Tower Foundations Ref: JN004/08

REPORT 5330

HUIA WATER TREATMENT PLANT
REVIEW OF HISTORICAL GEOTECHNICAL INFORMATION

VOLUME 1

For: Watercare Services Ltd
2 Nuffield Street
Newmarket, AUCKLAND

By: Tower Foundations Ltd
P O Box 20-294
Glen Eden,
Waitakere, 0641

Date: October 2008

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1. Introduction

The Huia Water Treatment Plant has been upgraded and expanded several times since it was first built in 1926. Most historical reports and data on the site is available from the Watercare archives although some information has either been thrown away or badly categorised when it was archived during the transition from the Auckland Regional Authority to Watercare Services Ltd.

Tower Foundations have been engaged to retrieve and review the available geotechnical information for the Huia Water Treatment Plant with the aim of collating the information so that it is available to designers of future upgrades and extensions to the Huia Water Treatment Plant.

The geological understanding of the site has evolved since the late 1980s and recent investigations have confirmed that although the site is underlain by a layer of colluvium or slope debris, the underlying rock is stable.

A search of the Watercare archives has produced a range of historical reports which provide good geological information. All of the available borehole logs have been located onto a master site plan to allow any geological section to be developed using all of the historical information. This should allow engineers to target additional investigations more effectively.

A wide range of test data has been retrieved and collated from the past reports. This data includes both insitu and laboratory tests of either material characteristics or engineering properties. The data has been sorted and plotted in a format that allows the composition and engineering performance of the underlying materials to be evaluated on the basis of a significant amount of test data.

The test results are often highly variable due mostly to the existence of blocks of unweathered rock embedded in the Colluvium. Despite this, many tests have been targeted at the weakest materials forming the matrix of weathered material in the Colluvium and the information should allow engineers to make reasonably conservative estimates of the following:

- Soil classification parameters can be estimated.
- Soil strength parameters can be estimated. The effective strength parameters can be estimated more accurately than the undrained shear strengths which exhibit extreme variability.
- Soil deformation parameters can be estimated and reasonably conservative estimates of settlement should be possible.

2. Scope of Work

The scope of work comprised the following:

- Search the Watercare archives for any geotechnical information on the site.
- Compile a master site plan showing the location of all boreholes.
- Collate and sort all test data.
- Compile factual report.

3. History of the Site

3.1 Development History

The site was originally developed in the 1920s as the new raw-water sources in the Waitakere Ranges replaced Western Springs as the main source of water for Auckland City. A flurry of development activity took place in the 1970s and 1980s when the treatment plant was expanded with a more recent period of upgrade work in the last eight years requiring civil infrastructure work.

Plate 1 shows the site as it is today with the areas of expansion and upgrade work annotated. The history of development can be summarised as:

- Circa 1926; original building constructed in reinforced concrete and founded on Spread footings,
- 1972; chemical building extension constructed in reinforced concrete and founded on spread footings,
- 1973; filter extension constructed in reinforced concrete and founded on spread footings,
- 1973; the clarifiers were constructed in reinforced concrete and founded on spread footings. Settlement monitoring indicated a maximum settlement of 39mm with an associated maximum differential of 30mm (rotational distortion 1:600),
- 2003; the wash-water tank was constructed in reinforced concrete founded on spread footings, although stone columns were installed below the footings.
- 2006: The lagoons below the treatment plant were expanded and upgraded to allow off-spec water to be released from the plant.

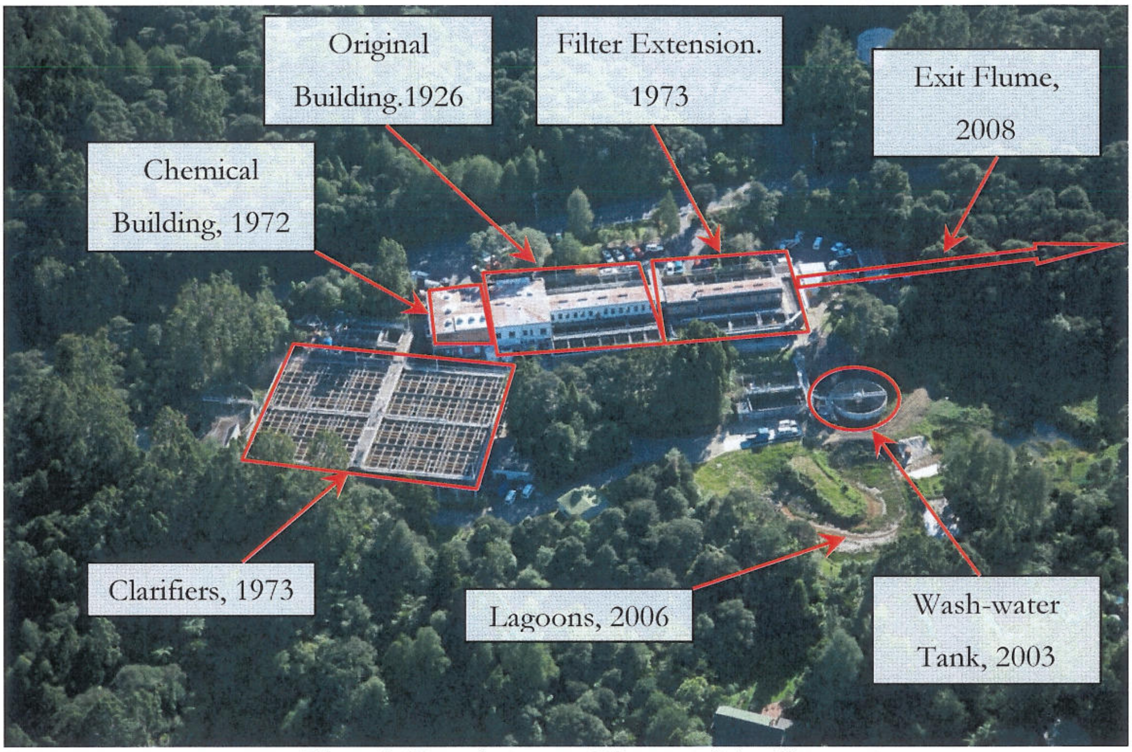


Plate 1. Development History of the Site

Further upgrade work currently in the design stage is:

- Chlorination Upgrade
- Titirangi No.3 Reservoir and pumping station.

These projects should benefit from the review of available geotechnical data.

4. Summary of Geotechnical Information

A thorough search of the Watercare archives has provided a range of reports and calculation files. Some historical borelogs have been retrieved although many laboratory test results seem to have been lost in the transition between the ARA entity and Watercare.

Although it is possible that undiscovered borelogs may be incorporated in reports which have not been retrieved due to no suggestion in the title that the report may contain geotechnical content, the information now compiled provides quite good coverage of the site.

4.1 History of Investigation

Although there are original design and construction drawings dating back to the 1920s, the search has not found any associated ground information. The earliest investigation information retrieved is related to the expansion of the site in the 1970's. The reports and information retrieved is summarised as follows:

- Auckland Regional Authority Borehole Logs (1970s to 1980s)
- Engineering Geology Report (Mansergh for DSIR, Sept 1988)
- Engineering Geology Report (Works Consultancy, Oct 1995)
- Huia WTP Geotech Risk Assessment (GHD Sept 2002)
- Structural assessment of Sludge Lagoons (T&T Oct 2005)
- Geological Risk Assessment (Beca Infrastructure, Oct, 2006)
- Exit Flume Slope Stability (Beca Infrastructure, Nov 2006)
- Chlorination Plant Upgrade (Harrison Grierson, Sept, 2008)
- Titirangi No.3 Reservoir (Tower Foundations, Oct, 2008)

4.2 Available Information

The above reports provide both analysis of the geology of the site and detailed geotechnical investigation information. The geology of the site and the detailed investigation information is presented in the following sections.

This review has indicated that 63 boreholes have been drilled, distributed across the site and up the road to the old caretaker's site at Manuka Road as shown on drawing 2005523.017 sheets 1 & 2 attached in **Appendix A**. These borehole logs and the associated laboratory tests are compiled in a separate volume (Volume 2) of this report.

There is a good geographical spread of information across the site although a few boreholes have almost been drilled over the top of previous boreholes due to the designer being unaware of the historical information. The compiled information has some minor limitations, discussed below.

