauge (mm)	Specimen Compression (mm)	Strain	Load Gauge (mm)	Axial Force (N)	Corrected Area (mm²)	Axial Stress (kPa)
0.00	3.064	0.000	0.000	5.256	0.0	2645.0	0
0.28	3.120	0.057	0.000	5.265	42.0	2646.3	16
0.58	3.183	0.120	0.001	5.270	70.8	2647.7	27
0.87	3.240	0.177	0.001	5.278	106.4	2648.9	40
1.15	3.297	0.234	0.002	5.286	149.7	2650.2	56
1.45	3.354	0.290	0.002	5.295	194.2	2651.5	73
1.73	3.406	0.343	0.003	5.305	245.3	2652.6	92
2.02	3.454	0.391	0.003	5.317	302.0	2653.7	114
2.32	3.507	0.443	0.004	5.327	353.9	2654.8	133
2.60	3.559	0.495	0.004	5.338	410.2	2656.0	154
2.88	3.612	0.548	0.005	5.349	464.8	2657.2	175
3.18	3.657	0.593	0.005	5.354	487.9	2658.2	184
3.47	3.697	0.633	0.005	5.358	508.1	2659.1	191
3.60	3.725	0.661	0.006	5.362	529.7	2659.7	199
3.75	3.754	0.690	0.006	5.366	550.0	2660.3	207
3.88	3.782	0.718	0.006	5.370	568.1	2661.0	213
4.02	3.811	0.747	0.006	5.373	584.8	2661.6	220
4.17	3.840	0.776	0.006	5.376	602.2	2662.3	226
4.30	3.867	0.804	0.007	5.380	619.5	2662.9	233
4.43	3.896	0.832	0.007	5.383	635.6	2663.5	239
4.58	3.923	0.860	0.007	5.386	651.6	2664.1	245
4.72	3.953	0.889	0.007	5.389	664.5	2664.8	249
4.85	3.982	0.918	0.008	5.392	678.4	2665.4	255
5.00	4.012	0.948	0.008	5.394	690.5	2666.1	259
5.13	4.042	0.978	0.008	5.396	701.4	2666.8	263
5.27	4.072	1.009	0.008	5.398	710.4	2667.5	266
5.42	4.103	1.040	0.009	5.400	720.3	2668.2	270
5.55	4.132	1.069	0.009	5.402	730.7	2668.8	274
5.68	4.162	1.098	0.009	5.404	740.2	2669.5	277
5.83	4.194	1.130	0.009	5.405	747.1	2670.2	280
5.97	4.226	1.162	0.010	5.406	751.9	2670.9	282
6.10	4.258	1.194	0.010	5.407	754.0	2671.6	282
6.25	4.291	1.227	0.010	5.407	754.5	2672.4	282
6.38	4.323	1.260	0.010	5.406	752.6	2673.1	282
6.52	4.359	1.295	0.011	5.405	747.2	2673.9	279
6.67	4.396	1.332	0.011	5.404	740.3	2674.7	277
6.80	4.431	1.367	0.011	5.402	729.7	2675.5	273
6.93	4.467	1.403	0.012	5.400	718.9	2676.3	269
7.08	4.502	1.439	0.012	5.397	707.6	2677.1	264
7.22	4.537	1.474	0.012	5.394	693.2	2677.9	259
7.35	4.573	1.509	0.013	5.391	674.0	2678.7	252

**Unconfined Compressive Strength:** 2

280



Job No:	Reg. No:	Report No:	Page 47 of 69
63532#L	2806	63532#L/UCS Waitakere LHRA	Version 3, July 2022

#### WAITAKERE LHRA - MURIWAI GROUND **INVESTIGATION**

**Unconfined Compressive Strength of Cohesive Soils** 

Test Methods: NZS4402: 1986: Test 2.1 / Test 6.3.1

Tested By:	WEC	27-Sep-23
Compiled By:	WEC	28-Sep-23
Checked By:	JF	2-Oct-23

Depth: 16.00 - 16.27m Borehole: BH-M03 Sample Number: UCS02

Test Performed on: rock / whole soil

Sample History: disturbed / remoulded / recompacted / unknown

Sample Method & Type: from core sample / from tube sample

**Initial Diameter:** 58.03 mm **Initial Length:** 119.99 Initial Mass: 612.76 Initial Bulk Density: 1.93

1.50 **Initial Dry Density:** t/m<sup>3</sup>

Water Content After Test: 30.8

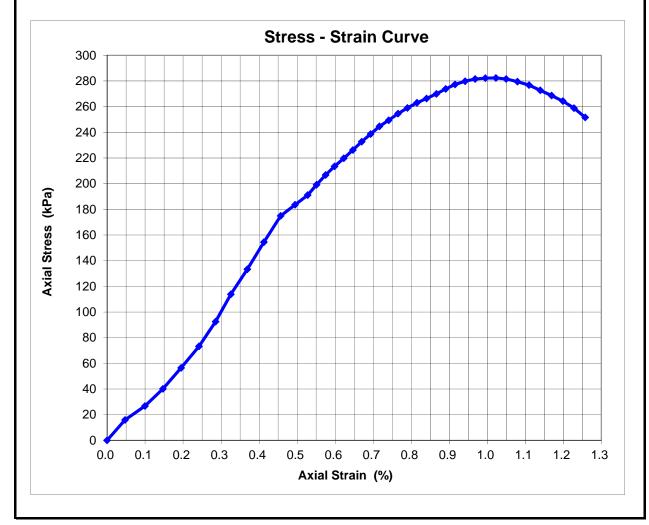
#### **Failure Conditions:**

1.0 Strain at failure:

Compression at failure: 1.2 mm

Rate of Compression: 0.20 mm / minute

Mode of Failure: brittle





Job No:	Reg. No:	Report No:	Page 48 of 69
63532#L	2806	63532#L/UCS Waitakere LHRA	Version 3, July 2022

# WAITAKERE LHRA - MURIWAI GROUND INVESTIGATION

Unconfined Compressive Strength of Cohesive Soils
Test Methods: NZS4402: 1986: Test 2.1 / Test 6.3.1

Tested By:	WEC	27-Sep-23
Compiled By:	WEC	28-Sep-23
Checked By:	JF	2-Oct-23

Borehole: BH-M03 Sample Number: UCS02 Depth: 16.00 - 16.27m

Sample Description (not part of BGL IANZ Accreditation):

SANDSTONE, fine, extremely weak, light grey, weakly cemented.

#### **SAMPLE BEFORE TEST**







Job No:	Reg. No:	Report No:	Page 49 of 69
63532#L	2806	63532#L/UCS Waitakere LHRA	Version 3, July 2022
PROJECT:	WAI	TAKERE LHRA	- MURIWAI

essive Strength of

Compiled By: WEC
Checked By: JF

**GROUND INVESTIGATION** 

Tested By:

WEC

27-Sep-23

28-Sep-23

2-Oct-23

Unconfined Compressive Strength of Cohesive Soils
Test Methods: NZS4402: 1986: Test 2.1 / Test 6.3.1

Borehole: BH-M03 Sample Number: UCS03 Depth: 29.55 - 29.75m

Time (minutes)	Compression Gauge (mm)	Specimen Compression (mm)	Strain	Load Gauge (mm)	Axial Force (N)	Corrected Area (mm²)	Axial Stress (kPa)
0.00	5.496	0.000	0.000	5.247	0.0	2820.6	0
0.30	5.564	0.068	0.001	5.250	16.3	2822.4	6
0.58	5.631	0.134	0.001	5.253	29.2	2824.1	10
0.87	5.695	0.199	0.002	5.256	46.7	2825.8	17
1.17	5.756	0.259	0.002	5.262	77.2	2827.3	27
1.45	5.817	0.321	0.003	5.267	100.9	2829.0	36
1.75	5.878	0.382	0.004	5.273	130.6	2830.5	46
2.03	5.936	0.440	0.004	5.280	166.8	2832.1	59
2.32	5.994	0.497	0.005	5.288	206.2	2833.6	73
2.62	6.053	0.557	0.005	5.295	242.8	2835.1	86
2.90	6.113	0.617	0.006	5.301	273.6	2836.7	96
3.18	6.173	0.676	0.006	5.306	294.6	2838.3	104
3.43	6.220	0.723	0.007	5.308	309.0	2839.5	109
3.63	6.264	0.768	0.007	5.309	313.3	2840.7	110
3.83	6.310	0.813	0.007	5.310	315.1	2841.9	111
4.05	6.360	0.863	0.008	5.309	311.4	2843.2	110
4.25	6.412	0.915	0.008	5.308	305.4	2844.5	107
4.45	6.468	0.971	0.009	5.304	287.5	2846.0	101
4.67	6.517	1.021	0.009	5.304	285.4	2847.3	100
4.87	6.569	1.072	0.010	5.302	275.7	2848.7	97
5.07	6.621	1.124	0.010	5.299	264.0	2850.1	93
5.28	6.675	1.179	0.011	5.297	254.3	2851.5	89
5.48	6.734	1.237	0.011	5.295	241.9	2853.1	85
5.68	6.797	1.300	0.012	5.291	219.8	2854.7	77

**Unconfined Compressive Strength:** 110



Job No:	Reg. No:	Report No:	Page 50 of 69
63532#L	2806	63532#L/UCS Waitakere LHRA	Version 3, July 2022

# WAITAKERE LHRA - MURIWAI GROUND INVESTIGATION

**Unconfined Compressive Strength of Cohesive Soils** 

Test Methods: NZS4402: 1986: Test 2.1 / Test 6.3.1

Tested By:	WEC	27-Sep-23
Compiled By:	WEC	28-Sep-23
Checked By:	JF	2-Oct-23

Borehole: BH-M03 Sample Number: UCS03 Depth: 29.55 – 29.75m

Test Performed on: rock / whole soil

Sample History: disturbed / undisturbed / remoulded / recompacted / unknown

Sample Method & Type: from core sample / from tube sample

Initial Diameter: 59.93 mm

Initial Length: 108.76 mm

Initial Mass: 614.84 g

Initial Bulk Density: 2.00 t/m<sup>3</sup>

Initial Dry Density: 1.60 t/m<sup>3</sup>

Water Content After Test: 23.4 %

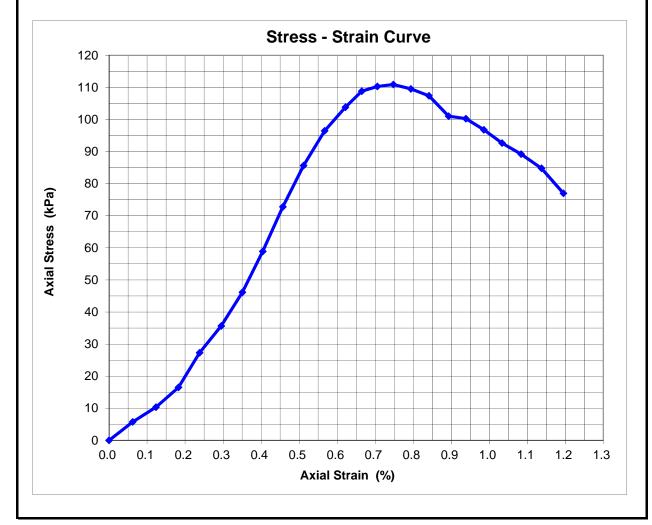
#### **Failure Conditions:**

Strain at failure: 0.75 %

Compression at failure: 0.81 mm

Rate of Compression: 0.21 mm / minute

Mode of Failure: planar





**Cohesive Soils** 

WAITAKERE LHRA -	<b>MURIWAI</b>	<b>GROUND</b>
INVESTI	GATION	

Report No:

63532#L/UCS Waitakere LHRA

Tested By:	WEC	27-Sep-23
Compiled By:	WEC	28-Sep-23
Checked By:	IE	2-Oct-23

Page 51 of 69

Version 3, July 2022

Test Methods: NZS4402: 1986: Test 2.1 / Test 6.3.1 Checked By:

Borehole: BH-M03 Sample Number: UCS03 Depth: 29.55 – 29.75m

Sample Description (not part of BGL IANZ Accreditation):

SANDSTONE, fine to medium, extremely weak, orange, weakly cemented.

#### **SAMPLE BEFORE TEST**





Job No:	Reg. No:	Report No:	Page 52 of 69
63532#L	2806	63532#L/UCS Waitakere LHRA	Version 3, July 2022
	\A/ A	TAVEDELLIDA	

### WAITAKERE LHRA - MURIWAI GROUND INVESTIGATION

Unconfined Compressive Strength of Cohesive Soils

Test Methods: NZS4402: 1986: Test 2.1 / Test 6.3.1

 Tested By:
 WEC
 27-Sep-23

 Compiled By:
 WEC
 28-Sep-23

 Checked By:
 JF
 2-Oct-23

Borehole: BH-M03 Sample Number: UCS04 Depth: 31.95 - 32.23m

Time (minutes)	Compression Gauge (mm)	Specimen Compression (mm)	Strain	Load Gauge (mm)	Axial Force (N)	Corrected Area (mm²)	Axial Stress (kPa)
0.00	2.463	0.000	0.000	5.251	0.0	2604.0	0
0.28	2.522	0.059	0.000	5.257	30.8	2605.2	12
0.58	2.580	0.117	0.001	5.262	54.0	2606.5	21
0.87	2.641	0.178	0.001	5.266	76.2	2607.8	29
1.15	2.702	0.239	0.002	5.271	99.0	2609.2	38
1.45	2.763	0.300	0.003	5.275	121.1	2610.5	46
1.73	2.825	0.362	0.003	5.280	144.3	2611.8	55
2.02	2.886	0.423	0.004	5.285	168.9	2613.2	65
2.32	2.947	0.484	0.004	5.290	193.3	2614.5	74
2.60	3.008	0.545	0.005	5.295	219.4	2615.9	84
2.88	3.069	0.606	0.005	5.300	244.7	2617.2	93
3.18	3.128	0.665	0.006	5.305	272.2	2618.5	104
3.47	3.188	0.725	0.006	5.311	300.2	2619.8	115
3.75	3.247	0.784	0.007	5.316	327.4	2621.1	125
3.97	3.289	0.826	0.007	5.321	349.2	2622.0	133
4.17	3.329	0.866	0.007	5.325	370.3	2622.9	141
4.37	3.370	0.907	0.008	5.329	391.0	2623.8	149
4.58	3.410	0.947	0.008	5.333	412.8	2624.7	157
4.78	3.451	0.988	0.008	5.338	436.1	2625.6	166
5.00	3.492	1.029	0.009	5.342	457.6	2626.5	174
5.40	3.550	1.087	0.009	5.347	480.5	2627.8	183
5.82	3.610	1.147	0.010	5.354	518.4	2629.1	197
6.23	3.692	1.229	0.010	5.364	565.2	2630.9	215
6.63	3.773	1.311	0.011	5.373	609.2	2632.7	231
7.05	3.857	1.394	0.012	5.381	653.1	2634.6	248
7.47	3.938	1.475	0.012	5.390	695.1	2636.4	264
7.87	4.020	1.557	0.013	5.398	735.0	2638.2	279
8.28	4.104	1.641	0.014	5.405	773.3	2640.1	293
8.48	4.146	1.683	0.014	5.409	790.8	2641.0	299
8.90	4.230	1.768	0.015	5.415	821.2	2642.9	311
9.12	4.273	1.810	0.015	5.417	834.9	2643.9	316
9.32	4.314	1.852	0.015	5.420	846.9	2644.8	320
9.52	4.358	1.895	0.016	5.422	856.1	2645.8	324
9.73	4.402	1.939	0.016	5.423	864.1	2646.8	326
9.93	4.447	1.984	0.017	5.424	866.5	2647.8	327
10.13	4.493	2.030	0.017	5.423	864.0	2648.8	326
10.35	4.541	2.078	0.017	5.420	849.7	2649.9	321
10.55	4.593	2.130	0.018	5.415	821.0	2651.1	310
10.75	4.649	2.186	0.018	5.407	782.4	2652.3	295
10.97	4.703	2.240	0.019	5.399	743.6	2653.5	280
11.17	4.761	2.298	0.019	5.388	685.5	2654.8	258

**Unconfined Compressive Strength:** 

330



Job No:	Reg. No:	Report No:	Page 53 of 69
63532#L	2806	63532#L/UCS Waitakere LHRA	Version 3, July 2022

# WAITAKERE LHRA - MURIWAI GROUND INVESTIGATION

**Unconfined Compressive Strength of Cohesive Soils** 

Test Methods: NZS4402: 1986: Test 2.1 / Test 6.3.1

Tested By:	WEC	27-Sep-23
Compiled By:	WEC	28-Sep-23
Checked By:	JF	2-Oct-23

Borehole: BH-M03 Sample Number: UCS04 Depth: 31.95 - 32.23m

Test Performed on: rock / whole soil

Sample History: disturbed / undisturbed / remoulded / recompacted / unknown

Sample Method & Type: from core sample / from tube sample

Initial Diameter: 57.58 mm

Initial Length: 119.87 mm

Initial Mass: 590.37 g

ial Bulk Density: 1.89 t/m³

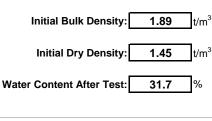
Failure Conditions:

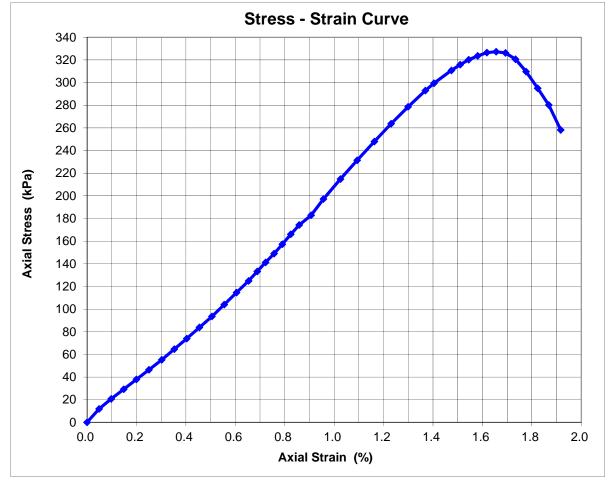
Strain at failure: 1.7 %

Compression at failure: 2.0 mm

Rate of Compression: 0.20 mm / minute

Mode of Failure: planar







Job No:	Reg. No:	Report No:	Page 54 of 69
63532#L	2806	63532#L/UCS Waitakere LHRA	Version 3, July 2022

# WAITAKERE LHRA - MURIWAI GROUND INVESTIGATION

 Unconfined Compressive Strength of
 Tested By:
 WEC
 27-Sep-23

 Cohesive Soils
 Compiled By:
 WEC
 28-Sep-23

 Test Methods:
 NZS4402: 1986: Test 2.1 / Test 6.3.1
 Checked By:
 JF
 2-Oct-23

Borehole: BH-M03 Sample Number: UCS04 Depth: 31.95 - 32.23m

Sample Description (not part of BGL IANZ Accreditation):

SANDSTONE, fine to medium, extremely weak, light grey, weakly cemented.

#### **SAMPLE BEFORE TEST**







Job No:	Reg. No:	Report No:	Page 55 of 69
63532#L	2806	63532#L/UCS Waitakere LHRA	Version 3, July 2022
	WA	TAKERE LHRA	- MURIWAI

#### WAITAKERE LHRA - MURIWAI GROUND INVESTIGATION

Unconfined Compressive Strength of Cohesive Soils
Test Methods: NZS4402: 1986: Test 2.1 / Test 6.3.1

Tested By:	WEC	28-Sep-23
Compiled By:	WEC	28-Sep-23
Checked By:	JF	2-Oct-23

Borehole: BH-M03 Sample Number: UCS05 Depth: 33.76 - 34.06m

Time (minutes)	Compression Gauge (mm)	Specimen Compression (mm)	Strain	Load Gauge (mm)	Axial Force (N)	Corrected Area (mm²)	Axial Stress (kPa)
0.00	2.069	0.000	0.000	5.248	0.0	2604.2	0
0.28	2.119	0.050	0.000	5.257	44.8	2605.3	17
0.58	2.169	0.100	0.001	5.268	97.1	2606.3	37
0.87	2.216	0.147	0.001	5.279	155.8	2607.4	60
1.15	2.258	0.189	0.002	5.293	225.9	2608.3	87
1.45	2.298	0.229	0.002	5.309	303.1	2609.2	116
1.73	2.336	0.267	0.002	5.325	383.4	2610.0	147
2.02	2.371	0.302	0.003	5.340	462.1	2610.7	177
2.32	2.388	0.319	0.003	5.344	479.2	2611.1	184
2.60	2.422	0.353	0.003	5.359	557.1	2611.9	213
2.88	2.457	0.388	0.003	5.376	643.8	2612.6	246
3.18	2.491	0.422	0.004	5.394	729.8	2613.4	279
3.47	2.530	0.462	0.004	5.409	806.0	2614.2	308
3.75	2.571	0.502	0.004	5.423	878.3	2615.1	336
4.05	2.610	0.541	0.005	5.438	953.2	2616.0	364
4.33	2.654	0.585	0.005	5.451	1017.4	2616.9	389
4.47	2.677	0.608	0.005	5.455	1040.6	2617.4	398
4.62	2.705	0.636	0.005	5.458	1055.4	2618.0	403
4.75	2.735	0.666	0.006	5.459	1059.4	2618.7	405
4.88	2.771	0.702	0.006	5.457	1047.5	2619.5	400
5.03	2.829	0.760	0.006	5.442	974.5	2620.8	372
5.17	2.877	0.808	0.007	5.434	931.8	2621.8	355
5.30	2.912	0.843	0.007	5.433	929.8	2622.6	355
5.45	2.942	0.873	0.007	5.434	932.4	2623.2	355
5.58	2.974	0.905	0.008	5.434	933.5	2623.9	356
5.72	3.005	0.936	0.008	5.433	930.4	2624.6	354
5.87	3.034	0.965	0.008	5.430	914.1	2625.3	348

Unconfined Compressive Strength: 400



Job No:	Reg. No:	Report No:	Page 56 of 69
63532#L	2806	63532#L/UCS Waitakere LHRA	Version 3, July 2022

WAITAKERE LHRA - MURIWAI GROUND INVESTIGATION

**Unconfined Compressive Strength of Cohesive Soils** 

Test Methods: NZS4402: 1986: Test 2.1 / Test 6.3.1

Tested By:	WEC	28-Sep-23
Compiled By:	WEC	28-Sep-23
Checked By:	JF	2-Oct-23

Borehole: BH-M03 Sample Number: UCS05 Depth: 33.76 - 34.06m

Test Performed on: rock / whole soil

Sample History: disturbed / undisturbed / remoulded / recompacted / unknown

Sample Method & Type: from core sample / from tube sample

Initial Diameter: 57.58 mm

Initial Length: 120.16 mm

Initial Mass: 611.10 g

Initial Bulk Density: 1.95 t/m<sup>3</sup>

Initial Dry Density: 1.55 t/m<sup>3</sup>

Water Content After Test: 24.6 %

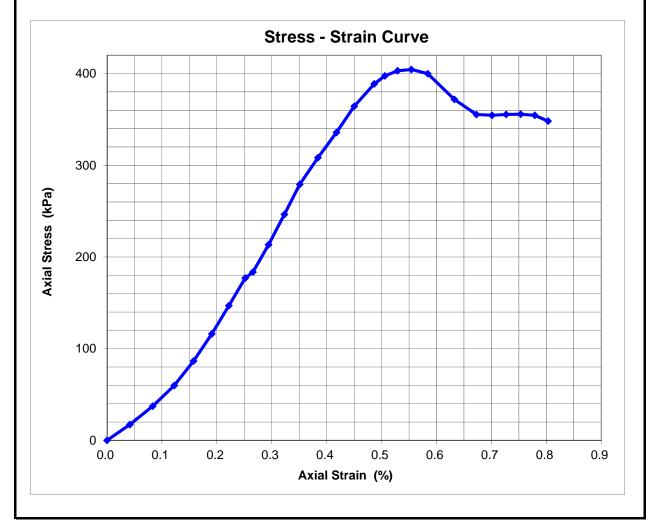
#### **Failure Conditions:**

Strain at failure: 0.55 %

Compression at failure: 0.67 mm

Rate of Compression: 0.14 mm / minute

Mode of Failure: planar / brittle





Job No:	Reg. No:	Report No:	Page 57 of 69
63532#L	2806	63532#L/UCS Waitakere LHRA	Version 3, July 2022

# WAITAKERE LHRA - MURIWAI GROUND INVESTIGATION

 Unconfined Compressive Strength of
 Tested By:
 WEC
 28-Sep-23

 Cohesive Soils
 Compiled By:
 WEC
 28-Sep-23

 Test Methods:
 NZS4402: 1986: Test 2.1 / Test 6.3.1
 Checked By:
 JF
 2-Oct-23

Borehole: BH-M03 Sample Number: UCS05 Depth: 33.76 - 34.06m

Sample Description (not part of BGL IANZ Accreditation):

SANDSTONE, fine to medium, extremely weak, dark orange, weakly cemented.

