

Efaté Earthquake Engineering Technical Assistance

Port Vila CBD Geotechnical Hazard Study: Geotechnical Factual Report

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1 Introduction

Tonkin & Taylor International Ltd (T+TI) has been engaged by Egis NZ Limited (Egis) to provide specialist geotechnical engineering services for the New Zealand Ministry of Foreign Affairs and Trade (MFAT) Efate Earthquake Engineering Technical Assistance (EEETA) programme. This programme supports the Government of Vanuatu (GoV) in its recovery efforts following the 17 December 2024 earthquake, which caused significant damage to buildings and infrastructure in Port Vila.

As part of the programme, a geotechnical hazard study (the Study) is underway to increase the long-term resilience of Port Vila's built environment. The Study encompasses two distinct areas as shown on Figure 1.1. A summary of these areas is detailed in Section 1.2.

The Study is being delivered in the following stages:

1 Data Compilation and stakeholder collaboration
2 Geotechnical investigation
3 Ground zoning
4 Geotechnical Guidance Document
5 Digital deployment to GIS portal

This Geotechnical Factual Report (GFR) is the main deliverable of the geotechnical investigation (Stage 2) – undertaken across 7 November 2025 to 6 March 2026 – and provides key information to support the ground zoning and subsequent Geotechnical Guidance Document. The scope of work completed includes:

- LiDAR and photogrammetry drone survey
- Machine boreholes at 11 No. locations
- Installation of 3 No. shallow piezometers and subsequent continuous groundwater monitoring over a period of nine weeks from 16 December to 24 February.
- Laboratory testing on selected soil and rock samples, including:
  - 2 No. Atterberg Limit tests
  - 15 No. Particle Size Distribution tests
  - 3 No. Allophane tests
  - 9 No. Unconfined Compressive Strength tests
  - 3 No. Consolidated-Undrained (single stage) triaxial compression tests
- Downhole geophysical (shear wave) testing in 6 No. boreholes locations
- Surface geophysical surveys along key road corridors, including:
  - Multi-Channel Analysis of Surface Waves across 5.5 km in length
  - Seismic Refraction Tomography across 1 km in length
  - Horizontal-Vertical Spectral Ratio Analysis at 12 No. locations
- Preparation of this GFR summarising the factual details of the site investigation works

Interpretation of this factual data – including development of the ground model and hazard assessment to inform the ground zoning and geotechnical guidance document – will be provided in a separate Geotechnical Assessment Report.

1.1 Project background

The post-earthquake recovery in Port Vila presents a critical opportunity to guide the rebuilding of the CBD to be more resilient to future natural hazards. This opportunity was identified during initial observations from post-earthquake reconnaissance undertaken by T+TI in March and April 2025 (independent of the MFAT-funded EEETA programme), and by GNS which recommended similar actions in their May 2025 report[1].

These initial observations revealed marked variability in ground conditions in specific areas of the CBD, evidenced by distinct patterns of land deformation. There has been substantial uncertainty regarding these conditions due to a lack of consolidated geotechnical data and testing. Characterising these ground conditions is therefore recognised as essential to understanding the geohazards and to guide the adoption of appropriate structural designs for future development. This reduces uncertainty, and enables geohazards pertinent to the conditions to be appropriately addressed through design and construction.

As part of the EEETA inception visit to Port Vila from 18 to 23 May 2025, T+TI – alongside MFAT – met with key stakeholders including the Port Vila City Council (PVCC), the Ministry of Infrastructure and Public Works (MIPU) and the Department of Urban Affairs and Planning (DUAP) to confirm the need for geotechnical hazard guidance to support the resilient rebuilding of the Port Vila CBD. The EEETA programme aims to provide the engineering guidance necessary to support this resilient long-term redevelopment. Combining visual evidence of ground deformation with subsurface data provides an opportunity to more reliably calibrate earthquake design guidelines for use in future development of the CBD and surrounding areas.

1.2 Study definitions

This Study defines two distinct areas to align the level of detail that will be undertaken as part of the geotechnical assessment and Geotechnical Guidance Document based on availability of pre-existing geotechnical data, the distribution of observed damage following the 17 December 2024 earthquake, and the type of development. These factors informed the proposed level of investigation for each of the following zones:

- **Broader (high-level) Study Area (Blue outline):** This area defines the full spatial extent of the Study, encompassing the wider CBD area provided by the PVCC[2]. Spatially, this area includes the Detailed Study Area, however the term is used herein to denote the broader regional context. Development within this zone is characterised by lower density and likely to generally comprise structures less than three storeys in height. Assessment in this zone relies primarily on compiled historical data and geomorphic mapping, with limited targeted geotechnical investigations undertaken as part of this study.
- **Detailed Study Area (Red outline):** This area encompasses the Port Vila Central Business District (CBD) downtown area. Future development in this area is expected to be high-density, with numerous multi-storey buildings, containing the highest economic investment and critical infrastructure, where the consequences of ground damage are likely to be more significant to Port Vila. Consequently, this area was the primary focus of the geotechnical investigations, allowing for a better understanding of the ground to support the resilience of existing and future key assets.

[1] Massey, C. I., Boyes, A. F., Lin, S. L., Lukovic, B., Morgenstern, R., & Farr, J. A. (2025). *Support for Vanuatu Earthquake 2024 – Landslide hazard identification and risk assessment: Efate field reconnaissance* (GNS Science Consultancy Report 2025/42). GNS Science.

[2] Manses Fatdal, email to Christopher Hartnett, 21 May 2025, subject "Fw: Map," attachment: "Location map Kawenu area to CBD.jpeg.