The location of the borelogs has been determined by overlaying old site plans and sketches onto the most recent site plan. Given the quality of some of the older site plans, there is possibly some error in the location of the older borelogs in particular. Furthermore, many of the borelogs either do not have a surface elevation on them or the survey datum is not explicit.

Both the colluvium and the residual Cornwallis formation comprise firm to stiff sands, silts and clays. Differentiating the two units in a narrow core requires experience and the interface shown on the borelogs seems to be dependent on the person logging the core. Given that the geological understanding of the site has evolved since the late 1980s, the earlier borelogs don't actually differentiate the colluviums from the Cornwallis Formation.

These limitations should not significantly affect the development of adequate geological cross sections for future projects. Using the borehole locations and the elevation contours shown on the attached plans should allow adequate accuracy in terms of the underlying geology with additional investigations targeted to fill gaps or inconsistencies in the information.

There is a wide range of both insitu and laboratory test data associated with the boreholes, including;

- Insitu vane shear
- Insitu SPT
- Unconfined compression
- Bulk and dry density.
- Specific gravity
- Natural moisture content

- Atterberg limits
- Triaxial tests
- One-dimensional consolidation
- Settlement monitoring records (clarifiers)

The information has been collated into a spreadsheet database and sorted into useful formats to allow estimation of engineering parameters. Some correlations have been applied to material characterisation tests for comparison with direct measurements. The results are presented below.

4.3 Geology

The geology of the site comprises a layer of colluvial material overlying the Cornwallis formation sandstones. The colluvial material originates from the bluffs above the site formed by the Nihotupu formation sandstones.

Both the Nohotupu and the Cornwallis formations are of Miocene age and comprise massive beds of sandstones with some thin beds of siltstone present in the Cornwallis formation. Both units vary considerably in rock strength from extremely weak to moderately strong and where they are exposed at the surface has weathered to residual soils comprising firm to very stiff clays. Weathering can be up to 20m deep.

There has been some contradictory opinions in the historical reports relating to the formation of the high bluffs above the site, with some fairly recent opinions that the feature is a relic of an ancient and deep-seated landslide. Recent work by Tower Foundations and Ormiston Associates provides compelling evidence that confirms the earlier work by the DSIR, concluding that there is no large scale landslide encompassing the Little Muddy Creek catchment (and the subject site). Extracts from the Tower Foundations report showing the geological plan and section through the site are attached in **Appendix B**.

The geological understanding of the site has evolved fairly recently in terms of the development of the site. The ARA borelogs of the 1970s and 1980s don't identify the geology. Given the similarity of the weathered materials from the Nihotupu and the Cornwallis formations, identifying the boundary between the colluvium and the top of the weathered Cornwallis formation has been difficult. The interface seems to be very dependent on the person logging the core.

4.4 Material Classification

There have been numerous laboratory tests carried out to characterise the cohesive materials in terms of the moisture content, and the liquid and plastic limits. These tests are useful in understanding the basic behaviour of the materials and provide the opportunity to apply correlations to derive engineering parameters.

It has been difficult to interpret the contact between Colluvium and Cornwallis formation, particularly for the ARA borelogs. For the purposes of this exercise most of the test results from the ARA borelogs have been interpreted as Colluvium.

There have been a total of eight complete Atterberg limit tests carried out. These are shown in the Casagrande chart shown in **Figure 1**. This chart shows quite variable plasticity materials from medium plasticity silts to high plasticity clays and reflects the variability of the parent material (coarse sandstone to siltstone). The chart indicates that the weathered materials exhibit plastic behaviour over a fairly large range of water contents (18% to 65%) and can sustain fairly high water contents before changing phase to the liquid state.

Given the similarity in composition of the Nihotupu and the Cornwallis formations we would not expect to see a significant difference between the liquid and plastic limits (and consequently the plasticity index).

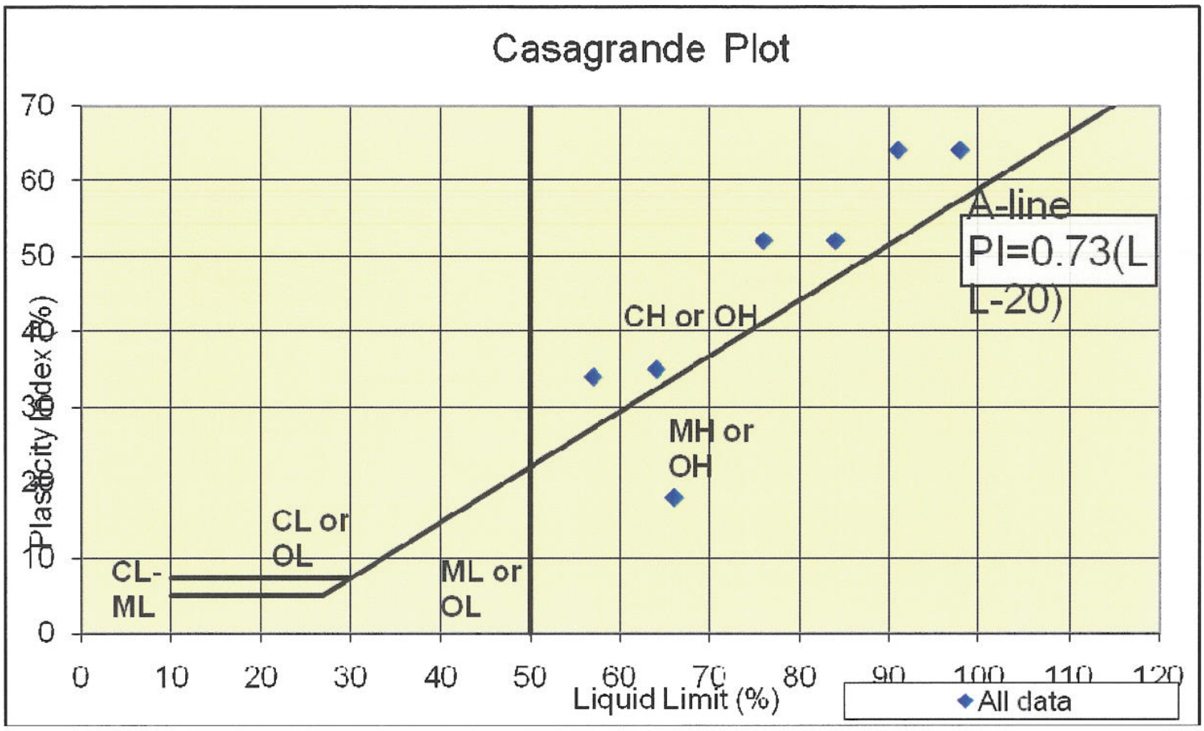


Figure 1: Casagrande Chart

There have been a total of 94 bulk density tests carried out on the cohesive subsoils. These tests are presented as a profile of density versus depth in **Figure 2,** undifferentiated in terms of whether the sample is derived from Colluvium or Cornwallis Formation. The colluvium has been highly disturbed by the slope failure mechanism which will probably result in these samples having lower bulk densities than the residual Cornwallis Formation samples.

