REPORT

Tonkin+Taylor

For a comprehensive understanding of this report, please also refer to the relevant s92 responses

Auckland Regional Landfill

Geotechnical Factual Report

Prepared for
Waste Management NZ Ltd
Prepared by
Tonkin & Taylor Ltd
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1 Introduction

Tonkin & Taylor Ltd (T+T) has been engaged by Waste Management NZ Ltd (WMNZ) to undertake geotechnical investigations for a proposed landfill located in the Wayby Valley area approximately 10 km north west of Warkworth. This factual report presents the results of these investigations.

1.1 Scope

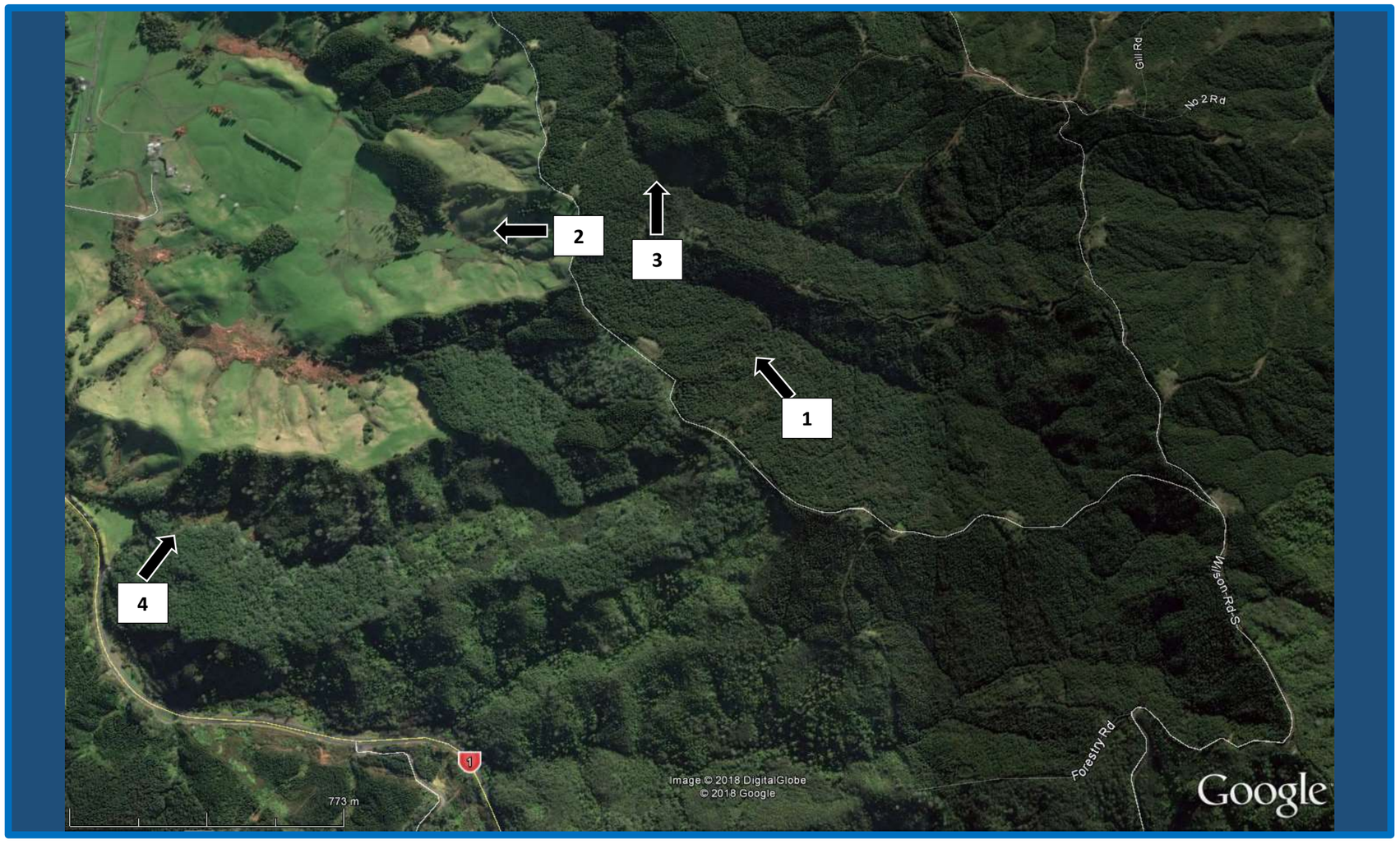
Geotechnical services have been provided in accordance with the T+T proposal dated June 2017[1]. Following completion of the intial investigation, further investigations have been undertaken in the Western Block area to locate a potential clay borrow source.

The geotechnical scope of works undertaken by T+T has included:

- Sub-surface investigation comprising:
  - 14 No. Machine drilled boreholes (BH) with in situ SPT testing through the soil profile and Lugeon testing at 3.0 m to 6.0 m depth intervals in the Pakiri Formation rock
  - 30 No. Hand augered boreholes (HA), including nine clay borrow investigation boreholes
  - 10 No. Test pits (TP)
  - 10 No. Dynamic cone penetrometer (Scala penetrometer) tests
- Installation of 50 and 65 mm diameter piezometers in all of the machine drilled boreholes to facilitate:
  - 5 No. groundwater level monitoring visits undertaken between 26/04/2018 and 31/05/2018
  - Installation of 7 No. data loggers to provide continuous monitoring of groundwater levels
- Geophysical investigations comprising:
  - Downhole shear wave velocity testing
  - Multichannel Analysis of Surface Waves (MASW)
- Geotechnical laboratory testing including:
  - 7 No. Atterberg limit tests
  - 9 No. Particle size distribution (PSD) tests
  - 2 No. Hydrometer tests
  - 7 No. Heavy compaction tests
  - 2 No. Unconfined compressive strength (UCS) tests
  - 4 No. CU Triaxial tests
  - 4 No. Triaxial permeability tests
  - 4 No. Pinhole tests
  - 4 No. Allophane content tests
- Preparation of this factual report presenting the results of the geotechnical, hydrogeological and geophysical investigations.

