REPORT

Te Tumu Natural Hazard Risk Assessment - Liquefaction

Prepared for
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Table of contents

1 Introduction

The Te Tumu Urban Growth Area is a 764 ha (approx.) greenfield site located to the east of the Papamoa/Wairakei developed area in Tauranga, Bay of Plenty. The land within the Te Tumu Urban Growth Area is owned by a number of different landowners and is proposed to be converted to residential land use. Tauranga City Council (TCC) is undertaking natural hazard investigations in accordance with the natural hazard provisions of the Bay of Plenty (BOP) Operative Regional Policy Statement (RPS).[1] TCC is undertaking this work on behalf of landowners to facilitate a plan change. Tonkin + Taylor (T+T) has been engaged by TCC to undertake a risk assessment in accordance with the RPS for the following natural hazards:

- Coastal Erosion
- Liquefaction
- Tsunami

The objectives of these natural hazards assessments include identification of the spatial distribution of natural hazard risks by mapping, identification of potential mitigation measures to maintain a low level of risk through the proposed urban development process and to maximise the potentially developable area through these mitigation measures.

This report focuses on the liquefaction and lateral spreading assessment of the Te Tumu Urban Growth Area and the report presents:

- The ground conditions and results of the geotechnical investigations undertaken;
- The groundwater models created for the purpose of the liquefaction assessment;
- The seismic shaking hazard for the Te Tumu Urban Growth Area;
- An assessment of the likelihood of liquefaction-induced land and building damage in accordance with the natural hazard provisions of the BOP RPS; and
- Preliminary mitigation options required for urban development to achieve and maintain a low level of risk.

The purpose of this report is to inform TCC of the liquefaction and lateral spreading vulnerability for the Te Tumu Urban Growth Area and the impact sea level rise may have on the liquefaction and lateral spreading vulnerability in this area. The assessment was undertaken at a high-level and the geotechnical investigation density is consistent with the minimum investigation density requirement for changes to the proposed land use specified in the MBIE liquefaction guidelines[2] (i.e. the investigation density is consistent with a Level B calibrated desktop assessment). However, the assessment is not suitable for use for consenting or foundation design purposes.

1.1 Scope of work

The scope of works comprises an assessment of liquefaction and lateral spreading vulnerability of the area using the proposed urban development ground surface levels in accordance with the natural hazard provisions of the of the BOP RPS. To undertake a liquefaction and lateral spreading assessment at a given site, it is important to have a good understanding of the subsurface ground conditions, groundwater levels and seismic shaking hazard. Therefore, the scope of this project was to:

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[1] Bay of Plenty Regional Council, 2016. "Operative Regional Policy Statement for the Bay of Plenty." Retrieved from https://www.boprc.govt.nz/plans-policies-and-resources/policies/operative-regional-policy-statement/

[2] Ministry of Business Innovation & Employment (MBIE), 2017. "Planning and engineering guidance for potentially liquefaction-prone land". Retrieved from https://www.building.govt.nz/building-code-compliance/b-stability/b1-structure/planning-engineering-liquefaction-land/

1. Undertake additional geotechnical site investigations to assess the subsurface ground conditions for the area.
2. Update the median groundwater level model for the area.
3. Undertake a liquefaction assessment using the proposed urban development ground surface levels.
4. Undertake a lateral spreading assessment using the proposed urban development ground surface levels.
5. Repeat the liquefaction and lateral spreading assessments assuming 1.25 m and 1.9 m of sea level rise.
6. Undertake a risk assessment in accordance with the natural hazard provisions of the BOP RPS.
7. Produce liquefaction and lateral spreading vulnerability maps and an accompanying technical report.
8. Present to TCC and the Te Tumu landowners the results of the technical assessment.

It is important to note TCC commissioned this risk assessment in accordance with the RPS in May 2017 and the first draft was completed in August 2017. The MBIE Liquefaction Guidelines[3] were in preparation when the project was first commissioned and were not released until September 2017. While this risk assessment has drawn on elements of the MBIE Liquefaction Guidelines (e.g. investigation density recommendations and land damage categorisations) its objective is to satisfy the natural hazard provisions of the BOP RPS and T+T has developed a methodology to achieve this. However, it does not follow all of the recommendations of the MBIE Liquefaction Guidelines, as that was not the objective of the assessment, and further those guidelines were not available at the time the project was first commissioned.