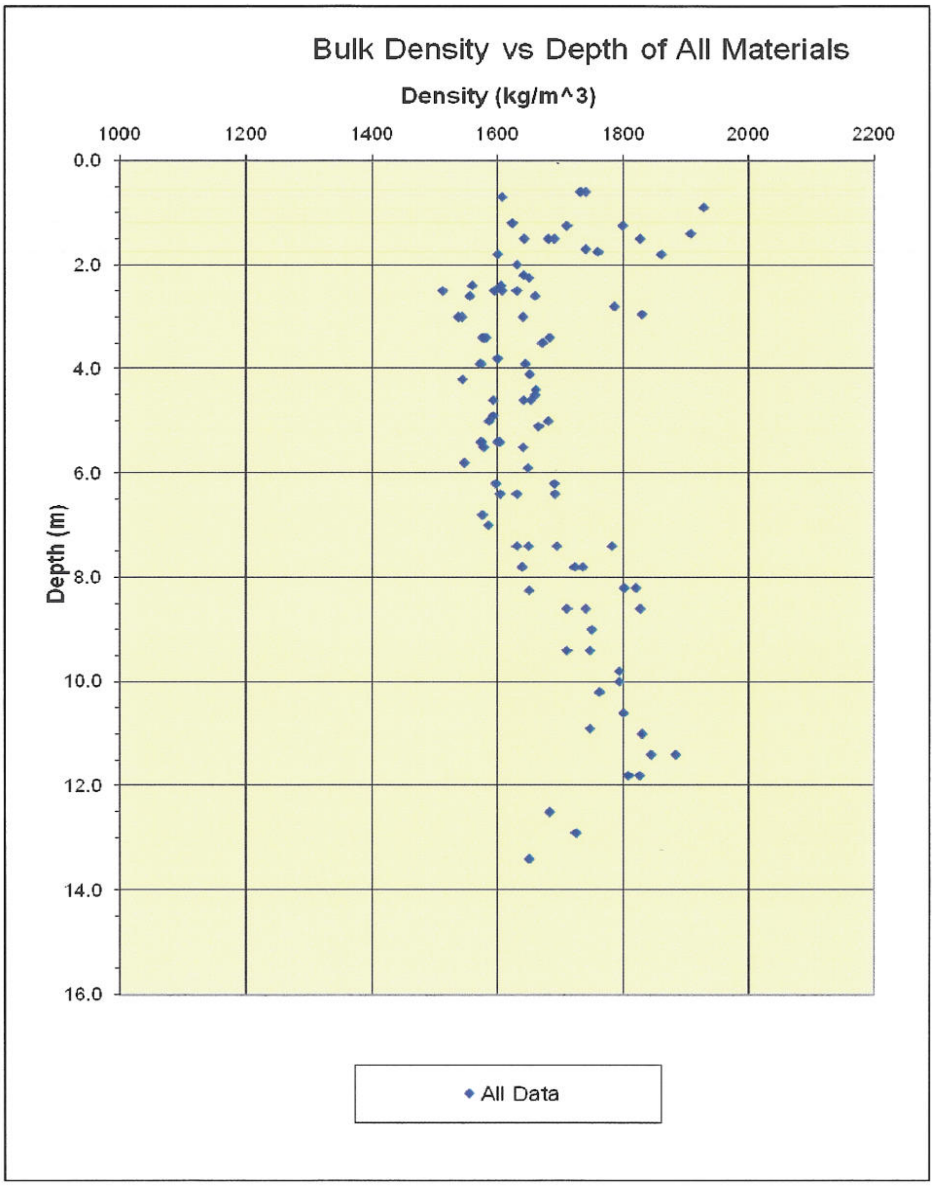


Figure 2: Bulk Density vs Depth Profile

Figure 2 indicates a relatively wide spread of bulk densities in the upper 4m of the soil profile, reflecting the disturbed nature of the colluvium. The densities become less variable below about 4m and show an expected increasing trend with depth as the overburden pressure increases.

There have been a total of 119 natural water content tests on the cohesive subsoils, presented in **Figure 3** as a profile with depth.

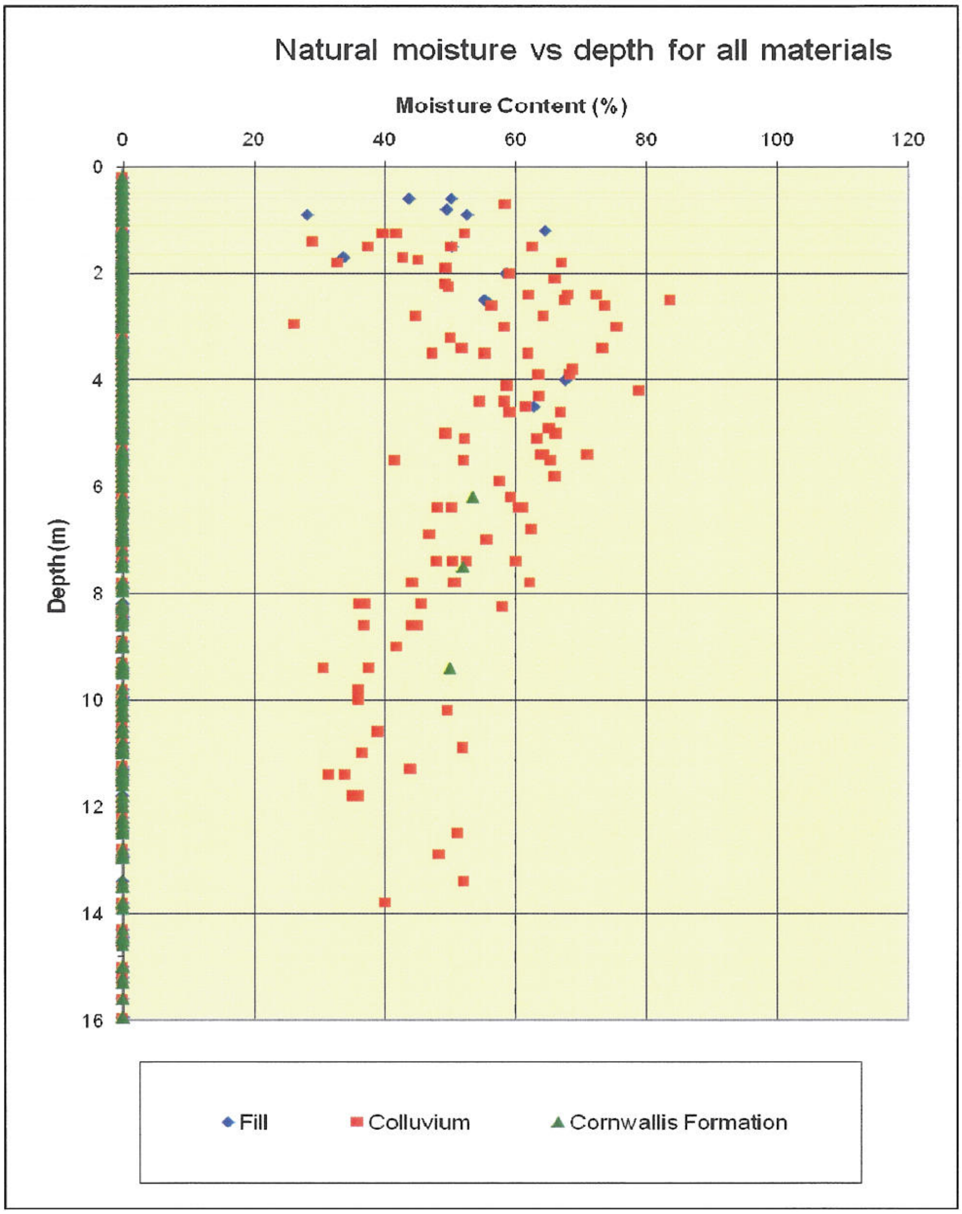


Figure 3: Natural Water Content vs Depth Profile

There has been an attempt to differentiate between Fill, Colluvium and Cornwallis Formation, although this was difficult for the ARA borelogs. Given that most interest is in the colluvium, the important point is to look for the upper limits of the water content test data.

Figure 3 shows the expected reverse trend from the density profile. The natural moisture contents reduce with depth as the overburden pressure increases. Again there is a wide variation in moisture content in the upper 4m reflecting the disturbed nature of the colluvium.

Figures 1 to 3 allow a good understanding of the variability and trends of the density, moisture content and plasticity of the weathered portions of colluvial unit and the residual soils derived from the Cornwallis formation. This understanding can be translated to engineering performance by correlations of strength and deformation parameters to moisture content. This has been carried out and is presented in the following sections.

4.5 Material Strength

4.5.1 Undrained Shear Strength

The SPT and vane shear test are good insitu tests that give some indication of the strength of the materials in the borehole. Despite having numerous SPT tests (150 tests) and insitu vane shear tests (245) they are unfortunately of limited value. Both sets of data show extreme variability with no discernible trend. For the colluvium this is due in part to the existence of large blocks of unweathered sandstone embedded in a matrix of weathered material.

Foundation design will be driven mainly by the parameters of the matrix of weathered material within the colluvium and it is difficult to assign the SPT and shear vane values accurately so that the test results in the matrix material can be sorted.

An added complication for the shear vane tests is that the standard practice of carrying out the tes in the end of the drill-barrel can give very low results due to the disturbance of the material. Without experience and judgement of the person carrying out the tests, this practice can provide unrealistically low results.
Despite all these limitations, an attempt has been made to correlate these tests to provide a profile of undrained shear strength with depth (**Figure 4**).