[1] Tonkin & Taylor Ltd (June 2017), Geotechnical Site Investigation Scope of Work. Job Ref: 24838.401.

2 Landholding description



Site Description

The proposed landfill is located in an existing forestry block in the Wayby Valley to the north of State Highway 1 (SH1), ~13 km north-west of Warkworth and ~6 km south-east of Wellsford.

The project footprint is bordered by Sunnybrook Scenic Reserve to the south, and Western Block to the west, as shown on the site plan attached as Figure 1, Appendix A.

The WMNZ's landholding is currently accessed from Forestry Road, which becomes Wilson Road after approximately 1 km, and forms the eastern boundary of the proposed valleys to be landfilled. Several forestry tracks lead west from Wilson Road along the valley ridges.

The project footprint comprises steep and undulating terrain, predominantly vegetated with pine forest, and dense native bush in the Southern Block valley, with localised areas of hakea and gorse.

The proposed landfill footprint comprises a single valley, with a total area of approximately 100 ha . The proposed landfill access is from SH1, just south of the Hōteo River Bridge, in the Southern Block.

A number of streams intersect WMNZ's landholding, typically flowing in a westerly direction towards the Hōteo River.

3 Published geology

A published geological map[2] for the area shows that the site is underlain by the Pakiri Formation of the Waitemata Group, comprising alternating thick-bedded, volcanic rich, graded sandstone and siltstone. The published geology also suggests an isolated valley of Mangakahia Complex of the Northland Allochthon, comprising sheared mudstones. The location of the project footprint in the context of the regional geology is presented on Figure 3.1 below.

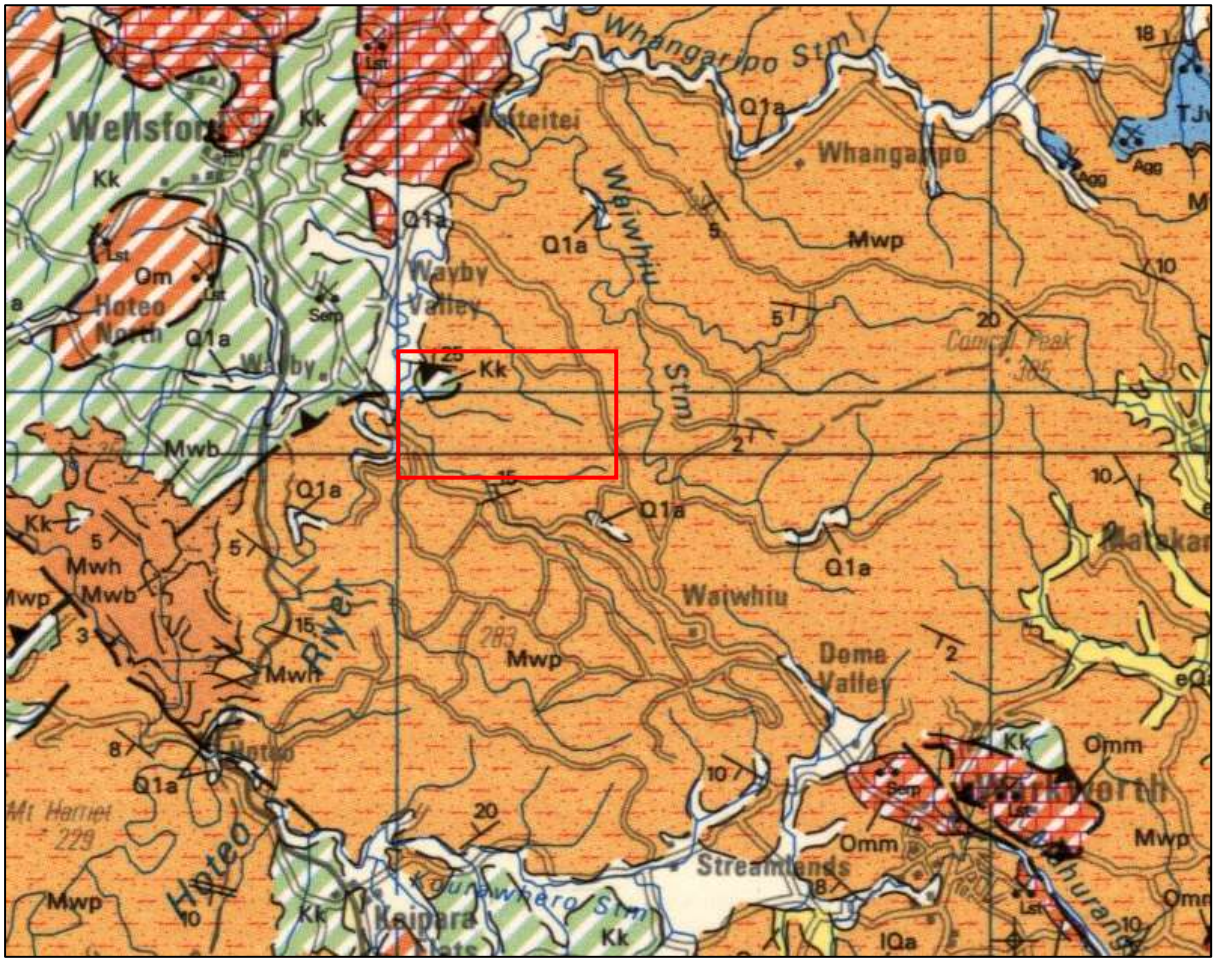


Figure 3.1: Geological setting (source: Edbrooke, 2001)

[2] Edbrooke, S.W. (compiler) 2001: *Geology of the Auckland area*. Institute of Geological & Nuclear Sciences 1:250,000 geological map 3. 1 sheet + 74 p. Lower Hutt, New Zealand. Institute of Geological & Nuclear Sciences Limited.