#### **SAMPLE BEFORE TEST**







Job No:	Reg. No:	Report No:	Page 58 of 69
63532#L	2806	63532#L/UCS Waitakere LHRA	Version 3, July 2022
	\A/ A	TAVEDELLIDA	NALIDIA/AI

### WAITAKERE LHRA - MURIWAI GROUND INVESTIGATION

**Unconfined Compressive Strength of Cohesive Soils** 

Test Methods: NZS4402: 1986: Test 2.1 / Test 6.3.1

 Tested By:
 WEC
 28-Sep-23

 Compiled By:
 WEC
 28-Sep-23

 Checked By:
 JF
 2-Oct-23

Borehole: BH-M03 Sample Number: UCS06 Depth: 37.00 - 37.25m

Time (minutes)	Compression Gauge (mm)	Specimen Compression (mm)	Strain	Load Gauge (mm)	Axial Force (N)	Corrected Area (mm²)	Axial Stress (kPa)
0.00	7.535	0.000	0.000	5.252	0.0	2836.6	0
0.13	7.564	0.028	0.000	5.254	14.0	2837.3	5
0.28	7.591	0.056	0.000	5.256	22.9	2838.0	8
0.42	7.614	0.079	0.001	5.259	35.4	2838.5	12
0.55	7.640	0.105	0.001	5.261	47.9	2839.1	17
0.70	7.667	0.132	0.001	5.263	59.7	2839.7	21
0.83	7.692	0.157	0.001	5.267	75.3	2840.3	27
0.98	7.720	0.184	0.002	5.270	90.2	2841.0	32
1.12	7.746	0.211	0.002	5.273	107.8	2841.6	38
1.27	7.772	0.237	0.002	5.276	124.0	2842.2	44
1.40	7.797	0.261	0.002	5.281	147.1	2842.8	52
1.53	7.821	0.286	0.002	5.286	170.8	2843.4	60
1.68	7.844	0.309	0.003	5.291	198.7	2844.0	70
1.82	7.867	0.332	0.003	5.297	226.6	2844.5	80
1.95	7.888	0.353	0.003	5.303	259.0	2845.0	91
2.10	7.910	0.374	0.003	5.310	291.7	2845.5	103
2.23	7.930	0.394	0.003	5.317	326.3	2846.0	115
2.37	7.949	0.414	0.003	5.324	363.7	2846.4	128
2.52	7.968	0.432	0.004	5.331	401.3	2846.9	141
2.65	7.986	0.451	0.004	5.340	443.2	2847.3	156
2.78	8.002	0.467	0.004	5.342	452.6	2847.7	159
2.93	8.015	0.480	0.004	5.343	458.5	2848.0	161
3.07	8.022	0.487	0.004	5.345	470.7	2848.2	165
3.20	8.040	0.505	0.004	5.354	513.3	2848.6	180
3.35	8.061	0.525	0.004	5.362	552.3	2849.1	194
3.48	8.082	0.546	0.005	5.369	590.8	2849.6	207
3.62	8.104	0.568	0.005	5.377	627.8	2850.1	220
3.77	8.127	0.591	0.005	5.384	662.6	2850.7	232
3.90	8.150	0.614	0.005	5.390	696.1	2851.2	244
4.03	8.176	0.640	0.005	5.396	724.0	2851.9	254
4.18	8.201	0.666	0.006	5.401	750.0	2852.5	263
4.32	8.226	0.691	0.006	5.406	773.8	2853.1	271
4.45	8.253	0.718	0.006	5.406	774.8	2853.7	271
4.60	8.344	0.809	0.007	5.363	558.7	2855.9	196
4.73	8.375	0.840	0.007	5.361	547.3	2856.6	192
4.87	8.401	0.866	0.007	5.361	551.3	2857.3	193
5.02	8.428	0.893	0.007	5.362	552.5	2857.9	193
5.15	8.470	0.934	0.008	5.358	533.5	2858.9	187

Unconfined Compressive Strength: 270



Job No:	Reg. No:	Report No:	Page 59 of 69
63532#L	2806	63532#L/UCS Waitakere LHRA	Version 3, July 2022

### WAITAKERE LHRA - MURIWAI GROUND INVESTIGATION

Unconfined Compressive Strength of Cohesive Soils

Test Methods: NZS4402: 1986: Test 2.1 / Test 6.3.1

Tested By:	WEC	28-Sep-23
Compiled By:	WEC	28-Sep-23
Checked By:	JF	2-Oct-23

Borehole: BH-M03 Sample Number: UCS06 Depth: 37,00 - 37,25m

Test Performed on: rock / whole soil

Sample History: disturbed / undisturbed / remoulded / recompacted / unknown

Sample Method & Type: from core sample / from tube sample

1.70

t/m<sup>3</sup>

Initial Diameter: 60.10 mm

Initial Length: 119.92 mm

Initial Mass: 686.61 g

Initial Bulk Density: 2.02 t/m³

initial Bulk Density: 2.02 | t/m<sup>2</sup>

Water Content After Test: 19.5 %

**Initial Dry Density:** 

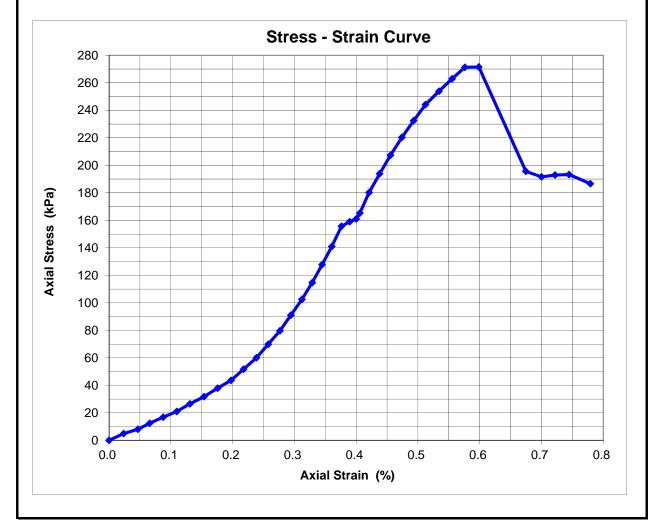
#### **Failure Conditions:**

Strain at failure: 0.60 %

Compression at failure: 0.72 mm

Rate of Compression: 0.16 mm / minute

Mode of Failure: planar / brittle





Job No:	Reg. No:	Report No:	Page 60 of 69
63532#L	2806	63532#L/UCS Waitakere LHRA	Version 3, July 2022

# WAITAKERE LHRA - MURIWAI GROUND INVESTIGATION

 Unconfined Compressive Strength of
 Tested By:
 WEC
 28-Sep-23

 Cohesive Soils
 Compiled By:
 WEC
 28-Sep-23

 Test Methods:
 NZS4402: 1986: Test 2.1 / Test 6.3.1
 Checked By:
 JF
 2-Oct-23

Borehole: BH-M03 Sample Number: UCS06 Depth: 37.00 - 37.25m

Sample Description (not part of BGL IANZ Accreditation):

SANDSTONE, fine to medium, extremely weak, dark orange, uncemented.

#### **SAMPLE BEFORE TEST**







Job No:	Reg. No:	Report No:	Page 61 of 69
63532#L	2806	63532#L/UCS Waitakere LHRA	Version 3, July 2022
	WΔ	TAKERE I HRA	- MURIWAI

### WAITAKERE LHRA - MURIWAI GROUND INVESTIGATION

Unconfined Compressive Strength of Cohesive Soils
Test Methods: NZS4402: 1986: Test 2.1 / Test 6.3.1

Tested By:	WEC	28-Sep-23
Compiled By:	WEC	28-Sep-23
Checked By:	JF	2-Oct-23

Borehole: BH-M03 Sample Number: UCS07 Depth: 40.14 - 40.43m

Time (minutes)	Compression Gauge (mm)	Specimen Compression (mm)	Strain	Load Gauge (mm)	Axial Force (N)	Corrected Area (mm²)	Axial Stress (kPa)
0.00	7.347	0.000	0.000	5.251	0.0	2830.7	0
0.15	7.381	0.035	0.000	5.252	5.1	2831.6	2
0.28	7.415	0.069	0.001	5.253	11.4	2832.4	4
0.42	7.450	0.103	0.001	5.255	18.4	2833.3	6
0.57	7.484	0.137	0.001	5.256	25.3	2834.1	9
0.70	7.518	0.171	0.001	5.257	32.3	2834.9	11
1.07	7.607	0.260	0.002	5.261	52.4	2837.2	18
1.45	7.695	0.348	0.003	5.267	78.9	2839.3	28
1.82	7.781	0.434	0.004	5.273	112.6	2841.5	40
2.18	7.863	0.516	0.004	5.281	151.3	2843.5	53
2.57	7.944	0.598	0.005	5.289	189.5	2845.5	67
2.93	8.024	0.677	0.006	5.296	224.6	2847.5	79
3.30	8.110	0.763	0.007	5.301	249.7	2849.7	88
3.68	8.200	0.853	0.007	5.303	262.0	2851.9	92
4.05	8.297	0.950	0.008	5.303	259.7	2854.4	91
4.42	8.393	1.047	0.009	5.301	250.7	2856.8	88
4.80	8.493	1.146	0.010	5.298	236.6	2859.3	83
5.17	8.589	1.242	0.011	5.295	223.9	2861.7	78
5.55	8.689	1.342	0.012	5.292	206.9	2864.2	72
5.92	8.793	1.446	0.013	5.290	198.4	2866.8	69

**Unconfined Compressive Strength:** 

92



Job No:	Reg. No:	Report No:	Page 62 of 69
63532#L	2806	63532#L/UCS Waitakere LHRA	Version 3, July 2022

#### WAITAKERE LHRA - MURIWAI GROUND **INVESTIGATION**

**Unconfined Compressive Strength of Cohesive Soils** 

Test Methods: NZS4402: 1986: Test 2.1 / Test 6.3.1

Tested By:	WEC	28-Sep-23
Compiled By:	WEC	28-Sep-23
Checked By:	JF	2-Oct-23

Depth: 40.14 - 40.43m Borehole: BH-M03 Sample Number: UCS07

Test Performed on: rock / whole soil

Sample History: disturbed / remoulded / recompacted / unknown

Sample Method & Type: from core sample / from tube sample

> **Initial Diameter:** 60.04 mm **Initial Length:** 114.86 **Initial Mass:** 660.65

Initial Bulk Density: 2.03 t/m<sup>3</sup>

**Initial Dry Density:** 1.65 t/m<sup>3</sup>

Water Content After Test: 23.4

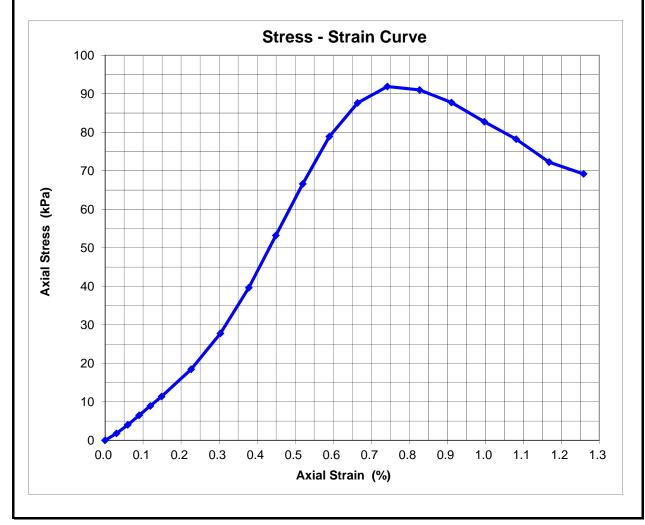
#### **Failure Conditions:**

0.74 Strain at failure:

0.85 Compression at failure: mm

Rate of Compression: 0.23 mm / minute

Mode of Failure: plastic





Job No:	Reg. No:	Report No:	Page 63 of 69
63532#L	2806	63532#L/UCS Waitakere LHRA	Version 3, July 2022

# WAITAKERE LHRA - MURIWAI GROUND INVESTIGATION

 Unconfined Compressive Strength of
 Tested By:
 WEC
 28-Sep-23

 Cohesive Soils
 Compiled By:
 WEC
 28-Sep-23

 Test Methods:
 NZS4402: 1986: Test 2.1 / Test 6.3.1
 Checked By:
 JF
 2-Oct-23

Borehole: BH-M03 Sample Number: UCS07 Depth: 40.14 – 40.43m

Sample Description (not part of BGL IANZ Accreditation):

SANDSTONE, fine to medium, extremely weak, dark orange, uncemented.

#### **SAMPLE BEFORE TEST**





Job No:	Reg. No:	Report No:	Page 64 of 69
63532#L	2806	63532#L/UCS Waitakere LHRA	Version 3, July 2022
	\ <b>\</b> \ \ \ \	TAKEDE I UDA	MIDIMAI

#### WAITAKERE LHRA - MURIWAI GROUND INVESTIGATION

Unconfined Compressive Strength of Cohesive Soils

Test Methods: NZS4402: 1986: Test 2.1 / Test 6.3.1

 Tested By:
 WEC
 28-Sep-23

 Compiled By:
 WEC
 2-Oct-23

 Checked By:
 JF
 2-Oct-23

Borehole: BH-M03 Sample Number: UCS08 Depth: 41.15 - 41.43m

Time (minutes)	Compression Gauge (mm)	Specimen Compression (mm)	Strain	Load Gauge (mm)	Axial Force (N)	Corrected Area (mm²)	Axial Stress (kPa)
0.00	10.723	0.000	0.000	5.249	0.0	2914.3	0
0.37	10.791	0.068	0.001	5.257	43.0	2916.0	15
0.75	10.855	0.133	0.001	5.267	89.7	2917.6	31
1.12	10.907	0.185	0.002	5.285	181.8	2918.9	62
1.50	10.953	0.230	0.002	5.308	295.4	2920.1	101
1.87	10.994	0.271	0.002	5.332	419.8	2921.1	144
2.23	11.015	0.293	0.003	5.345	482.5	2921.6	165
2.62	11.053	0.330	0.003	5.364	577.7	2922.6	198
2.98	11.099	0.376	0.003	5.388	701.2	2923.7	240
3.27	11.134	0.411	0.004	5.408	796.8	2924.6	272
3.53	11.168	0.445	0.004	5.428	899.7	2925.5	308
3.82	11.201	0.478	0.004	5.449	1003.2	2926.3	343
3.95	11.219	0.496	0.004	5.459	1056.8	2926.7	361
4.23	11.254	0.531	0.005	5.480	1161.6	2927.6	397
4.52	11.289	0.567	0.005	5.500	1263.3	2928.5	431
4.65	11.307	0.584	0.005	5.511	1315.4	2929.0	449
4.78	11.325	0.602	0.005	5.521	1366.7	2929.4	467
4.93	11.343	0.620	0.005	5.531	1419.0	2929.9	484
5.07	11.361	0.638	0.005	5.542	1470.3	2930.3	502
5.20	11.378	0.655	0.006	5.552	1522.3	2930.7	519
5.35	11.396	0.673	0.006	5.562	1573.4	2931.2	537
5.48	11.414	0.691	0.006	5.572	1623.3	2931.7	554
5.63	11.432	0.709	0.006	5.582	1673.5	2932.1	571
5.77	11.452	0.729	0.006	5.592	1720.6	2932.6	587
5.90	11.471	0.748	0.006	5.601	1769.1	2933.1	603
6.05	11.491	0.768	0.007	5.610	1814.7	2933.6	619
6.18	11.510	0.787	0.007	5.619	1859.9	2934.1	634
6.32	11.530	0.807	0.007	5.629	1907.0	2934.6	650
6.47	11.551	0.828	0.007	5.637	1948.9	2935.1	664
6.60	11.571	0.848	0.007	5.645	1988.8	2935.6	677
6.75	11.593	0.870	0.007	5.651	2020.2	2936.2	688
6.88	11.616	0.893	0.008	5.659	2058.3	2936.8	701
7.02	11.641	0.918	0.008	5.663	2081.5	2937.4	709
7.17	11.666	0.943	0.008	5.667	2101.4	2938.0	715
7.30	11.693	0.970	0.008	5.666	2096.0	2938.7	713
7.43	11.726	1.003	0.009	5.656	2046.6	2939.5	696
7.58	11.893	1.170	0.010	5.490	1212.5	2943.8	412
7.72	11.970	1.247	0.011	5.433	923.8	2945.7	314
7.87	12.025	1.302	0.011	5.421	863.6	2947.1	293
8.00	12.069	1.347	0.012	5.413	825.6	2948.3	280
8.13	12.106	1.383	0.012	5.408	800.0	2949.2	271

Unconfined Compressive Strength: 720



Job No:	Reg. No:	Report No:	Page 65 of 69
63532#L	2806	63532#L/UCS Waitakere LHRA	Version 3, July 2022

# WAITAKERE LHRA - MURIWAI GROUND INVESTIGATION

Unconfined Compressive Strength of Cohesive Soils

Test Methods: NZS4402: 1986: Test 2.1 / Test 6.3.1

Tested By:	WEC	28-Sep-23
Compiled By:	WEC	2-Oct-23
Checked By:	JF	2-Oct-23

Borehole: BH-M03 Sample Number: UCS08 Depth: 41.15 – 41.43m

Test Performed on: rock / whole soil

Sample History: disturbed / undisturbed / remoulded / recompacted / unknown

Sample Method & Type: from core sample / from tube sample

Initial Diameter: 60.92 mm

Initial Length: 116.96 mm

Initial Mass: 585.46 g

Initial Bulk Density: 1.72 t/m<sup>3</sup>

Initial Dry Density: 1.15 t/m<sup>3</sup>

Water Content After Test: 49.9 %

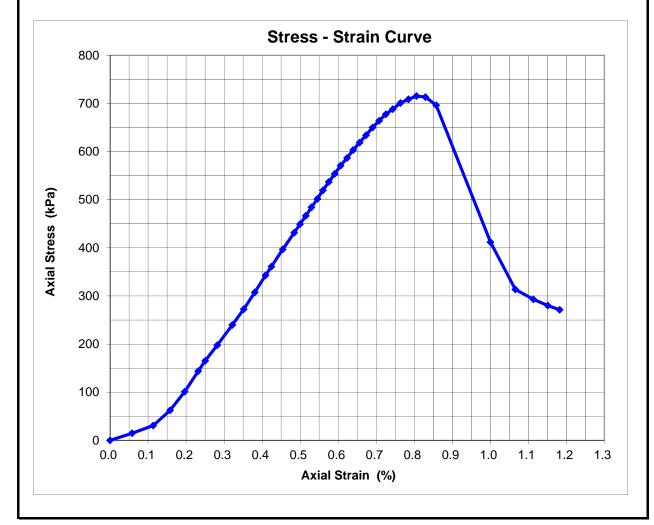
#### **Failure Conditions:**

Strain at failure: 0.81 %

Compression at failure: 0.94 mm

Rate of Compression: 0.13 mm / minute

Mode of Failure: planar





Job No:	Reg. No:	Report No:	Page 66 of 69
63532#L	2806	63532#L/UCS Waitakere LHRA	Version 3, July 2022

# WAITAKERE LHRA - MURIWAI GROUND INVESTIGATION

 Unconfined Compressive Strength of
 Tested By:
 WEC
 28-Sep-23

 Cohesive Soils
 Compiled By:
 WEC
 2-Oct-23

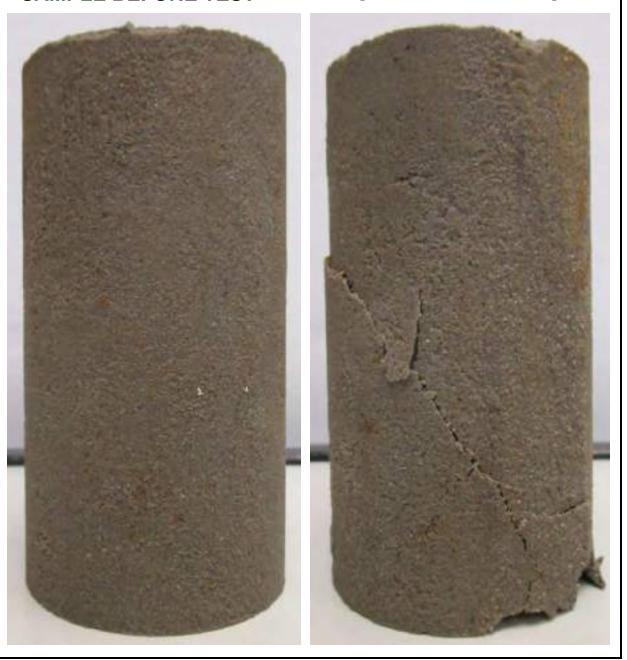
 Test Methods:
 NZS4402: 1986: Test 2.1 / Test 6.3.1
 Checked By:
 JF
 2-Oct-23

Borehole: BH-M03 Sample Number: UCS08 Depth: 41.15 - 41.43m

Sample Description (not part of BGL IANZ Accreditation):

SILTSTONE, extremely weak, grey.

#### **SAMPLE BEFORE TEST**





Job No:	Reg. No:	Report No:	Page 67 of 69
63532#L	2806	63532#L/UCS Waitakere LHRA	Version 3, July 2022
PROJECT:	WAI	TAKERE LHRA	- MURIWAI

Unconfined Compressive Strength of

 Compiled By:
 WEC
 28-Sep-23

 Checked By:
 JF
 2-Oct-23

WEC

28-Sep-23

**GROUND INVESTIGATION** 

Tested By:

Cohesive Soils
Test Methods: NZS4402: 1986: Test 2.1 / Test 6.3.1

Borehole: BH-M03 Sample Number: UCS09 Depth: 50.73 - 51.00m

Time (minutes)	Compression Gauge (mm)	Specimen Compression (mm)	Strain	Load Gauge (mm)	Axial Force (N)	Corrected Area (mm²)	Axial Stress (kPa)
0.00	2.137	0.000	0.000	5.253	0.0	2801.8	0
0.13	2.174	0.037	0.000	5.257	19.6	2802.7	7
0.52	2.267	0.130	0.001	5.270	87.2	2804.8	31
0.88	2.353	0.216	0.002	5.288	177.0	2806.9	63
1.27	2.437	0.300	0.003	5.309	282.7	2808.8	101
1.63	2.478	0.341	0.003	5.331	392.2	2809.8	140
2.00	2.494	0.357	0.003	5.348	477.4	2810.2	170
2.38	2.536	0.399	0.003	5.381	641.6	2811.2	228
2.75	2.580	0.444	0.004	5.419	832.4	2812.2	296
3.12	2.622	0.485	0.004	5.460	1041.1	2813.2	370
3.50	2.665	0.528	0.004	5.504	1262.1	2814.2	448
3.87	2.704	0.567	0.005	5.551	1495.8	2815.1	531
4.25	2.744	0.607	0.005	5.598	1730.3	2816.1	614
4.62	2.784	0.647	0.005	5.645	1966.2	2817.0	698
4.98	2.826	0.689	0.006	5.691	2199.5	2818.0	781
5.37	2.882	0.745	0.006	5.728	2383.7	2819.3	846
5.73	3.458	1.321	0.011	5.302	244.1	2833.0	86
6.10	3.562	1.425	0.012	5.300	237.1	2835.5	84

**Unconfined Compressive Strength:** 

850



Job No:	Reg. No:	Report No:	Page 68 of 69
63532#L	2806	63532#L/UCS Waitakere LHRA	Version 3, July 2022

### WAITAKERE LHRA - MURIWAI GROUND INVESTIGATION

**Unconfined Compressive Strength of Cohesive Soils** 

Test Methods: NZS4402: 1986: Test 2.1 / Test 6.3.1

Tested By:	WEC	28-Sep-23
Compiled By:	WEC	28-Sep-23
Checked By:	JF	2-Oct-23

Borehole: BH-M03 Sample Number: UCS09 Depth: 50.73 - 51.00m

Test Performed on: rock / whole soil

Sample History: disturbed / undisturbed / remoulded / recompacted / unknown

Sample Method & Type: from core sample / from tube sample

Initial Diameter: 59.73 mm

Initial Length: 119.88 mm

Initial Mass: 652.28 g

Initial Bulk Density: 1.94 t/m<sup>3</sup>

Initial Dry Density: 1.60 t/m<sup>3</sup>

Water Content After Test: 20.2 %

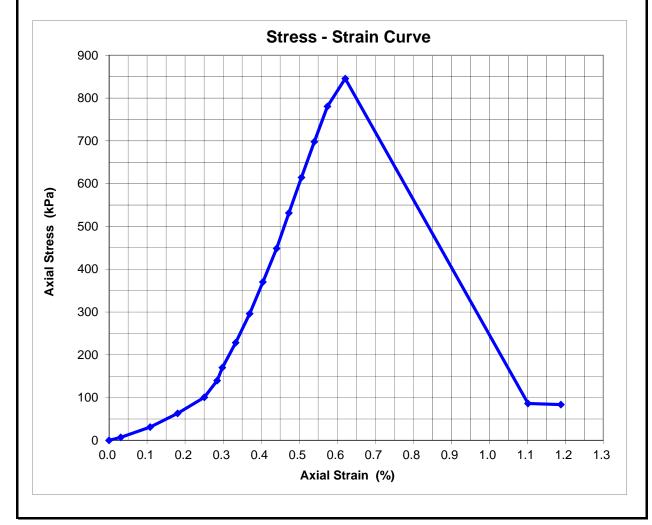
#### **Failure Conditions:**

Strain at failure: 0.62 %

Compression at failure: 0.74 mm

Rate of Compression: 0.14 mm / minute

Mode of Failure: brittle





Job No:	Reg. No:	Report No:	Page 69 of 69
63532#L	2806	63532#L/UCS Waitakere LHRA	Version 3, July 2022

### WAITAKERE LHRA - MURIWAI GROUND INVESTIGATION

 Unconfined Compressive Strength of
 Tested By:
 WEC
 28-Sep-23

 Cohesive Soils
 Compiled By:
 WEC
 28-Sep-23

 Test Methods:
 NZS4402: 1986: Test 2.1 / Test 6.3.1
 Checked By:
 JF
 2-Oct-23

Borehole: BH-M03 Sample Number: UCS09 Depth: 50.73 - 51.00m

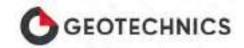
Sample Description (not part of BGL IANZ Accreditation):

SANDSTONE, fine to medium, extremely weak, dark orange, weakly cemented.

#### **SAMPLE BEFORE TEST**







18 October 2023

Our Ref: 1092481.0.1.0 & 1092481.0.2.0/Rep1

Customer Ref: 12612462

GHD Limited Level 2, GHD Centre 27 Napier Street Freemans Bay Auckland 1011

Attention: John Southworth

Dear John

#### Muriwai

#### **Laboratory Test Report**

Customer's Instructions

The detailed testing instructions were provided with a schedule from Mr. John Southworth.

Sampling Procedure

Samples have been tested as received from the customer.

Sample Location Plan

Not applicable.

Samples

Three core samples were received. All samples were labelled with Borehole number, sample reference, and depth.

Date of Sample Receipt

27 September 2023

Test Method(s)

ASTM D4647-13 (2020) - Pinhole

BS 1377: Part 5: 1990 Clause 6.3 - Dispersibility by the Crumb Method (not IANZ accredited)

NZS 4402: 1986 Test 2.1 - Water Content

Material Description

Descriptions are provided in the attached presentation pages.

#### **Test Results**

Test results are attached.

#### **Test Remarks**

Test remarks are detailed on the presentation pages.

#### **General Remarks**

Samples not destroyed during testing, will be retained for one month from the date of this report before being discarded.

Descriptions are enclosed for your information but are not covered under the IANZ endorsement of this report.

This report has been prepared for the benefit of GHD Limited, with respect to the particular brief given to us and it cannot be relied upon in other contexts or for any other purpose without our prior review and agreement.

Please reproduce this report in full when transmitting to others or including in internal reports.

If we can be of any further assistance, feel free to get in touch. Contact details are provided at the bottom of the letterhead page.

#### **GEOTECHNICS LTD**

Report approved by: Authorised for Geotechnics by:

Helen Wang

Triaxial Laboratory Manager

Key Technical Person

Melen Way

Corey Papu-Gread
Project Director



1092481.0.1.0

G OTECHNICS 1 Hill Street Onehunga

Auckland

Auckland QESTLab Work Order
New Zealand Customer Project ID:

Geotechnics Project ID: QESTLab Work Order ID:

Customer Project ID: 12612462

p. +64 9 356 3510

Site/Location: Muriwai Location ID: BH-M01

Sample Ref.: C5 Depth: 2.02 - 2.06 (m)

Test Method Used: ASTM D4647-13 (2020) Pinhole Test (Method A)

NZS 4402:1986 Test 2.1 Determination of Water Content

Initial Water Content 48.7 (%) Initial Bulk Density 1.65 (t/m³)

Final Water Content 61.5 (%) Initial Dry Density 1.11 (t/m³)

Hydraulic	Duration of	Rate of flow		Cloudine	ess of flow		
head H (mm)	flow (min)	q (mL/sec)	From s	side		From top	
		1.14	Dark		Very dark		
50	5	1.25	Dark		Very dark		
		1.28	Dark		Very dark		
50							
180							
380							
							_
1020							
Hole diameter a	fter test:	2.2	(mm)	Dispersion Ca	ategory:	D1	

Sample Description: Clayey SILT, dark brown; very soft, wet, high plasticity.

Sample History: Undisturbed core trimmed at natural water content.

Test Remarks: 1. The pinhole was formed with 1.1 mm diameter pin.

2. Distilled water was used in test.

3. Classification:

D1, D2 -- Dispersive;

ND4, ND3 -- Moderately to slightly dispersive;

ND2, ND1 -- Non-dispersive.