The SPT "N" values have been transformed to undrained shear strength using the following relationship:

$S_u/P_a = 0.06N$, where P_a is atmospheric pressure.

The above relationship is considered to be weak.

The vane shear tests have been adjusted by a factor of 0.85 based on the work by Bjerrum and updated by Ladd, et al (ref 1) who back-analysed embankment failures and found that shear vanes can over estimate undrained shear strength significantly as plasticity increases. A factor of 0.85 has been selected to represent moderately plastic materials.

Note the extreme variation of test results and all results derived from SPTs and shear vanes carried out in the core barrel have been faeded out as they are of little value. The results from the hand augers carried out by Harrison Grierson are the best quality results giving the best indication of undrained shear strength. This is due to these tests being carried out by inserting the vanes into the soil at the base of the hole using extension rods. These test points show a much narrower variation of results between approximately 50kPa and 110kPa.

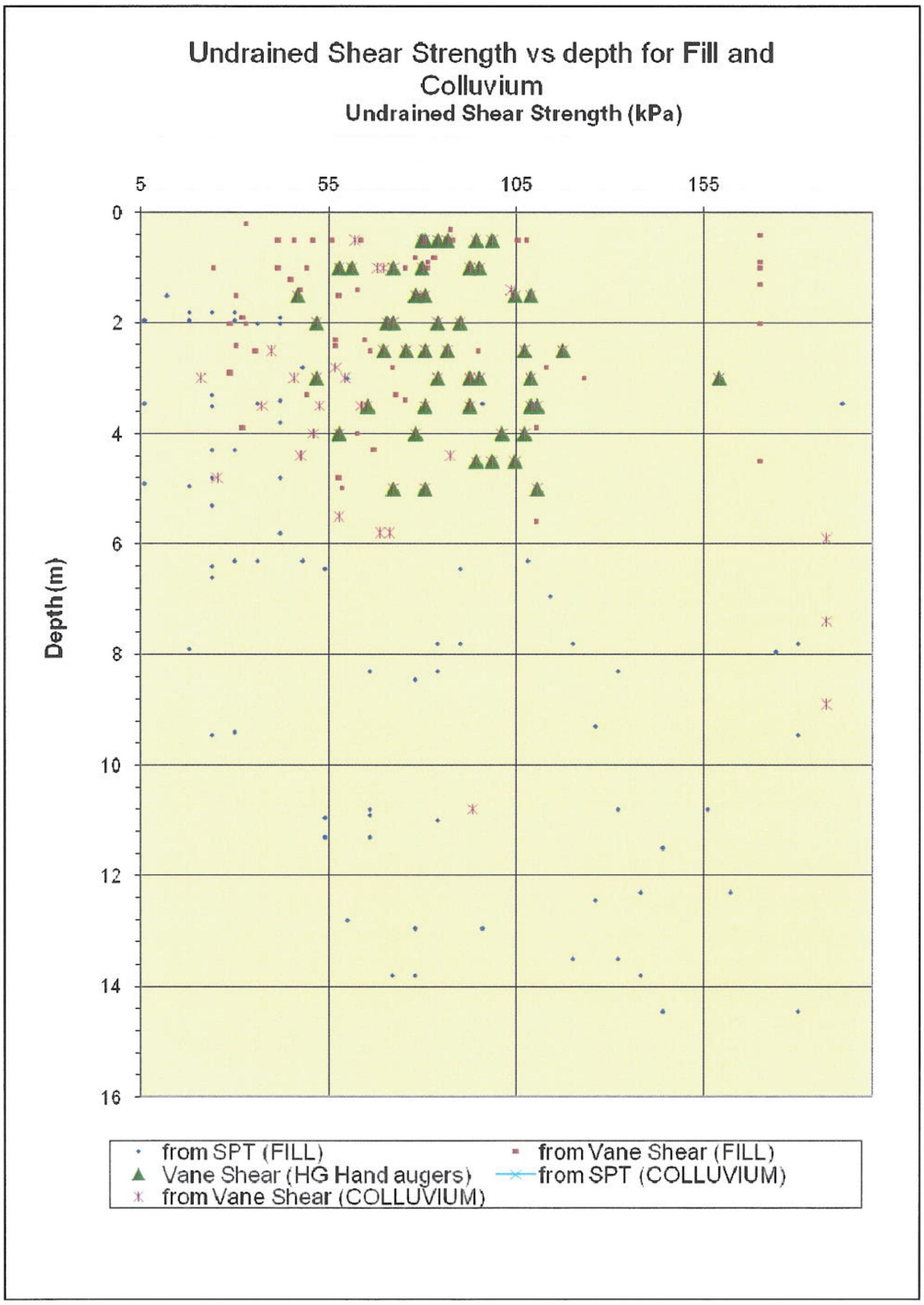


Figure 4: Undrained Strength vs Depth Profile

4.5.2 Effective Shear Strength

The recovery and testing of good quality undisturbed samples provides a much more accurate picture of the effective strength properties of the weathered materials. There has been a total of 18 consolidated-undrained triaxial tests carried out on materials from the upper on 7m of the ground profile. The three tests carried out by Tower Foundations were in the worst colluvial materials recovered. There is some uncertainty as to whether the rest of the tests were in colluvial materials or weathered Cornwallis materials although the consolidation process should have brought the materials back to their natural moisture contents.

The major and minor stresses at failure have been used to develop the p-q plot shown in **Figure 5**. The results show a definite trend with high correlation to the best fit linear regression line shown.

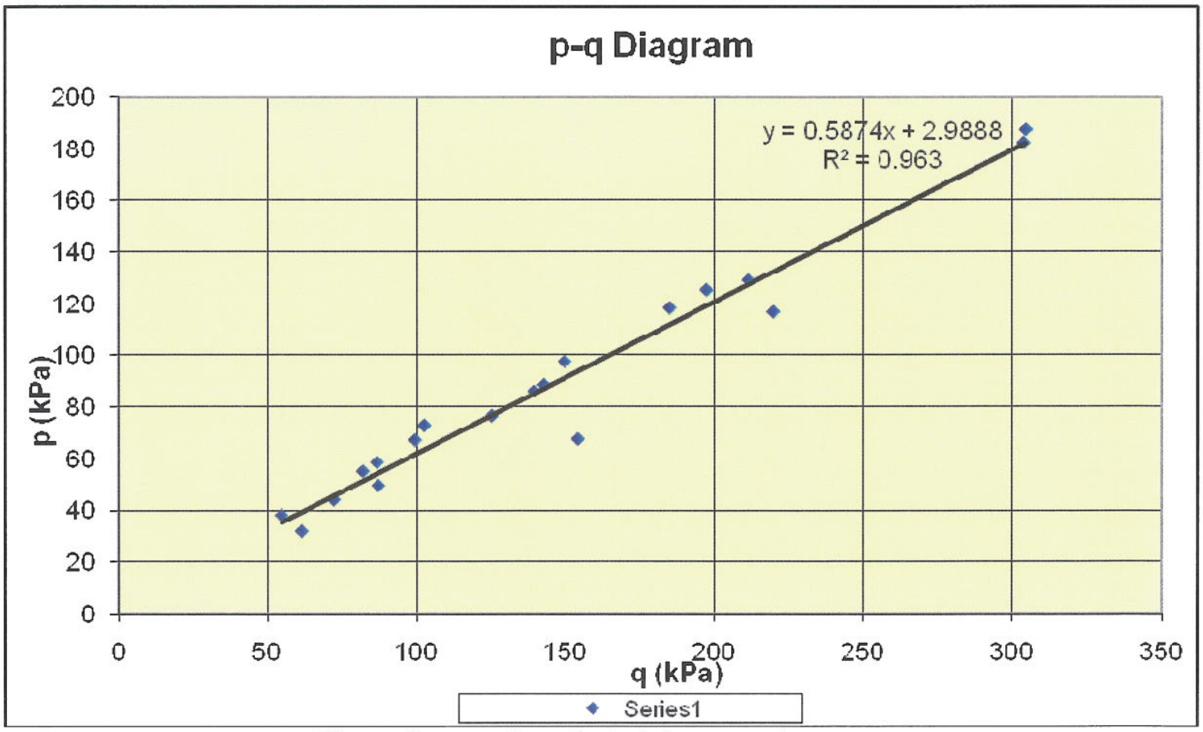


Figure 5: p-q plot of triaxial test results.