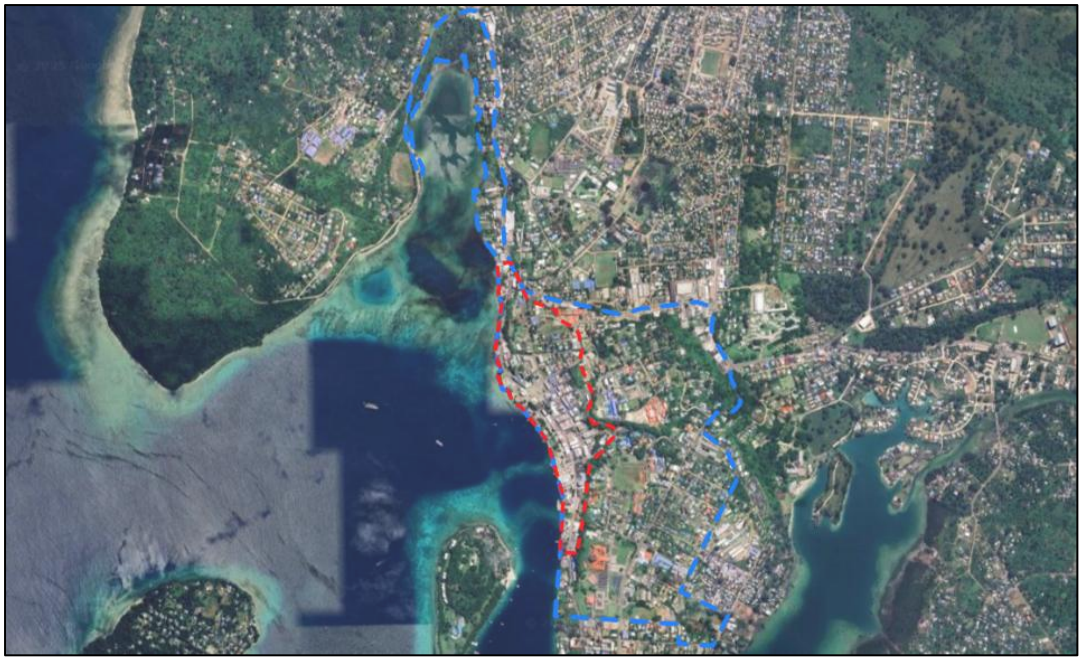

Figure 1.1: Proposed detailed study area (outlined red) and high-level study area (outlined blue).

1.3 Supplementary reports

Supplementary reports have been prepared as part of this geotechnical hazard study and should be read in conjunction with this report. These reports are summarised below Table 1.1.

Table 1.1: Summary of supplementary reports – 1097984.1000

Document	Date	Summary
Investigation Implementation Plan	3 November 2025	Sets out the proposed scope, methodology and locations for the geotechnical investigations, providing the planning framework to undertake the boreholes, groundwater monitoring, laboratory testing and geophysical survey.
Reconnaissance Report	18 December 2025	Documents the outcomes of the Request for Information (RFI) workshops and consolidates pre-existing geotechnical, geological and geospatial data from stakeholders and the T+TI database, forming the existing-information baseline that this GFR builds upon
Preliminary Ground Zoning Report	9 February 2026	Presents an initial geomorphic and ground-condition zoning of the Study Area developed from existing data and early field observations. The factual data compiled in this GFR will be used to refine and validate that zoning in the subsequent Geotechnical Assessment Report.
Traffic Management – Surface Geophysical Testing	12 February 2026	Describes the traffic management arrangements required to safely deliver the road-corridor to support the surface geophysical fieldwork reported in Section 3.5 of this GFR.
Investigation progress update and proposed changes	23 February 2026	An interim update on investigation progress and proposed scope adjustments (e.g. Deferral of BH01), explaining the changes from the original Implementation Plan that are reflected in the completed scope summarised in this GFR.

2 Published geology

The island of Efaté is predominantly volcanic in origin and lies within the Tertiary to Recent volcanic island arc system that forms Vanuatu. The volcanic sequence is dominated by the Efaté Pumice Formation which consists of a succession of non-welded pumice breccia and beds of sand and silt deposited during a major eruptive event approximately 1 Ma (million years ago).

The upper section of the Efaté Pumice Formation consists of the Rentabau Tuffs, a sequence of well sorted sand to silt beds. These beds were deposited within a submarine environment, likely as density currents[3]. These materials are extremely weak to weak in strength.

Upon the cessation of volcanic activity in the Pleistocene, abundant fringing coral reef growth occurred around Efaté, unconformably overlying the older volcanic deposits. These reef deposits form the Reef Limestone Formation[3]. Periods of uplift and fluctuating sea levels during glacial and interglacial periods of the Quaternary have resulted in the formation of several coral terraces up to 400 m above sea level in Efaté[4]. Large areas of Efaté Island's coastal edge have a capping of coral reefs. The published geological map presented in Figure 2.1 indicates that the site is underlain by recent raised reef, older raised reef and Efaté Pumice Formation.

The broad tectonic setting involves uplift of the island on the hanging wall of the Vanuatu Subduction Zone (VSZ). Inter-plate deformation includes extensional normal faulting as evidenced by reports of the trend and dip of the fault rupture in December 2024, and normal fault grabens that are observed across the island. Normal faults shown on the geological map (Figure 2.1) were mapped from lineations and scarps visible on aerial photographs.