4. The soil classified as non-dispersive still can erode in some circumstances.

Tested by: PIHE Date: 12/10/2023 Approved by KTP: 18/10/2023 Date: 18/10/2023

OTECHNICS

Sample Ref.:

1 Hill Street Onehunga

Auckland

Geotechnics Project ID: QESTLab Work Order ID: Customer Project ID: 1092481.0.1.0

12612462

BH-M02

New Zealand

p. +64 9 356 3510

Site/Location: Muriwai

Muriwai Location ID: C15 Depr

Depth: 1.96 - 2.00 (m)

Test Method Used: ASTM D4647-13 (2020) Pinhole Test (Method A)

NZS 4402:1986 Test 2.1 Determination of Water Content

Initial Water Content 52.3 (%) Initial Bulk Density 1.69 (t/m³)

Final Water Content 47.9 (%) Initial Dry Density 1.11 (t/m³)

Hydraulic	Duration of	Rate of flow		Cloudiness of flow	
head H (mm)	flow (min)	q (mL/sec)	From side		From top
		0.36	Perfectly clear	Perfectly cle	ear
50	5	0.36	Perfectly clear	Perfectly cle	ear
		0.35	Perfectly clear	Perfectly cle	ear
		0.33	Perfectly clear	Perfectly cle	ear
50	5	0.34	Perfectly clear	Perfectly cle	ear
		0.34	Perfectly clear	Perfectly cle	ear
	5	0.75	Perfectly clear	Perfectly cle	ear
180		0.76	Perfectly clear	Perfectly cle	ear
		0.74	Perfectly clear	Perfectly cle	ear
		1.20	Perfectly clear	Perfectly cle	ear
380	5	1.16	Perfectly clear	Perfectly cle	ear
		1.15	Perfectly clear	Perfectly cle	ear
		2.39	Perfectly clear	Perfectly cle	ear
1020	5	2.43	Perfectly clear	Perfectly clear	
		2.38	Perfectly clear	Perfectly cle	ear .
Hole diameter after test:		1.0	(mm) D	Dispersion Category:	ND1

Sample Description: Silty CLAY, orange brown; very soft, wet, high plasticity.

Sample History: Undisturbed core trimmed at natural water content.

Test Remarks: 1. The pinhole was formed with 1.1 mm diameter pin.

2. Distilled water was used in test.

3. Classification:

D1, D2 -- Dispersive;

ND4, ND3 -- Moderately to slightly dispersive;

ND2, ND1 -- Non-dispersive.

4. The soil classified as non-dispersive still can erode in some circumstances.

Tested by: PIHE Date: 10/10/2023 Approved by KTP: 18/10/2023 Date: 18/10/2023



1 Hill Street, Onehunga, Auckland 1061

GEOTECHNICS	P 64 09 356 3510					
GEOTECHNICS	www.geotechnics.co.n	Determination of Dispersibilty - Crumb Method - BS 1377: Part 5: 1990 Clause	6.2			
		Determination of Dispersionty - Crumb Method - B3 1377. Part 3: 1990 Clause				
ite:	Muriwai		Job No:	1092481.0000.2.0		
est Pit/BH No:	BH-M01 / C5	Sample No: AKL657.1	Depth (m):	2.0 m		
topwatch ID:	S0596					
ample Description:	clayey SILT, dark bi	rown; very soft, wet, high plasticity				
escriptive behaviour of the crui						
Observations:		Grade 4 - Strong reaction				
he soil classified as	dispersive	according to this test method.				
emarks:						
est Pit/BH No:	BH-M02 / C15	Sample No: AKL657.2	Depth (m):	1.95 m		
topwatch ID:	S0596					
ample Description: silty CLAY, orange brown; very soft, wet, high plasticity						
escriptive behaviour of the crui fter allowing to stand for 5 to 10						
Observations:		Grade 4 - Strong reaction				
he soil classified as	dispersive	according to this test method.				
emarks:						
alance ID:		B0012				
eagent Used: 0.001M solution of Sodiu	um Hydroxide: Dissolve	e 0.04g of anhydrous sodium hydroxide in distilled water to make 1L of solution.				
		ameter, from a representative portions of the soil at the natural moisture content.  f the sodium hydroxide solution. Observe the reaction after allowing to stand for				
astervations: Observe the behaviour of the crumbs in accordance with the following guidelines.  and 1: No reaction: Crumbs may slake or run out to form a shallow heap on the bottom of the beaker, but there is no sign of cloudiness caused by colloids in suspension.  and 2: Slight reaction: A very slight cloudiness can be seen in the water at the surface of a crumb.  and 3: Moderate reaction: There is an easily recognizable cloud of colloids in suspension, usually spreading out in thin streaks at the bottom of the beaker  and 4: Strong reaction: A colloidal cloud covers most of the bottom beaker, usually as a thin skin. In extreme cases all the water becomes cloudy.						
rades 1 and 2 represent a non- dispers rades 3 and 4 represent a dispersive re emarks:  ested by: KESA D		23 <b>Checked by:</b> GEGO <b>Date:</b> 10/10/2023				
	10, 10, 202					

# Appendix F4

**Calibration Certificates for Shear Vane and SPT Hammer** 



#### **Calibration Certificate**

Certificate No: M720664.01

Certificate Issued To	GHD Limited	GHD Limited		3/27 Napier Street Freemans Bay			
Purchase Order No			Address	Auckland			
Manufacturer	Geotechnics	Model	Geovane		S/No	902	
wanulacturer	Geotechnics		Geovaile		Unique ID		
Description	Handheld shear var	ne with matching l	blade(s)				
Calibration Date	3/04/2023		Temp During Test		19.7 to 20.1 °C		
Method	MCC 5.51c.01 – Har 2001) was used as a		Vane Testers (	2021), Guide	eline for Hand H	eld Shear Vane Test (NZGS,	
Results	<u>'</u>						

#### 19 mm Ø Vane Blade

Shear Strength = A × Reading	A (kPa/div)	1.446		Area Ratio	23.3%
------------------------------	-------------	-------	--	------------	-------

Reading	Shear	Reading	Shear	Reading	Shear	Reading	Shear	Reading (div)	Shear
(div)	Strength (kPa)	(div)	Strength (kPa)	(div)	Strength (kPa)	(div)	Strength (kPa)	(aiv)	Strength (kPa)
0	0	30	43	60	87	90	130	120	174
2	3	32	46	62	90	92	133	122	176
4	6	34	49	64	93	94	136	124	179
6	9	36	52	66	95	96	139	126	182
8	12	38	55	68	98	98	142	128	185
10	14	40	58	70	101	100	145	130	188
12	17	42	61	72	104	102	148	132	191
14	20	44	64	74	107	104	150	134	194
16	23	46	67	76	110	106	153	136	197
18	26	48	69	78	113	108	156	138	200
20	29	50	72	80	116	110	159	140	202
22	32	52	75	82	119	112	162		
24	35	54	78	84	121	114	165		
26	38	56	81	86	124	116	168		
28	40	58	84	88	127	118	171		
	d uncertainty	of measurem	ent. expresse		confidence lev	vel. is ±4.1 kPa	a. The coverag	ge factor (k) is	2.

#### Remarks

When received, this equipment was in good condition.

Measurement results are traceable to the International System of Units (SI), or other recognised references via an unbroken chain of comparisons to the New Zealand National Standards or to the National Standards of other Signatories to the CIPM MRA.

This certificate has been prepared for the benefit of GHD Limited, with respect to the particular brief given to us and it cannot be relied upon in other contexts or for any other purpose without our prior review and agreement.

This calibration was performed at 1 Hill Street, Onehunga, Auckland, NZ.

Prepared by

Ivan Caresosa

Checked by

Senior Metrologist

**Key Technical Person** 

Agnelo Vaz Senior Metrolog





#### **Calibration Certificate**

Certificate No: M720829.03

Certificate Issued To	GHD Limited - Auckland		Address	3, GHD Centre 27 Napier Street Freemans Bay				
Purchase Order No	11910201_BG-01.BG-01-0	4	Address	Auckland 1011				
Manufacturer	Geotechnics	Model	Geovane		S/No	1060		
ivianutacturer	Geotechnics	iviodei			Unique ID			
Description	Handheld shear vane with	matching bla	ide(s)					
<b>Calibration Date</b>	15/05/2023		Temp During	g Test	19.1 to 19.5	°C		
Method	MCC 5.51c.01 – Handheld 2001) was used as a guide		ane Testers (2021), Guideline for Hand Held Shear Vane Test (N					

#### 19 mm Ø Vane Blade

Shear Strength = A × Reading	A (kPa/div)	1.547	Area F	atio	23.5%
------------------------------	-------------	-------	--------	------	-------

Reading (div)	Shear Strength (kPa)	Reading (div)	Shear Strength (kPa)	Reading (div)	Shear Strength (kPa)	Reading (div)	Shear Strength (kPa)	Reading (div)	Shear Strength (kPa)
0	0	30	46	60	93	90	139	120	186
2	3	32	49	62	96	92	142	122	189
4	6	34	53	64	99	94	145	124	192
6	9	36	56	66	102	96	148	126	195
8	12	38	59	68	105	98	152	128	198
10	15	40	62	70	108	100	155	130	201
12	19	42	65	72	111	102	158	132	204
14	22	44	68	74	114	104	161	134	207
16	25	46	71	76	118	106	164	136	210
18	28	48	74	78	121	108	167	138	213
20	31	50	77	80	124	110	170	140	217
22	34	52	80	82	127	112	173		
24	37	54	84	84	130	114	176		
26	40	56	87	86	133	116	179		
28	43	58	90	88	136	118	183		

#### Remarks

Results

When received, this equipment was in good condition.

Measurement results are traceable to the International System of Units (SI), or other recognised references via an unbroken chain of comparisons to the New Zealand National Standards or to the National Standards of other Signatories to the CIPM MRA.

This certificate has been prepared for the benefit of GHD Limited - Auckland, with respect to the particular brief given to us and it cannot be relied upon in other contexts or for any other purpose without our prior review and agreement.

This calibration was performed at 1 Hill Street, Onehunga, Auckland, NZ.

**Prepared by** 

Ivan Caresosa

Checked by

Annalyse Ryan

**Key Technical Person** 

Annalyse Ryan

Metrologist | Team Leade



V9.6: 05 May 2023 Date Issued: 16/05/2023



NZBN: 9429050784509

Job No.: 1015 2302

Date: 30 March 2023

Attention: Dave Penney

Organisation: DCN Drilling Limited

Email: dave@dcndrilling.co.nz

#### Letter Report:

#### SPT Energy Measurements on 5No. SPT Trip Hammers

#### 1. Introduction

This letter report summarises the results of the Standard Penetration Test (SPT) energy measurements on 5No. SPT trip hammers for DCN Drilling Limited on 9 February 2023, at the site of 70A Maxwell Road, Maramarua, Waikato.

The SPT energy measurements were carried out to determine the average energy transfer ratio from the SPT hammer to the SPT rods during the Standard Penetration Tests. The SPT energy measurements were undertaken in accordance with ASTM D4633-16: Standard Test Method for Energy Measurement for Dynamic Penetrometers.

A Pile Driving Analyzer (PDA) Model 8G with add on SPT Analyzer software and a NW size instrumented SPT rod (manufactured by Pile Dynamics, Inc.) were used to acquire the test data. Adaptors from NW thread to tapered API thread were used on both ends of the instrumented rod to connect to the SPT rods.

The PDA system uses the Case Method equations to evaluate the test data. The maximum energy transfer (EMX) at the gauge location was obtained as the maximum value from integrating the product of force (F) and velocity (v) over time: EMX =  $max \int F(t)v(t)dt$ .

In summary, the measured energy transfer ratios (ETR) for the 5No. SPT trip hammers are:

- Trip Hammer #1, average ETR of 68.1%.
- Trip Hammer #2, average ETR of 69.0%.
- Trip Hammer #3, average ETR of 68.5%.
- Trip Hammer #4, average ETR of 73.5%.
- Trip Hammer #5, average ETR of 63.9%.

The calibration certificates of the instruments used for SPT energy measurements are attached in Appendix A. The results of energy measurements are attached in Appendix B. The representative force and velocity plots are attached in Appendix C.



NZBN: 9429050784509

Job No.:1015\_2302

Date: 30 March 2023

#### 2. Drill Rigs

The Morooka drill rig and approximate 61 mm outer diameter SPT rods were used for energy measurements on the trip hammers #1 and #2. The trailer mounted drill rig and approximate 60 mm outer diameter SPT rods were used for energy measurements on the trip hammers #3, #4 and #5. Photos of the two rigs are presented in Figures 2-1 and 2-2 below.





Figure 2-1: Photos of the Morooka drill rig and the instrumented SPT rod assembly.





Figure 2-2: Photos of the trailer mounted drill rig and the instrumented SPT rod assembly.



NZBN: 9429050784509

Job No.:1015\_2302

Date: 30 March 2023

#### 3. Energy Measurements of SPT Trip Hammer #1

Photos of the SPT trip hammer #1 are presented in Figure 3-1 below.





Figure 3-1: Photos of SPT trip hammer #1

A summary of energy measurements on the trip hammer #1 is presented in Table 3-1 below.

Table 3-1: Summary of energy measurements on SPT trip hammer #1

SPT Hammer No.	Test No.	Depth below ground level (m)	SPT 'N'	Range of Transferred Energy (kN-m)	Average Transferred Energy (kN-m)	Range of Energy Transfer Ratio	Average Energy Transfe Ratio
Trip Hammer #1	1	13.5	35	0.281 - 0.351	0.303	59.2% - 73.9%	63.9%
	2	15	35	0.306 - 0.380	0.339	64.4% - 80.1%	71.3%
	3	16.5	44	0.311 - 0.352	0.327	65.5% - 74.1%	69.0%
		Overall		14	0.323	2	68.1%



NZBN: 9429050784509

Job No.:1015\_2302

Date: 30 March 2023

#### 4. Energy Measurements of SPT Trip Hammer #2

Photos of the SPT trip hammer #2 are presented in Figure 4-1 below.





Figure 4-1: Photos of SPT trip hammer #2

A summary of energy measurements on the trip hammer #2 is presented in Table 4-1 below.

Table 4-1: Summary of energy measurements on SPT trip hammer #2

SPT Hammer No.	Test No.	Depth below ground level (m)	SPT 'N'	Range of Transferred Energy (kN-m)	Average Transferred Energy (kN-m)	Range of Energy Transfer Ratio	Average Energy Transfe Ratio
Trip Hammer #2	1	9	31	0.265 - 0.330	0.299	55.8% - 69.6%	63.0%
	2	10.5	37	0.329 - 0.364	0.347	69.2% - 76.7%	73.1%
	3	12	29	0.319 - 0.363	0.336	67.2% - 76.5%	70.8%
		Overall		72.1	0.327		69.0%



NZBN: 9429050784509

Job No.:1015\_2302

Date: 30 March 2023

### 5. Energy Measurements of SPT Trip Hammer #3

Photos of the SPT trip hammer #3 are presented in Figure 5-1 below.





Figure 5-1: Photos of SPT trip hammer #3

A summary of energy measurements on the trip hammer #3 is presented in Table 5-1 below.

Table 5-1: Summary of energy measurements on SPT trip hammer #3

SPT Hammer No.	Test No.	Depth below ground level (m)	SPT 'N'	Range of Transferred Energy (kN-m)	Average Transferred Energy (kN-m)	Range of Energy Transfer Ratio	Average Energy Transfer Ratio
	1	9	19	0.336 - 0.401	0.360	70.7% - 84.4%	75.9%
T-1- 11	2	10.5	34	0.292 - 0.336	0.312	61.5% - 70.9%	65.7%
Trip Hammer #3	3	12	50	0.277 - 0.323	0.304	58,5& - 68,1%	64.0%
		Overall		-	0.325	9-1	68.5%



NZBN: 9429050784509

Job No.:1015\_2302

Date: 30 March 2023

### 6. Energy Measurements of SPT Trip Hammer #4

Photos of the SPT trip hammer #4 are presented in Figure 6-1 below.





Figure 6-1: Photos of SPT trip hammer #4

A summary of energy measurements on the trip hammer #4 is presented in Table 6-1 below.

Table 6-1: Summary of energy measurements on SPT trip hammer #4

SPT Hammer No.	Test No.	Depth below ground level (m)	SPT 'N'	Range of Transferred Energy (kN-m)	Average Transferred Energy (kN-m)	Range of Energy Transfer Ratio	Average Energy Transfe Ratio
	1	9	32	0.321 - 0.376	0.354	67.7% - 79.2%	74.7%
2111 00	2	10.5	35	0.335 - 0.377	0.359	70.6% - 79.4%	75.6%
Trip Hammer #4	3	12	50	0.288 - 0.372	0.334	60.6% - 78.4%	70.3%
		Overall		14	0.349		73.5%



NZBN: 9429050784509

Job No.:1015\_2302

Date: 30 March 2023

### 7. Energy Measurements of SPT Trip Hammer #5

Photos of the SPT trip hammer #5 are presented in Figure 7-1 below.





Figure 7-1: Photos of SPT trip hammer #5

A summary of energy measurements on the trip hammer #5 is presented in Table 7-1 below.

Table 7-1: Summary of energy measurements on SPT trip hammer #5

SPT Hammer No.	Test No.	Depth below ground leyel (m)	SPT 'N'	Range of Transferred Energy (kN-m)	Average Transferred Energy (kN-m)	Range of Energy Transfer Ratio	Average Energy Transfe Ratio
	1	9	49	0.274 - 0.340	0.301	57.6% - 71.7%	63.5%
Trin Unamer #5	2	10.5	29	0.270 - 0.339	0.300	56.9% - 71.4%	63.3%
Trip Hammer #5	3	12	48	0.278 - 0.330	0.309	58.5% - 69.6%	65.0%
		Overall		141	0.303		63.9%



NZBN: 9429050784509

Job No. 1015 2302

Date: 30 March 2023

#### 8. Limitations

This letter report has been prepared solely for the benefit of our client DCN Drilling Limited with respect to the particular instructions and relevant information provided to us. This letter report shall not be relied upon by any third parties or for any other purposes without our prior review and written agreement.

Authorised for Roc Consulting Limited by:

Richard (Liqiang) Zhang

Director | Principal Geotechnical Engineer

Email: Richard@rocconsulting.co.nz Phone: +64 27 506 5893

### Appendix:

- A. Instrument Calibration Certificates
- B. SPT Energy Measurements Results
- C. Representative Force and Velocity Plots



NZBN: 9429050784509

Job No.:1015\_2302

Date: 30 March 2023

### Appendix A

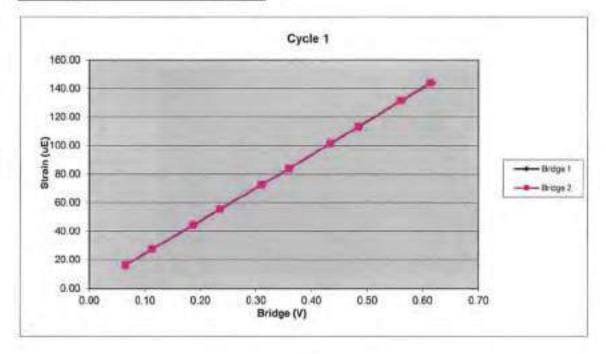
Instrument Calibration Certificates



680NW		Cycle 1		
Sample	Force (lb)	Strain (µE)	Bridge 1 (V)	Bridge 2 (V)
1	0.00	0.00	0.00	0.00
2	1047.49	16,11	0.07	0.06
3	1838.02	27.52	0.11	0.11
4	3029,38	44.17	0.19	0.19
5	3792.43	55.49	0.24	0.23
6	4997.05	72.74	0.31	0.31
7	5790.22	84.07	0.36	0.36
8	6984,70	101.62	0.44	0.43
9	7812.18	113.27	0.49	0.48
10	9035.41	131.64	0.56	0.56
11	9892.03	143.89	0.62	0.61

Bridge 1		Bridge 2	
Force Calibration (lb/V)	16069.95	Force Calibration (lb/V)	16102.53
Offset	-7.33	Offset	12.05
Correlation	0.999998	Correlation	0.999997
Strain Calibration (µE/V)	232.27	Strain Calibration (µE/V)	232.74
Offset	0.58	Offset	0.86
Correlation	0.999985	Correlation	0.999981

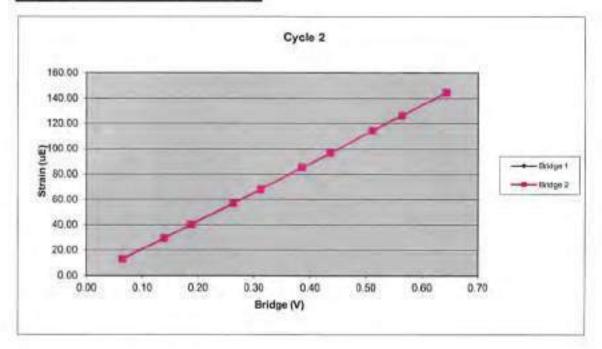
Force Strain Calibration	E care construction
EA (Kips)	69183.82
Offset	-47.26
Correlation	0.999980



680NW		Cycle 2		
Sample	Force (lb)	Strain (µE)	Bridge 1 (V)	Bridge 2 (V)
1	0.00	0.00	0.00	0.00
2	1021.07	12.60	0.06	0.06
3	2216.04	29.05	0.14	0.14
4	2992.44	40.06	0.19	0.19
5	4197.45	56.78	0.26	0.26
.6	4972.97	67.81	0.31	0.31
7	6170.08	84.96	0.39	0.39
8	6996.98	96.33	0.44	0.44
9	8196.33	113.89	0.51	0.51
10	9059.10	125.94	0.57	0.56
11	10316.06	143.97	0.64	0.64

Bridge 1		Bridge 2	
Force Calibration (lb/V)	16051.95	Force Calibration (lb/V)	16067.32
Offset	-10.90	Offset	-22.23
Correlation	0.999998	Correlation	0.999998
Strain Calibration (µE/V)	227.16	Strain Calibration (µE/V)	227.38
Offset	-2.46	Offset	-2.62
Correlation	0.999971	Correlation	0.999975

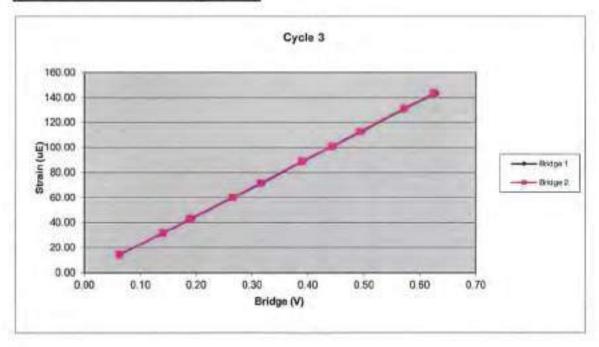
Force Strain Calibration	Landa or morning
EA (Kips)	70660.67
Offset	163.19
Correlation	0.999981



680NW		Cycle 3		
Sample	Force (lb)	Strain (µE)	Bridge 1 (V)	Bridge 2 (V)
1	0.00	0.00	0.00	0.00
2	1020.49	14.40	0.06	0.06
3	2263.02	31.58	0.14	0.14
4	3049.95	43.03	0.19	0.19
5	4268.70	60.16	0.27	0.27
6	5085.36	71.61	0.32	0.32
7	6271.27	88.94	0.39	0.39
8	7122.33	100.84	0.44	0.44
9	7937.92	112.58	0.50	0.49
10	9201.80	131.04	0.57	0.57
11	10082.99	143,34	0.63	0.62

Bridge 1		Bridge 2	
Force Calibration (lb/V)	16048.19	Force Calibration (lb/V)	16118.06
Offset	-13.64	Offset	2.18
Correlation	0.999997	Correlation	0.999996
Strain Calibration (µE/V)	228.89	Strain Calibration (µE/V)	229.89
Offset	-0.75	Offset	-0.52
Correlation	0.999975	Correlation	0.999975

Force Strain Calibration	Variable and the
EA (Kips)	70109.18
Offset	39.07
Correlation	0.999984



Bridge Excitation (V) Shunt Resitor (ohm)

60.4k

Calibration Factors	680NW		
Bridge 1 (µE/V)	229.44	Bridge 2 (µE/V)	230.00
EA Factor (Kips)	69984.56	Area (in^2)	2.33

Calibrated by: \_\_ Calibrated Date:

1/12/2023

Pile Dynamics Inc 30725 Aurora Rd Solon, OH 44139

Traceable to N.I.S.T.

## Accelerometer Calibration Certificate Pile Dynamics, Inc.



Calibrated by Pile Dynamics, Inc. Calibration performed on 1 4 JAN 2023

Serial No:

K12864

Temperature: 73.0 °F

Model:

PR

Humidity:

49%

Calibrated on: Channel 3 on 8G 5161 LE

Ref Acc 1:

72505

1035 g's/volt

Cal on:

24Mar2022

Ref Acc 2:

72517! 1049 g's/volt Cal on:

24Mar2022

Reference accelerometer calibrations are traceable to the United States National Institute of Standards and Technology (NIST).

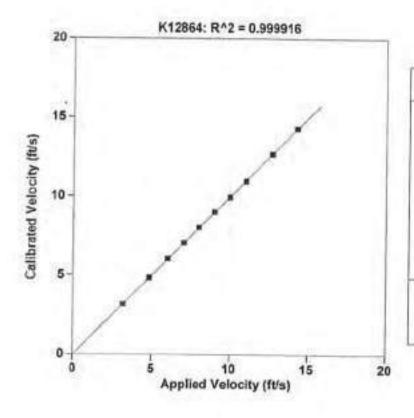
### PDA CALIBRATION FACTOR

416.1 mv/5000g

(83.2 µv/g)

R^2: 0.999916 [Chip programmed]

Operator, William Johnson



S/N K12864	Reference Velocity
Velocity ft/s	ft/s
3.180	3.178
4.851	4.832
6.063	6.009
7.059	7.063
8.055	8.019
9.034	9.010
9.952	9.990
10.962	11.010
12.691	12.703
14.318	14.307

## Accelerometer Calibration Certificate Pile Dynamics, Inc.



Calibrated by Pile Dynamics, Inc. Calibration performed on 1 4 JAN 2023

Serial No:

K12865

Temperature: 73.0 °F

Model:

PR

Humidity:

50%

Calibrated on: Channel 3 on 8G 5161 LE

Ref Acc 1:

72505!

1035 g's/volt

Cal on:

24Mar2022

Ref Acc 2:

725171 1049 g's/volt

Cal on:

24Mar2022

Reference accelerometer calibrations are traceable to the United States National Institute of Standards and Technology (NIST).