The slope and intersection of the best-fit line from the p-q plot has be transformed to the effective strength failure envelope (tengent to the mohrs circles) by the following formulae:

Effective friction angle $\phi = \sin^{-1} \psi$, where ψ = the angle from the p-q plot

Effective cohesion $c' = d/\cos \phi$, where δ = the intercept on the p-axis

The above transformations have been applied to the best-fit curve shown in **Figure 5** as well as the estimated upper and lower-bound limits. The results are presented in **Table 1**.

	Analysis of effective strength parameters		
	lower bound	best fit	Upper bound
y-intercept "d" (kPa)	0.0	3	12
TAN ψ	0.5	0.587	0.6
effective friction "ϕ" (kPa)	32.2	36.0	36.9
effective cohesion "c" (kPa)	0.0	3.7	15.0

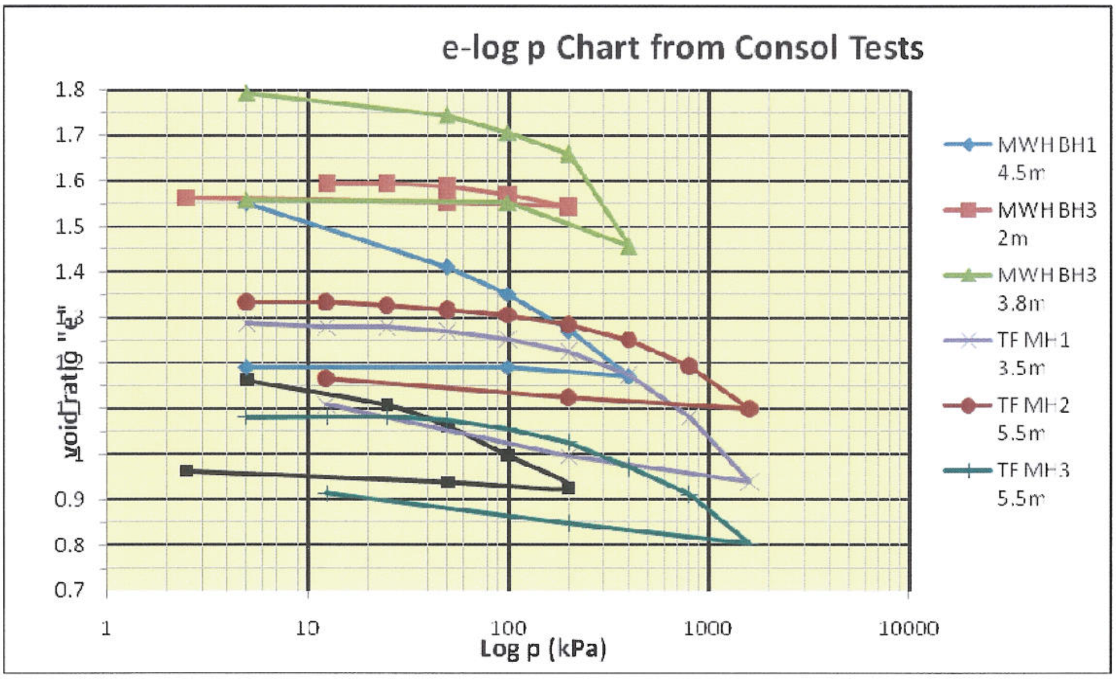
Table 1. Range of Effective strength Parameters

4.6 Deformability

Most of the structures already built on the site have been built on spread footings. The records indicate that numerous one-dimensional consolidation tests were carried out for the expansion works in the 1970's but these records have not been found.

Monitoring data from the clarifiers indicates a maximum settlement of 36mm with a maximum differential of 30mm. The resulting 1:600 rotational distortion has not affected the structure and it appears from the condition of the rest of the existing structures that they have also performed well in regards to settlement.

Seven one-dimensional consolidation tests have been recovered from the Watercare Files. The three tests carried out by Tower Foundations were carried out on the worst possible samples of Colluvium. The four tests carried out by MWH do not specify whether the materials were colluvium or weathered Cornwallis formation. There is a way of overcoming this uncertainty by correlating the compression indeces back to the respective moisture contents. This is expanded in more detail below.



<u>**Figure 6**: e-log p plot of consolidation test results.</u>

Figure 6 shows that there is a large variation in the initial void ratio. This is expected given the large variation in initial moisture contents which ranged from 29% to 69%. Despite this, the form and slope of the curves are broadly similar. One point to note is that there is no distinct pre-consolidation point which is expected given that the materials are disturbed residual soils.

The compression index for the last three stages of loading (from 25kPa to 200kPa) has been calculated from the e-log p curves and plotted against initial moisture content. The results are shown in **Figure 7**.

Although there is some scatter in the results there is a trend of increasing compression index with increasing initial moisture content. The correlation shown in the plot is the one proposed by Terzaghi and Peck. This is still popular although there is wide variation in the available correlations as summarised by Kulhawy and Mayne (ref 2). An extract showing the range of correlations is shown in **Appendix C.**

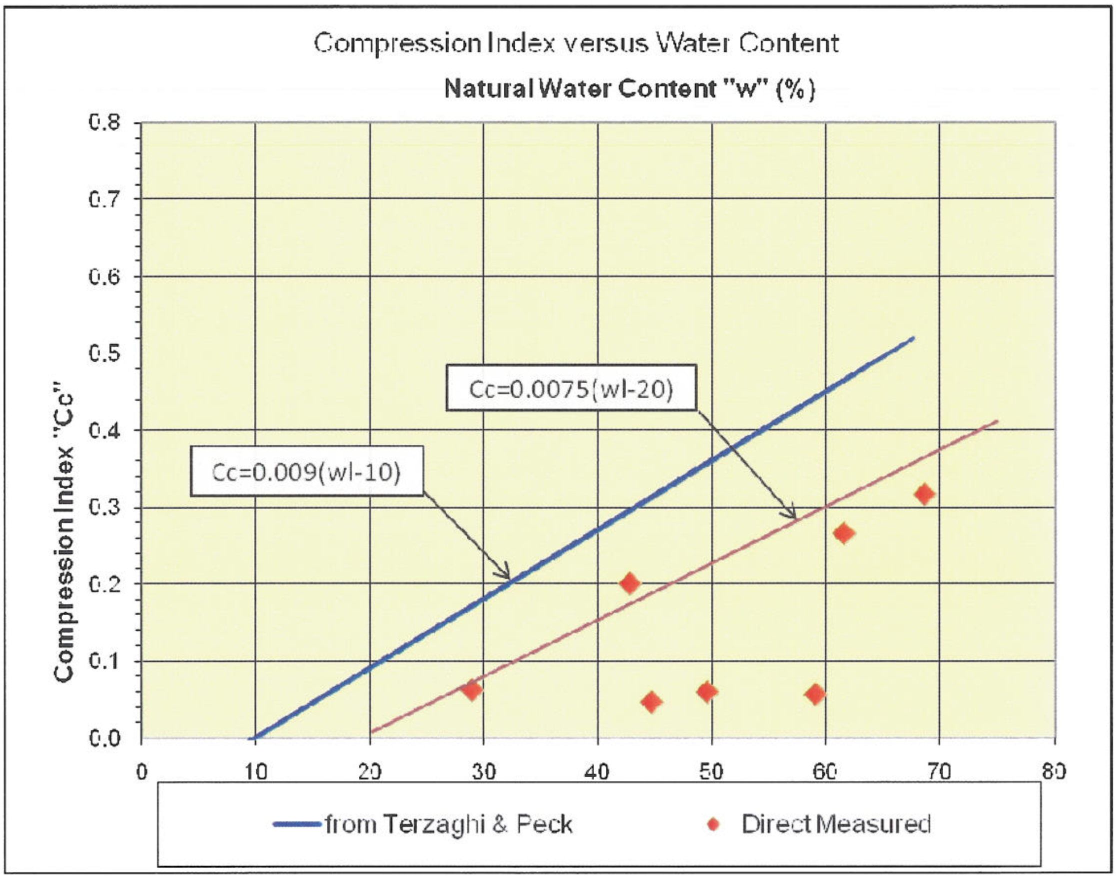


Figure 7: Compression Index "C_c" versus initial Water Content "w"

It can be seen that the compression indeces are significantly lower than those proposed by Terzaghi and Peck for normally consolidated soils. Given that these soils are not layed down in a low-energy depositional environment and that they derive from residually weathered rock, one would expect the compression indeces to be lower.