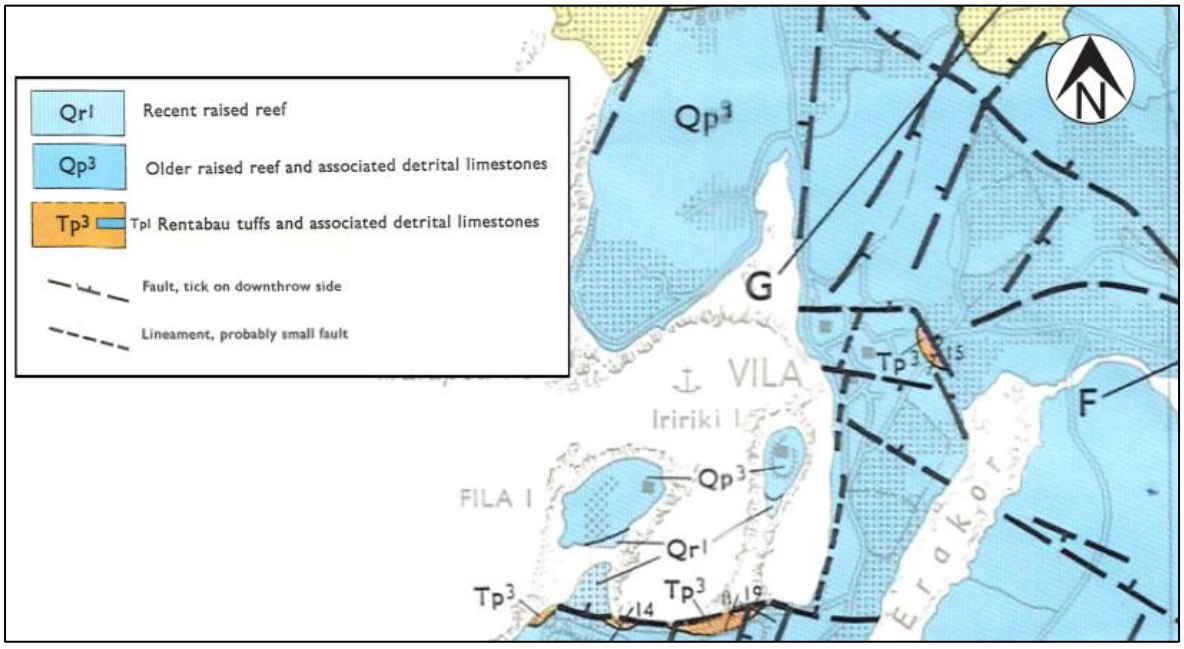

Figure 2.1: Geological setting of Port Vila (Geology of Efaté 1:100,000 New Hebrides Geological Survey Sheet 9).

[3] Roas, A. M., & McPhie, J. (2003). The submarine record of a large-scale explosive eruption in the Vanuatu Arc: ~ 1 Ma Efaté Pumice Formation. Explosive Subaqueous Volcanism, Geophysical Monograph 140, 273-283. American Geophysical Union.

[4] J. Lecolle & M. Bernat (1985), "Late Quaternary surrection history of Efaté Island, New Hebrides Island arc (Vanuatu): Th/U dates from uplifted terraces," in C. Gabrie & J. L. Toffart (Eds.), Proceedings of the Fifth International Coral Reef Congress, Tahiti, 27th May-1st June 1985 (pp. 179-184).

3 Site investigations

Site investigations to support the Port Vila CBD Geotechnical Hazard Study were undertaken between 7 November 2025 and 6 March 2026. The investigations comprised:

- Drone LiDAR and photogrammetry survey.
- Machine boreholes at 11 No. locations.
- Groundwater monitoring at 3 No. locations.
- Laboratory testing.
- Downhole geophysical testing at 6 No. locations.
- Surface geophysical testing to bridge the gaps between the borehole locations, including:
  - Multi-Channel Analysis of Surface Waves (MASW).
  - Seismic Refraction Tomography (SRT).
  - Horizontal-Vertical Spectral Ratio Analysis (HVSR).

T+TI selected the investigation locations to target key areas of interest within the Study Area, subject to site accessibility, the presence of buried and overhead services, and traffic management constraints.

3.1 Drone LiDAR and photogrammetry survey

A combined drone LiDAR and photogrammetry survey of the Study Area was undertaken by Kahuto Pacific – covering an area 2.776 km^2 – between 7 and 11 November 2025. The objective of the survey was to produce a high-resolution bare earth model and orthomosaic of the Study Area to support:

- Geomorphic mapping and ground zoning.
- Characterisation of the cliff and slope features to support assessment of slope susceptibility.
- Comparison against pre-earthquake LiDAR datasets to assess vertical and lateral ground displacement attributable to the seismic event.

Survey control comprised 17 No. ground control points (GCPs) distributed across the Study Area, supplemented by three No. LiDAR check grids established at elevated locations to validate vertical (Z) accuracy. GCP coordinates were tied to local site control with an as-specified tolerance of ≤ 50 mm in both plan and height. Coordinates are reported in horizontal projection WGS 84 / UTM Zone 59 South and vertical datum Mean Sea Level (Local).

Deliverables provided to T+TI comprise a high-resolution orthomosaic (TIF, ECW and PDF formats), a bare earth digital terrain model (DTM) (TIF format), contours (DWG format), point cloud (.laz format) and a five-sheet CAD plan set (PDF).The Kahuto Pacific report and associated PDF outputs are presented in Appendix E.