4 Site investigations

Geotechnical investigations were carried out over the project footprint between 26 February and 7 June 2018 for the initial investigations and 13 August 2018 for the clay borrow investigations. The investigations comprised:

- 14 No. Machine drilled boreholes to depths of between 25.5 m bgl and 50.0 m bgl, with in situ SPT testing in the soil horizon
- 30 No. Hand augured boreholes to depths of between 1.1 m bgl and 4.0 m bgl
- 10 No. Test pits to depths of between 3.0 m bgl and 4.5 m bgl
- 10 No. Scala penetrometer tests advanced from ground level to depths of between 1.3 m bgl and 4.0 m bgl
- Lugeon testing in the machine drilled boreholes at approximately 3.0 m to 6.0 m intervals in the Pakiri Formation rock
- Geophysics comprising of downhole shear wave velocity testing and Multichannel Analysis of Surface Waves (MASW)

The site investigation locations were selected on criteria outline in the scoping document dated June 2017 and also influenced by access considerations.

The locations of the investigations were surveyed by hand held GPS and formal survey and are presented on Figure 1 attached in Appendix A.

4.1 Project specific investigations

The following sections describe and summarise the geotechnical investigations undertaken for this project.

4.1.1 Machine boreholes

The drilling of fourteen vertical boreholes (BH1 to BH14) was undertaken over the period between 28 February 2018 and 31 May 2018. The works were carried out using two rotary coring drilling rigs, supplied and operated by McMillan Drilling Limited. The boreholes were advanced from ground level using PQ3 and HQ3 triple tube coring. Following completion of the drilling, the six boreholes selected for downhole shear wave velocity testing were reamed out with a wider diameter HW casing in order to accommodate the required 65 mm internal diameter piezometer pipes (Figure 1).

In situ Standard Penetration Testing (SPT) was carried out at regular (1.5 m) depth intervals through the soil horizon. Hand held shear vane tests were undertaken at the end of the core barrel at the completion of each core run where cohesive soil was present. Corrected shear vane values are presented on the borehole logs. All drilling works were completed under the full time supervision of an Engineering Geologist / Geotechnical Engineer from T+T. All recovered core was logged and photographed on site in accordance with NZGS 'Field Description of Soil and Rock' guidelines.

The boreholes were drilled at key locations along the project footprint; the investigation locations are presented on Figure 1, Appendix A. Summary borehole logs and core photographs are presented in Appendix B Summary borehole details are presented in Table 4.1 below.

Table 4.1: Machine borehole summary

BH ID	Location NZTM		Ground surface elevation RL (m)	Depth (m bgl)
	Northing (m)	Easting (m)		
BH1	5977897	1741423	148.0	50.0
BH2	5977396	1742111	204.3	49.5
BH3	5977815	1742966	245.5	49.5
BH4	5977991	1742576	193.7	49.5
BH5	5977990	1742359	161.2	49.5
BH6	5978241	1741643	128.0	49.5
BH7	5978542	1741380	74.4	25.5
BH8	5978252	1742802	208.2	49.5
BH9	5978794	1742574	240.5	49.5
BH10	5978417	1742247	183.5	49.5
BH11	5977562	1741186	129.2	49.5
BH12	5977251	1740969	106.4	33.0
BH13	5977170	1740472	60.1	35.0
BH14	5977380	1739925	28.0	26.8

4.1.2 Hand augered boreholes

The drilling of twenty one hand augered boreholes was undertaken between 10 April and 7 June 2018, by a T+T Engineering Geologist. An additional nine hand augered boreholes (HA32 to HA40) were undertaken on 13 August 2018 in the Western Block area, by a Geotechnician from Geotechnics Ltd.

In situ shear strength testing was undertaken at approximately 0.3 to 0.5 m depth intervals throughout the soil horizon. All hand augured boreholes were logged in accordance with NZGS 'Field Description of Soil and Rock' guidelines.

Investigation locations are presented on Figure 1, Appendix A. Summary hand auger logs are presented in Appendix B. A summary of the hand auger details is presented in Table 4.2 below.

Table 4.2: Hand augered borehole summary

HA ID	Location (NZTM)		Ground surface elevation RL (m)	Depth (m bgl)	Reason for termination
	Northing (m)	Easting (m)			
HA1	5977952	1741520	137.1	3.3	Refusal
HA2	5977513	1742187	176.9	4.0	Target depth reached
HA4	5977519	1742486	161.0	3.3	Refusal
HA5	5977806	1742737	198.0	4.0	Target depth reached
HA7	5977930	1742603	187.0	4.0	Target depth reached
HA9	5978075	1741681	85.7	4.0	Target depth reached
HA13	5978615	1741367	74.0	1.0	Refusal
HA14	5978418	1741574	78.0	0.8	Refusal

HA ID	Location (NZTM)		Ground surface elevation RL (m)	Depth (m bgl)	Reason for termination
	Northing (m)	Easting (m)			
HA15	5978334	1741728	88.0	1.1	Refusal
HA16	5978397	1742002	105.0	4.0	Target depth reached
HA17	5978154	1742141	117.0	4.0	Target depth reached
HA18	5978721	1742349	206.5	4.0	Target depth reached
HA19	5977980	1741867	92.1	4.0	Target depth reached
HA20	5977751	1742251	95.2	4.0	Target depth reached
HA21	5977699	1741799	173.3	2.1	Refusal
HA22	5977606	1741416	158.0	4.0	Target depth reached
HA23	5977437	1741566	151.0	4.0	Target depth reached
HA24	5977319	1741258	116.0	4.0	Target depth reached
HA25	5977263	1741036	112.0	4.0	Target depth reached
HA26	5977161	1740622	74.0	4.0	Target depth reached
HA27	5977270	1740222	49.0	2.9	Refusal
HA32	5978610	1740095	34.6	4.0	Target depth reached
HA33	5978708	1740176	35.2	4.0	Target depth reached
HA34	5978584	1740249	43.4	4.0	Target depth reached
HA35	5978554	1740422	47.6	3.0	Refusal
HA36	5978418	1740296	56.8	3.2	Refusal
HA37	5978279	1740902	74.5	4.0	Target depth reached
HA38	5978256	1740377	55.1	1.8	Refusal
HA39	5978128	1740906	76.9	4.0	Target depth reached
HA40	5978108	1740359	59.5	2.7	Refusal