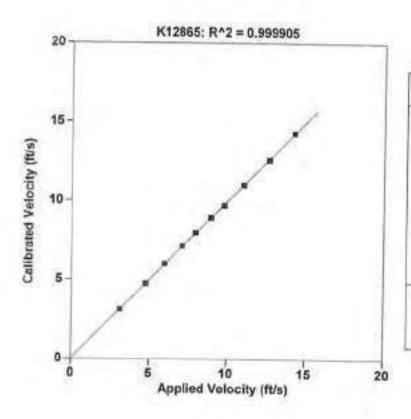


430.9 mv/5000g (86.2 µv/g)

R^2: 0.999905 [Chip programmed]

Operator: William Johnson

Signed



Molanitu	S/N K12865
Velocity	Velocity
ft/s	ft/s
3.173	3,138
4.769	4.760
5.982	6.019
7.127	7.146
7.959	7.988
8.938	8.943
9.775	9.724
11.013	11.001
12.641	12.601
14.249	14.294
14.248	14.294



NZBN: 9429050784509

Job No.:1015\_2302

Date: 30 March 2023

### Appendix B

**SPT Energy Measurements Results** 

### Case Method & ICAP® Results

2023-02-09 DC	N Drilling - SPT	Drop Hammer No.1

BH02 Test 1 at 13.5m OP: RZ Date: 09-February-2023 15.03 cm2 SP: 77.3 kN/m3 EM: 206,843 MPa LE: 15.2 m WS: 5,123.0 m/s JC: 0.90

EMX: Maximum Energy AMX: Maximum Acceleration ETR: Energy Transfer Ratio - Rated DMX: Maximum Displacement CSX: Compression Stress Maximum FMX: Maximum Force VT1: Velocity at time 1 FVP: Force/Velocity Proportionality

BPM:	Blows/Mi					FVF. Porcervelocity Proportionality						
BL#	Depth	BLC	EMX	ETR	FMX	VT1	BPM	AMX	DMX	CSX	FVP	
	m	bl/m	J	(%)	kN	m/s	bpm	g's	mm	MPa		
14	13.5	0	284.7	60.0	140	2.24	21.0	2,170	15	92.8	0.5	
15	13.5	0	293.1	61.8	161	2.42	23.0	2,208	10	107.0	1.1	
16	13.5	0	289.2	60.9	140	2.21	22.8	2,040	18	93.3	0.5	
17	13.5	0	310,3	65.4	152	2.31	21.7	2.223	24	101.0	0.4	
18	13.5	0	309.9	65.3	155	2.43	21.2	2,237	25	103.0	0.9	
19	13.5	0	305.3	64.3	159	2.44	21.0	2,295	20	105.5	1.0	
20	13.5	0	317.4	66.9	156	2.70	21.6	2,377	25	103.7	0.9	
21	13.5	0	332.1	70.0	153	2.31	20.9	2,298	42	101.7	0.6	
22	13.5	0	280.8	59.2	145	2.24	21.0	2,152	21	96.4	0.4	
23	13.5	0	350.6	73.9	152	2.37	20.5	2,358	71	101.1	0.4	
24	13.5	0	301.4	63.5	144	2.30	12.2	2,283	31	95.5	0.5	
25	13.5	0	334.0	70.4	161	2.51	18.2	2,405	41	107.4	0.3	
26	13.5	0	280.8	59.2	149	2.29	21.3	2,250	12	99.3	0.3	
27	13.5	0	288.6	60.8	150	2.31	21.8	2,294	13	99.9	0.5	
28	13.5	0	300.1	63.2	151	2.29	21.8	2,220	28	100.4	0.2	
29	13.5	0	304.3	64.1	162	2.49	22.1	2,254	16	107.7	0.9	
30	13.5	0	317.5	66.9	175	2.80	21.7	2,344	29	116.6	0.7	
31	13.5	0	308.1	64.9	157	2.49	12.7	2,112	18	104.3	1.0	
32	13.5	0	322.6	68.0	159	2.41	21.6	2,190	33	106.0	0.5	
33	13.5	0	299.1	63.0	156	2.72	21.5	2,228	8	104.0	0.8	
34	13.5	0	292.0	61.5	157	2.28	21.1	2,092	10	104.4	0.8	
35	13.5	0	300.1	63.2	161	2.69	21.4	2,145	12	107.2	0.7	
36	13.5	0	299.7	63.2	170	2.77	20.7	2,045	8	113.2	0.8	
37	13.5	0	311.7	65.7	162	2.51	21.4	2,095	36	107.8	0.8	
38	13.5	0	300.9	63.4	165	2.39	20.8	2,033	25	109.8	0.9	
39	13.5	0	302.9	63.8	160	2.45	21.9	2,017	16	106.3	1.0	
40	13.5	0	301.4	63.5	165	2.62	22.3	1,846	8	109.9	0.8	
41	13.5	0	304.4	64.2	149	2.32	21.1	1,818	19	99.4	0.8	
42	13.5	0	290.0	61.1	151	2,32	21.3	1.861	18	100.7	1.1	
43	13.5	0	287.3	60.5	145	2.29	21.5	1,860	14	96.8	0.7	
44	13.5	0	306.6	64.6	161	2.65	22.4	1,851	25	106.9	0.9	
45	13.5	0	283.6	59.8	163	2.19	22.5	1,836	22	108.3	0.5	
46	13.5	0	301.2	63.5	165	2.52	22.5	1,875	10	109.7	1.0	
47	13.5	0	294.6	62.1	146	2.31	21.4	1,750	10	97.4	0.7	
48	13.5	0	312.1	65.8	160	2.80	20.9	1,898	15	106.5	0.7	
		verage	303.4	63.9	156	2.44	20.9	2,113	21	103.7	0.7	
				Takal and			Long de 191				47.5	

Total number of blows analyzed: 35

BL# Sensors

14-48 F1: [680NW1] 229.4 (1.00); F2: [680NW2] 230.0 (1.00); A3: [K12864] 416.1 (1.00); A4: [K12865] 430.9 (1.00)

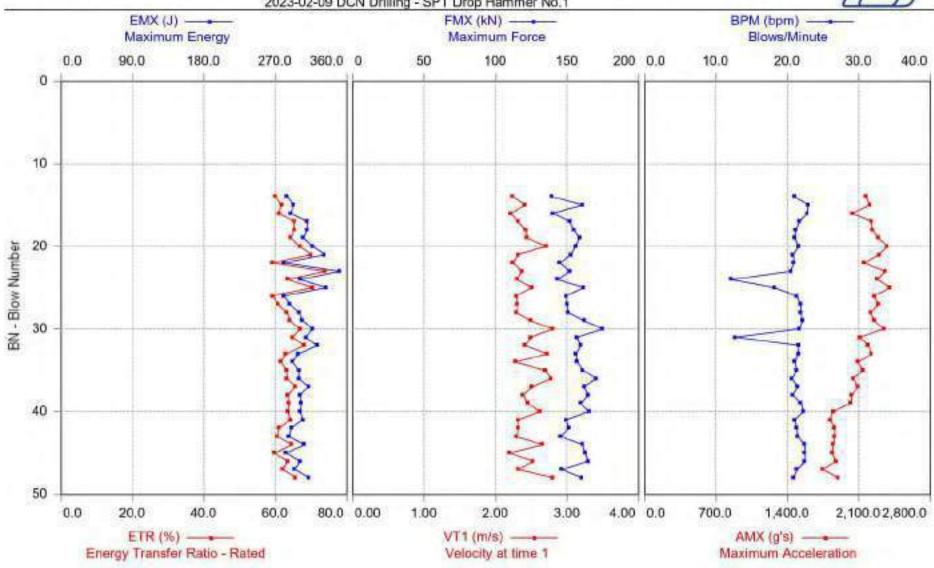
Time Summary

Drive 2 minutes 19 seconds 12:16 pm - 12:18 pm BN 1 - 48

Roc Consulting Limited - PDIPLOT2 Ver 2021,1,61.0 - Case Method & iCAP® Results

Printed: 26-March-2023

Test started: 09-February-2023 2023-02-09 DCN Drilling - SPT Drop Hammer No.1



### Case Method & ICAP® Results

2023-02-09 DCN Drilling - SPT Drop Hammer No.1_1 OP: RZ	BH02 Test 2 at 15m Date: 09-February-2023
AR: 15,03 cm <sup>2</sup>	SP: 77.3 kN/m <sup>3</sup>
LE: 16.7 m	EM: 206,843 MPa
WC. E 103.0 m/s	10 0.00

EMX: Maximum Energy	AMX: Maximum Acceleration
ETR: Energy Transfer Ratio - Rated	DMX: Maximum Displacement
FMX: Maximum Force	CSX: Compression Stress Maximum
VT1: Velocity at time 1	FVP: Force/Velocity Proportionality
DOLL D. A	

VT1:	Velocity a			FVP: Force/Velocity Proportionality								
	Blows/Mi		m			1.001		*****			-	
BL#	Depth	BLC	EMX	ETR	FMX	VT1	BPM	AMX	DMX	CSX	FVP	
10.00	m	bl/m	J	(%)	kN	m/s	bpm	9'5	mm	MPa	10035	
16	15.0	0	349.9	73.7	151	2.75	21.3	2,928	36	100.3	0.5	
17	15.0	0	351.4	74.1	156	2.79	21.8	3,026	30	103.5	0.7	
18	15.0	0	379.9	80.1	157	2.76	23.0	2,919	50	104.3	0.6	
19	15.0	0	362.2	76.3	147	2.71	22.8	2,782	47	97.5	0.6	
20	15.0	0	336,4	70.9	150	2.74	21.3	2,909	34	99.8	0.5	
21	15.0	0	335.8	70.8	145	2.68	21.2	2,754	34	96.8	0.6	
22	15.0	0	360.9	76.1	152	2.71	21.1	2,915	39	101.2	0.6	
23	15.0	0	366.7	77.3	152	2.70	20.9	2,829	38	101.2	0.6	
24	15.0	0	344.4	72.6	161	2.70	22.0	2,940	27	107.3	0.6	
25	15.0	0	340.2	71.7	150	2.71	20.4	2,861	34	100.1	0.6	
26	15.0	0	349.4	73.6	153	2.73	9.2	2,982	33	102.0	0.7	
27	15.0	0	342.0	72.1	150	2.63	21.8	2,826	32	99.5	0.7	
28	15.0	0	313.5	66.1	143	2.59	22.9	2,668	31	95.0	0.6	
29	15.0	0	343.0	72.3	145	2.62	21.5	2,763	39	96.5	0.6	
30	15.0	0	338.3	71.3	147	2.63	21.3	2,721	41	98.0	0.6	
31	15.0	0	334.4	70.5	158	2.74	22.0	2,952	31	105.2	0.6	
32	15.0	0	374.1	78.8	149	2.68	22.0	2,892	38	99.5	0.5	
33	15.0	0	343.9	72.5	152	2.67	22.2	2,891	32	101.2	0.6	
34	15.0	0	342.9	72.3	141	2.63	22.3	2,633	40	94.1	0.6	
35	15.0	0	311.1	65.6	149	2.62	22.4	2,762	31	98.8	0.6	
36	15.0	0	338.7	71.4	147	2.64	22.3	2,690	43	97.8	0.6	
37	15.0	0	348.5	73.4	145	2.60	22.1	2,629	38	96.4	0.6	
38	15.0	0	315.0	66.4	147	2.62	21.6	2,704	32	98.1	0.6	
39	15.0	0	334.4	70.5	147	2.59	21.5	2,760	28	97.9	0.7	
40	15.0	0	318.1	67.0	148	2.64	22.9	2,756	26	98.5	0.6	
41	15.0	0	324.2	68.3	145	2.53	22.1	2,659	23	96.6	0.6	
42	15.0	0	331.0	69.7	144	2.63	21.5	2,782	29	96.0	0.7	
43	15.0	0	334.2	70.4	151	2.58	21.6	2,779	29	100.6	0.5	
44	15.0	0	324.7	68.4	146	2.54	22.6	2,548	30	96.8	0.5	
45	15.0	0	305.6	64.4	149	2.54	21.5	2,586	23	99.2	0.5	
46	15.0	0	329.9	69.5	148	2.58	22.3	2,653	30	98.4	0.5	
47	15.0	0	309.1	65.1	146	2.58	21.9	2,614	17	96.9	0.6	
48	15.0	0	323.0	68.1	145	2.59	16.4	2,660	19	96.2	0.7	
49	15.0	0	349.4	73.6	145	2.64	21.4	2,699	37	96.8	0.6	
50	15.0	0	341.2	71.9	165	2.93	21.3	3.043	29	109.9	0.8	
		verage	338.5	71.3	149	2.66	21.3	2,786	33	99.4	0.6	

Total number of blows analyzed: 35

BL# Sensors

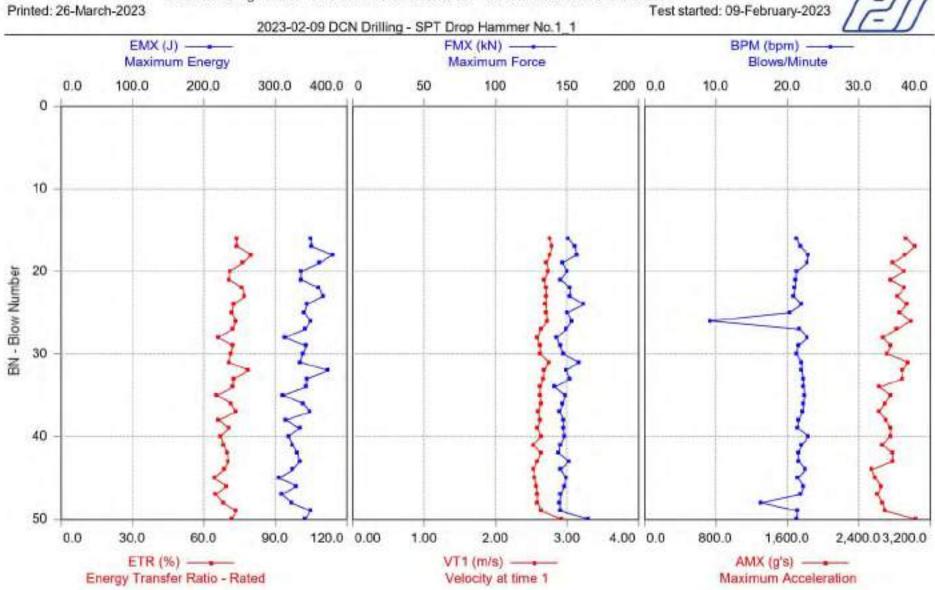
16-50 F1: [680NW1] 229.4 (1.00); F2: [680NW2] 230.0 (1.00); A3: [K12864] 416.1 (1.00); A4: [K12865] 430.9 (1.00)

Time Summary

Drive 2 minutes 18 seconds 12:54 pm - 12:57 pm BN 1 - 50

Roc Consulting Limited - PDIPLOT2 Ver 2021.1.61.0 - Case Method & iCAP® Results

Printed: 26-March-2023



BH02 Test 3 at 16.5m

#### Case Method & ICAP® Results

2023-02-09	DCN Drilling	-SPT	Drop Hammer	No.1 2
				1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1

 OP: RZ
 Date: 09-February-2023

 AR: 15.03 cm²
 SP: 77.3 kN/m³

 LE: 18.2 m
 EM: 206,843 MPa

 WS: 5,123.0 m/s
 JC: 0.90

EMX: Maximum Energy
ETR: Energy Transfer Ratio - Rated
ETR: Energy Transfer Ratio - Rated
EMX: Maximum Displacement
DMX: Maximum Displacement
CSX: Compression Stress Maximum
VT1: Velocity at time 1
EVP: Force/Velocity Proportionality
EVP: Force/Velocity Proportionality

BPM:	Blows/Mir	nute					- UVSTN	UP HOUSE POST	00102350	January Court 25	UMBON .
BL#	Depth	BLC	EMX	ETR	FMX	VT1	BPM	AMX	DMX	CSX	EVP
	m	bl/m	J	(%)	kN	m/s	bpm	g's	mm	MPa	
19	16.5	0	311.8	65.7	156	2.89	20.7	2,551	13	104.0	0.7
20	16.5	0	314.7	66.3	162	2.94	21.8	2,543	19	107.8	0.7
21	16.5	0	329.9	69.5	209	3.18	20.8	2,737	10	139.4	0.4
22	16.5	0	331.7	69.9	193	3.43	20.2	2,758	12	128.5	0.4
23	16.5	0	311.9	65.7	173	2.86	20.6	2,647	14	115.3	0.7
24	16.5	0	331.9	69.9	182	3.26	19.9	2,765	12	121.1	0.5
25	16.5	0	351.7	74.1	217	3.51	19.8	2,703	18	144.4	0.3
26	16.5	0	323.2	68.1	179	3.06	21.3	2,644	9	118.9	0.6
27	16.5	0	318.4	67.1	179	2,82	21.2	2,635	14	119.3	0.7
28	16.5	0	341.3	71.9	238	3.67	21.1	2,927	9	158.1	0.2
29	16.5	0	324.5	68.4	237	3.18	21.6	3,022	10	157.7	0.2
30	16.5	0	324.3	68.3	183	3.14	21.1	2,749	11	121.6	0.5
31	16.5	0	321.3	67.7	218	3.40	21.9	2,838	10	144.7	0.3
32	16.5	0	319.7	67.4	178	3.10	22.3	2,664	13	118.3	0.5
33	16.5	0	319.6	67.4	179	2.97	20.7	2,590	8	119.3	0.6
34	16.5	0	330.5	69.6	174	3.25	21.6	2,582	8	115.7	0.5
35	16.5	0	321.9	67.8	182	3.19	21.7	2,682	12	121.4	0.5
36	16.5	0	322.6	68.0	176	3.28	21.6	2,616	9	117.0	0.4
37	16.5	0	314.6	66.3	185	3.35	15.4	2,407	8	123.3	0.6
38	16,5	0	326.2	68.7	253	3.13	21.1	2,811	8	168.4	0.7
39	16.5	0	326.8	68.9	169	3.00	21.2	2,466	17	112.4	0.7
40	16.5	0	325.5	68.6	255	3.10	22.0	2,826	8	169.9	0.7
41	16.5	0	347.9	73.3	236	3.85	21.9	2,771	15	156.8	0.3
42	16.5	0	344.1	72.5	200	3.35	20.6	2,427	14	132.9	0.6
43	16.5	0	335.8	70.8	210	3.64	21.3	2,687	8	139.4	0.4
44	16.5	0	322.4	67.9	196	3.47	21.3	2,545	8	130.7	0.5
45	16.5	0	343.5	72.4	209	3.55	21.7	2,452	17	139.2	0.4
46	16.5	0	325.9	68.7	244	3.69	12.3	2,704	8	162.2	0.2
47	16.5	0	349.0	73.5	186	3.28	20.3	2,490	19	123.6	0.6
48	16.5	0	320.3	67.5	185	3.17	21.7	2,482	8	123.2	0.7
49	16.5	0	345.7	72.8	210	3.64	21.0	2,486	18	140.0	0.4
50	16.5	0	321.9	67.8	204	3.59	21.6	2,550	8	135.6	0.5
51	16.5	0	310.7	65.5	247	3.60	22.1	2,705	11	164.4	0.2
52	16.5	0	331.4	69.8	218	3.75	21.8	2,560	19	144.7	0.4
53	16.5	0	323.4	68.2	247	3.60	22.0	2,690	8	164.6	0.3
54	16.5	Ö	319.6	67.3	260	3.28	17.7	2,712	12	172.9	0.5
55	16.5	0	316.4	66.7	189	3.33	21.7	2,525	31	125.5	0.5
56	16.5	Ö	332.6	70.1	251	3.73	20.8	2,627	18	167.3	0.2
57	16.5		335.2	70.6	242	3.54	20.3	2,508	31	161.3	0.2
		0		70.4							0.4
58	16.5		334.2		210	3.50	21.1	2,429	29	139.5	
59	16.5	0	327.9	69.1	243	3.71	21.5	2,540	22	161.9	0.2
60	16.5	0	321.9	67.8	204	3,62	21.0	2,408	23	135.5	0.4
61	16.5	0	321.5	67.7	262	3.32	20.5	2,760	17	174.1	0.5
62	16.5	0	329.8	69.5	237	3.71	11.4	2,475	27	158.0	0.3
	A	verage	327.4	69.0	208	3.36	20.6	2,629	14	138.6	0.5

Roc Consulting Limited PDIPLOT2 2021.1.61.0

Case Method & iCAP® Results

Page 2 Printed 26-March-2023

2023-02-09 DCN Drilling - SPT Drop Hammer No.1\_2 OP: RZ

BH02 Test 3 at 16.5m Date: 09-February-2023

BL# Sensors

19-62 F1: [680NW1] 229.4 (1.00); F2: [680NW2] 230.0 (1.00); A3: [K12864] 416.1 (1.00); A4: [K12865] 430.9 (1.00)

Time Summary

Drive 2 minutes 59 seconds 1:30 pm - 1:33 pm BN 1 - 62

Roc Consulting Limited - PDIPLOT2 Ver 2021, 1,61.0 - Case Method & iCAP® Results

Printed: 26-March-2023

0.0

0

15

30

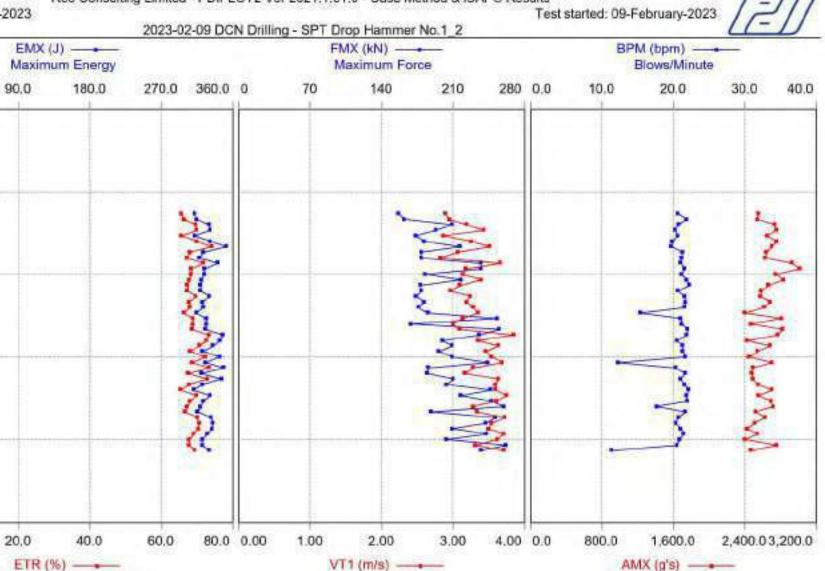
60

75

0.0

Energy Transfer Ratio - Rated

BN - Blow Number



Velocity at time 1

Maximum Acceleration

0.500	700	1111000		Carel	Wethod &	CAPIDE	opulte:			0.00000	
2023-	-02-09 DC	N Drilling	g - SPT D			2 BH02 Test 1 at 9n					
OP: F	RZ	3000	MO-SHIPTING	2302 (1920)					Date: 09	-Februar	y-2023
AR:	15.03 cm	nz							SP:		kN/m <sup>3</sup>
LE:	10.7 m								EM	206,843	MPa
WS:	5,123.0 m	/s							JC:	0.90	
	Maximun			VIOTA II				X: Maxim			
ETR:	Energy T	ransfer I	Ratio - Ra	ted						lacement	
	Maximum						CS.	X: Comp	ression S	Stress Ma	ximum
	Velocity a						FVF	Force	<b>Velocity</b>	Proportio	nality
BPM:	Blows/Mi	nute					- Usan	ADPROVED SE	0.5-10000350	Menugi Course	TERROR.
BL#	Depth	BLC	EMX	ETR	FMX	VT1	BPM	AMX	DMX	CSX	FVP
1006	m	bl/m	J	(%)	kN	m/s	bpm	g'5	mm	MPa	
12	9.0	0	281.0	59.2	184	2.24	13.0	1,329	18	122.7	0.6
13	9.0	0	317.7	66.9	210	3.02	10.4	1,457	21	139.9	0.6
14	9.0	0	317.3	66.9	249	3.16	12.3	1,640	19	165.7	0.5
15	9.0	0	288.4	60.8	192	2.60	19.6	1,240	21	127.9	0.7
16	9.0	0	294.9	62.2	202	2.63	14.7	1,359	16	134.3	0.6
17	9.0	0	317.1	66.8	254	3.03	18.8	1,652	21	169.3	0.6
18	9.0	0	290.8	61.3	215	2.91	18.8	1.248	19	143.1	0.6
19	9.0	0	292.1	61.5	191	2.50	19.8	1,112	19	126.9	0.5
20	9.0	0	276.7	58.3	184	2.15	17.7	1,048	18	122.6	0.4
21	9.0	0	279.3	58.9	197	2.17	19.8	1,083	16	130.9	0.8
22	9.0	0	315.5	66.5	252	3.12	21.0	1,712	18	167.7	0.6
23	9.0	0	264.6	55.B	185	2.40	18.9	1,126	16	123.1	0.7
24	9.0	0	294.5	62.1	231	2.92	11.2	1,548	16	153.5	0.6
25	9.0	0	297.0	62.6	205	2.80	19.9	1,137	14	136.5	0.6
26	9.0	0	287.0	60.5	225	2.78	18.7	1,217	17	149.5	0.6
27	9.0	0	295.2	62.2	246	2.97	19.9	1,450	15	163.9	0.7
28	9.0	0	316.8	66.8	226	2.83	11.2	1,736	20	150.2	0.6
29	9.0	0	330.4	69.6	222	3.09	11.7	1,485	17	147.9	0.5
30	9.0	0	315.6	66.5	194	3.12	15.2	1,185	11	129.2	0.5
31	9.0	0	285.0	60.1	219	2.38	16.1	1,277	15	145.4	0.8
32	9.0	0	279.7	58.9	251	2.90	10.3	1,463	16	166.9	0.6
33	9.0	0	302.1	63.7	197	2.40	18.4	1,070	19	131.2	0.6
34	9.0	0	311.2	65.6	243	3.00	19.1	1,481	12	161.6	0.7
35	9.0	0	308.3	65.0	245	3.15	16.6	1,528	15	162.8	0.6
36	9.0	0	324.3	68.3	254	3.17	17.5	1,718	19	169.1	0.6
37	9.0	0	303.9	64.0	183	2.96	16.2	1,716	19	121.8	0.5
38	9.0	0	274.9	57.9	196	2.64	15.5	1,152	15	130.3	0.6
39	9.0	0	291.6	61.4	190	2.60	19.5	1,315	13	126.1	0.6
40	9.0	0	290.8	61.3	193	2.76	14.2	1,127	15	128.5	0.6
41	9.0	0	308.1	64.9	224	3.19	20.7	1,342	16	149.2	0.6
4.00			W. J. J. 36	00.0	20.00	0.00	A 2 4	4 500	4.0	A 100 100 100	2 4

Total number of blows analyzed: 31

3,09

2.79

1,599

1,373

14.7

16.5

162.1

143.9

15

17

0.6

0.6

244

216

BL# Sensors

9.0

42

12-42 F1: [680NW1] 229.4 (1.00); F2: [680NW2] 230.0 (1.00); A3: [K12864] 416.1 (1.00); A4: [K12865] 430.9 (1.00)