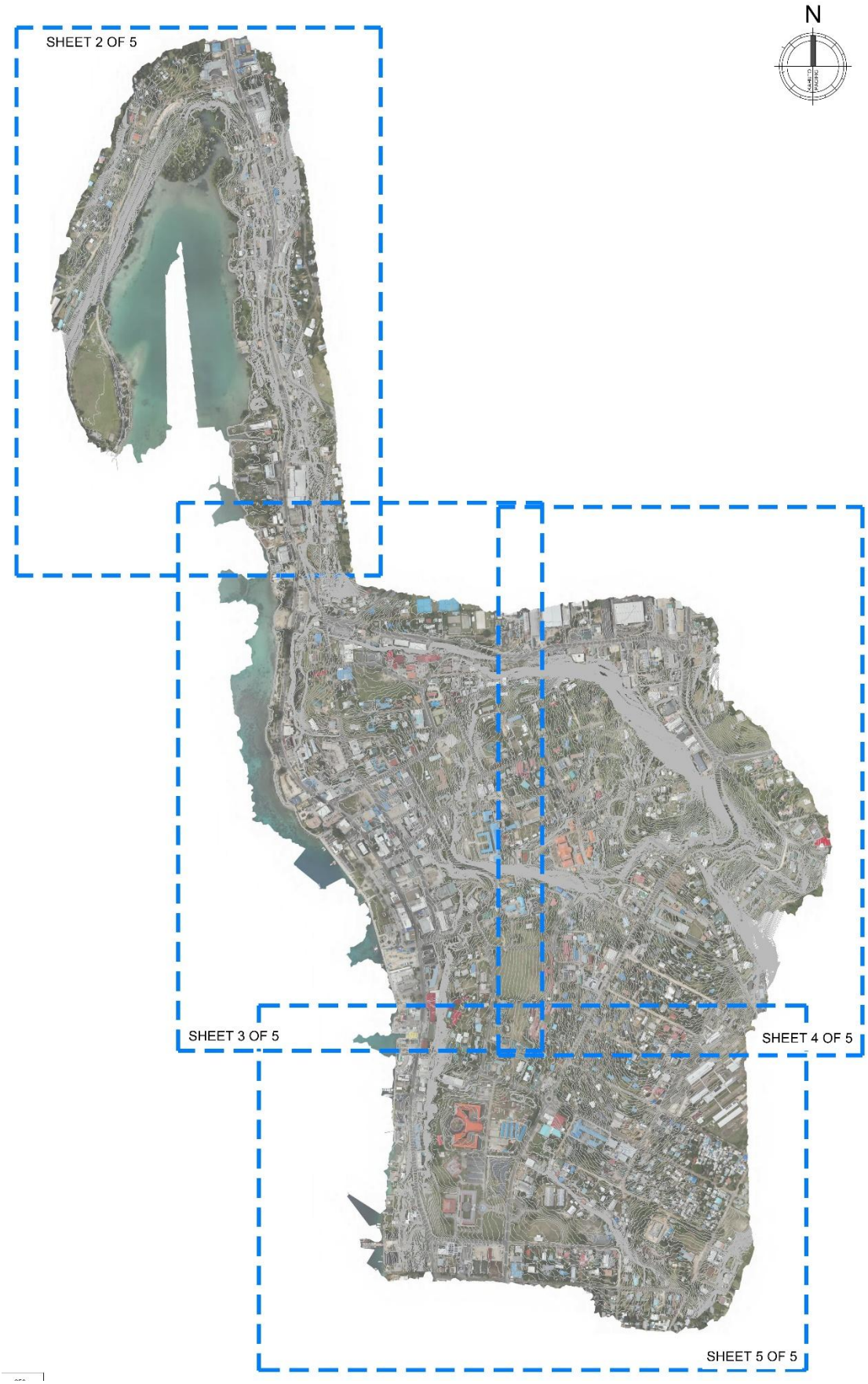

Figure 3.1: Kahuto overall contour plan (PDF format)

3.2 Machine boreholes

The drilling of eleven (11 No.) rotary cored machine boreholes was undertaken over the period between 2 December 2025 and 18 February 2026. The works were carried out using a rotary coring drilling rig, supplied and operated by Vanuatu Drilling. The boreholes were advanced from ground level to termination depth using HQ3 triple tube coring.

In situ Standard Penetration Testing (SPT) was carried out at regular (1.5 m) intervals through the soil horizon. All drilling works were completed under the full-time supervision of an engineering geologist from T+TI. The recovered drill core was photographed and logged to NZGS 'Field Description of Soil and Rock' guidelines.

The investigation locations are presented in Appendix A. Summary borehole logs and core photographs are presented in Appendix B. Summary borehole details are presented in Table 3.1 below.

Table 3.1: Machine borehole summary

BH ID	Location (UTM)[1]		Ground Surface Elevation RL (m)[2]	Depth (m)	Comments
	Easting	Northing			
BH01	-	-	-	-	Deferred due to drilling data from nearby BH02
BH02	215149.12	8036461.10	1.8	30.1	Reached target depth
BH03	215195.93	8036683.17	2.3	30.0	Reached target depth
BH04	215231.67	8036789.23	5.3	15.17	Reached target depth
BH04A	215216.66	8036784.92	5.3	21.0	Reached target depth
BH05	215067.75	8036836.62	2.1	19.5	Reached target depth
BH06	215241.97	8036922.62	21.6	30	Reached target depth
BH07	215044.21	8036984.14	4.0	31.5	Reached target depth
BH08	215478.74	8035894.82	35.6	6.45	Terminated due to rod deviation risking damaging equipment
BH08A	215482.60	8035894.02	35.4	3.0	
BH09	214759.26	8037694.22	1.4	31.0	Reached target depth
BH10	214853.80	8037021.40	2.0	20	Reached target depth
BH11	215442.62	8037108.41	51.1	23.2	Terminated due to risk of equipment getting stuck inground
BH12	215712.99	8037042.20	73.2	31.5	Reached target depth
BH12A	215656.80	8037036.20	68.3	12.0	Terminated due to risk of equipment getting stuck inground

Note: [1] Coordinates have been estimated using the Kahuto Pacific 2025 aerial imagery.
[2] Ground surface elevation have been estimated using the Kahuto Pacific 2025 LiDAR.

3.3 Groundwater monitoring

3.3.1 Piezometer details

Groundwater piezometers were installed in 3 No. of the machine boreholes. The standpipe piezometers were installed to monitor groundwater levels within the reclamation fill and quaternary sediments. Summary details of the piezometer installations are presented in Table 3.2 below. Installation records are attached to the summary borehole logs in Appendix B.