4.1.3 Test pits

The excavation of ten test pits was undertaken by Clearwater Dredging Limited on 4 April 2018, 5 April 2018 and 2 May 2018, under the supervision of an Engineering Geologist / Geotechnical Engineer from T+T. In all cases, the test pits were taken to either a target depth of 4.0 m bgl or 'refusal' which occurred due to encountering weathered rock. The ability to excavate the overburden soils was noted by the Geotechnical Engineer and the test pits were logged to NZGS 'Field Description of Soil and Rock' guidelines.

Scala penetrometer tests were undertaken adjacent to each test pit from ground level to depths of between 1.3 and 4.0 m bgl.

The test pit locations are presented on Figure 1, Appendix A. The test pit logs and photographs are attached in Appendix B. The Scala penetrometer logs are presented on the test pit logs. Summary test pit details are presented in Table 4.3 below.

Table 4.3: Test pit summary

Test Pit ID	Location (NZTM)		Ground surface elevation RL (m)	Depth (m bgl)	Reason for termination
	Northing (m)	Easting (m)			
TP3	5977349	1742551	178.4	4.0	Target depth reached
TP6	5978152	1742834	211.4	3.0	Refusal due to weathered rock
TP8	5978080	1741963	142.4	4.1	Target depth reached
TP10	5978696	1742785	237.2	4.5	Target depth reached
TP11	5978548	1742406	206.3	4.0	Target depth reached
TP12	5978713	1742026	184.8	4.0	Target depth reached
TP28	5977551	1743010	233.0	4.0	Target depth reached
TP29	5977561	1741758	200.3	4.0	Target depth reached
TP30	5978053	1741268	143.6	4.0	Target depth reached
TP31	5978391	1741228	162.1	4.0	Target depth reached

4.1.4 Lugeon (packer) testing

Rock mass permeability was assessed in all machine drilled boreholes (BH1 to BH14) by undertaking a series of single packer Lugeon tests. Tests were typically carried out at 3.0 to 6.0 m intervals. The maximum test pressures used were between 40 and 75 % of overburden pressure. The Lugeon test was carried out as a "pressure loop" as shown in Table 4.4.

Table 4.4: Pressure loop used for Lugeon tests

Test stage	Description	Pressure step
1st	Low	0.50·PMAX
2nd	Medium	0.75·PMAX
3rd	Maximum (peak)	PMAX
4th	Medium	0.75·PMAX
5th	Low	0.50·PMAX

The data has been presented as plots of Lugeon values versus test pressure as suggested by Houlsby (1976) and flow loss versus test pressure as suggested by Camilo Quinones-Rozo (2010).

Lugeon values from the boreholes are presented in Table 4.5, along with the inferred flow behaviour. Full test results may be found in Appendix B.

In the majority of cases negligible water take was observed. However, where water loss occurred, most of the Lugeon tests showed laminar, void filling or dilatant flow behaviour. For tests that indicate dilation of the rock mass, Houlsby (1976) recommends that the high Lugeon value recorded at the maximum test pressure be ignored. In the case of void filling flow behaviour, Houlsby recommends taking the final (lowest) Lugeon value. Five of the Lugeon tests showed wash-out flow behaviour, for which case Houlsby recommends taking the highest (Stage 5) Lugeon value, and for turbulent flow (which occurred in three of the tests) to take the Lugeon value corresponding with the highest pressure (Stage 3).

The representative Lugeon values have been selected following the Houlsby (1976) methods briefly outlined above.

Table 4.5: Summary Lugeon test values

Borehole ID	Test depth (m bgl)	Assumed Lugeon value	Comments
BH1	15 – 18	0.0	Void Filling
	18 – 21	19.2	Laminar Flow
	24 – 27	0.0	Void Filling
	30 – 33	0.0	No water take
	36 – 39	4.9	Dilatant
	39 – 43.5	6.7	Dilatant
	47 – 50	56.7	Laminar Flow
BH2	10.5 – 13.5	0.0	Void Filling
	16.5 – 19.5	2.4	Dilatant
	22.5 – 25.5	1.7	Dilatant
	28.5 – 31.5	0.0	No water take
	34.5 – 37.5	0.0	No water take
	40.5 – 43.5	0.0	No water take
	46.5 – 49.5	0.0	No water take
BH3	9 – 12	16.4	Wash-out
	15 – 18	0.0	Void Filling
	21 – 24	0.0	No water take
	27 – 30	0.0	Void Filling
	33 – 36	153.3	Dilatant
	39 – 42	0.0	No water take
	45 – 48	0.0	Void Filling
BH4	13.5 – 16.5	12.2	Dilatant
	19.5 – 22.5	0.0	No water take
	25.5 – 28.5	0.0	No water take
	31.5 – 34.5	0.0	No water take
	37.5 – 40.5	0.0	No water take
	43.5 – 46.5	11.7	Laminar
BH5	28.5 – 31.5	7.3	Wash-out becoming laminar from Step 3 to Step 5
	34.5 – 37.5	118.1	Laminar
	40.5 – 43.5	143.8	Wash-out
	46.5 – 49.5	-	Unable to fill rod string with pump on full