Time Summary

Drive 2 minutes 26 seconds 10:16 am - 10:18 am BN 3 - 42

311.9

298.8

0

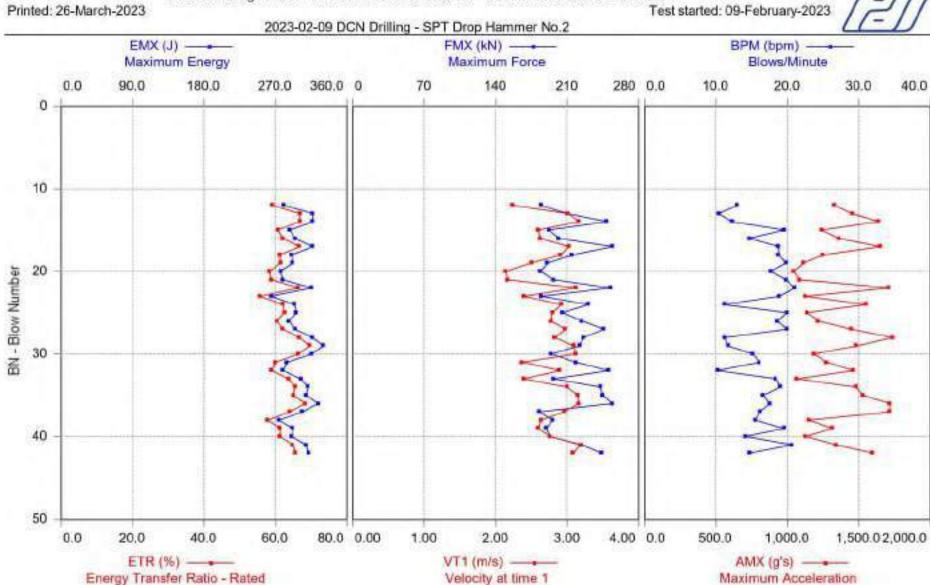
Average

65.7

63.0

Roc Consulting Limited - PDIPLOT2 Ver 2021.1.61.0 - Case Method & iCAP® Results

Printed: 26-March-2023



#### Case Method & ICAP® Results

2023-02-09 DCN Drilling - SPT Drop Hammer No.2 1

BH02 Test 2 at 10.5m Date: 09-February-2023

OP: RZ 15.03 cm<sup>2</sup> SP: 77.3 kN/m3 EM: 206,843 MPa LE: 12.2 m WS: 5,123.0 m/s JC: 0.90 EMX: Maximum Energy AMX: Maximum Acceleration

ETR: Energy Transfer Ratio - Rated DMX: Maximum Displacement CSX: Compression Stress Maximum FMX: Maximum Force VT1: Velocity at time 1 FVP: Force/Velocity Proportionality

BPM:	Blows/Mir	nute			22.4		- 00000	WHITE YES	0.17/0.030	Tenugi Stones	Unitide .
BL#	Depth	BLC	EMX	ETR	FMX	VT1	BPM	AMX	DMX	CSX	EVP
	m	bl/m	J.	(%)	kN	m/s	bpm	g's	mm	MPa	
13	10.5	0	350.1	73.8	219	3.26	20.7	2,702	34	145.8	0.2
14	10.5	0	352.0	74.2	238	3.40	22.4	2,814	25	158.3	0.2
15	10.5	0	359.0	75.7	211	3.43	21.7	2,752	29	140.1	0.3
16	10.5	0	343.3	72.4	200	3.32	22.2	2,692	24	133.1	0.3
17	10.5	0	359.2	75.7	216	3.39	22.4	2,579	28	143.7	0.3
18	10.5	0	348.5	73.4	233	3.13	22.8	2,699	27	155.3	0.1
19	10.5	0	339.5	71.5	205	3.42	23.1	2,606	29	136.5	0.5
20	10.5	0	348.7	73.5	210	3.28	22.9	2,723	29	139.7	0.5
21	10.5	0	341.4	71.9	188	3.28	22.4	2,506	19	125.3	0.6
22	10.5	0	340.6	71.8	232	3.51	22.3	2,547	21	154.1	0.2
23	10.5	0	336.8	71.0	244	3.30	21.4	2,813	24	162.4	0.1
24	10.5	0	352.2	74.2	219	3.54	22.0	2,694	24	145.5	0.3
25	10.5	0	351.3	74.0	228	3.45	21.7	2,871	25	151.9	0.2
26	10.5	0	338.8	71.4	212	3.43	23.1	2,623	24	141.1	0.3
27	10.5	0	352.3	74.2	211	3.35	22.4	2,690	27	140.6	0.4
28	10.5	0	358.3	75.5	267	3.43	21.4	3,219	22	177.6	0.2
29	10.5	0	340.4	71.7	213	3.50	22.0	2,673	25	141.9	0.3
30	10.5	Ö	328.6	69.2	192	2.95	22.1	2,652	28	127.5	0.7
31	10.5	0	348.9	73.5	197	3.25	22.8	2,770	24	130.8	0.5
32	10.5	0	349.8	73.7	202	3.08	22.2	2,757	27	134.4	0.5
33	10.5	0	348.8	73.5	196	3.42	22.3	2,811	25	130.3	0.4
34	10.5	0	338.0	71.2	192	3.31	22.7	2,795	27	128.0	0.4
35	10.5	0	340.4	71.7	200	3.09	23.6	2,721	25	132.8	0.5
36	10.5	0	340.3	71.7	224	3.57	22.6	2,812	18	149.3	0.3
37	10.5	Ö	344.9	72.7	205	3.15	22.2	2,587	33	136.6	0.5
38	10.5	0	352.7	74.3	255	3.49	21.6		19	169.7	0.2
39	10.5	0	339.4	71.5	197	3.20	22.0	3,164	24		
		0	364.0				22.1	2,741		130.8 130.5	0.5
40	10.5			76.7	196	3.20		2,719	29		0.5
41	10.5	0	355.2	74.8	196	3.02	23.1	2,565	29	130.2	0.6
42	10.5	0	357.7	75,4	202	3.20	22.2	2,688	24	134.5	0.4
43	10.5	0	349.9	73.7	212	3.31	22.4	2,783	26	141.2	0.3
44	10.5	0	354.8	74.8	227	3.59	22.0	2,839	20	150.8	0.2
45	10.5	0	333.5	70.3	197	3.33	22.3	2,651	13	130.8	0.4
46	10.5	0	360.5	76.0	206	3.12	22.6	2,523	31	136.9	0.6
47	10.5	0	341.5	72.0	196	2.98	22.0	2,643	27	130.6	0.6
48	10.5	0	337.0	71.0	189	3.24	21.2	2,530	23	125.6	0.6
49	10.5	0	339.5	71.5	211	3,43	21.9	2,745	21	140.4	0.4
	A	verage	347.0	73.1	212	3.31	22.2	2,722	25	140.9	0.4
				Lotal our	wher of h	nuic one	STORY 3	1			

Total number of blows analyzed: 37

BL# Sensors

13-49 F1: [680NW1] 229.4 (1.00); F2: [680NW2] 230.0 (1.00); A3: [K12864] 416.1 (1.00); A4: [K12865] 430.9 (1.00)

Roc Consulting Limited PDIPLOT2 2021.1.61.0

Case Method & ICAP® Results

Page 2 Printed 26-March-2023

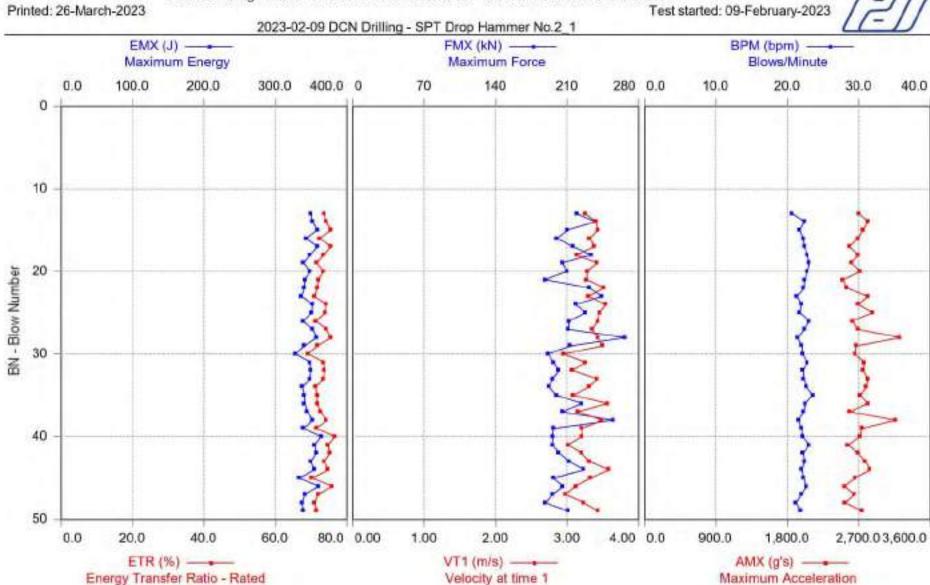
2023-02-09 DCN Drilling - SPT Drop Hammer No.2\_1 OP: RZ

BH02 Test 2 at 10.5m Date: 09-February-2023

Time Summary

Drive 2 minutes 9 seconds 10:45 am - 10:47 am BN 1 - 49

Roc Consulting Limited - PDIPLOT2 Ver 2021, 1,61.0 - Case Method & iCAP® Results



#### Case Method & ICAP® Results

E: 13.7 m	BH02 Test 3 at 12m Date: 09-February-2023
AR: 15.03 cm <sup>2</sup>	SP: 77.3 kN/m <sup>3</sup>
LE: 13.7 m	EM: 206,843 MPa
WS: 5 123 0 m/s	IC: 0.90

WS:	5,123.0 m					JC: 0.90							
EMX: ETR: FMX: VT1:	Maximum Energy T Maximum Velocity a Blows/Min	Energy ransfer I Force at time 1		ted	AMX: Maximum Acceleration DMX: Maximum Displacement CSX: Compression Stress Maximum FVP: Force/Velocity Proportionality								
BL#	Depth	BLC	EMX	ETR	FMX	VT1	BPM	AMX	DMX	CSX	FVP		
	m	bl/m	J	(%)	kN	m/s	bpm	g's	mm	MPa			
10	12.0	0	336.6	70.9	252	3.39	20.8	2,896	24	167.7	0.6		
11	12.0	0	336.2	70.8	255	3.18	21.3	3,276	30	169.9	0.7		
12	12.0	0	325.6	68.6	198	3.27	20.6	2,627	24	131.8	0.6		
13	12.0	0	335.9	70.B	251	3.73	20.6	2,792	25	167.1	0.3		
14	12.0	0	352.5	74.3	213	3.48	21.9	2,577	30	141.9	0.4		
15	12.0	0	339.4	71,5	258	3.63	21.3	2,951	29	171.4	0.3		
16	12.0	0	356.7	75.2	216	3.45	21.4	2,658	29	144.0	0.3		
17	12.0	0	336.5	70.9	260	3.26	15.3	3,163	23	172.7	0.7		
18	12.0	0	344.9	72.7	229	3.51	21.8	2,761	23	152.3	0.3		
19	12.0	0	318.7	67.2	192	2.82	21.6	2,536	25	127.9	0.8		
20	12.0	0	338.4	71.3	260	3.29	21.6	3,115	25	173.3	0.6		
21	12.0	0	335.9	70.B	208	3.40	21.8	2,556	21	138.2	0.6		
22	12.0	0	346.6	73.0	248	3.69	21.3	2,699	33	165.0	0.3		
23	12.0	0	328.9	69.3	210	3.39	20.5	2,548	22	140.0	0.4		
24	12.0	0	329.0	69.3	266	3.23	21.9	2,843	22	177.1	0.6		
25	12.0	0	352.7	74.3	230	3.34	21.6	2,707	36	152.7	0.4		
26	12.0	0	340.6	71.8	258	3.23	22.3	2,937	22	171.3	0.7		
27	12.0	0	344.2	72.5	266	3.64	21.4	3,132	22	177.1	0.2		

Total number of blows analyzed: 29

BL# Sensors

28

29

30

31

32

33

34

35

36

37

38

12.0

12.0

12.0

12.0

12.0

12.0

12.0

12.0

12.0

12.0

12.0

10-38 F1; [680NW1] 229.4 (1.00); F2: [680NW2] 230.0 (1.00); A3: [K12864] 416.1 (1.00); A4: [K12865] 430.9 (1.00)

Time Summary

Drive 1 minute 45 seconds 11:18 am - 11:19 am BN 1 - 38

322.5

325.9

328.3

330.6

321.8

326.1

362.9

335.3

342.1

325.4

328.0

336.1

0

0

0

0

0

0

0

0

0

0

0

Average

68.0

68.7

69.2

69.7

67.8

68.7

76.5

70.7

72.1

68.6

69.1

70.8

229

259

259

213

230

256

259

253

262

198

248

239

3.74

3.60

3.43

3.53

3.58

3.39

3.70

3.79

3.41

3.09

3.66

3.44

21.7

21.1

22.1

21.7

21.6

22.6

21.7

22.2

21.7

21.2

21.8

21.3

2,627

2,771

2,742

2.657

2,615

2,535

2,792

2,753

2,777

2,370

2,617

2,760

20

17

19

21

19

14

39

23

23

23

21

24

152.2

172.4

172.0

141.5

152.8

170.1

172.0

168.0

174.2

131.8

165.3

159.1

0.3

0.3

0.5

0.4

0.3

0.5

0.3

0.2

0.3

0.7

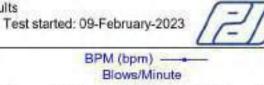
0.2

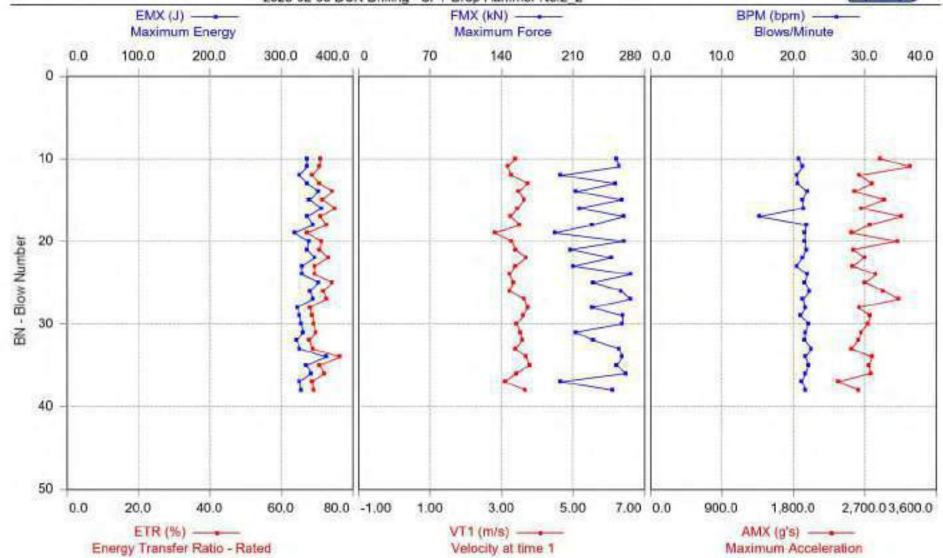
0.4

Roc Consulting Limited - PDIPLOT2 Ver 2021,1,61.0 - Case Method & iCAP® Results

Printed: 26-March-2023

2023-02-09 DCN Drilling - SPT Drop Hammer No.2\_2





and the same		06.34744110	or commence		viethod &		Results		11360	and an arrangement of	
2023- OP: F	-02-09 DC	N Drilling	g - SPT D	rop Ham	mer No.3					103 Test 1 3-Februar	
AR:	15.03 cm	n 2.							SP:		kN/m <sup>3</sup>
LE:	10.7 m									206,843	
	5,123.0 m							JC	0.90		
							ARA	X: Maxim			
	Maximum			had							
	Energy T		(allo - Ka	ted						lacement	
	Maximum									Stress Ma	
DOMA.	Velocity a	it time 1					FVI	- Force	velocity	Proportion	панку
	Blows/Mir		EMX	ETR	FMX	VT1	BPM	ALIV	DMX	COV	FVP
BL#	Depth	BLC	EMA					AMX		CSX	FVE
	m	bl/m	2017	(%)	kN	m/s	bpm	g's	mm	MPa	0.5
8	9.0	0	361.7	76.2	226	3.75	19.0	2,910	32	150.5	0.5
9	9.0	0	366.2	77.2	219	3.94	20.6	2,749	24	145.8	0.5
10	9.0	0	348.7	73.5	276	3.53	20.6	3,211	24	183.5	0.3
11	9.0	0	349.1	73.6	197	3.33	21.1	2,718	24	131.2	0.8
12	9.0	0	400.6	84.4	206	3.77	20.0	2,654	44	136.9	0.6
13	9.0	0	359,3	75.7	223	3.99	18.3	2,859	29	148.2	0.5
14	9.0	0	353.2	74.4	243	3.85	21.0	3,051	22	161.4	0.5
15	9.0	0	354.6	74.7	188	3.58	21.2	2,601	25	124.9	0.7
16	9.0	0	343.7	72.4	192	3.43	20.2	2,668	25	127.9	0.8
17	9.0	0	360.1	75.9	236	3.97	14.0	2,844	23	156.7	0.6
18	9.0	0	367.2	77.4	199	3.93	20.8	3,131	21	132.1	0.6
19	9.0	0	363.3	76.6	209	3.92	20.0	2,563	20	138.8	0.7
20	9.0	0	370.6	78.1	210	4.07	21.4	2,653	22	139.7	0.6
21	9.0	0	357.6	75.4	263	3.91	20.2	2,882	24	175.2	0.6
22	9.0	0	368.3	77.6	233	4.22	21.3	2,711	21	155.1	0.5
23	9.0	0	347.6	73.3	201	3.69	21.0	2,595	17	133.8	0.7
24	9.0	0	358.8	75.6	248	4.33	20.7	2,636	17	164.8	0.5

224 Total number of blows analyzed: 19

3.58

4.59

3.86

21.1

19.8

20.1

2,770

2,912

2,796

25

17

24

162.1

161.9

149.0

0.5

0.5

0.6

244

243

### BL# Sensors

9.0

9.0

0

0

Average

335.5

373.5

360.0

25

26

8-26 F1: [680NW1] 229.4 (1.00); F2: [680NW2] 230.0 (1.00); A3: [K12864] 416.1 (1.00); A4: [K12865] 430.9 (1.00)

70.7

78.7

75.9

### Time Summary

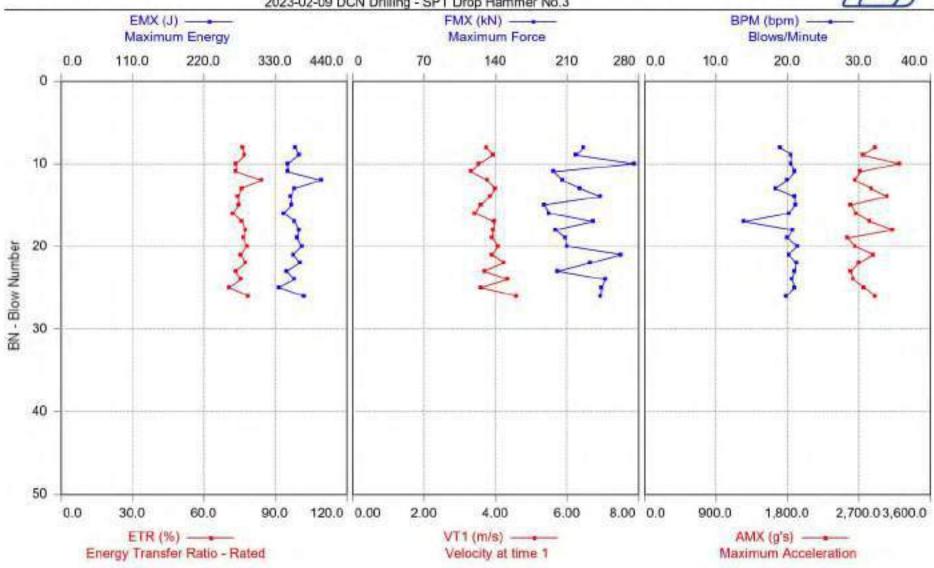
Drive 1 minute 16 seconds 11:35 am - 11:36 am BN 1 - 26

Roc Consulting Limited - PDIPLOT2 Ver 2021,1,61.0 - Case Method & iCAP® Results

Printed: 26-March-2023

2023-02-09 DCN Drilling - SPT Drop Hammer No.3

Test started: 09-February-2023



#### Case Method & ICAP® Results

2023-02-09 DCN Drilling - SPT Drop Hammer No.3\_1

BH03 Test 2 at 10.5m Date: 09-February-2023

 OP; RZ
 Date: 09-February-2023

 AR: 15.03 cm²
 SP: 77.3 kN/m³

 LE: 12.2 m
 EM: 206,843 MPa

 WS: 5,123.0 m/s
 JC: 0.90

EMX: Maximum Energy
ETR: Energy Transfer Ratio - Rated
ETMX: Maximum Force
DMX: Maximum Displacement
CSX: Compression Stress Maximum
VT1: Velocity at time 1
EVP: Force/Velocity Proportionality

BPM:	Blows/Mir											
BL#	Depth	BLC		ETR	FMX	VT1	BPM	AMX	DMX	CSX	FVP	
	m	bl/m	J	(%)	kN	m/s	bpm	g's	mm	MPa		
11	10.5	0	336.4	70.9	219	3.51	16.9	3,086	30	145.6	0.3	
12	10.5	0	301.1	63.4	191	3.06	22.9	2,665	27	126.7	0.6	
13	10.5	0	296.2	62.4	181	2.72	23.0	2,513	20	120.4	0.4	
14	10.5	0	318.4	67.1	215	3.25	22.3	3,115	23		0.5	
15	10.5	0	304.8	64.2	233	3.15	21.4	3,315	21	155.2	0.2	
16	10.5	0	299.0	63,0	184	3.44	14.7	2,607	17			
17	10.5	0	308.2	64.9	203	3.56	21.3	2,676	17	134.8	0.4	
18	10.5	0	310.0	65.3	222	3.30	20.9	2,853	16		0.2	
19	10.5	0	313.6	66.1	192	3.32	21.0	2,604	17		0.4	
20	10.5	0	304.9	64.3	242	3.10	21.2	3,208	16		0.6	
21	10.5	0	315.6	66.5	236	3.28	21.4	3,203	20		0.6	
22	10.5	0	312.5	65.9	210	3.69	21.3	2,855	15	139.6	0.4	
23	10.5	0	320.3	67.5	192	3,54	21.4	2,741	24	127.4	0.5	
24	10.5	0	318.7	67.2	246	3.33	21.7	3,153	21	163.6	0.2	
25	10.5	0	291.7	61.5	185	3.04	21.6	2,518	14	123.4	0.6	
26	10.5	0	298.1	62.8	191	2.76	22.8	2,470	18	126.8	0.4	
27	10.5	0	319.1	67.2	232	3.56	22.3	2,990	24	154.6	0.2	
28	10.5	0	325.6	68.6	226	3,50	22.9	3,013	21	150.3	0.3	
29	10.5	0	319.0	67.2	254	3.55	21.0	3,225	20	168.9	0.2	
30	10.5	0	308.7	65.1	166	3.16	20.3	2,466	26	110.4	0.8	
31	10,5	0	321.2	67.7	174	3.40	22.0	2,368	35	115.6		
32	10.5	0	315.2	66.4	183	3.42	21.3	2,562	25		0.4	
33	10.5	0	303.4	63.9	238	3.12	21.3	3,327	19	158.5	0.3	
34	10.5	0	313.3	66.0	173	3,12	22.5	2,428	22	115.3	0.5	
35	10.5	0	318.3	67.1	186	3.65	20.9	2,520	16	123.6	0.4	
36	10.5	0	307.0	64.7	184	3.56	21.2	2,451	14	122.2	0.5	
37	10.5	0	317.8	67.0	192	3.66	20.9	2,438	17		0.5	
38	10.5	0	315.5	66.5	194	3.66	21.5	2,462	16	129.2	0.5	
39	10.5	0	309.8	65.3	241	3.38	20.8	3.034			0.4	
40	10.5	0	316.7	66.7	233	3.41	20.5	3,042	19	155.2	0.3	
41	10.5	0	295.5	62.3	172	2.95	20.6	2,384	18	114.6	0.6	
42	10.5	0	318.7	67.2	208	3.78	20.7	2,418	17	138.3	0.3	
43	10.5	0	296.9	62.6	177	2.91	15.7	2,272	16		0.7	
44	10.5	0	327.8	69.1	196	3.30	20.2	2,518	32	130.4	0.5	
17.00		verage	311.7	65.7	205	3.33	20.9	2,750	20	136.4	0.4	

65.7 205 3.33 20.9 Total number of blows analyzed: 34

BL# Sensors

11-44 F1: [680NW1] 229.4 (1.00); F2: [680NW2] 230.0 (1.00); A3: [K12864] 416.1 (1.00); A4: [K12865] 430.9 (1.00)

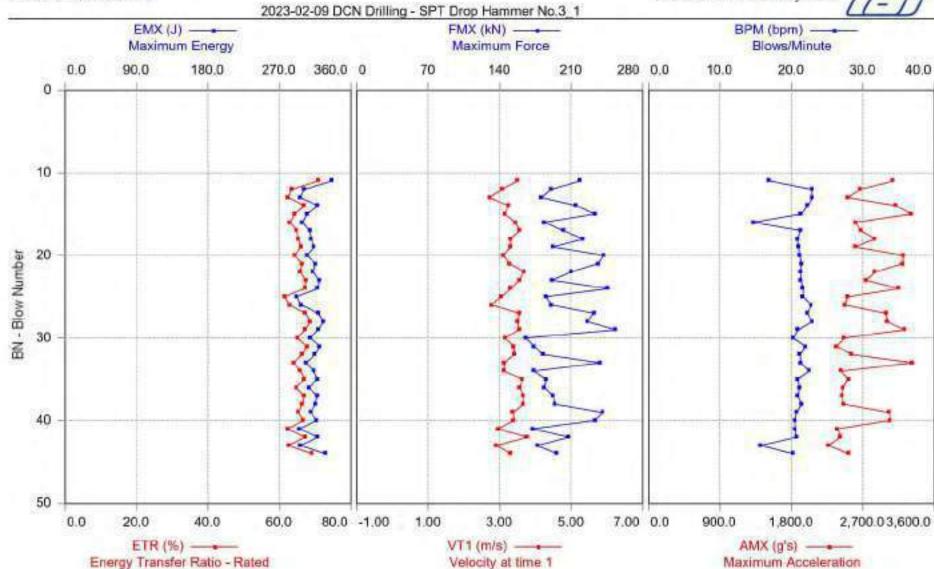
Time Summary

Drive 2 minutes 26 seconds 12:03 pm - 12:05 pm BN 1 - 44

Roc Consulting Limited - PDIPLOT2 Ver 2021,1,61.0 - Case Method & iCAP® Results

Printed: 26-March-2023

Test started: 09-February-2023



### Case Method & ICAP® Results

2023-02-09 DCN Drilling - SPT Drop Hammer No.3\_2

BH03 Test 3 at 12m Date: 09-February-2023 15.03 cm<sup>2</sup>

SP: 77.3 kN/m3 LE: 13.7 m EM: 206,843 MPa JC: WS: 5,123.0 m/s 0.90 EMX: Maximum Energy AMX: Maximum Acceleration

DMX: Maximum Displacement CSX: Compression Stress Maximum ETR: Energy Transfer Ratio - Rated FMX: Maximum Force