Table 3.2: Piezometer details

Borehole ID	Collar RL (m)	Installation depth (m)	Type	Geological unit over screened depth
BH04	5.30	6.0 – 9.0	Standpipe	Peri-reef Deposits[1]
BH05	2.10	3.0 – 6.0	Standpipe	Reef Limestone Formation
BH10	2.00	3.0 – 6.0	Standpipe	Peri-reef Deposits

Note: [1]Sediments that accumulate adjacent to, but outside the reef framework itself, including fore-reef, back-reef, intra-reef, and lagoonal sediments.

3.3.2 Groundwater levels

Groundwater levels were recorded within the open boreholes during drilling and within piezometers using an electronic dip meter. Continuous monitoring of groundwater levels was undertaken in the piezometers detailed above for a minimum period of two months using dataloggers installed into the 3 No. standpipe piezometers. The recorded groundwater levels are presented below in Table 3.3 as metres below ground level (mbgl) and the elevation reduced level (RL). A summary plot of continuous monitoring of the groundwater elevation is presented in Figure 3.2 below.

The continuous groundwater monitoring indicates tidal influence of between 0.2 to 0.4 m, due to proximity to the coastline.

Table 3.3: Groundwater summary

Borehole ID	Groundwater depth (mbgl)	Groundwater Elevation RL (m)	Investigation depth (mbgl)	Date and time[1]	Measurement type
BH02	1.6	0.2	10.95	21/01/2026 1649	During drilling
	1.6	0.2	30.0	22/01/2026 1600	Completion of drilling
BH03	2.1	0.2	21.0	23/01/2026 1622	During drilling
	2.2	0.1	24.0	24/01/2026 0704	During drilling
BH04	4.8	0.5	15	15/12/2025 0959	During drilling
	3.7	1.6	20	16/12/2025 1535	Completion of drilling
	4.82	0.48	-	16/01/2026 0800	Piezometer
	4.8	0.6	-	24/02/2026 1515	Piezometer
BH05	1.8	0.3	19.5	12/12/2025 0710	Completion of drilling
	1.3	0.8	-	16/12/2025 1524	Piezometer
	1.4	0.7	-	16/01/2026 0831	Piezometer
	1.5	0.6	-	24/02/2026 1505	Piezometer
BH06	Dry	-	9	02/12/2025	During drilling

Borehole ID	Groundwater depth (mbgl)	Groundwater Elevation RL (m)	Investigation depth (mbgl)	Date and time[1]	Measurement type
	Dry	-	12	03/12/2025	During drilling
	21.0	0.6	30	04/12/2025	On completion
BH07	3	1.0	13.5	05/12/2025	During drilling
	3.3	0.7	19.5	08/12/2025	During drilling
	3.4	0.6	31.5	09/12/2025	On completion
BH08	Dry	-	6.45	31/01/2026	During drilling
BH09	1.4	0.0	31.0	14/02/2026	On completion
BH10	1.7	0.3	15	11/12/2025	During drilling
	1.7	0.3	20	11/12/2025	On completion
	1.4	0.6	-	16/12/2025	Piezometer
	1.45	0.55	-	16/01/2026	Piezometer
	1.25	0.75	-	24/02/2026	Piezometer
BH11	Dry	-	7.95	19/01/2026	During drilling
	Dry	-	23.2	21/01/2026	On completion

Note: [1] Local time zone in Vanuatu (GMT+11)

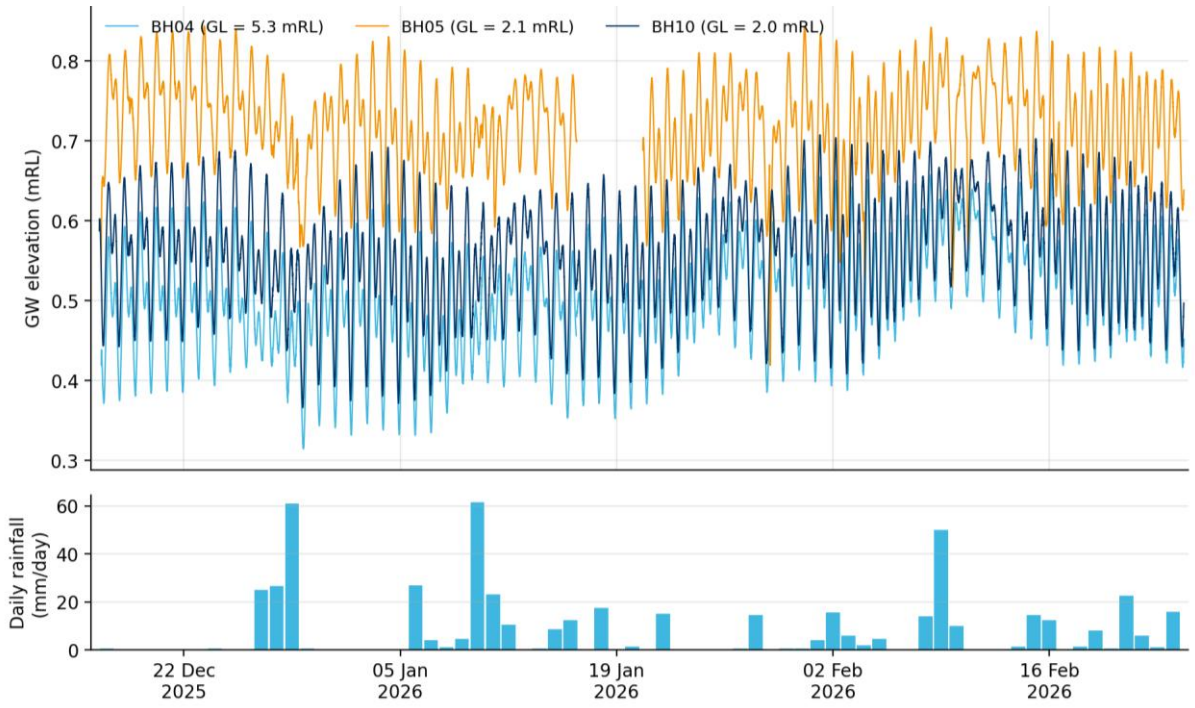

Figure 3.2: Continuous groundwater monitoring summary plot vs daily rainfall

3.4 Laboratory testing

Representative samples were collected from the material recovered during drilling and submitted for laboratory testing at Geotechnics Ltd laboratory in New Zealand. A total of 32 No. tests were undertaken including:

- 2 No. Atterberg Limits tests: NZS4402:1986 Test 2.2, 2.3 & 2.4 (**refer Table 3.4 and Figure 3.3**)
- 15 No. Particle Size Distribution (PSD) sieve tests: NZS 4402:1986 Test 2.8.1 **(refer Table 3.5 and Figure 3.4)**
- 3 No. Allophane tests: NZS4402:1986 Test 3.4 **(refer Table 3.6)**
- 9 No. Unconfined Compressive Strength (UCS) tests: NZS4402 Test 6.3.1 **(refer Table 3.7)**
- 3 No. Consolidated-Undrained (CU) triaxial compression tests, single stage: ISO 17892-8:2018 Part 9 **(refer Table 3.8)**

Detailed results of the laboratory testing are presented in Appendix C.

Table 3.4: Atterberg Limits test results

BH ID	Depth (m bgl)	Liquid Limit	Plastic Limit	Plasticity Index
BH11	0.0 – 0.4	82	39	43
BH12	7.5 – 7.95	115	86	29

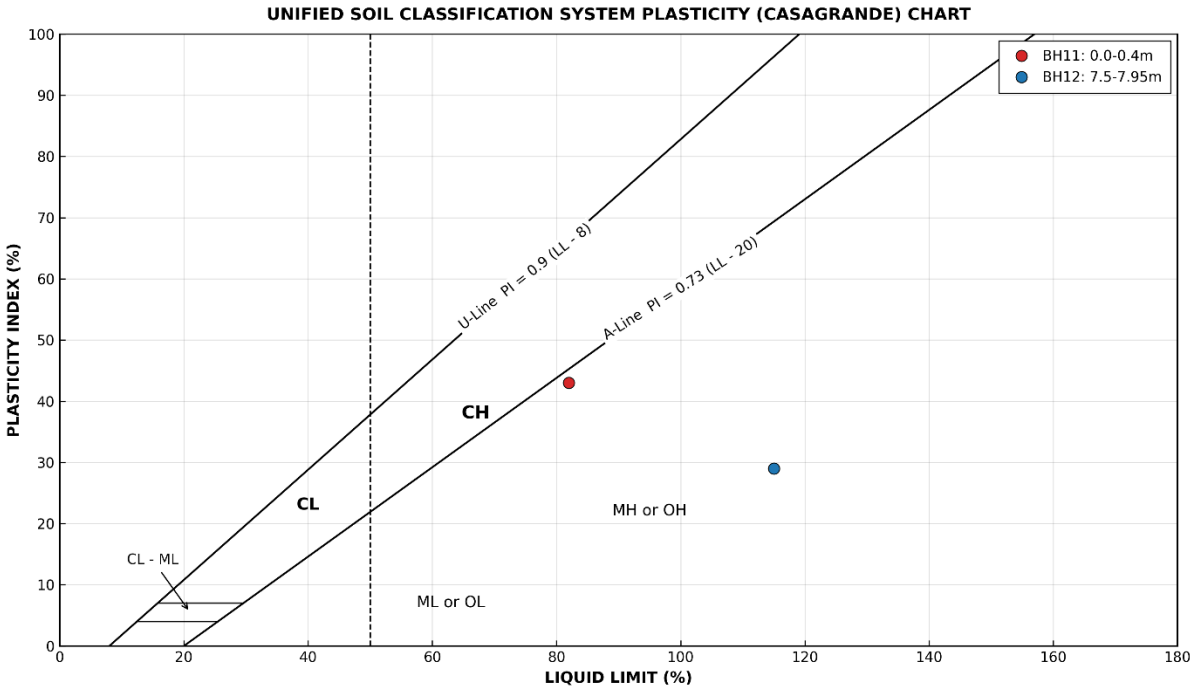

Figure 3.3: Atterberg Limit test results presented on a USCS Casagrande Chart

Table 3.5: Particle Size Distribution (PSD) test results

BH ID	Depth (m bgl)	Particle size distribution		
		Gravel (>2mm)	Sand (>0.06mm)	Fines (<0.06mm)
BH02	1.5 – 1.95	12	62	26
	3.0 – 3.45	43	36	21
	7.5 – 7.95	24	42	34
	9.0 – 9.45	36	32	32
	13.5 – 13.95	33	36	31
BH03	1.5 – 1.95	34	57	9
	4.5 – 4.95	42	43	15
	7.5 – 7.95	22	54	24
BH04	1.5 – 1.95	27	45	26
BH04A	3.0 – 3.45	49	46	5
	9.0 – 9.45	39	39	22
BH09	4.5 – 4.95	27	53	20
	9.0 – 9.45	31	26	43
	12.0 – 12.45	46	26	28
	15.0 – 15.45	40	34	26