Table 4.5 (continued): Summary Lugeon test values

Borehole ID	Test depth (m bgl)	Assumed Lugeon value	Comments
BH6	10.5 – 13.5	32.2	Wash-out becoming laminar from Step 3 to Step 5
	16.5 – 19.5	0.0	No water take
	22.5 – 25.5	0.0	No water take
	28.5 – 31.5	0.0	No water take
	34.5 – 37.5	28.7	Wash-out
	40.5 – 43.5	0.0	No water take
	46.5 – 49.5	8.4	Wash-out becoming laminar from Step 2 to Step 5
BH7	7.5 – 10.5	0.0	No water take
	10.5 – 13.5	0.0	No water take
	13.5 – 16.5	0.0	No water take
	16.5 – 19.5	0.0	No water take
	19.5 – 22.5	0.0	No water take
	22.5 – 25.5	0.0	No water take
BH8	18.0 – 19.5	27.1	Dilatant
	24.0 – 25.5	0.0	No water take
	30.0 – 31.5	19.4	Dilatant
	36.0 – 37.5	0.0	No water take
	42.0 – 43.5	32.8	Unable to increase pressure beyond Stage 1 (pump on full)
	45.0 – 46.5	67.6	Unable to increase pressure beyond Stage 1 (pump on full)
	48.0 – 49.5	0.0	No water take
BH9	12.0 – 13.5	N/A	Packer failed to seal (water bypassing packer)
	15.0 – 16.5	4.5	Void Filling
	21.0 – 22.5	49.8	Void filling becoming progressively laminar
	27.0 – 28.5	0.0	No water take
	33.0 – 34.5	0.0	No water take
	39.0 – 40.5	0.0	No water take
	45.0 – 46.5	0.0	No water take

Table 4.5 (continued): Summary Lugeon test values

Borehole ID	Test depth (m)	Assumed Lugeon value	Comments
BH10	12.0 – 15.0	92.2	Turbulent
	18.0 – 21.0	1.2	Dilatant
	24.0 – 27.0	0.0	Void Filling
	30.0 – 33.0	0.0	No water take
	36.0 – 39.0	0.0	No water take
	40.5 – 43.5	0.0	Void Filling
	46.5 – 49.5	N/A	Packer failed to seal (water bypassing packer)
BH11	15.0 – 18.0	0.0	No water take
	21.0 – 24.0	68.7	Wash-out
	27.0 – 30.0	0.5	Dilatant
	33.0 – 36.0	0.4	Dilatant
	36.0 – 39.0	94.9	Likely dilatant, full test pressures could not be achieved.
	42.0 – 45.0	0.1	Dilatant
	46.5 – 49.5	103	Laminar
BH12	12.0 – 15.0	32.4	Turbulent
	18.0 – 21.0	0.0	Void Filling
	24.0 – 27.0	0.0	No water take
	30.0 – 33.0	0.0	No water take
BH13	12.0 – 15.0	105.5	Wash-out
	16.0 – 18.0	129.6	Unable to achieve full pressure (water starting to bypass packer)
	18.0 – 21.0	98.3	Turbulent
	21.0 – 24.0	142.5	Unable to increase pressure beyond Stage 1 (pump on full)
	27.0 – 30.0	107.4	Unable to increase pressure beyond Stage 1 (pump on full)
	32.0 – 35.0	74.7	Unable to increase pressure beyond Stage 1 (pump on full)
BH14	13.5 – 16.5	77.1	Void Filling
	18.0 – 21.0	96.0	Turbulent
	22.5 – 25.5	88.9	Void Filling becoming laminar from Stage 3 to Stage 5.

4.1.5 Geophysics

The geophysical investigations were undertaken by Resource Development Consultants Ltd (RDCL), which included downhole shear wave velocity testing and Multichannel Analysis of Surface Waves (MASW). The results of the geophysics investigation are attached in Appendix E. The RDCL geophysical investigation report is provided under separate cover.

4.2 Groundwater monitoring

4.2.1 Piezometer details

Groundwater piezometers were installed in all of the machine boreholes (BH1 to BH14). The piezometers were installed to monitor groundwater levels within the Pakiri Formation rock. Summary details of the piezometer installations are presented in Table 4.6 below. Installation records are presented on the borehole logs attached in Appendix B.

Table 4.6: Piezometer details

Borehole ID	Collar RL (m)	Screen depth (m)	Piezometer ID (mm)	Data logger monitoring[1]	Geological unit within screened depth
BH1	148.0	43 – 49	65	Yes	Pakiri Formation rock
BH2	204.3	39.7 – 45.7	65	Yes	Pakiri Formation rock
BH3	245.5	43 – 49	65	Yes	Pakiri Formation rock
BH4	193.7	43 – 49	65	-	Pakiri Formation rock
BH5	161.2	46 – 49	50	Yes	Pakiri Formation rock
BH6	128.0	43 – 49	65	-	Pakiri Formation rock
BH7	TBC	22 – 25	50	Yes	Pakiri Formation rock
BH8	208.2	43 – 49	65	-	Pakiri Formation rock
BH9	240.5	46 – 49	50	Yes	Pakiri Formation rock
BH10	183.5	46 – 49	50	Yes	Pakiri Formation rock
BH11	TBC	46 – 49	50	-	Pakiri Formation rock
BH12	TBC	29 – 32	50	-	Pakiri Formation rock
BH13	TBC	31 – 34	50	-	Pakiri Formation rock
BH14	28.0	20.1 – 26.1	50	-	Pakiri Formation rock

Notes:

[1] 'Continuous' (once every 5 minutes) groundwater level monitoring using Solinst Leveloggers

4.2.2 Groundwater levels

Groundwater levels within the piezometers were recorded using an electronic dip meter once every two to three weeks over the course of the investigation. The dip meter recorded groundwater levels are presented in Table 4.7 below.