Although the test samples had a wide range of initial moisture contents (29% to 69%), the overall sample of moisture contents shown in **Figure 3** range from 26% to 84%. A conservative correlation for relating the compression index to moisture content is shown in Figure F. The correlation is:

$$Cc = 0.075(w - 20),$$

All data points except one lie beneath compression index so the correlation is quite conservative and is a worthwhile first estimate in the absence of more specific data. This correlation has been applied to all of the water content test results as shown in **Figure 8**. This allows the following:

- The compression index can be extrapolated out to the limits of the water contents observed
- The trend of compression index with depth can be observed.

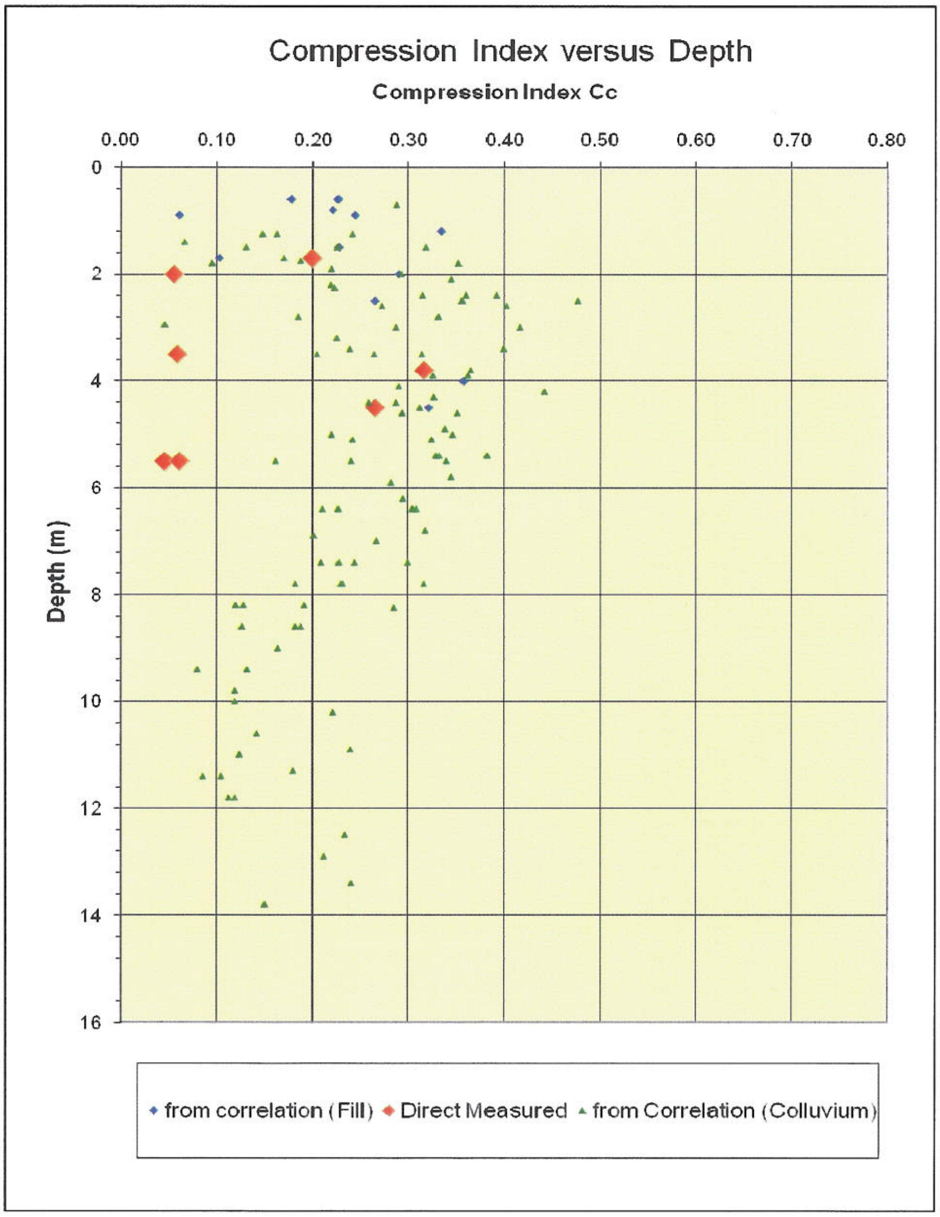


Figure 8: Compression Index "C_c" versus Depth

Figures 7 and **8** should allow design engineers to estimate reasonably conservative parameters for settlement calculations at the Huia Water Treatment Plant.

5. Summary

All known boreholes have been transposed onto one master site plan. The geographical spread of boreholes at the Huia Water Treatment Plant should allow engineers engaged to assess future projects at the site to:

- Create preliminary geological cross sections with the benefit of all of the previous borelog information
- Target additional investigations very accurately to fill in any gaps or to confirm uncertain information.

The range of test results has been collected and sorted into useful form to show variability and trends. Despite highly variable results for some tests, the information should allow engineers to make reasonably conservative estimates of the following:

- Soil classification parameters can be estimated from **Figures 1** to **3**.
- Soil strength parameters can be estimated from **Figures 4** and **5** and **Table 1**. The effective strength parameters can be estimated more accurately than the undrained shear strengths which exhibit extreme variability.
- Soil deformation parameters can be estimated from **Figures 6, 7** and **8**. Reasonably conservative estimates of settlement should be possible by selecting parameters form this information.

6. Limitation

This report has been prepared for the sole benefit of ***Watercare Services Ltd*** as our client with respect to the brief for the proposed development. It is not to be relied upon or used out of context by any other person without reference to Tower Foundations Ltd. The reliance by other parties on the information or opinions contained in the report shall, without prior review and agreement in writing, be at such parties sole risk.

We trust the above meets your present requirements. If there are any further queries, please do not hesitate to contact the undersigned.

Yours faithfully,
TOWER FOUNDATIONS LTD.