1.2 Regulatory context

The management of natural hazards in New Zealand is influenced by five main statutes as summarised in Figure 1-1. The scope of this report is limited to the BOP RPS (refer to the green box in Figure 1-1).

As discussed in Section 1.1, T+T has been engaged by TCC to undertake a risk assessment in accordance with the natural hazard provisions of the of the BOP RPS[4] in order to facilitate a plan change to convert the Te Tumu area from rural to residential land use. The BOP RPS gives effect to the purpose of the Resource Management Act (RMA) i.e. the sustainable management of natural and physical resources in the region.

The methodology for undertaking that risk assessment is provided in Appendix L of the BOP RPS. The performance requirement that the BOP RPS requires the assessor to consider is the likelihood of buildings or structures being "functionally compromised" as a result of the earthquake event under consideration. Functionally compromised is defined as a condition that "…will generally occur when a building cannot continue to be used for its intended use immediately after an event." Further, Appendix L of the BOP RPS specifies that the assessor undertaking the risk assessment should consider 500, 1,000, and 3,030 year return period interval earthquakes.

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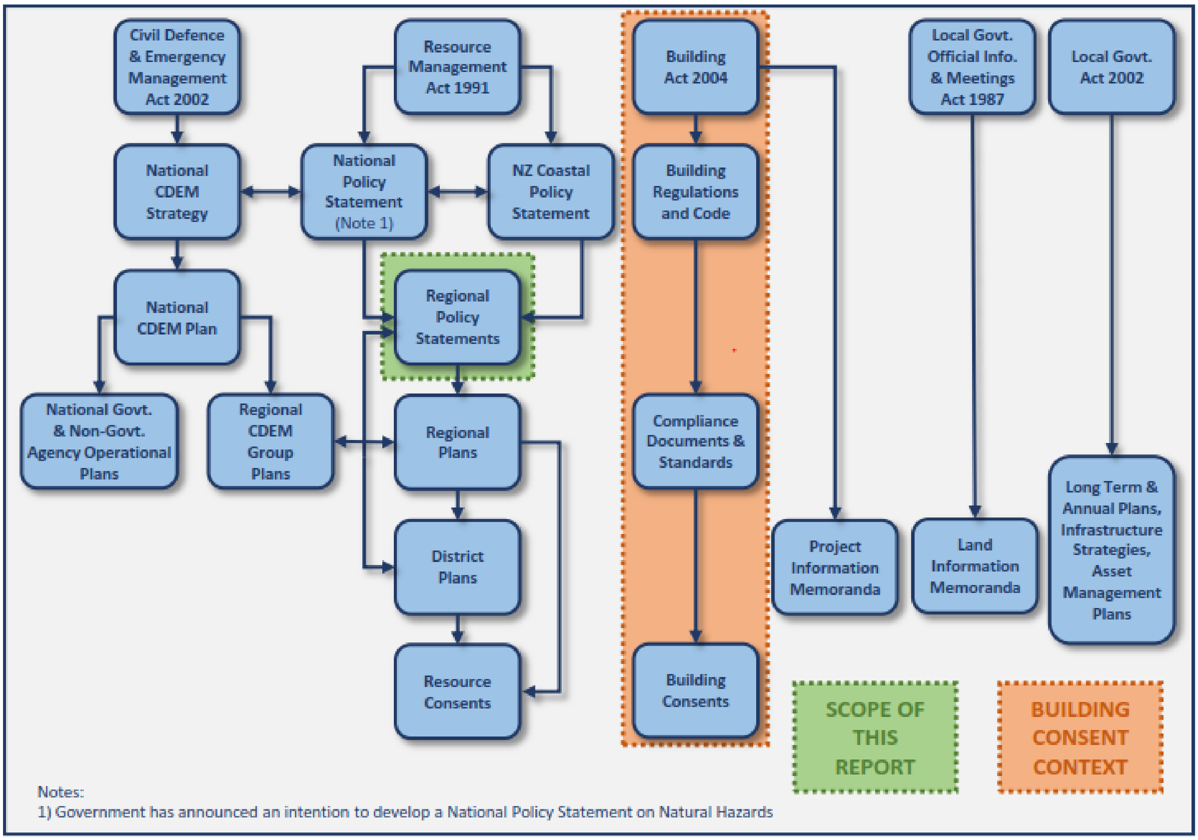
[3] Ministry of Business Innovation & Employment (MBIE), 2017. "Planning and engineering guidance for potentially liquefaction-prone land". Retrieved from https://www.building.govt.nz/building-code-compliance/b-stability/b1-structure/planning-engineering-liquefaction-land/