Regular ('continuous') monitoring of groundwater levels was undertaken in seven of the piezometers using Solinst Leveloggers. The data loggers were programmed to take groundwater level readings once every 5 minutes. The Leveloggers were installed in borehole No's. BH1, BH2, BH7 and BH9 on 3 May 2018, BH3 and BH5 on 25 May 2018, and BH10 on 31 May 2018. The recorded groundwater levels are presented below in Table 4.7 and the summary plots of the 'continuous' groundwater levels are presented in Appendix D.

Groundwater depth measurements were also recorded during drilling of the boreholes on average twice daily during the investigation (28 February and 31 May 2018).

Table 4.7: Groundwater levels (dip meter)

PZ ID [base of install]	26/04/2018		3/05/2018		18/05/2018		25/05/2018		31/05/2018	
	RL (m)	Depth (m bgl)	RL (m)	Depth (m bgl)	RL (m)	Depth (m bgl)	RL (m)	Depth (m bgl)	RL (m)	Depth (m bgl)
BH1 [49.0]	121.0	27.0	121.2	26.9	120.7	27.3	-	-	-	-
BH2 [45.7]	200.6	3.7	199.6	4.7	197.8	6.5	-	-	-	-
BH3 [49.0]	-	-	-	-	232.8	12.7	232.5	13.0	-	-
BH4 [49.0]	-	-	-	-	176.0	17.7	-	-	158.8	34.9
BH5 [49.0]	-	-	-	-	123.5	37.7	121.1	39.7	-	-
BH6 [49.0]	-	-	-	-	108.7	19.4	-	-	105.8	22.2
BH7 [25.0]	71.5	2.9	71.6	2.8	71.7	2.7	-	-	-	-
BH8 [49.0]	-	-	-	-	167.0	41.2	-	-	167.1	41.1
BH9 [49.0]	218.8	21.7	218.7	21.8	218.5	22.0	-	-	-	-
BH10 [49.0]	-	-	-	-	-	-	-	-	166.4	17.1
BH11 [49.0]	94.1	35.1	-	-	94.0	35.2	-	-	-	-
BH12 [32.0]	88.8	17.6	-	-	89.0	17.4	-	-	TBC	17.2
BH13 [34.0]	34.8	25.3	-	-	34.9	25.2	-	-	34.9	25.2
BH14 [26.1]	-	-	-	-	-	-	-	-	29.3	>-1.31

Notes:

1. BH14 is artesian (groundwater head is greater than 1.3 m above ground level).

4.3 Laboratory Testing

Twenty-four samples were collected from the machine boreholes and test pits for testing. The samples were tested at the Geotechnics laboratory for determination of geotechnical and hydrogeological properties.

Summary details of the locations of the samples for each laboratory test type is presented in Table 4.8 below. The following sections describe and summarise the laboratory test results. The full results of the laboratory testing are presented in Appendix C.

Table 4.8: Geotechnical testing sample location summary

Test ID	Atterberg limits (m bgl)	PSD (m bgl)	Heavy compaction (m bgl)	UCS (m bgl)	CU triaxial (m bgl)	Triaxial permeability (m bgl)	Pinhole (m bgl)	Allophane (m bgl)
BH1	2.0	5.0		15.3	1.5			
BH2		3.0		16.1				
BH3	2.0				1.5			
BH4								
BH5								
BH6								
BH7		2.0			1.5			
BH8					1.5			
BH9	1.5							
BH10								
BH11	1.5	3.0						
BH12	2.0							
BH13	1.5	6.0						
BH14								
TP3		0.2	0.2			0.2	0.2	0.2
TP6		0.7	0.7			0.7	0.7	
TP8		2.6	2.6			2.6	2.6	2.6
TP10	0.1		0.1					
TP11								
TP12								
TP28								
TP29			1.8					1.8
TP30		0.5	0.5			0.5	0.5	0.5
TP31			0.6					

Notes:

1. Depths are depths to top of sample.

4.3.1 Atterberg limits

Atterberg limit testing was undertaken on six samples collected from the machine boreholes and one sample from test pit TP10. The results of the Atterberg limit testing are attached in Appendix C. A summary of the results is presented in Table 4.9 below. The results are also plotted on a USCS plasticity chart and presented in Figure 4.1 below.

Table 4.9: Atterberg limit summary table

Test ID	Sample depth (m bgl)	Brief laboratory description of sample	Liquid Limit, LL (%)	Plastic Limit, PL (%)	Plasticity Index, PI (%)	Water Content, WC (%)

BH1	2.0 – 2.5	SILT, minor clay, trace sand	96	36	60	49.0
BH3	2.0 – 2.5	SILT, trace to minor clay, minor sand	64	27	37	-
BH9	1.5 – 2.0	SILT, minor clay, trace sand, trace organics	78	39	39	-
BH11	1.5 – 2.0	SILT, minor clay, trace sand	96	39	57	48.7
BH12	2.0 – 2.5	SILT, minor to some clay, trace sand	121	37	84	61.9
BH13	1.5 – 2.0	SILT, minor clay, trace sand, trace organics	75	40	35	52.7
TP10	0.1 – 1.0	Clayey SILT, minor sand, trace gravel	76	37	39	42.9