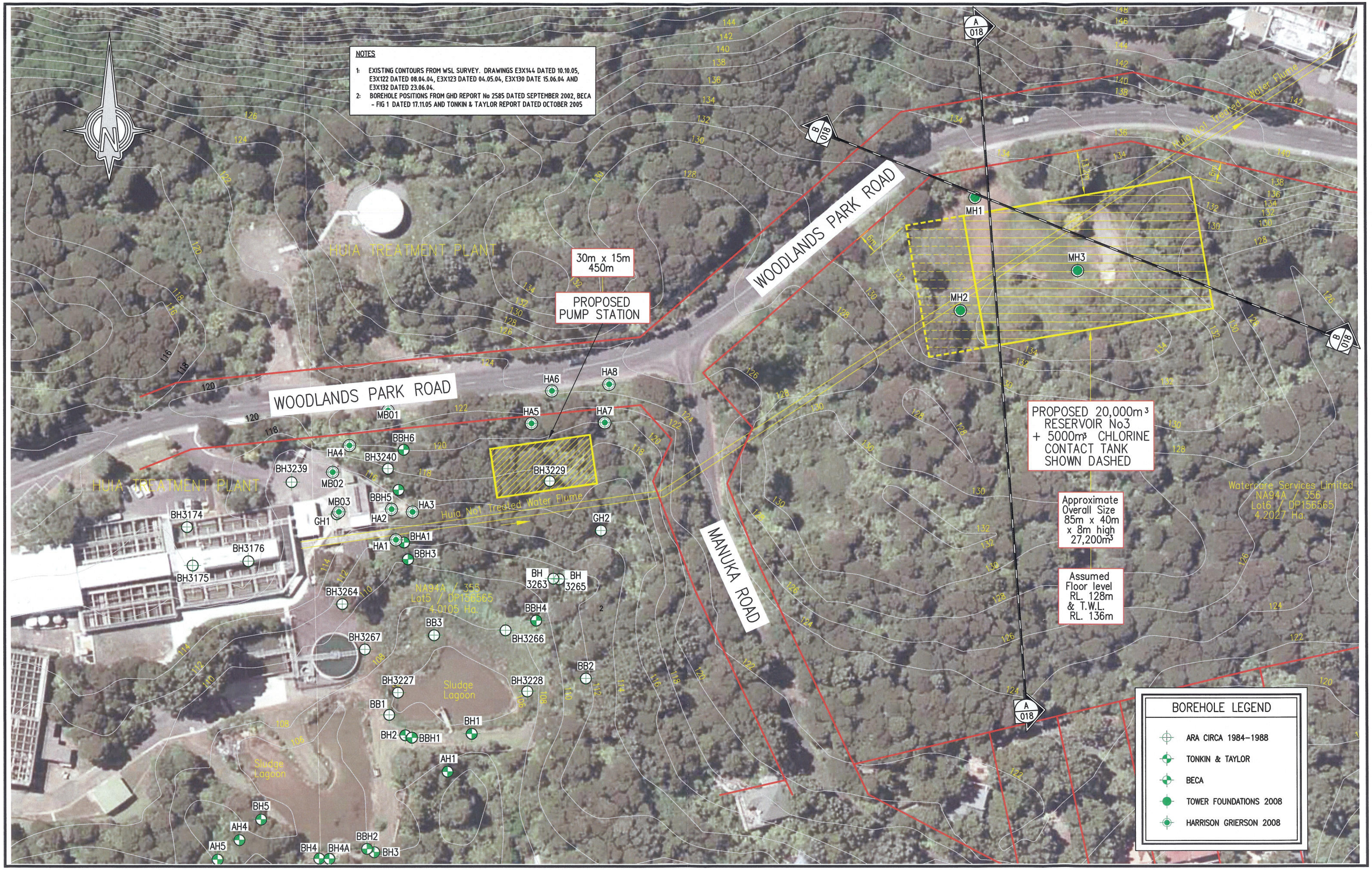
N.K. Jacka

Neil K Jacka Be (Hons)
Principal Engineer

7. References

1. Ladd C C, Foote R, Ishihara K, Schlosser F and Poulos H G, "Stress – Deformation and Strength Characteristics", Proceedings 9th International Conference on Soil Mechanics and Foundation Engineering, Vol 2, Tokyo 1977, pp421-494
2. Kulhawy F H, and Mayne P W, "Manual for Estimating Soil Properties for Foundation Design, Cornell University, August 1990.

Appendix A
Borehole Location Plans



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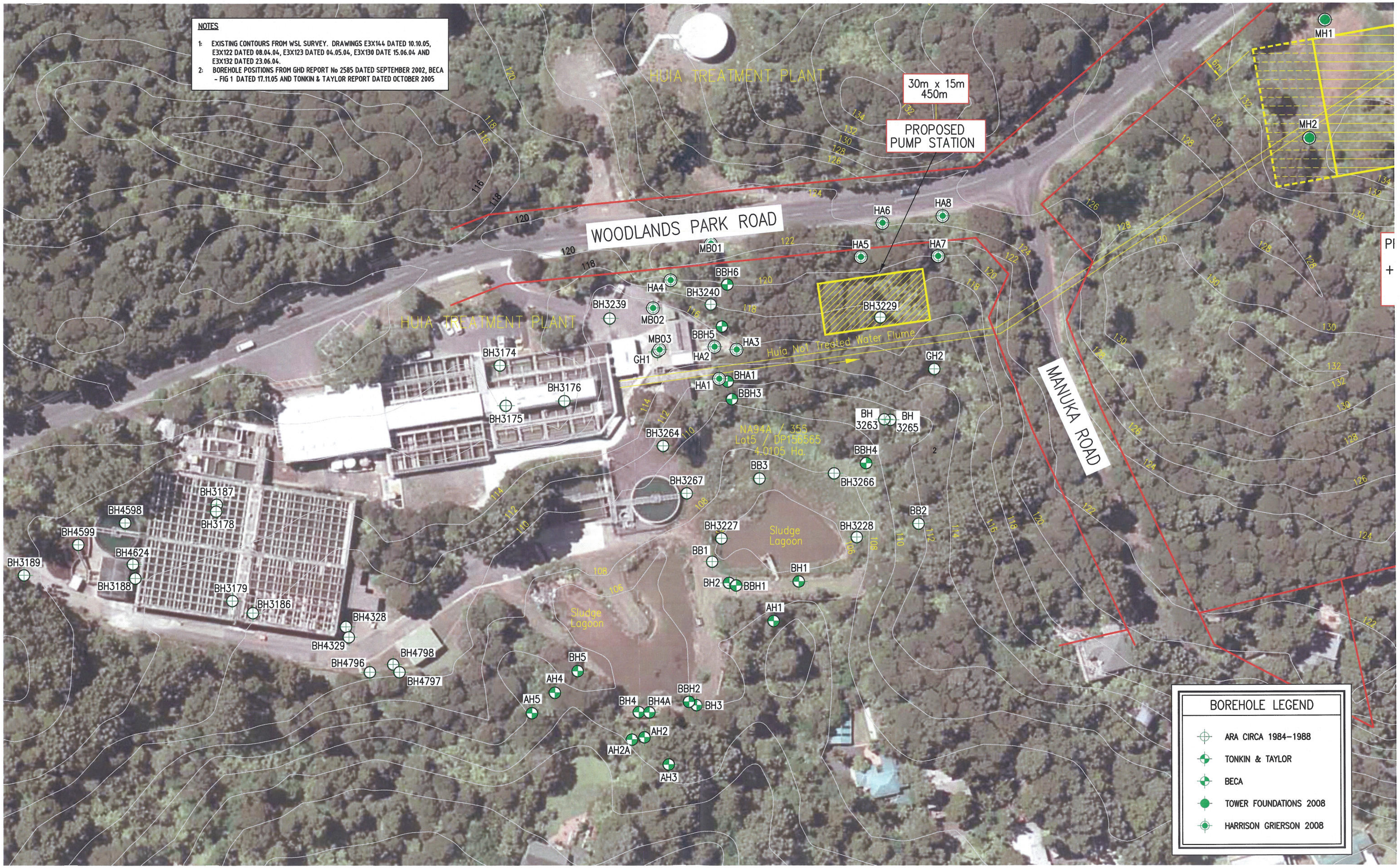
					DES. CHECKED	J.P.	7-08		
					DRAWN	G.B.	7-08	OPERATIONS	
					DWG. CHECKED	I.M.	7-08		
					PROJECT LEADER	T.C.	7-08		
–	7:08	FOR CLIENT CONSIDERATION	G.B.	T.C.	AM APPROVED	A.S.	7-08	ASSET MANAGEMENT	
ISSUE	DATE	AMENDMENT	BY	APPD.		BY	DATE		

watercare services limited

PROPOSED TITIRANGI RESERVOIR No3
RESERVOIR SITING – SCHEME 11
BOREHOLE LOCATION PLAN – SHEET 1

CAD FILE 2005523.017	DATE 9-09-08	
ORIGINAL SCALE A1 1:500 (A1)	CONTRACT No. –	
DRAWING No. 2005523 .017		ISSUE –



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PROPOSED TITIRANGI RESERVOIR No3
RESERVOIR SITING - SCHEME 11
BOREHOLE LOCATION PLAN - SHEET 2