	Velocity a					FVP: Force/Velocity Proportionality						
	Blows/Min						100000	0.00		100000000000000000000000000000000000000	100	
BL#	Depth	BLC	EMX	ETR	FMX	VT1	BPM	AMX	DMX	CSX	EVE	
	m	bl/m	1	(%)	kN	m/s	bpm	g's	mm	MPa		
11	12.0	0	323.3	68.1	252	3.24	16.1	2,854	14	167.9	0.5	
12	12.0	0	318.7	67.2	251	3.33	20.0	2,831	9	166.7	0.3	
13	12.0	0	323.1	68.1	191	3.23	20.6	2,498	24	127.3	0.6	
14	12.0	0	305.7	64.4	186	3.11	20.3	2,444	9	123.9	0.5	
15	12.0	0	310.6	65.4	188	3.25	20.3	2,318	14	125.2	0.4	
16	12.0	0	319.3	67.3	197	3.45	21.6	2,464	8	131.0	0.	
17	12.0	0	321.2	67.7	237	3.43	20.5	2,464	10	157.6	0.	
18	12.0	0	322.9	68.0	231	3.44	20.0	2,423	17	154.0	0.	
19	12.0	0	312.5	65.8	208	3.27	20.7	2,350	9	138.2	0.	
20	12.0	0	300.2	63.3	174	3.29	20.4	2,202	8	115.6	0.	
21	12.0	0	305.4	64.4	213	3.66	19.9	2,187	8	141.4	0.	
22	12.0	0	319.0	67.2	225	3.78	19.8	2,288	8	149.4	0.	
23	12.0	0	290.2	61.2	245	3,11	20.0	2,478	10	162.7	0.	
24	12.0	0	316.6	66.7	243	3.50	20.6	2,711	8	161.6	0.	
25	12.0	0	296.5	62.5	216	3.24	19.8	2,006	7	143.5	0.	
26	12.0	0	299.9	63.2	181	3.08	21.4	2,168	10	120.4	0.	
27	12.0	ő	310.2	65.4	181	3.45	20.2		7	120.5	Ö.	
28	12.0	Ö	296.5		166	3.12		2,130	7			
				62.5			20.7	2,093		110.4	0.	
29	12.0	0	290.9	61.3	170	3.01	19.4	2,005	7	112.9	0.	
30	12.0	0	309.5	65.2	218	3.65	19.0	2,106	7	144.7	0.	
31	12.0	0	293.9	61.9	240	3.39	19.6	2,337	7	159.8	0.	
32	12.0	0	307.7	64.8	228	3.58	20.1	2,303	7	151.8	0.	
33	12.0	0	294.5	62.1	209	3.19	20.7	1,979	10	138.9	0.	
34	12.0	0	288.0	60.7	188	3.21	20.2	1,984	7	125.4	0.	
35	12.0	0	300.2	63.3	245	3.32	19.7	2,100	7	163.0	0.	
36	12.0	0	297.8	62.8	243	3.48	19.6	2,151	7	161.4	0.	
37	12.0	0	319.6	67.3	215	3.58	22.4	2,166	15	143.2	0.	
38	12.0	0	295.4	62.2	202	3.08	16.7	1,918	7	134.5	0.	
39	12.0	0	300.1	63.2	194	3.14	20.4	1,940	7	129.2	0.	
40	12.0	0	291.4	61.4	167	2.99	21.5	1,804	7	111.1	0.	
41	12.0	0	306.9	64.7	226	3.60	20.8	1,933	7	150.3	0.	
42	12.0	0	316.1	66.6	232	3.81	21.3	2,104	7	154.1	0.	
43	12.0	0	306.4	64.6	159	2.91	15.9	1,571	12	105.8	0.	
44	12.0	0	307.9	64.9	200	3.29	20.5	1,664	7	133,1	0.	
45	12.0	0	310.8	65.5	173	3.07	20.2	1,701	9	115.4	0.	
46	12.0	0	298.9	63.0	157	3.05	14.7	1,633	9	104.5	0.	
47	12.0	0	312.3	65.8	175	3.01	19.6	1,707	11	116.2	0.	
48	12.0	0	304.1	64.1	231	3.33	20.9	2,221	7	153.9	0.	
49	12.0	D	302.1	63.7	193	3.29	19.8	1,583	7	128.3	0.	
50	12.0	0	300.7	63.4	194	3.17	20.6	1,584	9		0.	
51	12.0	0	296.0	62.4	171	2.88	20.8	1,438	8	113.5	0.	
52	12.0	0	299.9	63.2	187	3.03	19.5	1,581	9	124.5	0.	
53	12.0	0	301.4	63.5	247	3.50	20.4	2,237	7	164.2	0.	
54	12.0	0	311.2	65.6	248	3.45	19.4	1,980	15	164.8	0.	
55	12.0		291.8	61.5	213	3.30	19.8	1,517	10	141.6	0.	
56		0				3.06						
	12.0	0	285.2	60.1	235		20.9	1,381	7	156.6	0.	
57	12.0	0	277.4	58.5	224	2.88	20.4	1,593	7	148.9	0.	
58	12.0	0	293.2	61.8	188	3.06	20.7	1,340	13	125.3	0.	
59	12.0	0	295.5	62.3	239	3.24	13.5	1,853	9		0.	
60	12.0	0	277.6	58.5	224	2.93	20.5	1,408	7	149,3	0.	

Roc Consulting Limited PDIPLOT2 2021.1.61.0

Case Method & iCAP® Results

Page 2 Printed 26-March-2023

2023-02-09 DCN Drilling - SPT Drop Hammer No.3\_2

BH03 Test 3 at 12m

OP: R	Z	67.202.207.005	96. http://doi.org/10.00	1990	00523007057	AND			Date: 09	-Februar	y-2023
BL#	Depth m	BLC bl/m	EMX	ETR (%)	FMX kN	VT1 m/s	BPM	AMX g's	DMX	CSX MPa	FVP
	A	verage	303.5	64.0	208	3.27	19.8	2,035	9	138.6	0.5

Total number of blows analyzed: 50

BL# Sensors

11-60 F1: [680NW1] 229.4 (1.00); F2: [680NW2] 230.0 (1.00); A3: [K12864] 416.1 (1.00); A4: [K12865] 430.9 (1.00)

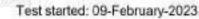
Time Summary

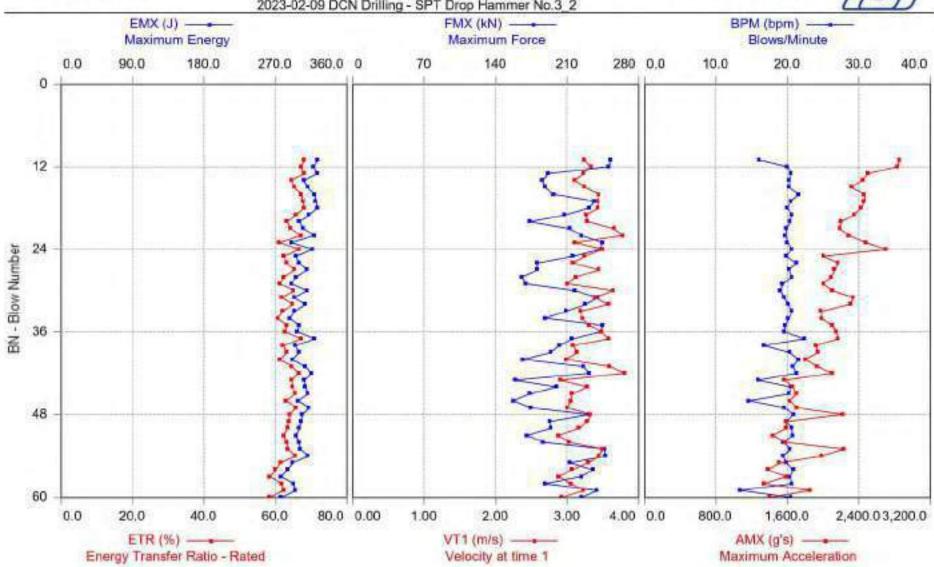
Drive 2 minutes 58 seconds 12:27 pm - 12:30 pm BN 1 - 60

Roc Consulting Limited - PDIPLOT2 Ver 2021, 1,61.0 - Case Method & iCAP® Results

Printed: 26-March-2023

2023-02-09 DCN Drilling - SPT Drop Hammer No.3\_2





### Case Method & ICAP® Results

2023- OP: F	-02-09 DC		01 Test 1								
AR:	15.03 cm	n².							SP:		kN/m²
LE:	10.7 m								EM	206,843	
WS:	5,123.0 m	/s							JC:	0.90	Sales Sales
EMX:	Maximum	Energy	Company Ingin	ALIAN TIL				X: Maxim			
ETR:	Energy T	ransfer I	Ratio - Ra	ted						lacement	
	Maximum									Stress Ma.	
	Velocity a						FVF	: Force	/Velocity	Proportio	nality
	Blows/Mi				Julian	Marian Carlo Service	W.FE-637/07/PC	Vinence Connect	UDITION .		
BL#	Depth	BLC	EMX	ETR	FMX	VT1	BPM	AMX	DMX	CSX	FVP
10/53	m	bl/m	J	(%)	kN	m/s	bpm	g's	mm	MPa	
12	9.0	0	339.0	71.4	210	3.25	14.8	3,041	21	139.8	0.8
13	9.0	0	376.0	79.2	202	3.22	18.9	2,998	52	134.5	0.8
14	9.0	0	353.8	74.6	218	3.37	20.6	3,239	18	145.4	0.8
15	9.0	0	344.4	72.6	222	3.23	19.6	2,876	20	147.7	0.7
16	9.0	0	336.5	70.9	211	3.24	19.3	3,012	20	140.2	0.7
17	9.0	0	321.0	67.7	202	3.23	15.5	2,990	20	134.5	0.8
18	9.0	0	353.5	74.5	228	3.34	18.1	3,156	16	151.4	0.6
19	9.0	0	368.9	77.7	234	3,45	18.6	3,285	20	155.4	0.6
20	9.0	0	356.2	75.1	231	3.39	20.8	3,278	19	154.0	0.8
21	9.0	0	355,5	74.9	214	3.52	18.8	3,105	18	142.2	0.6
22	9,0	0	356.5	75.1	290	3.96	20.3	4,159	12	193.2	0.6
23	9.0	0	368.7	77.7	249	3.68	18.5	3,610	20	165.9	0.7
24	9.0	0	359.9	75.8	235	3.54	19.0	3,450	15	156.0	0.5
25	9.0	0	367.4	77.4	235	3.46	18.6	3,211	21	156.4	0.6
26	9.0	0	345.3	72.8	208	3.50	18.4	3,180	15	138.5	0.6
27	9.0	0	369.9	78.0	256	3.71	19.9	3,858	15	170.6	0.6
28	9.0	0	347.4	73.2	210	3.48	18.9	3,104	19	139.6	0.7
29	9.0	0	373.4	78.7	237	3.70	20.0	3,391	18	157.6	0.6
30	9.0	0	328.4	69.2	206	3.21	14.5	2,959	20	136.9	0.7
31	9.0	0	370.7	78.1	223	3.46	19.9	3,128	16	148.6	0.8
32	9,0	0	356.5	75.1	240	3,53	12.7	3,377	13	159.9	0.5
33	9.0	0	366.3	77.2	215	3.56	19.0	2,875	23	142.8	0.7
34	9.0	0	354.3	74.7	242	3.74	18.4	3,016	12	160.9	0.5
35	9.0	0	352.8	74.3	217	3.64	18.4	2,767	21	144.4	0.6
36	9.0	0	337.8	71.2	219	3.51	19.3	2,793	14	145.4	0.6
37	9.0	0	360.7	76.0	233	3.73	18.8	2,649	18	155.1	0.6
38	9.0	0	366.0	77.1	239	3.72	17.4	2,884	19	158.8	0.6
39	9.0	0	349.3	73.6	225	3.51	19.5	2,742	13	150.0	0.7
40	9.0	0	346.4	73.0	239	3.95	18.8	2,732	17	159.3	0.6
41	9.0	0	347.8	73.3	223	3.81	18.6	2,835	22	148.0	0.6
42	9.0	0	367.0	77.3	226	3.67	18.2	2,778	18	150.5	0.7
43	9.0	0	344.3	72.5	217	3.67	18.2	2,739	9	144.4	0.7

BL# Sensors

12-43 F1: [680NW1] 229.4 (1.00); F2: [680NW2] 230.0 (1.00); A3: [K12864] 416.1 (1.00); A4: [K12865] 430.9 (1.00)

227

Total number of blows analyzed: 32

3.53

18.4

3,101

19

150.9

0.7

74.7

Time Summary

Drive 2 minutes 24 seconds 9:09 am - 9:11 am BN 1 - 43

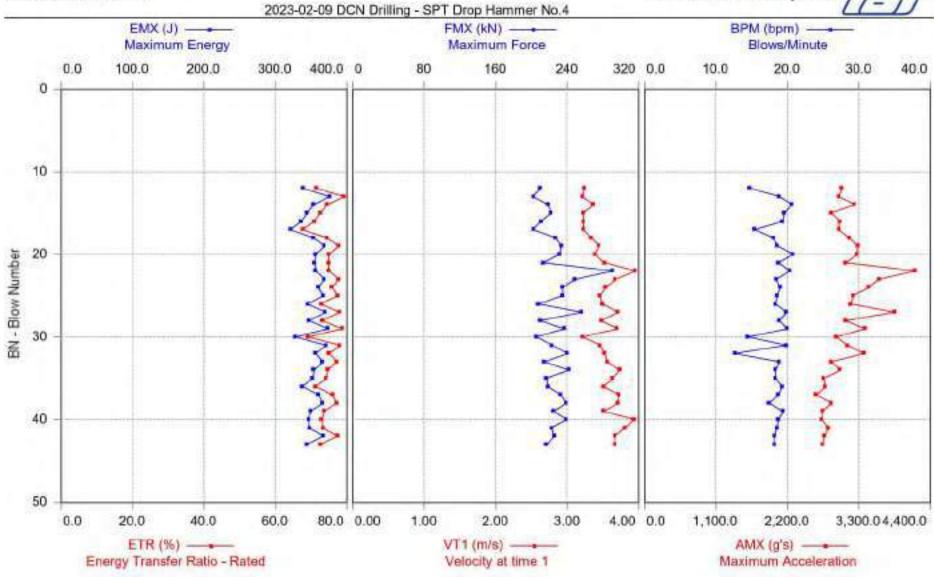
354.4

Average

Roc Consulting Limited - PDIPLOT2 Ver 2021.1.61.0 - Case Method & iCAP® Results

Printed: 26-March-2023

Test started: 09-February-2023



#### Case Method & ICAP® Results

2023-02-09 DCN Drilling - SPT Drop Hammer No.4\_1

BH01 Test 2 at 10.5m Date: 09-February-2023

 OP; RZ
 Date: 09-February-2023

 AR: 15.03 cm²
 SP: 77.3 kN/m²

 LE: 12.2 m
 EM: 206,843 MPa

 WS: 5,123.0 m/s
 JC: 0.90

EMX: Maximum Energy
ETR: Energy Transfer Ratio - Rated
ETR: Energy Transfer Ratio - Rated
EMX: Maximum Displacement
EMX: Maximum Force
EMX: Maximum Displacement
CSX: Compression Stress Maximum
EVP: Force/Velocity Proportionality

BPM:	Blows/Mi	nute					- 8/19	OPPLIES OF THE PROPERTY OF THE	0=2000	Mang Strate	1000
BL#	Depth	BLC	EMX	ETR	FMX	VT1	BPM	AMX	DMX	CSX	EVP
	m	bl/m	1	(%)	kN	m/s	bpm	g's	mm	MPa	
13	10.5	0	376.8	79.4	254	3.49	19.7	3,351	20	169.2	0.7
14	10.5	0	362.5	76.4	231	3.47	19.6	3,022	22	153.9	0.7
15	10.5	0	372.8	78.6	235	3.52	19.9	2,980	27	156.6	0.6
16	10.5	0	359.4	75.7	267	3.66	19.7	3,594	20	177.5	0.6
17	10.5	0	369.6	77.9	236	3.45	19.5	2,948	26	156.7	0.7
18	10.5	0	374.7	79.0	237	3.47	15.3	3,226	20	157.6	0.7
19	10.5	0	372.2	78.4	250	3.52	19.8	3,493	24	166.4	0.6
20	10.5	0	357.9	75.4	279	3.90	18.5	3,818	17	185.6	0.6
21	10.5	0	350.7	73.9	239	3.54	18.9	3,061	18	159.0	0.5
22	10.5	0	346.3	73.0	209	3,41	19.9	3,111	17	138.8	0.7
23	10.5	0	364.7	76.9	296	4.02	20.2	3,935	21	197.1	0.6
24	10.5	0	348.8	73.5	243	3.77	19.0	3,008	14	161.5	0.6
25	10.5	0	370.7	78.1	257	3.68	15.8	3,150	18	170.9	0.5
26	10.5	0	357.2	75.3	257	3.85	19.6	3,090	18	170.7	0.5
27	10.5	0	348.5	73.4	215	3.19	20.3	2,820	22	143.0	0.7
28	10.5	0	341.9	72.1	200	3.26	18.8	2,803	25		0.8
29	10.5	0	357.9	75.4	220	3.64	14.7	2,891	18	146.3	0.7
30	10.5	0	355.1	74.8	259	4.00	20.4	2,920	17	172.2	0.5
31	10.5	0	374.4	78.9	238	3.91	19.2	2,980	19	158.5	0.6
32	10.5	0	362.2	76.3	220	3.69	20.5	2,985	13	146.5	0.5
33	10,5	0	362.3	76.4	219	3.89	19.2	2,728	17	145.6	0.5
34	10.5	0	346.6	73.0	285	3.61	19.6	3,169	16	189.9	0.2
35	10.5	0	365.1	76.9	222	3.82	20.1	2,822	20	147.7	0.6
36	10.5	0	334.9	70.6	217	3.67	20.0	2,501	15	144.6	0.6
37	10.5	0	365.9	77.1	220	3.94	13.3	2,840	20	146.6	0.5
38	10.5	0	362.2	76.3	241	4.01	19.1	2,736	18	160.0	0.6
39	10.5	0	337.7	71.2	210	3.45	19.7	2,549	17	140.0	0.7
40	10.5	0	361.4	76.2	277	3.84	19.9	3,192	16	184.4	0.6
41	10.5	0	370.0	78.0	286	3.73	19.5	3,606	15	190.2	0.6
42	10.5	0	350.2	73.8	224	3.77	19.8	2,726	12	148.9	0.7
43	10.5	0	363.3	76.6	256	3.93	19.9	2,754	19	170.3	0.6
44	10.5	0	357.0	75.2	231	3.89	18.9	2,673	13	153.5	0.5
45	10.5	0	357.6	75.4	240	4.08	19.5	2,699	19	160.0	0.6
46	10.5	0	347.5	73.2	225	3.89	19.2	2,589	14	149.4	0.5
47	10.5	0	347.9	73.3	213	3.14	18.2	2,388	25	141.4	0.9
-47		verage	358.7	75.6	240	3.69	19.0	3,005	19	159.8	0.6
		Actond	000.1	14.4	6.79	M. Will	19.0	2,000	100	Tub.u	0.0

Total number of blows analyzed: 35

BL# Sensors

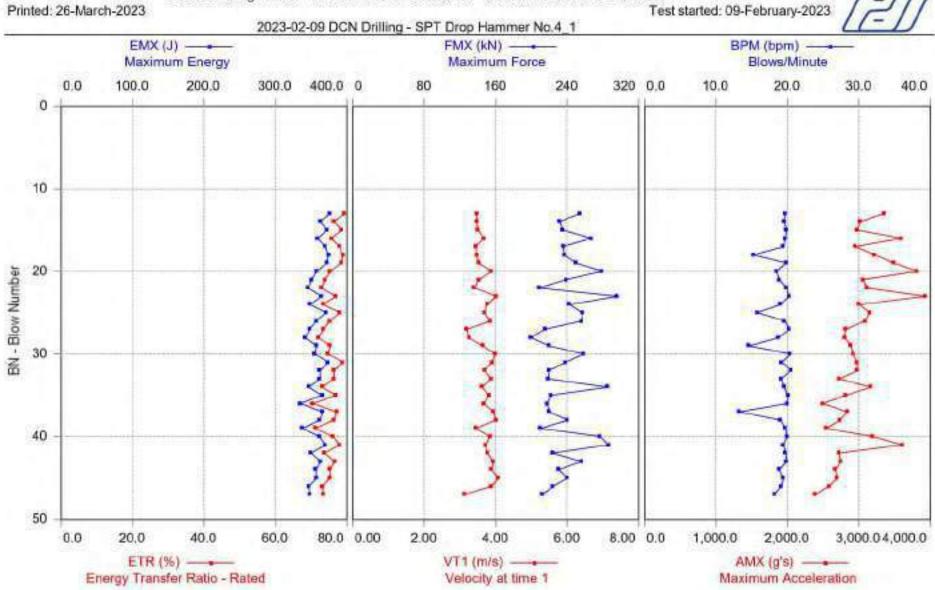
13-47 F1: [680NW1] 229.4 (1.00); F2: [680NW2] 230.0 (1.00); A3: [K12864] 416.1 (1.00); A4: [K12865] 430.9 (1.00)

Time Summary

Drive 2 minutes 25 seconds 9:35 am - 9:38 am BN 1 - 47

Roc Consulting Limited - PDIPLOT2 Ver 2021, 1,61.0 - Case Method & ICAP® Results

Printed: 26-March-2023



BH01 Test 3 at 12m

#### Case Method & ICAP® Results

2023-02-09 DCN	Drilling - SPT Dro	p Hammer No.4_2
	Committee of the Commit	TO A STATE OF THE PARTY OF THE

 OP: RZ
 Date: 09-February-2023

 AR: 15.03 cm²
 SP: 77.3 kN/m³

 LE: 13.7 m
 EM: 206,843 MPa

 WS: 5,123.0 m/s
 JC: 0.90

EMX: Maximum Energy
ETR: Energy Transfer Ratio - Rated
DMX: Maximum Displacement
DMX: Maximum Displacement
CSX: Compression Stress Maximum
VT1: Velocity at time 1
VT1: Velocity at time 1

	Velocity a Blows/Mir						FVP: Force/Velocity Proportionality				
BL#	Depth	BLC	EMX	ETR	FMX	VT1	BPM	AMX	DMX	CSX	EVP
	m	bl/m	J	(%)	kN	m/s	bpm	g's	mm	MPa	
10	12.0	0	358.9	75.6	226	3.28	20.2	2,659	17	150.3	0.7
11	12.0	0	354.2	74.6	224	3.17	20.4	2,822	19	149.2	0.5
12	12.0	0	322.2	67.9	212	2.95	16.2	2,586	23	140.9	0.5
13	12.0	0	371.9	78.4	236	3.79	20.5	3,096	17	157.3	0.6
14	12.0	0	358.4	75.5	231	3.66	20.7	2,572	25	153.7	0.6
15	12.0	0	338.3	71.3	216	3.34	21.5	2,414	20	143.7	0.7
16	12.0	0	368.5	77.6	233	3.97	21.4	2,755	22	155.1	0.6
17	12.0	0	332.9	70.2	208	2.78	21.0	2,351	27	138.3	0.7
18	12.0	0	364.0	76.7	224	3.74	21.4	2,953	18	149.2	0.6
19	12.0	0	347.2	73.2		3.34	21.9			144.0	
					216			2,324	25		0.6
20	12.0	0	357.2	75.3	235	3.81	14.8	2,925	18	156.0	0.7
21	12.0	0	347.4	73.2	203	2.80	20.8	2,562	31	135.2	0.5
22	12.0	0	358.2	75.5	228	3.72	16.7	2,984	11	151.6	0.6
23	12.0	0	344.7	72.6	219	2.84	22.4	2,286	42	145.4	0.8
24	12.0	0	353.4	74.5	242	4.01	22.8	2,790	17	160.9	0.5
25	12.0	0	342.9	72.3	239	3,98	20.0	2,514	15	158.9	0.5
26	12.0	0	330.3	69.6	255	3.47	19.9	2,761	11	169.9	0.7
27	12.0	0	346.4	73.0	233	3.80	20.6	2,468	13	154.7	0.6
28	12.0	0	348.3	73.4	222	3.62	21.1	2,186	14	147.7	0.7
29	12.0	0	341.4	71.9	235	3.71	21.7	2,268	10	156.4	0.6
30	12.0	0	344.3	72.6	257	3.98	21.5	2,583	12	171.1	0.5
31	12.0	0	347.2	73.2	258	3.89	20.9	2,314	14	171.9	0.5
32	12.0	0	356.7	75.2	244	4.02	20.4	2,300	11	162.3	0.6
33	12.0	0	342.3	72.1	230	3.55	17.6	2,133	13	152.7	0.6
34	12.0	Ö	358.3	75.5	241	4.16	19.6	2,220	10	160.2	0.5
35	12.0	ő	319.3	67.3	227	3.25	19.2	2,011	16	150.7	0.7
36	12.0	ő	304.6	64.2	211	2.75	20.0	1,792	12	140.7	0.6
37	12.0	0	348.6	73.5		4.10		2,363	11	158.3	
					238		19.6				0.5
38	12.0	0	316.5	66.7	216	2.80	19.9	2,094	9	143.4	0.6
39	12.0	0	347.9	73.3	227	3.94	20.1	2,388	15	151.2	0.5
40	12.0	0	321.7	67.8	236	3.81	16.7	2,071	9	157.1	0.5
41	12.0	0	325.0	68.5	231	3.66	12.2	1,943	13	153.9	0.6
42	12.0	0	316.2	66.6	223	3.80	19.2	2,144	9	148.4	0.5
43	12.0	0	363.6	76.6	220	3.83	20.4	2,585	22	146.3	0.6
44	12.0	0	334.1	70.4	273	3.47	19.9	2,400	10	181.6	0.6
45	12.0	0	287.8	60.6	212	2.66	19.4	1,925	10	140.9	0.6
46	12.0	0	330.4	69.6	223	3.58	19.3	1,865	10	148.3	0.5
47	12.0	0	288.2	60.7	262	2.68	20.1	1,790	8	174.3	0.8
48	12.0	0	300.0	63.2	207	2.64	20.2	1,616	8	137.4	0.4
49	12.0	0	309.6	65.3	217	2.61	20.9	1,759	12	144.1	0.5
50	12.0	0	320.9	67.6	228	2.82	16.6	1,677	12	151.7	0.6
51	12.0	0	299.9	63.2	178	2.25	19.2	1,458	18	118.1	0.7
52	12.0	0	319.5	67.3	261	2.86	19.0	1,933	12	173.9	0.8
53	12.0	0	318.6	67.1	229	2.87	20.9	1,823	12	152.1	0.6
54	12.0	0	299.3	63.1	206	2.85	20.6	1,547	12	136.9	
55	12.0	ő	297.7	62.7	204	2.81	14.3	1,558	9	135.5	0.5
56	12.0	0			207				14		
			328.9	69.3		2.84	20.7	1,566		137.9	0.6
57	12.0	0	316.0	66.6	254	2.63	21.8	1,865	13		0.6
58	12.0	0	316.2	66.6	219	2.98	20.5	1,605	11	145.6	0.6
59	12.0	0	308,8	65.1	191	2.36	20.9	1,338	9	126.9	0.6

Roc Consulting Limited PDIPLOT2 2021, 1.61.0

Case Method & ICAP® Results

Page 2 Printed 26-March-2023

2023-02-09 DCN Drilling - SPT Drop Hammer No.4 2

BH01 Test 3 at 12m

OP: R	Z		K-549-10-141		Date: 09-February-2023						
BL#	Depth m	BLC bl/m	EMX	ETR (%)	FMX kN	VT1 m/s	BPM	AMX g's	DMX	CSX MPa	FVP
	A	verage	333.5				Section of the second	2,219	15	151.2	0.6
				Total motor	to be more staff. In	Acres de la	Lambert C.				