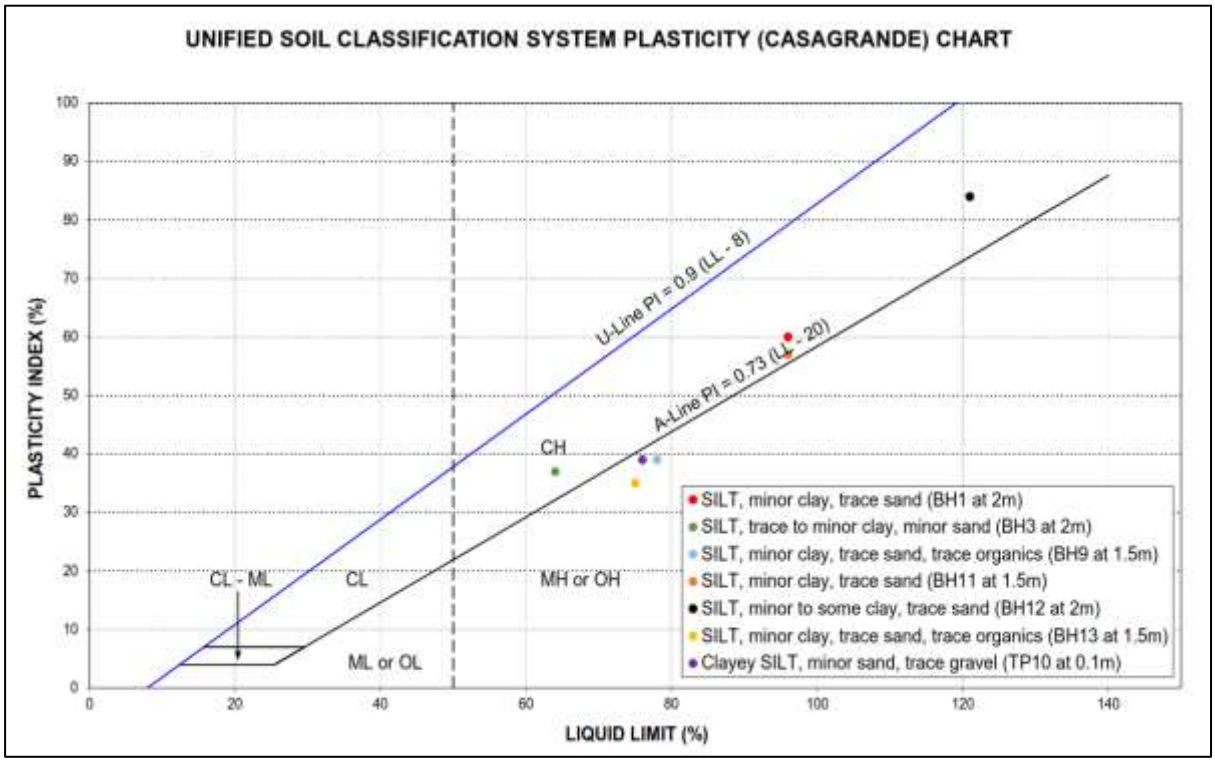


Figure 4.1: Unified Soil Classification System (USCS) plasticity chart

4.3.2 Particle size distribution (PSD)

The grading curves for sampled soils were determined using the wet sieve method (NZS 4402: 1986 Test 2.8.1) and hydrometer (NZS 4402: 1986 Test 2.8.4). A total of nine tests were conducted on samples retrieved from machine boreholes and test pits across the landholding. A summary of the results is presented in Figure 4.2 below. The test results are attached in Appendix C.

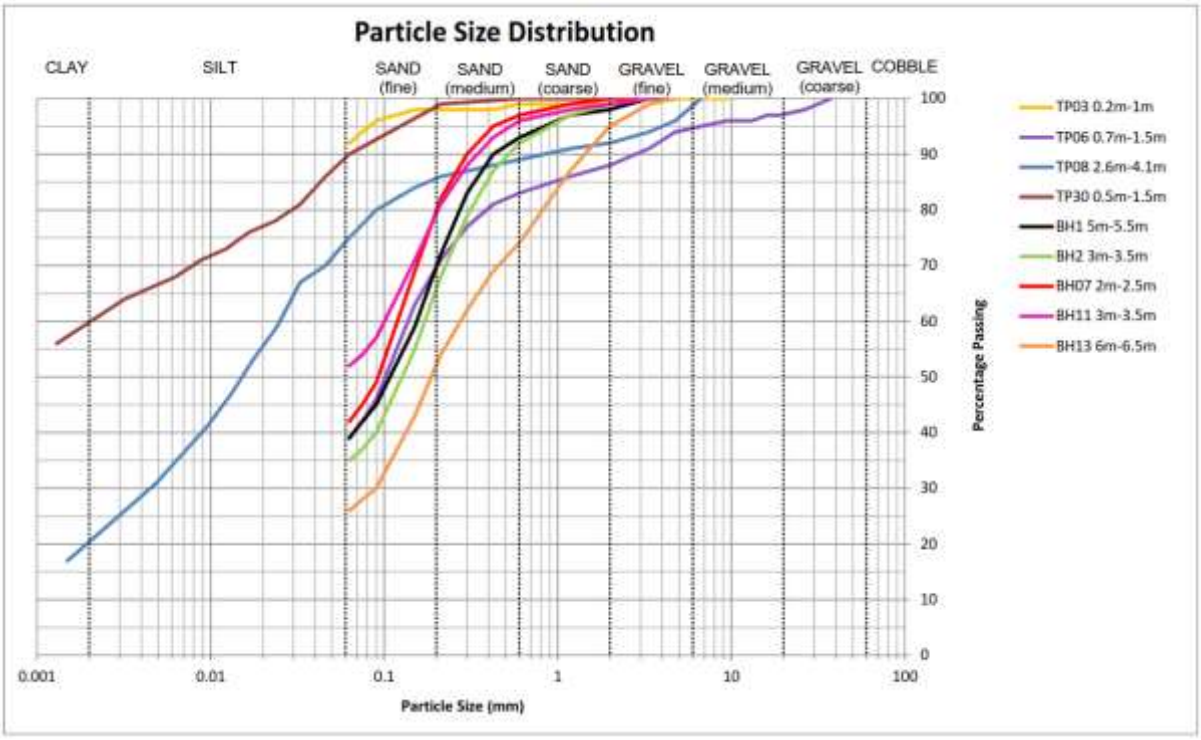


Figure 4.2: Particle size distribution analyses summary of results

4.3.3 Heavy compaction

Seven heavy compaction tests were undertaken on bulk samples of residual Pakiri Formation sediments. The test results indicate an optimum moisture content for the material sampled between 20 % and 27 %. The test results are summarised in Table 4.10 below. The full test results are presented in Appendix C.