CAD FILE 2005523.017
DATE 9-09-08
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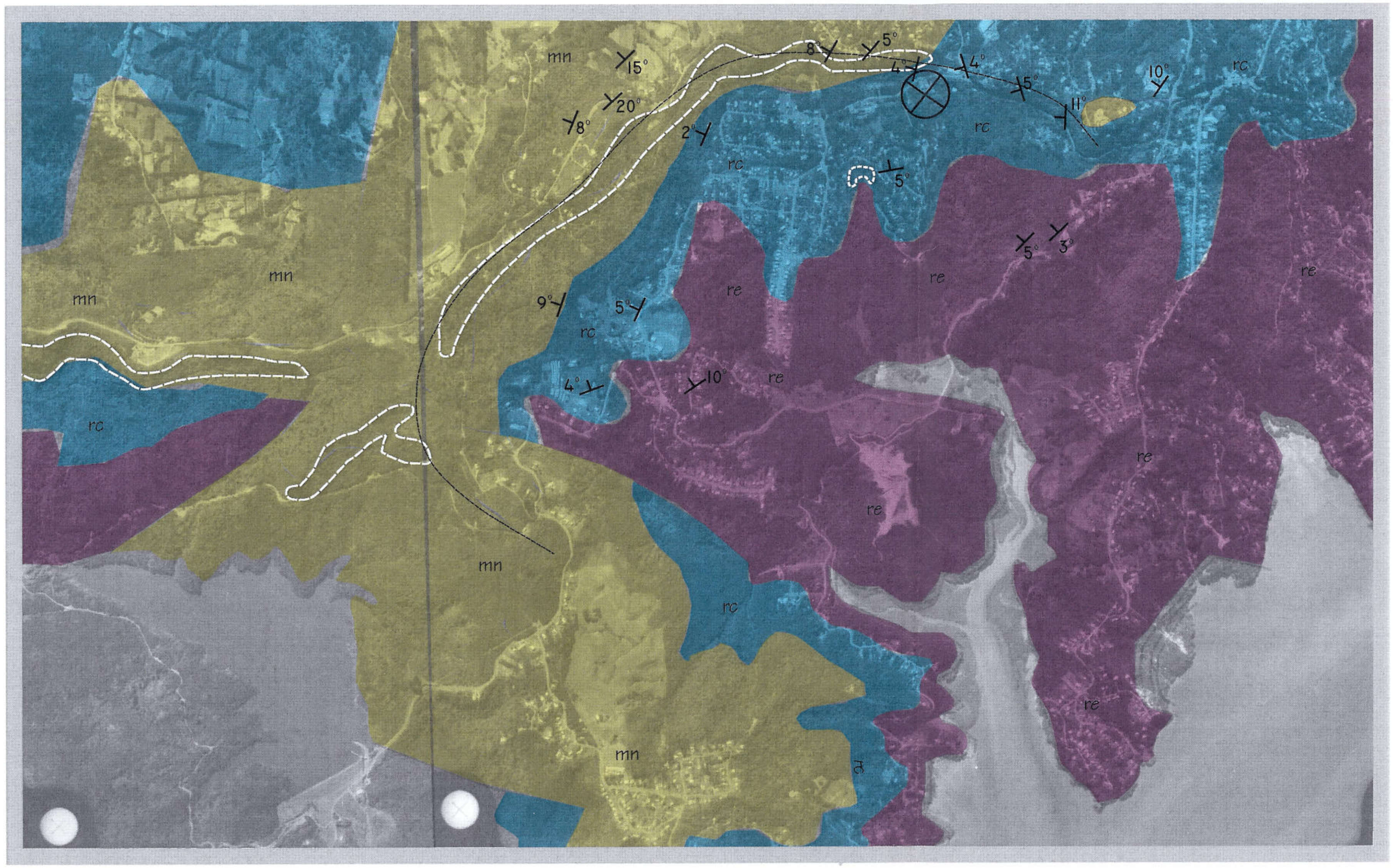
DRAWING No. 2005523 .017
ISSUE -

Appendix B
Geological Plan and Section



Legend

mn Waitakere Formation (Nihotupu Fm) - Alternating Mudstone & Sandstone

rc Cornwallis Formation - Volcanic grit and Alternating Siltstones & Sandstones

re East Coast Bays Formation - Alternating Siltstones & Sandstones

10° Strike & Dip

Approximate extent of Major Bluff

Approximate location of Reservoir No 3

Approximate extent of arcuate feature

Note: Geologic interpretation is approximate only being based on field observations and Sheet N42/7, Cornwallis, Industrial Map Series

ORMISTON ASSOCIATES LTD
CONSULTANTS IN GEOTECHNICAL ENGINEERING, GEOLOGY & ENGINEERING GEOLOGY
18 St Martins Lane, Auckland City
P O Box 47-822 Ponsonby, Auckland New Zealand
Ph (00649) 378 1081 Fax (00649) 378 9834

water Care services limited

TOWER FOUNDATIONS

CLIENT:	Watercare Services Ltd
LOCATION:	Titirangi No 3 Reservoir
TITLE:	Geological Map

SCALE: 1:24000 @ A3
DRAWN: BXH
DATE: 17th Sept 2008
CHECKED: LGD

DRAWING NO
2113/2950-1
SHEET 1 OF 1

NOTES:

1. The subsurface conditions as shown on these drawings have been determined only at the locations and within the depths of the various boreholes shown.
2. The subsurface conditions have been projected between the boreholes and represent a rational assessment based on all available data.
3. In making any assessment of subsurface conditions from small diameter boreholes it should be noted that such an assessment is based upon data obtained at the test locations. Such an assessment will not identify any variations that may exist away from those locations.
4. No guarantee can be given as to the validity of and the nature and continuity of the various subsurface features shown.
5. The soil descriptions on this drawing have been simplified for this presentation. For detailed descriptions refer to the logs of the boreholes.
6. Property boundaries were not located during the investigation, nor was it our brief to do so. Property boundaries should be accurately located by a Registered Surveyor.

ORMISTON ASSOCIATES LTD
CONSULTING GEOTECHNICAL ENGINEERS, GEOLOGISTS & ENGINEERING GEOLOGISTS
Level 1, 18 St Martins Lane, Auckland City
PO Box 47 822 Ponsonby Auckland New Zealand
Ph (09) 378 1081 & 827 7728 Fax (09) 378 9834

CLIENT : WaterCare Services Ltd
LOCATION : Huia Filter Station, Titirangi
TITLE : Schematic Geologic Cross-section

SCALES	Approx
DRAWN	BXH
DATE	18 Sept 2008
CHECKED	AWO

DRAWING NO

Figure 1

SHEET 1 OF 1

Appendix C
Extract from Kulhawy and Mayne

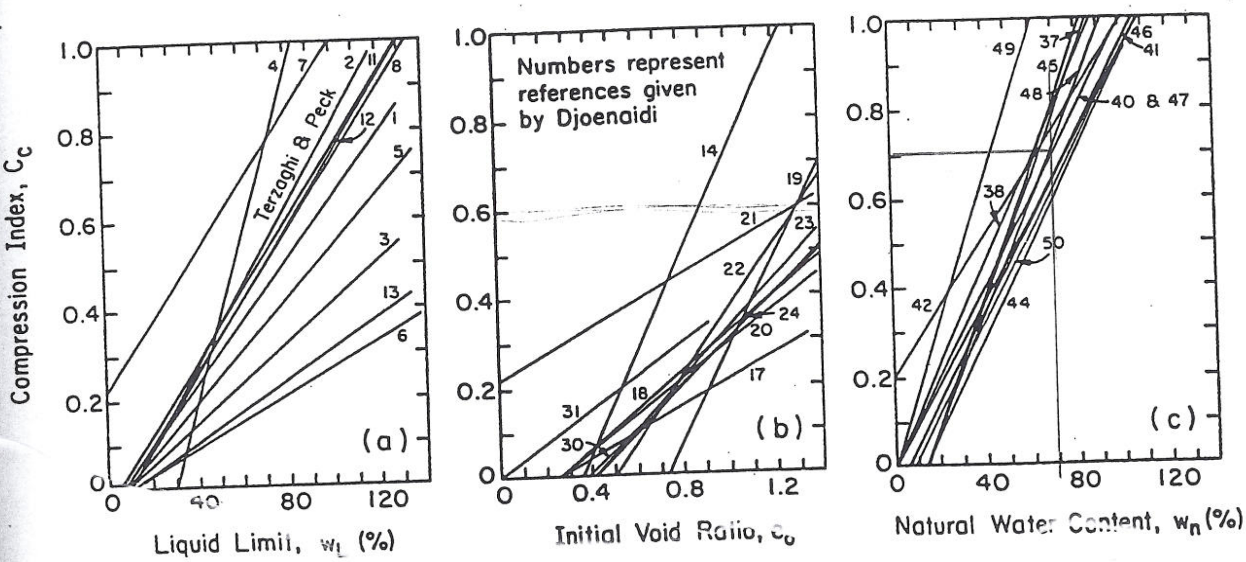


Figure 6-3. Representative C_c Relationships for Cohesive Soils

Source: Djoenaidi (1), p. 6-67.