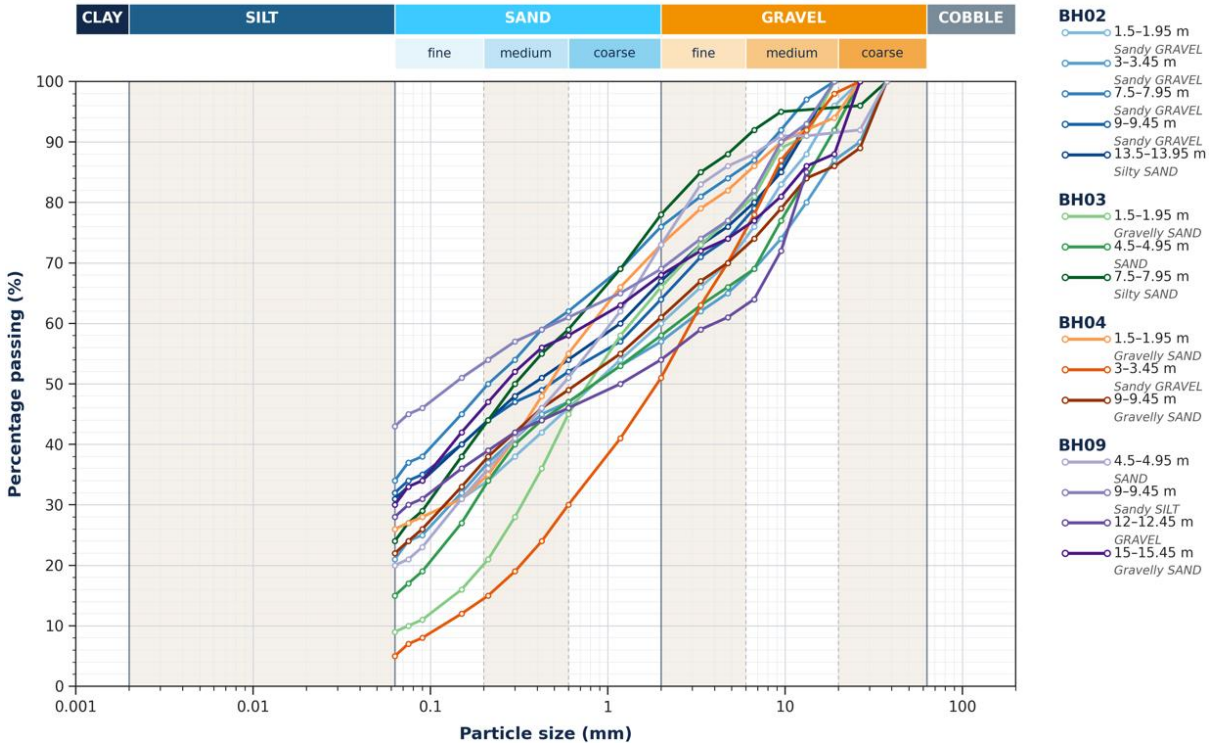

Figure 3.4: PSD test results

Table 3.6: Allophane test results

BH ID	Depth (m bgl)	Allophane content (%)
BH08	0.25 – 0.4	5 – 7 %
BH11	0.0 – 0.4	5 – 7 %
BH12	9.0 – 9.45	5 – 7 %

Table 3.7: Uniaxial Compression Strength test results

BH ID	Depth (m bgl)	Initial water content (%)	Initial bulk density (t/m³)	Peak UCS (MPa)	Axial Strain at Peak UCS (%)	Mode of failure
BH02	17.56 – 17.88	4.9	2.16	6.8	0.97	Axial
BH03	12.66 – 12.86	7.8	2.01	1.4	0.49	Axial
	13.7 – 13.8	4.3	2.26	8.1	1.46	Axial
BH05	9.35 – 9.55	8.1	1.94	2.0	0.35	Axial
BH06	8.57 – 8.79	5.5	1.99	2.5	0.25	Axial
BH09	20.7 – 20.8	29.8	1.90	9.9	0.89	Axial
BH10	8.69 – 8.9	6.1	1.98	7.6	0.35	Shear
	10.8 – 11.1	6.2	2.35	11.9	0.9	Axial
BH11	11.65 – 11.76	8.7	2.01	3.8	1.15	Axial

Table 3.8: Consolidated-undrained (CU) triaxial compression test results

BH ID	Depth (m bgl)	Initial water content (%)	Initial bulk density (t/m³)	Deviator stress at failure (MPa)	Undrained shear strength (kPa) $su = ½(\sigma_1 - \sigma_3)$ at failure	Mode of failure
BH12	14.10 – 14.25	16	2.05	10.8	5,400	Planar
BH12	25.05 – 25.25	18	2.07	11.4	5,600	Planar
BH12	29.7 – 29.82	34	1.76	1.9	900	Planar / Plastic

3.5 Geophysical testing

T+TI engaged the specialist geophysical investigation contractor Resource Development Consultants Limited (RDCL) to undertake the geophysical testing across the Study Area between 10 February and 6 March 2026. This included:

- Downhole shear wave testing in 6 No. boreholes locations
- Multi-Channel Analysis of Surface Waves across 5.5 km in length
- Seismic Refraction Tomography across 1 km in length
- Horizontal-Vertical Spectral Ratio Analysis at 12 No. locations

3.5.1 Downhole shear wave testing

Downhole shear wave testing was undertaken at BH02, BH03, BH06, BH07, BH09, and BH12.

It involves lowering a probe down a PVC tube that is grouted into place and measuring shear waves generated from a source at the surface. The seismic source is produced by a sledgehammer striking a shear beam weighted by a vehicle. Downhole shear wave testing was used to provide a measurement of variations in shear wave velocity (Vs) across the ground profile. By measuring the difference in arrival times of the waves at known depths, the seismic wave velocities can be calculated.

Shear wave velocities (Vs) were measured in the boreholes from ground surface to target depths of 30.0 m bgl with measurements at 1.0 m intervals.

The RDCL testing report is provided in Appendix D.