Table 4.10: Heavy compaction summary of results

Test ID	Sample depth (m bgl)	Brief laboratory description	Max dry density (t/m^3)	Solid density (t/m^3)	Natural moisture (%)	Optimum moisture (%)	Peak shear strength (kPa)
TP03	0.2 - 1.8	SILT, minor sand, trace gravel	1.52	2.72	N/A	26	UTP
TP06	0.7 - 1.5	Silty fine to coarse SAND, some gravel	1.62	2.72	N/A	22	UTP
TP08	2.6 - 4.1	Clayey SILT, some sand, minor gravel	1.53	2.72	N/A	26	UTP
TP10	0.1 - 1.0	Clayey SILT, minor sand, trace gravel	1.54	2.72	42.9	26	UTP

Test ID	Sample depth (m bgl)	Brief laboratory description	Max dry density (t/m^3)	Solid density (t/m^3)	Natural moisture (%)	Optimum moisture (%)	Peak shear strength (kPa)
TP29	1.8 - 4.0	Clayey SILT, minor sand, trace rootlets	1.49	2.72	N/A	27	UTP
TP30	0.5 - 1.5	Silty CLAY, some sand	1.54	2.72	N/A	25	UTP
TP31	0.6 - 1.5	SILT, some clay, minor sand	1.69	2.72	N/A	20	UTP

4.3.4 Unconfined compressive strength (UCS)

Unconfined compressive strength (UCS) tests were undertaken on two samples of siltstone / sandstone retrieved from machine drilled boreholes BH1 and BH2. A summary of the test results is presented in Table 4.11 below. The full results are presented in Appendix C.

Table 4.11: Summary of unconfined compressive strength (UCS) tests

Test ID	Sample depth (m bgl)	Brief laboratory description of sample	UCS, q_u (kPa)
BH1	15.35 – 15.50	Highly weathered, Light brown, silty fine to medium SANDSTONE. Extremely weak.	223
BH2	16.10– 16.25	Unweathered, Light greenish grey mottled white, fine SANDSTONE. Moderately strong.	22,949

4.3.5 Consolidated undrained triaxial compression (CU Triaxial test)

Three undisturbed push tube samples were recovered from the machine boreholes and selected for consolidated undrained triaxial (CU Triaxial) testing. The results are summarised in Table 4.12 below and presented in full in Appendix C.

Table 4.12: Consolidated-undrained triaxial compression summary test results

Test ID	Sample depth (m bgl)	Brief laboatory description of sample	Effective angle of friction Φ' (deg °)	Effective cohesion c' (kPa)
BH1	1.56 - 1.68	Clayey SILT; orange brown with light brown, white and red mottles	25	24
BH3	1.62 - 1.73	SILT, some clay, minor sand; light brown with orange brown and black mottles	31	12
BH7	1.51 - 1.62	Silty SAND, some organics; orange brown with black mottles.	37	10
BH8	1.58 - 1.69	SILT, minor clay, trace to minor sand; reddish brown with light brown, black and light grey mottles.	31	8

4.3.6 Triaxial permeability

Three samples collected from the test pits were selected for constant head permeability testing. The samples were tested at 95% of the dry density and 3% wet of optimum water content. The results of

the triaxial permeability testing are summarised in Table 4.13 below. The full results are presented in Appendix C.

Table 4.13: Triaxial permeability summary test results

Test ID	Sample depth (m bgl)	Brief laboratory description of sample	Coefficient of permeability (m/s)
TP03	0.2 – 1.8	SILT, minor fine to coarse sand, trace fine gravel; reddish brown	5.8×10^{-10}
TP06	0.7 – 1.5	Silty fine to coarse SAND, some gravel; light brown	9.0×10^{-10}
TP08	2.6 – 4.1	Clayey SILT, some fine to coarse sand, minor gravel; reddish brown mottled light grey	7.6×10^{-10}
TP30	0.5 – 1.5	Silty CLAY, some sand; yellowish brown	3.5×10^{-10}

4.3.7 Pinhole testing

Pinhole testing was undertaken on four samples retrieved from the test pit investigations. The results of the four pinhole tests indicate the soils to be non-dispersive (ND1) to moderately dispersive (ND3). A summary of the pinhole test results is presented in

Table 4.14: Pinhole summary test results

Test ID	Sample depth (m bgl)	Brief laboratory description of sample	Classification
TP03	0.2 – 1.8	SILT, minor fine to coarse sand, trace fine gravel	Non-dispersive (ND1)
TP06	0.7 – 1.5	Silty fine to coarse SAND, some gravel	Moderately to slightly dispersive (ND3)
TP08	2.6 – 4.1	Clayey SILT, some sand, minor gravel	Non-dispersive (ND1)
TP30	0.5 – 1.5	Silty CLAY, some sand	Non-dispersive (ND1)

4.3.8 Allophane content

Four samples from the test pits were selected for allophane content testing. The allophane content ranged from less than 5 %, to between 5 and 7 %. The Allophane content test results are summarised in Table 4.15 below, and presented in full in Appendix C.

Table 4.15: Allophane content testing summary

Test ID	Sample depth (m bgl)	Brief laboratory description of sample	Allophane content
TP03	0.2 – 1.8	SILT, minor fine to coarse sand, trace fine gravel; reddish brown	5% – 7%
TP08	2.6 – 4.1	Clayey SILT, some fine to coarse sand, minor gravel; reddish brown mottled light grey	5% – 7%
TP29	1.8 – 4.0	Clayey SILT, minor sand, trace rootlets; reddish brown mottled light grey	5% – 7%
TP30	0.5 – 1.5	Silty CLAY, some sand; yellowish brown	Less than 5%

5 Applicability

This report has been prepared for the exclusive use of our client Waste Management NZ Ltd, 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.

Tonkin & Taylor Ltd

Report prepared by:	Authorised for Tonkin & Taylor Ltd by:
	
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DSA
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