BL# Sensors

10-59 F1: [680NW1] 229.4 (1.00); F2: [680NW2] 230.0 (1.00); A3: [K12864] 416.1 (1.00); A4: [K12865] 430.9 (1.00)

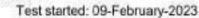
Time Summary

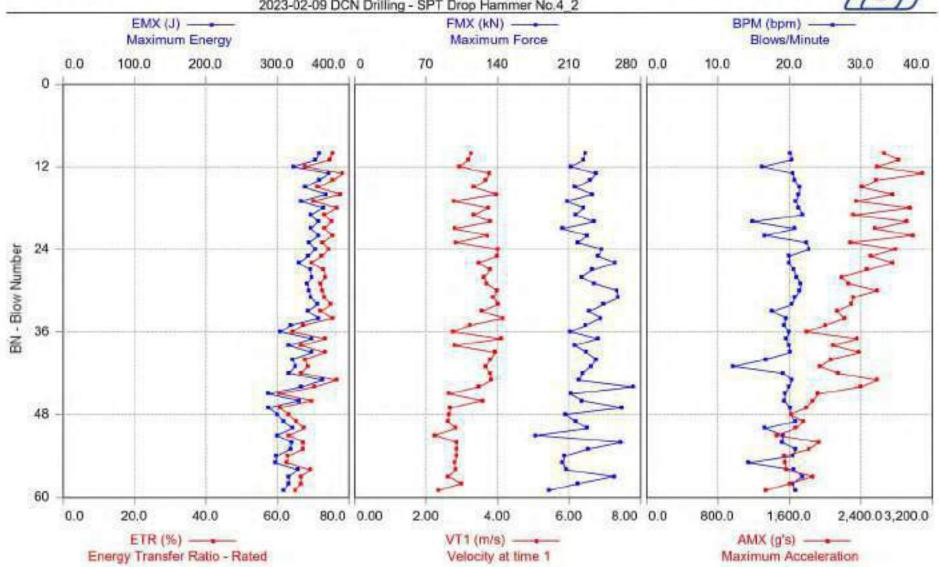
Drive 2 minutes 57 seconds 10:05 am - 10:08 am BN 1 - 59

Roc Consulting Limited - PDIPLOT2 Ver 2021, 1,61.0 - Case Method & iCAP® Results

Printed: 26-March-2023

2023-02-09 DCN Drilling - SPT Drop Hammer No.4\_2





WS: 5,123.0 m/s

SP:

JC:

BH04 Test 1 at 9m

EM: 206,843 MPa

0.90

77.3 kN/m3

#### Case Method & ICAP® Results

2023-02-09 DCN Drilling - SPT Drop Hammer No.5

OP: RZ Date: 09-February-2023 15.03 cm<sup>2</sup> LE: 10.7 m

EMX: Maximum Energy AMX: Maximum Acceleration ETR: Energy Transfer Ratio - Rated FMX: Maximum Force DMX: Maximum Displacement CSX: Compression Stress Maximum

VT1:	Velocity a									Proportion	
	Blows/Mi						10000	94,250		Transport	-
BL#	Depth	BLC	EMX	ETR	FMX	VT1	BPM	AMX	DMX	CSX	FVP
	m	bl/m	L	(%)	kN	mis	bpm	g's	mm	MPa	
15	9.0	0	292.3	61.6	168	2.60	22.3	2,670	19	111.6	0.3
16	9.0	0	280.0	59.0	165	2.59	22.5	2,573	21	109.5	0.4
17	9.0	0	296.2	62.4	173	2.67	20.3	2,697	15	114.8	0.8
18	9.0	0	310.4	65.4	182	2.77	23.1	2,765	21	121.3	0.3
19	9.0	0	304.2	64.1	187	2.87	20.2	2,883	18	124.4	0.3
20	9.0	0	309.0	65.1	204	3.25	21.0	2,914	12	135.4	0.5
21	9.0	0	302.1	63.7	196	2.84	22.0	2,699	17	130.6	0.4
22	9.0	0	299.9	63.2	198	2.96	21.8	2,803	16	132.0	0.3
23	9.0	0	295.8	62.3	202	2.91	22.4	2,830	14	134.3	0.3
24	9.0	0	311.5	65.6	206	3.35	22.0	2,817	14	137.0	0.5
25	9,0	0	305.1	64.3	190	2.88	21.7	2,730	18	126.3	0.3
26	9.0	0	293.0	61.8	197	2.94	21.5	2,781	12	130.9	0.3
27	9,0	0	296.6	62.5	204	2.97	21.5	2,860	16	136.0	0.4
28	9.0	0	293.2	61.8	197	2.94	21.8	2,838	12	131.1	0.4
29	9.0	0	294.9	62.1	192	2.83	21.7	2.679	19	127.6	0.5
30	9.0	0	327.8	69.1	200	3.41	22.2	2,896	19	133.3	0.4
31	9.0	0	292.8	61.7	193	2.84	22.3	2,705	18	128.3	0.4
32	9.0	0	300.5	63.3	200	2.92	20.9	2,815	15	133.1	0.8
33	9.0	0	312.4	65.8	190	2.78	21.7	2,643	26	126.6	0.4
34	9.0	0	308.1	64.9	206	3.09	20.9	2,909	11	136.9	0.6
35	9.0	0	303.9	64.0	194	2.84	21.1	2,646	18	129.1	0.4
36	9.0	0	291.6	61.5	197	2.95	21.6	2,777	12	130.8	0.4
37	9.0	0	299.2	63.0	205	2.98	21.6	2,859	13	136.4	0.5
38	9.0	0	298.8	63.0	211	2.98	22.8	2,840	11	140.1	0.4
39	9.0	0	298.1	62.8	208	2.95	22.6	2,843	11	138.2	0.4
40	9.0	0	292.1	61.5	206	2.90	17.8	2,778	10	137.2	0.7
41	9.0	0	295.0	62.2	200	2.83	23.2	2,651	19	133.1	0.4
42	9.0	0	297.8	62.8	192	2.84	23.8	2,745	26	127.5	0.5
43	9.0	0	292.6	61.7	197	2.92	22.1	2,731	17	130.8	0.4
44	9.0	0	283.8	59.8	200	2.91	22.3	2,755	10	132,8	0.4
45	9.0	0	306.3	64.5	203	2.88	22.2	2,680	24	135.0	0.5
46	9.0	0	285.1	60.1	203	2.90	22.0	2,708	11	135.1	0.5
47	9.0	0	297.7	62.7	205	2.94	22.2	2,807	15	136.6	0.4
48	9.0	0	288.8	60.9	201	2.90	21.1	2,659	12	133.9	0.4
49	9.0	0	296.1	62.4	207	2.90	20.3	2,722	13	137.6	0.5
50	9.0	0	273.5	57.6	197	2.85	21.7	2,628	12	131.1	0.4
51	9.0	0	335.1	70.6	224	3.63	21.5	2,901	13	148.7	0.4
52	9.0	0	291.5	61.4	194	2.91	21.7	2,599	14	129.3	0.7
53	9.0	0	300.4	63.3	207	3.09	21.6	2,765	12	137.8	8.0
54	9.0	0	295.9	62.4	200	2.89	23.6	2,581	11	132.8	0.7
55	9.0	0	317.3	66.9	204	2.91	22.5	2,774	21	135.5	0.4
56	9.0	0	340.2	71.7	237	3.59	21.2	3,105	12	157.8	0.3
57	9.0	0	305.1	64.3	211	3.13	21.0	2,689	10	140.7	0.7
58	9.0	0	333.6	70.3	230	3.61	21.0	2,861	13	152.9	0.4
59	9.0	0	302.2	63.7	212	3.01	21.4	2,619	18	140.8	0.7
60	9.0	0	321.3	67.7	225	3.60	21.2	2,930	. 7	149.7	0.4
61	9.0	0	306.4	64.6	206	2.76	22.1	2,582	28	136.8	0.5
62	9.0	0	291.8	61.5	203	2.81	21.3	2,657	13	134.8	0.5
63	9.0	0	303.8	64.0	198	2.77	20.8	2,592	30	132.0	0.5
	A	verage	301.4	63.5	200	2.97	21.7	2,755	16	133.4	0.5

Roc Consulting Limited PDIPLOT2 2021.1.61.0

Case Method & ICAP® Results.

Page 2 Printed 26-March-2023

2023-02-09 DCN Drilling - SPT Drop Hammer No.5

BH04 Test 1 at 9m

OP: RZ Date: 09-February-2023 BLC BPM AMX BL# Depth **EMX** ETR VT1 DMX CSX FVP kN MPa bl/m (%) m/s bpm g's mm Total number of blows analyzed: 49

BL# Sensors

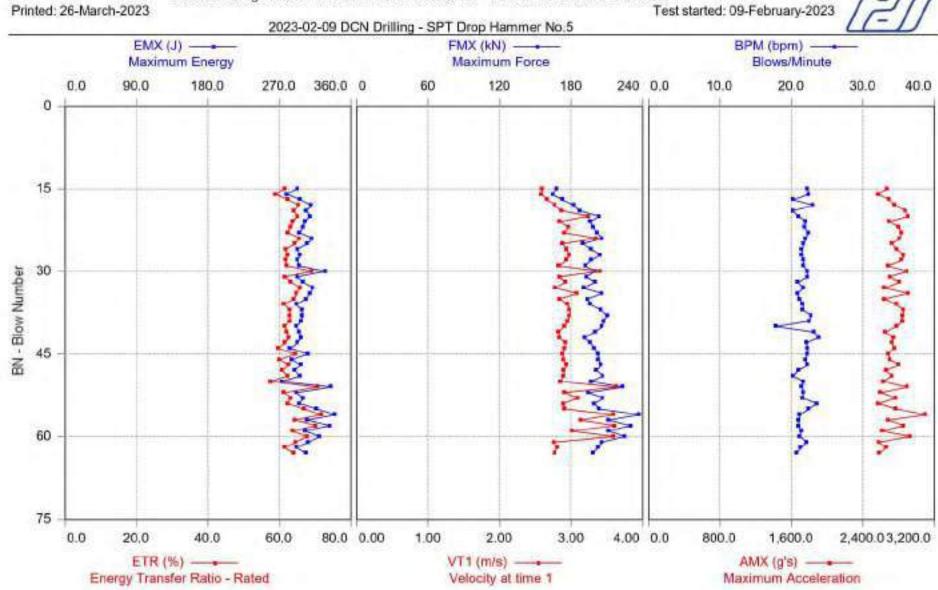
15-63 F1: [680NW1] 229.4 (1.00); F2: [680NW2] 230.0 (1.00); A3: [K12864] 416.1 (1.00); A4: [K12865] 430.9 (1.00)

Time Summary

Drive 2 minutes 51 seconds 2:05 pm - 2:08 pm BN 1 - 63

Roc Consulting Limited - PDIPLOT2 Ver 2021.1.61.0 - Case Method & iCAP® Results

Printed: 26-March-2023



WS: 5,123.0 m/s

0.90

JC:

#### Case Method & iCAP® Results

2023 OP: F	-02-09 DCN Drilling - SPT Drop Hammer No.5_1 RZ	BH04 Test 2 at 10.5m Date: 09-February-2023			
AR:	15.03 cm²	SP: 77.3 kN/m <sup>3</sup>			
LE:	12.2 m	EM: 206,843 MPa			

EMX: Maximum Energy
ETR: Energy Transfer Ratio - Rated
DMX: Maximum Displacement
DMX: Maximum Displacement
CSX: Compression Stress Maximum
VT1: Velocity at time 1
FVP: Force/Velocity Proportionality

	Velocity a Blows/Mir					FVP: Force/Velocity Proportionalit						
BL#	Depth	BLC	EMX	ETR	FMX	VT1	BPM	AMX	DMX	CSX	FVP	
	m	bl/m	J	(%)	kN	mis	bpm	9'5	mm	MPa		
9	10.5	0	294.4	62.0	160	2.66	19.5	2,541	46	106.5	0.5	
10	10.5	0	339.0	71.4	174	2.82	19.8	2,957	47	115.5	0.4	
11	10.5	0	318.2	67.1	168	2.64	19.8	2,705	38	111.8	0.4	
12	10.5	0	312.6	65.9	177	2.94	19.6	2,896	27	117.9	0.7	
13	10.5	0	296.9	62.6	170	2.64	19.5	2,605	29	113.3	0.5	
14	10.5	0	299.7	63.2	168	2.46	14.1	2,547	33	112.0	0.4	
15	10.5	0	280.6	59.1	178	2.77	22.1	2,662	39	118.2	0.4	
16	10.5	0	287.2	60.5	177	2.73	20.9	2,571	33	117.7	0.4	
17	10.5	0	319.7	67.4	183	2.81	19.4	2,806	34	121.8	0.5	
18	10.5	0	270.1	56.9	180	2.78	20.9	2,743	28	120.1	0.4	
19	10.5	0	320.7	67.6	190	2.96	19.7	2,978	36	126.7	0.4	
20	10.5	0	280.8	59.2	178	2.78	21.5	2,650	34	118.2	0.5	
21	10.5	0	321.8	67.8	187	3,28	16.4	2,812	25	124.5	0.6	
22	10.5	0	316.1	66.6	192	2.94	21.1	2,620	28	127.8	0.8	
23	10.5	0	315.1	66.4	189	2.77	14.8	2,698	32	125.5	0.7	
24	10.5	0	311.7	65.7	195	2.87	20.8	2,760	29	129.5	0.8	
25	10.5	0	288.5	60.8	190	2.82	19.8	2,665	19	126.4	0.4	
26	10.5	0	284.7	60.0	192	2.84	21.2	2,683	20	127.5	0.4	
27	10.5	0	285.6	60.2	195	2.87	19.3	2,691	16	130.0	0.4	
28	10.5	0	280.4	59.1	195	2.81	20.5	2,647	17	130.0	0.5	
29	10,5	0	301.1	63.5	196	2.78	20.2	2,557	20	130.5	0.4	
30	10.5	0	301.1	63.5	205	3.10	19.9	2,775	15	136.1	0.6	
31	10.5	0	287.3	60.6	192	2.76	20.8	2,591	28	127.7	0.4	
32	10.5	0	299.6	63.1	202	3.01	20.1	2,713	17	134.4	0.7	
33	10.5	0	317.7	66.9	201	3.25	20.6	2,633	20	133.9	0.7	
34	10.5	0	292.7	61.7	196	2.84	20.7	2,712	15	130.2	0.7	
35	10.5	0	294.2	62.0	204	2.99	15.8	2,642	16	135.8	8.0	
36	10.5	0	279.7	58.9	199	2.76	21.0	2,548	15	132.6	0.4	
37	10.5	0	310.7	65.5	195	3.06	16.3	2,662	24	129.6	0.8	
- 1034	A	verage	300.3	63,3	187	2.85	19.5	2,692	27	124.5	0.5	

Total number of blows analyzed: 29

BL# Sensors

9-37 F1: [680NW1] 229.4 (1.00); F2: [680NW2] 230.0 (1.00); A3: [K12864] 416.1 (1.00); A4: [K12865] 430.9 (1.00)

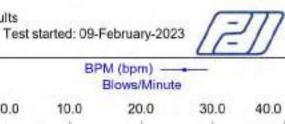
Time Summary

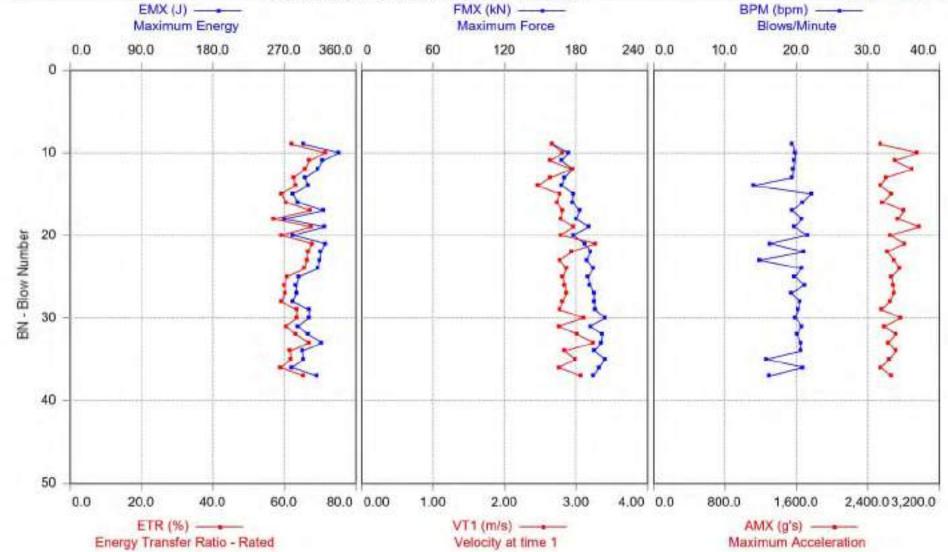
Drive 1 minute 51 seconds 2:38 pm - 2:40 pm BN 1 - 37

Roc Consulting Limited - PDIPLOT2 Ver 2021.1.61.0 - Case Method & iCAP® Results

Printed: 26-March-2023

2023-02-09 DCN Drilling - SPT Drop Hammer No.5\_1





BH04 Test 3 at 12m

#### Case Method & ICAP® Results

2023-02-09 DCN Drilling - SPT Drop Hammer No.5\_2

 OP: RZ
 Date: 09-February-2023

 AR: 15.03 cm²
 SP: 77.3 kN/m³

 LE: 13.7 m
 EM: 206,843 MPa

 WS: 5,123.0 m/s
 JC: 0.90

EMX: Maximum Energy
ETR: Energy Transfer Ratio - Rated
DMX: Maximum Displacement
DMX: Maximum Displacement
CSX: Compression Stress Maximum
VT1: Velocity at time 1
VT1: Velocity at time 1

	Velocity a Blows/Mir					FVP: Force/Velocity Proportionality							
BL#	Depth	BLC	EMX	ETR	FMX	VT1	BPM	AMX	DMX	CSX	FVP		
DL#	m	bl/m	J	(%)	kN	m/s	bpm		mm	MPa	1.41		
10	12.0	0	313.0	66.0	199	2.99	20.2	g's 2,997	33	132.7	0.4		
11	12.0	0	312.5	65.9	191	2.93	21.9	2,933	26	126.9	0.4		
12	12.0	0	308.5	65.0	193	2.96	19.5	2,999	26	128.2	0.4		
13	12.0	0	289.0	60.9	186	2.88	20.1	2,838	25	123.6	0.4		
14	12.0	0	283.8	59.8	194	2.86	18.9	2,765	25	128.8	0.5		
15	12.0	0	291.0	61,3	195	2.83	19.6	2,774	27	129.4	0.5		
16	12.0	0	308.0	64.9	200	2.89	19.4	2,881	35	133.1	0.5		
17	12.0	0	307.3	64.8	200	2.98	19.5	2,968	35	132.9	0.5		
18	12.0	0	295.6	62.3	203	2.91	19.8	2,825	36	135.1	0.5		
19	12.0	0	325.8	68.7	199	3.00	20.9	2,939	35	132.5	0.4		
20	12.0	0	295.5	62.3	187	2.88	16.5	2,837	18	124.7	0.4		
21	12.0	0	299.2	63.1	181	2.84	19.2	2,758	20	120.7	0.8		
22	12.0	0	303.3	63.9	198	2.88	20.0	2,793	31	131.7	0.6		
23	12.0	0	307.7	64.8	203	2.95	19.5	2,874	25	135.3	0.7		
24	12.0	0	296.5	62.5	203	2.95	21.0	2,833	30	135.3	0.4		
25	12.0	0	314.8	66.3	206	2.97	12.6	2,890	23	137.2	0.5		
26	12.0	0	304.0	64.1	189	3.26	19.1	2,823	13	125.7	0.6		
27	12.0	0	321.8	67.8	193	3.27	19.9	2,897	13	128.4	0.7		
28	12.0	0	329.4	69.4	192	3.29	19.8	2,972	16	127.5	0.8		
29	12.0	0	314.0	66.2	208	3.40	19.2	3,069	14	138.2	0.5		
30	12.0	0	303.7	64.0	197	3.12	19.3	2,789	13	130.8	0.6		
31	12.0	0	309.1	65.1	210	3.18	19.7	2,987	13	139.5	0.6		
32	12.0	0	290.4	61.2	200	2.82	19.7	2,733	20	133.0	0.5		
33	12.0	0	291.3	61.4	185	2.52	18.2	2,603	29	122.8	0.4		
34	12.0	0	292.4	61.6	191	2.98	20.5	2,743	15	126.9	0.8		
35	12.0	0	308.4	65.0	197	2.85	21.0	2,837	25	131.0	0.5		
36	12.0	0	318.7	67.2	202	2.89	17.3	2,829	38	134.7	0.4		
37	12.0	0	310.5	65.4	206	2.96	21.5	2,838	20	137.1	0.5		
38	12.0	0	315.8	66.5	202	2.91	19.7	2,889	23	134.7	0.5		
39	12.0	0	309.3	65.2	204	2.98	21.0	3,013	15	135.7	0.5		
40	12.0	0	308.9	65.1	208	2.96	20.4	2,918	24	138.2	0.5		
41	12.0	0	310.3	65.4	201	2.94	19.8	2,800	28	133.5	0.5		
42	12.0	0	277.8	58.5	192	2.88	19.5	2,650	24	127.6	0.5		
43	12.0	0	308.1	64.9	201	2.93	19.6	2,879	26	133.6	0.5		
44	12.0	0	309.5	65.2	194	3.10	20.1	3,028	15	129.0	0.7		
45	12.0	Ö	315.8	66.5	188	3.13	17.1		18		0.8		
46	12.0	0	324.1	68.3	208	3.35		2,750	23	138.6	0.6		
							20.7						
47	12.0	0	296.9	62.6	195	2.87	19.1	2,895	16	129.6	0.5		
48	12.0	0	316.8	66.8	199	3.07	20.0	2,935	18		8.0		
49	12.0	0	323.5	68.2	210	3.30	19.4	3,144	23	139.7	0.6		
50	12.0	0	330.3	69.6	224	3.67	19.5	3,098	17	149.0	0.4		
51	12.0	0	307.0	64.7	214	3.29	20.1	2,844	17		0.6		
52	12.0	0	310.2	65.4	196	2.80	20.8	2,724	21	130.5	0.5		
53	12.0	0	328.2	69.2	203	3.27	19.2	2,830	24	134.9	0.7		
54	12.0	0	328.1	69.1	219	3.53	19.8	3,162	14	146.0	0.5		
55	12.0	0	312.5	65.9	203	2.99	19.5	2,808	21	134.8	0.8		
56	12.0	0	306.5	64.6	203	3.00	19.0	2,954	17	134.8	0.6		
57	12.0	0	327.3	69.0	200	2.85	20.1	2,754	30	132.7	0.4		
	A	verage	308.6	65.0	199	3.02	19.5	2,877	23	132.6	0.6		

Total number of blows analyzed: 48

Roc Consulting Limited PDIPLOT2 2021.1.61.0

Case Method & ICAP® Results

Page 2 Printed 26-March-2023

2023-02-09 DCN Drilling - SPT Drop Hammer No.5\_2 OP; RZ

BH04 Test 3 at 12m

Date: 09-February-2023 BL# Depth BLC EMX ETR FMX VT1 BPM AMX DMX CSX bl/m MPa (%) kN m/s bpm g's mm

BL# Sensors

10-57 F1; [680NW1] 229.4 (1.00); F2; [680NW2] 230.0 (1.00); A3; [K12864] 416.1 (1.00); A4: [K12865] 430.9 (1.00)

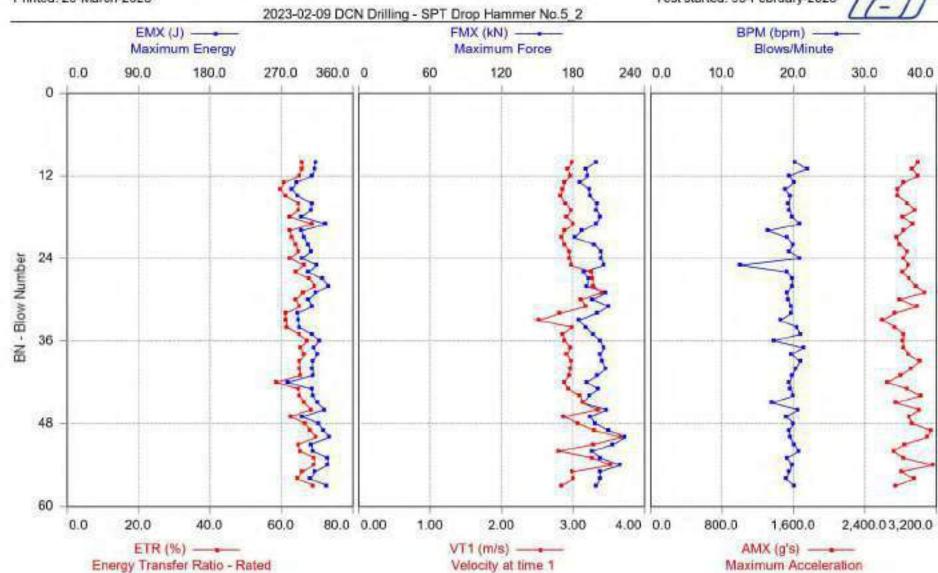
Time Summary

Drive 2 minutes 52 seconds 3:04 pm - 3:06 pm BN 1 - 57

Roc Consulting Limited - PDIPLOT2 Ver 2021, 1,61.0 - Case Method & iCAP® Results

Printed: 26-March-2023

Test started: 09-February-2023





## Roc Consulting Ltd New Zealand & South Pacific

NZBN: 9429050784509

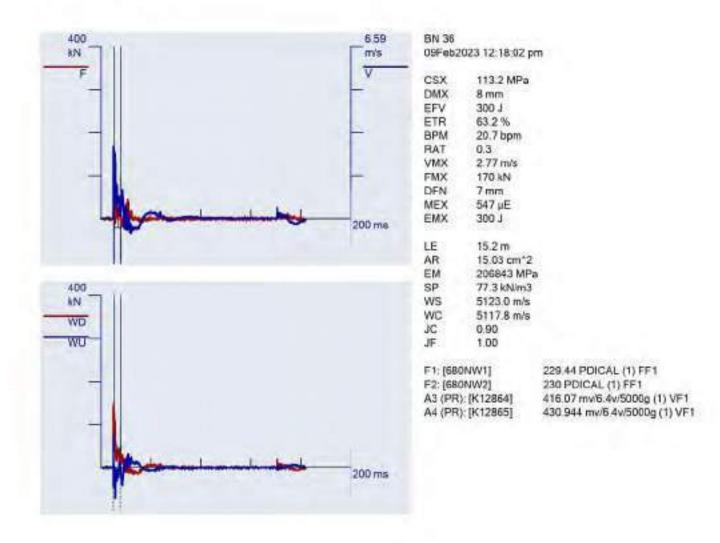
Job No.:1015\_2302

Date: 30 March 2023

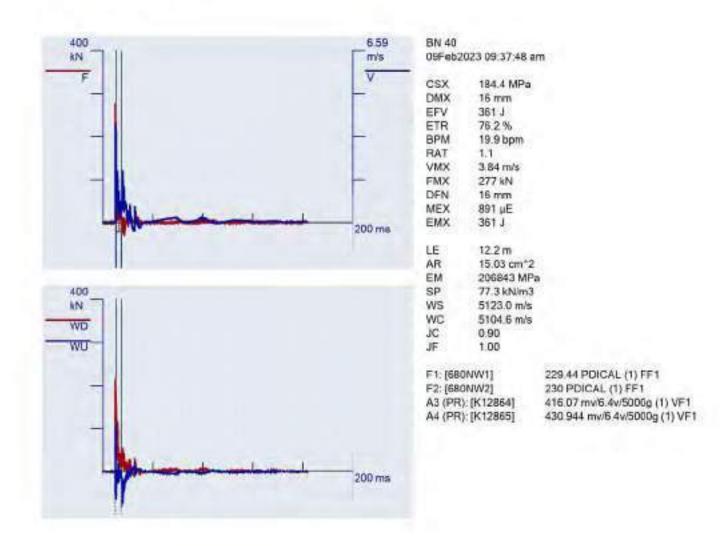
# Appendix C

Representative Force and Velocity Plots

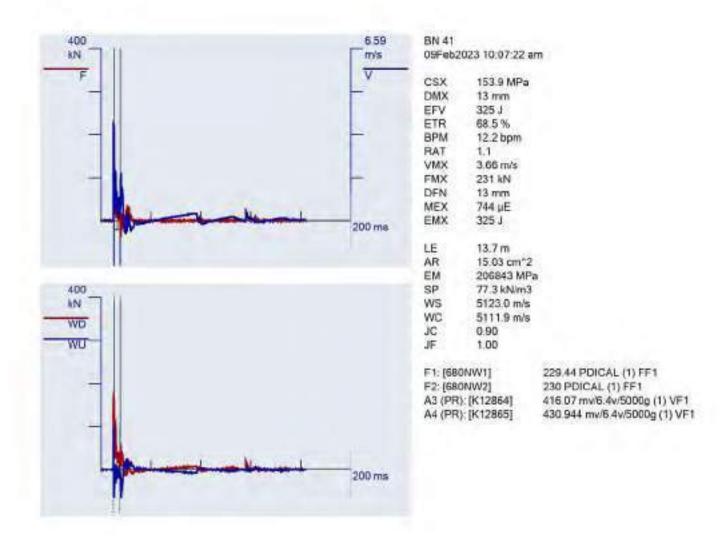
## Roc Consulting Limited 2023-02-09 DCN Drilling SPT Drop Hammer No.1 BH02 Test 1 at 13.5m PDA Operator: RZ