3.5.2 Multi-channel Analysis of Surface Waves (MASW)

A total of 5.55 km of MASW data was collected along 13 No. individual lines and 16 No. soundings. Where lines were not long enough to generate a quasi-2D Vs section, a 1D-sounding profile was undertaken. This occurred due to obstructions (such as road crossings) or tight bends in the road where the array could not be positioned in a straight line.

MASW was carried out by towing a 46 m long surface array consisting of 24 geophones placed at 2 m centres behind a vehicle. While stationary a seismic source was produced at the surface for the array to monitor. Seismic shots were created by striking a sledgehammer against a steel plate in quick succession. Each shot was stacked 3 to 5 times to improve signal to noise ratio.

The summary details of the MASW testing are shown below in Table 3.9.

Table 3.9: MASW summary details

Line ID	Length (m)	Approx. orientation	Start Location		End Location		Type
			Easting	Northing	Easting	Northing	
01a	380	SE-NW	215107.1	8036526	214939.8	8036880	Quasi-2D
01b	48	SE-NW	214889	8036912	214870.3	8036959	Sounding
01c	48	SE-NW	214851.3	8036978	214841.8	8037001	Sounding
02	270	SE-NW	215155.5	8036619	215020.5	8036857	Quasi-2D
03	680	NW-SE	214860.3	8037051	215200.7	8036477	Quasi-2D
04	470	SE-NW	215243.5	8036642	215015	8037080	Quasi-2D
05a	48	W-E	215020.1	8036765	215061	8036793	Sounding
05b	48	W-E	215088.1	8036834	215133.2	8036856	Sounding
05c	48	W-E	215152.8	8036863	215186.4	8036900	Sounding

Line ID	Length (m)	Approx. orientation	Start Location		End Location		Type
			Easting	Northing	Easting	Northing	
06a	48	W-E	215060.7	8036699	215102.8	8036726	Sounding
06b	48	W-E	215194.9	8036773	215147.7	8036756	Sounding
06c	48	W-E	215246.8	8036789	215223.3	8036780	Sounding
07a	48	W-E	215085	8036599	215135.9	8036614	Sounding
07b	90	W-E	215148.7	8036601	215268.7	8036631	Quasi-2D
08	48	W-E	215132.8	8036480	215197.8	8036497	Sounding
09	510	N-S	215188.2	8036518	215178.9	8036001	Quasi-2D
10a	48	W-E	214924.2	8036890	214979.6	8036941	Sounding
10b	48	W-E	215011.7	8036941	215056.3	8036963	Sounding
11a	60	E-W	215855	8036839	215791.1	8036879	Quasi-2D
11b	210	S-N	215714.9	8036896	215687.8	8037100	Quasi-2D
11c	50	E-W	215633.8	8037039	215578.2	8036989	Quasi-2D
12	430	N-S	214874.5	8037561	214850.1	8037068	Quasi-2D
13	330	N-S	214851.8	8037971	214870.6	8037626	Quasi-2D
14	48	W-E	214752	8037707	214813.7	8037690	Sounding
15	830	S-N	214398.3	8038130	214700.4	8038819	Quasi-2D
16	90	E-W	215270.8	8037531	215182.3	8037578	Sounding
17	430	W-E	215041.1	8037434	215444.2	8037346	Quasi-2D
18a	48	W-E	214981.8	8036854	215024.8	8036880	Sounding
18b	48	W-E	215046.9	8036888	215088.9	8036915	Sounding

3.5.3 Seismic Refraction Tomography (SRT)

SRT was carried out in conjunction with the MASW along key transit corridors. Four (4 No.) SRT lines were undertaken, totalling 972 m. SRT uses P-wave velocity (Vp) to identify subsurface geological layers and depth to interfaces, using seismic waves generated from an energy source (sledgehammer) and wave detection using 24 No. geophones placed at 2 m centres.

Summary details of the SRT testing is shown below in Table 3.10.

Table 3.10: SRT test summary details

Line ID	Length (m)	Approx. orientation	Start Location		End Location		Type
			Easting	Northing	Easting	Northing	
SRT01a	197	S-N	215113.1	8036533	215061.5	8036726	SRT
SRT01b	197	SE-NW	215060	8036725	214935	8036885	SRT
SRT02	289	N-S	215022.5	8036909	215181.2	8036644	SRT
SRT03	289	S-N	215235.7	8036642	215117.5	8036918	SRT

3.5.4 Horizontal-Vertical Spectral Ratio (HVSR)

HVSR was undertaken at 12 No. locations within the study area. The HVSR method analyses ambient seismic noise at the surface. A single three-component seismometer is placed on the ground to record ambient vibrations for several minutes. The ratio between the horizontal and vertical components of ground motion can vary depending on subsurface variability. Peaks in this ratio correspond to the resonance frequency of soft sediment layers overlying stiffer bedrock or a velocity contrast. A summary of the HVSR locations is shown in Table 3.11 below.

Table 3.11: HVSR test summary details

Line ID	Easting	Northing	Measured site period (T_0)
HVSR01	215147.6	8036752	0.25
HVSR02	215078.3	8036717	0.40
HVSR03	215074.2	8036802	0.31
HVSR04	215509.2	8037097	0.13
HVSR05	215806.6	8037029	0.06
HVSR06	215498.1	8036207	0.03
HVSR07	215920.7	8037121	0.20
HVSR08	215248.9	8037545	0.08
HVSR09	214756.5	8037689	0.22
HVSR10	214797.7	8037776	0.28
HVSR11	214552.1	8038762	0.03
HVSR12	214369.9	8038123	0.04

4 Applicability

This report has been prepared for the exclusive use of our client Egis NZ Limited, with respect to the particular brief given to us and it may not be relied upon in other contexts or for any other purpose, or by any person other than our client, without our prior written agreement.

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