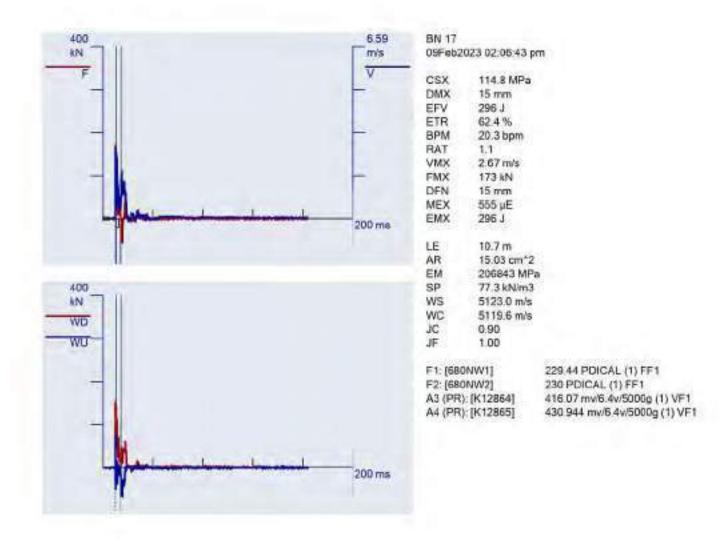
## Roc Consulting Limited 2023-02-09 DCN Drilling SPT Drop Hammer No.4\_1 BH01 Test 2 at 10.5m PDA Operator: RZ



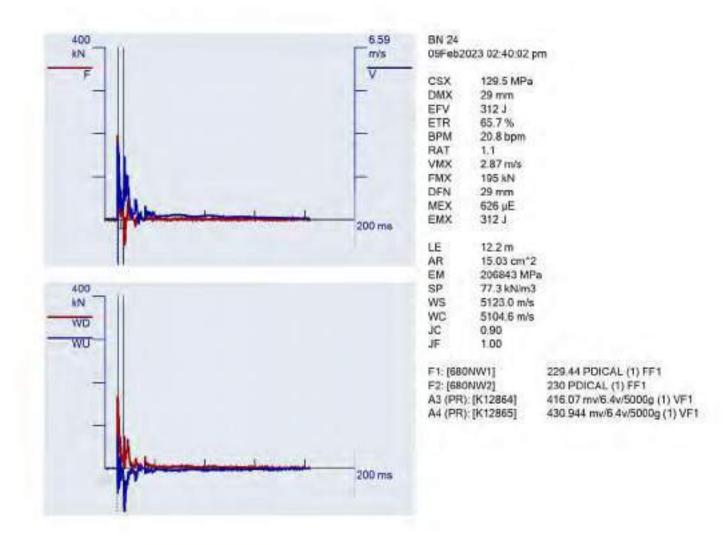
## Roc Consulting Limited 2023-02-09 DCN Drilling SPT Drop Hammer No.4\_2 BH01 Test 3 at 12m PDA Operator: RZ



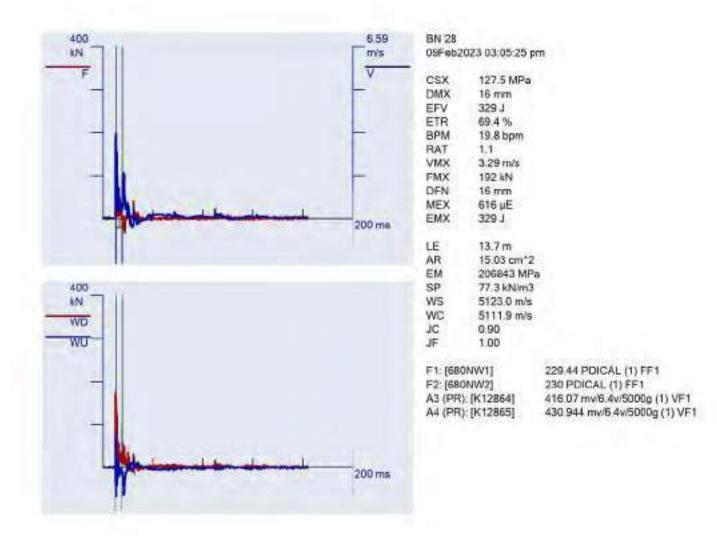
## Roc Consulting Limited 2023-02-09 DCN Drilling SPT Drop Hammer No.5 BH04 Test 1 at 9m PDA Operator: RZ



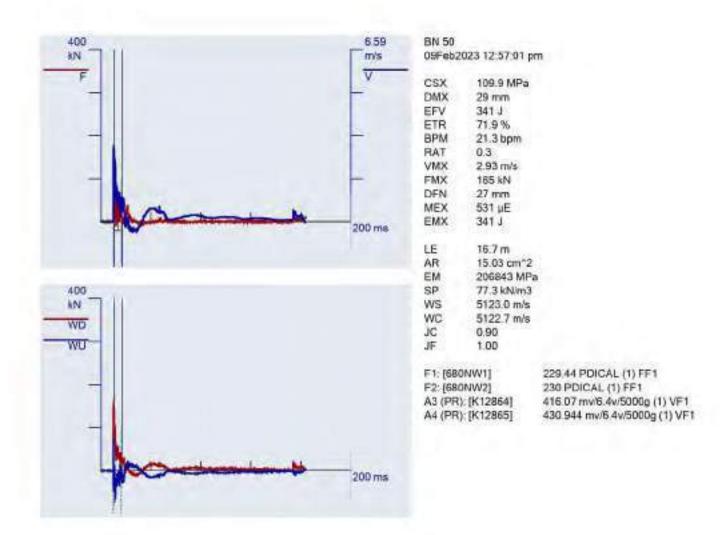
## Roc Consulting Limited 2023-02-09 DCN Drilling SPT Drop Hammer No.5\_1 BH04 Test 2 at 10.5m PDA Operator: RZ



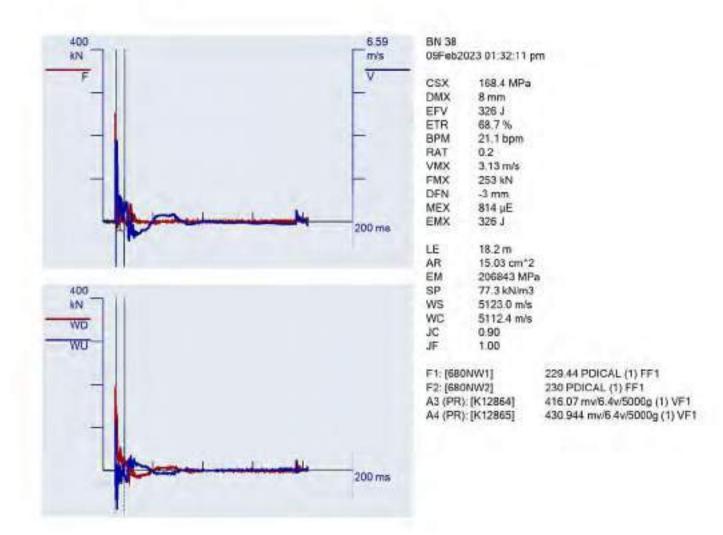
## Roc Consulting Limited 2023-02-09 DCN Drilling SPT Drop Hammer No.5\_2 BH04 Test 3 at 12m PDA Operator: RZ



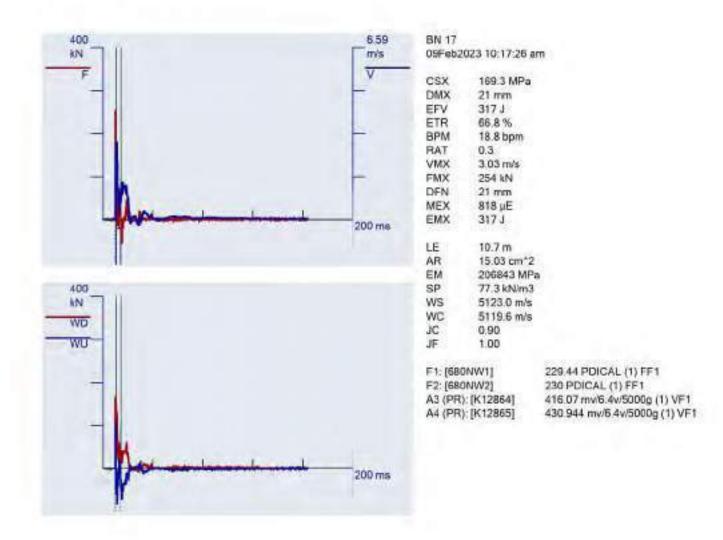
## Roc Consulting Limited 2023-02-09 DCN Drilling SPT Drop Hammer No.1\_1 BH02 Test 2 at 15m PDA Operator: RZ



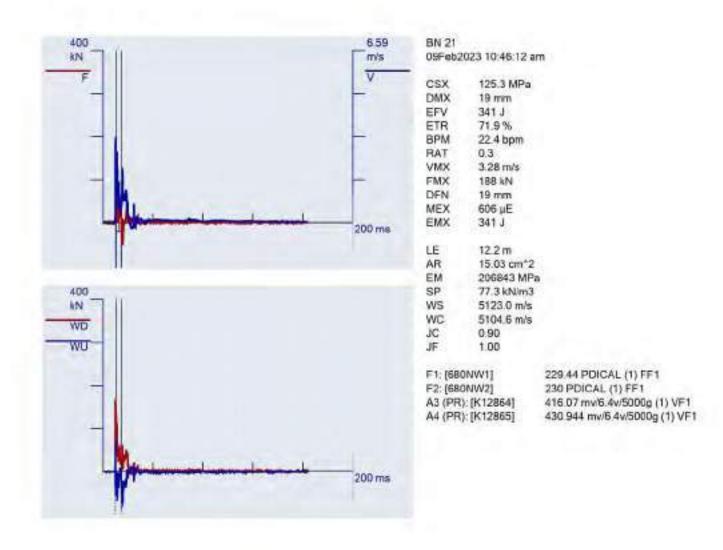
## Roc Consulting Limited 2023-02-09 DCN Drilling SPT Drop Hammer No.1\_2 BH02 Test 3 at 16.5m PDA Operator: RZ



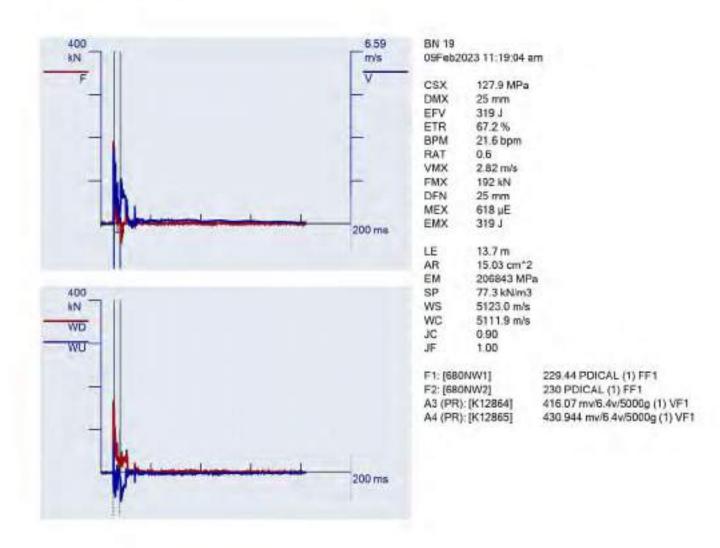
## Roc Consulting Limited 2023-02-09 DCN Drilling SPT Drop Hammer No.2 BH02 Test 1 at 9m PDA Operator: RZ



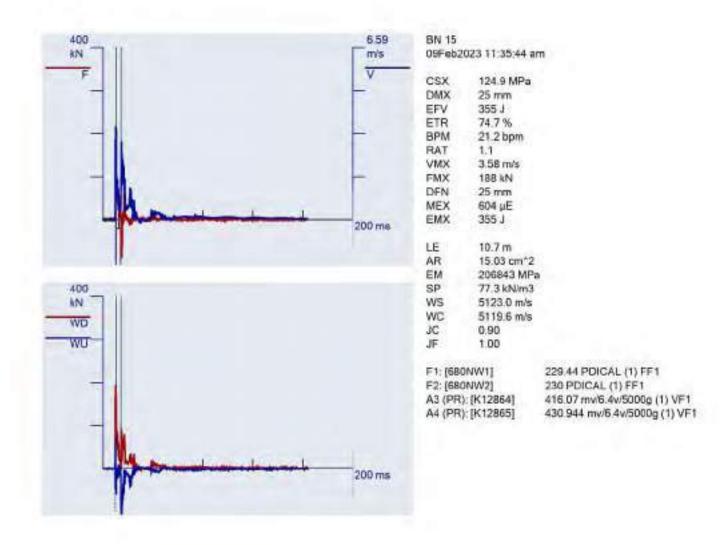
## Roc Consulting Limited 2023-02-09 DCN Drilling SPT Drop Hammer No.2\_1 BH02 Test 2 at 10.5m PDA Operator: RZ



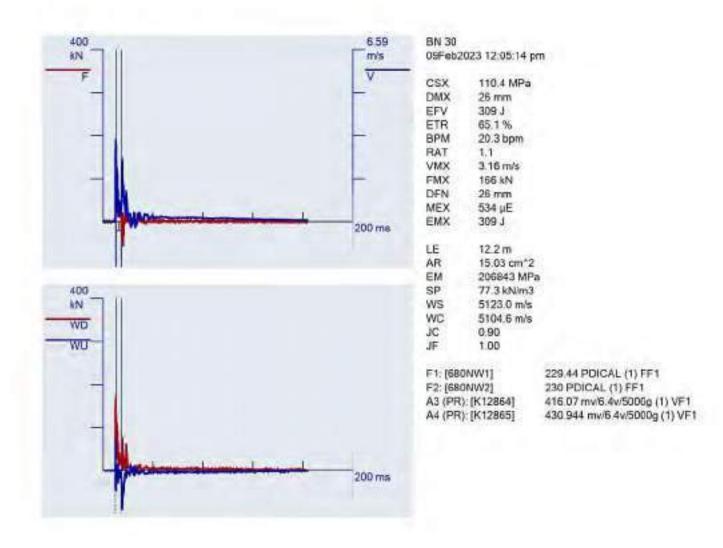
## Roc Consulting Limited 2023-02-09 DCN Drilling SPT Drop Hammer No.2\_2 BH02 Test 3 at 12m PDA Operator: RZ



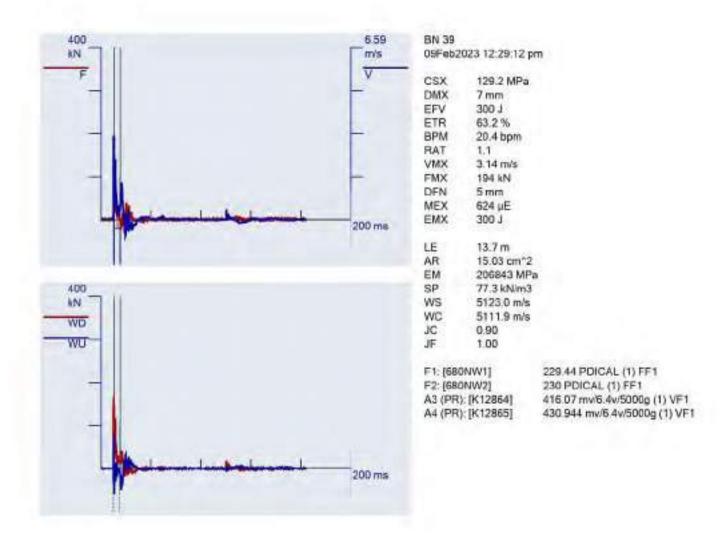
## Roc Consulting Limited 2023-02-09 DCN Drilling SPT Drop Hammer No.3 BH03 Test 1 at 9m PDA Operator: RZ



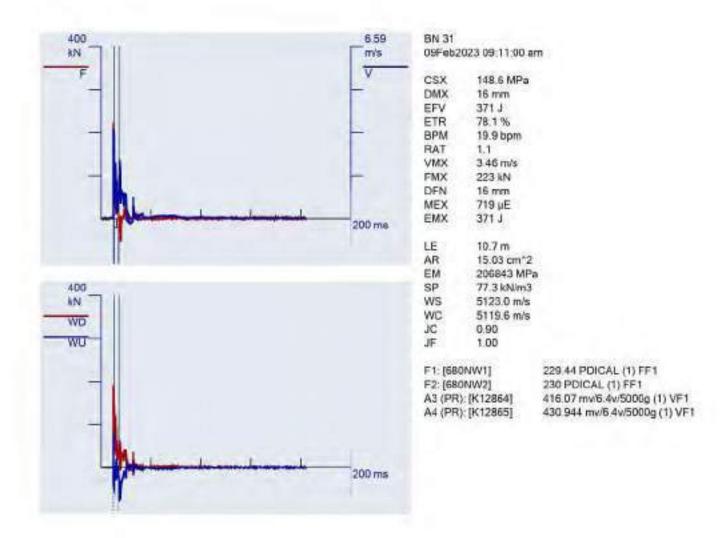
## Roc Consulting Limited 2023-02-09 DCN Drilling SPT Drop Hammer No.3\_1 BH03 Test 2 at 10.5m PDA Operator: RZ



## Roc Consulting Limited 2023-02-09 DCN Drilling SPT Drop Hammer No.3\_2 BH03 Test 3 at 12m PDA Operator: RZ



## Roc Consulting Limited 2023-02-09 DCN Drilling SPT Drop Hammer No.4 BH01 Test 1 at 9m PDA Operator: RZ



# Appendix F5

**Telemetered Groundwater Data Plots** 



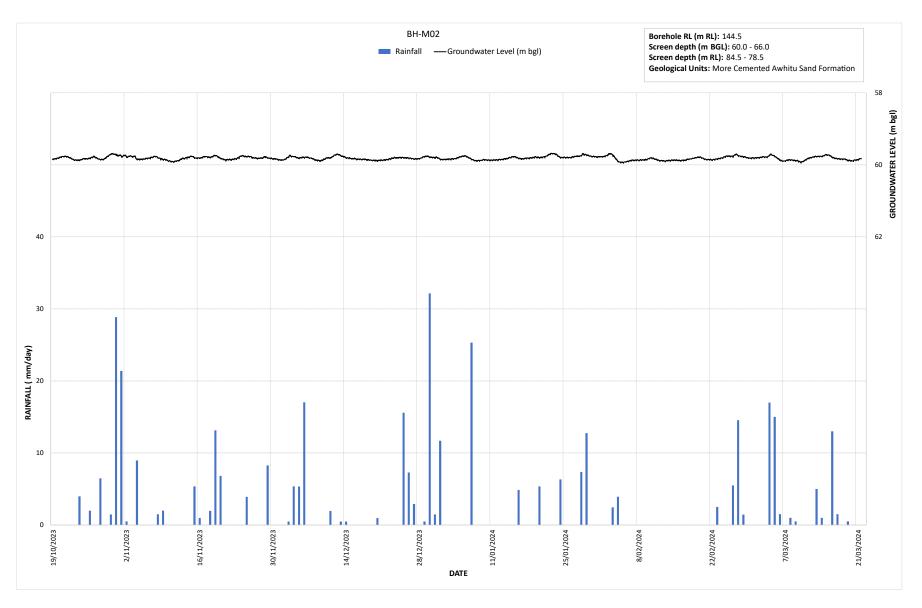
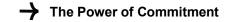


Figure F5-1: Plot of rainfall and telemetered groundwater data from BH-M02. Rainfall data sourced from Auckland Council's Environmental Data Portal





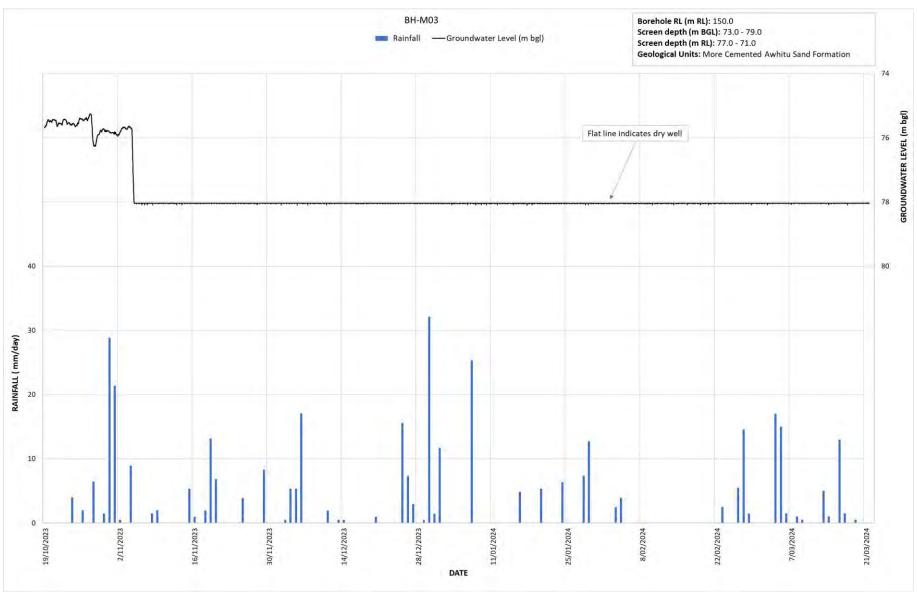


Figure F5-2: Plot of rainfall and telemetered groundwater data from BH-M03. Rainfall data sourced from Auckland Council's Environmental Data Portal



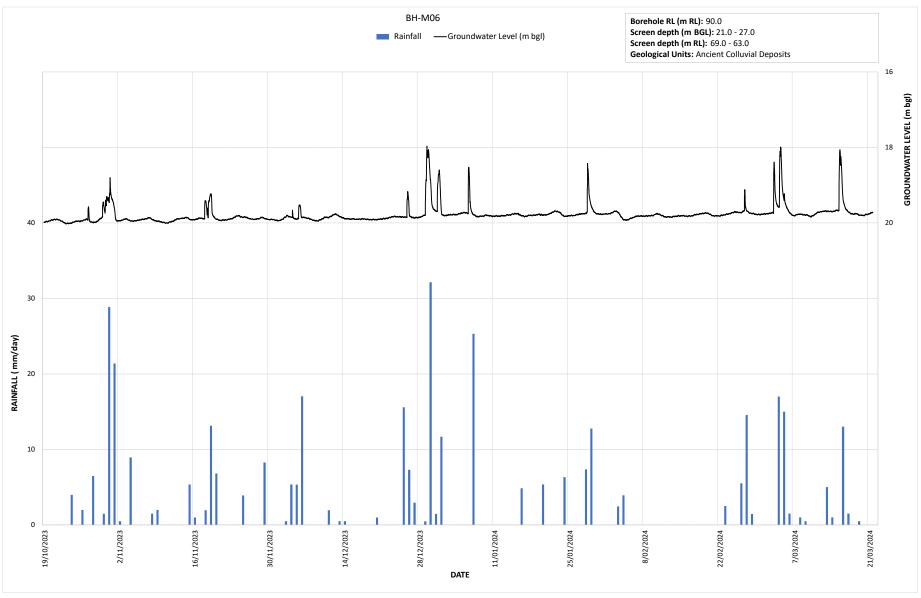


Figure F5-3: Plot of rainfall and telemetered groundwater data from BH-M06. Rainfall data sourced from Auckland Council's Environmental Data Portal



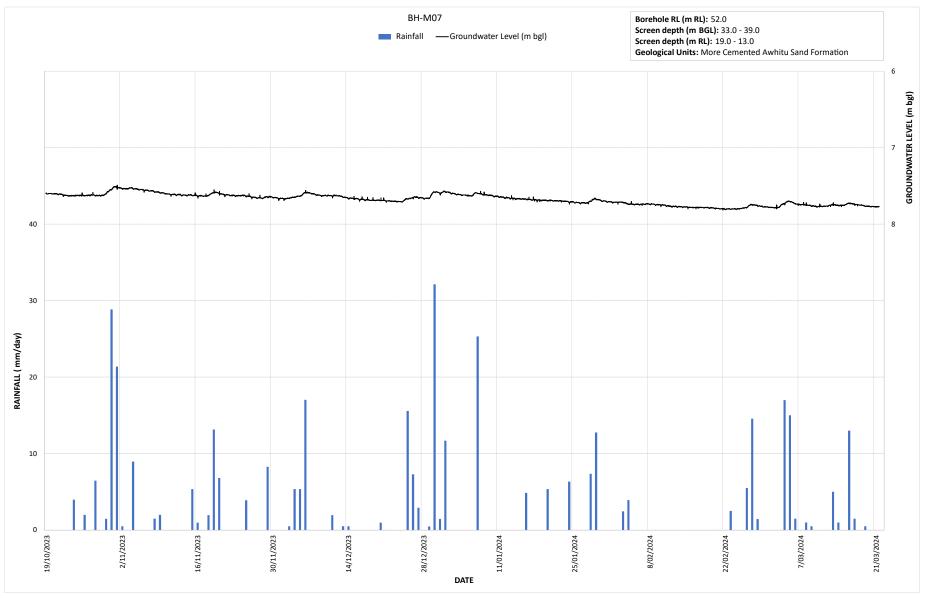


Figure F5-4: Plot of rainfall and telemetered groundwater data from BH-M07. Rainfall data sourced from Auckland Council's Environmental Data Portal

Waitākere Coastal Communities landslide Risk Assessment Overall Report - Muriwai ISBN 978-1-991146-40-3 (PDF) May 2024

Auckland Council disclaims any liability whatsoever in connection with any action taken in reliance of this document for any error, deficiency, flaw or omission contained in it. © 2024 Auckland Council