[4] Bay of Plenty Regional Council, 2016. "Operative Regional Policy Statement for the Bay of Plenty." Retrieved from https://www.boprc.govt.nz/plans-policies-and-resources/policies/operative-regional-policy-statement/



Notes:
1) Government has announced an intention to develop a National Policy Statement on Natural Hazards

Figure 1-1: Legislative framework for natural hazard management in New Zealand. The scope of this report is indicated by the green box (adapted from the MBIE Planning and engineering guidance for potentially liquefaction-prone land in New Zealand)

In parallel with the RMA is the Building Act as indicated in the orange box in Figure 1-1. The purpose of the Building Act is to regulate building work to ensure (amongst other things) that buildings are safe for people to occupy, and promotes their health and wellbeing. This is achieved through the Building Code and supporting documents, such as technical standards and guidelines, as a means of compliance with the Code.

While the BOP RPS concept of functionally compromised shares some characteristics in common with terms used in the Building Act and supporting documents, the details of how these concepts are implemented differ. Neither the RMA nor the Building Act supersedes the other and both must be applied and adhered to within their relevant contexts (i.e. the Regional Policy Statement, Regional and District Plans, and consents under the RMA, and consenting and building standards for individual buildings under the Building Act).

Our assessment of risk in Section 8 uses the concept of loss of amenity as defined in the Building Code and detailed in guidance documents to help define the term functionally compromised. However, it should not be construed to apply to a councils functions under the Building Act, or the way they interpret the requirements or performance standards for buildings in the Building Act, Building Code, standards or guidelines.

1.3 Site description

The study area is outlined in Figure 1-2 and comprises a greenfield site situated between Papaoma East and Maketu. The Kaituna River is located along the southern and eastern boundary, and Papamoa Beach is located to the north.

The study area comprises approximately 764 ha of rural land. The topography of this area is variable. The stretch of land along Papamoa Beach consists of sand dunes that are at a relatively high elevation (ranging from approximately 3 to 11 m above sea level) whereas the land along the Kaituna River and the Wairakei Stream is at lower elevation (ranging from approximately 1 to 3 m above sea level). The central land throughout the site comprises mainly flat and slightly undulating land (elevation of approximately 4 to 7 m above sea level), with the land becoming increasingly hilly to the east. A ridge, which extend across most of the site, is located adjacent to the low lying areas along the Kaituna River, with the portion of land to the north of the ridge is also low lying. Wairakei Stream runs parallel to Papamoa Beach, which ponds within the eastern portion of the site.

The study area is owned by several landowners. A map outlining property boundaries is presented in Figure A2 in Appendix A. An operational sand mine is located within the eastern portion of the site and both a headrace and pump station as a part of a land drainage scheme are located adjacent to Bell Road.

Figure 1-2: Aerial showing the Te Tumu Urban Growth Area - Source: Google Earth (refer to Figure A1 in Appendix A for a scaled Aerial Image)

2 Ground conditions

2.1 Geology and faulting

The published geological information[5] indicates that the site is mostly underlain by coastal beach deposits to the north, and swamp or alluvial deposits to the south. Both sets of deposits are identified on the geological maps as Holocene-aged. The coastal beach deposits comprise sand and minor gravel of the Tauranga Group. The southern swamp/alluvial deposits run adjacent to the northern bank of the Kaituna River and comprise dark brown to black peat, organic rich mud, silt and sand also of the Tauranga Group.

A recent study undertaken by GNS found no evidence of active faults within the study area.[6] However, that study also notes that the sediments in the area are young (<7,000 years) and as a result evidence of active faults could have been concealed. There are a significant number of active faults within close proximity of the study area. Identified faults are shown in Figure 2-1 below which has been taken from the National Seismic Model for New Zealand: 2010 Update[7].

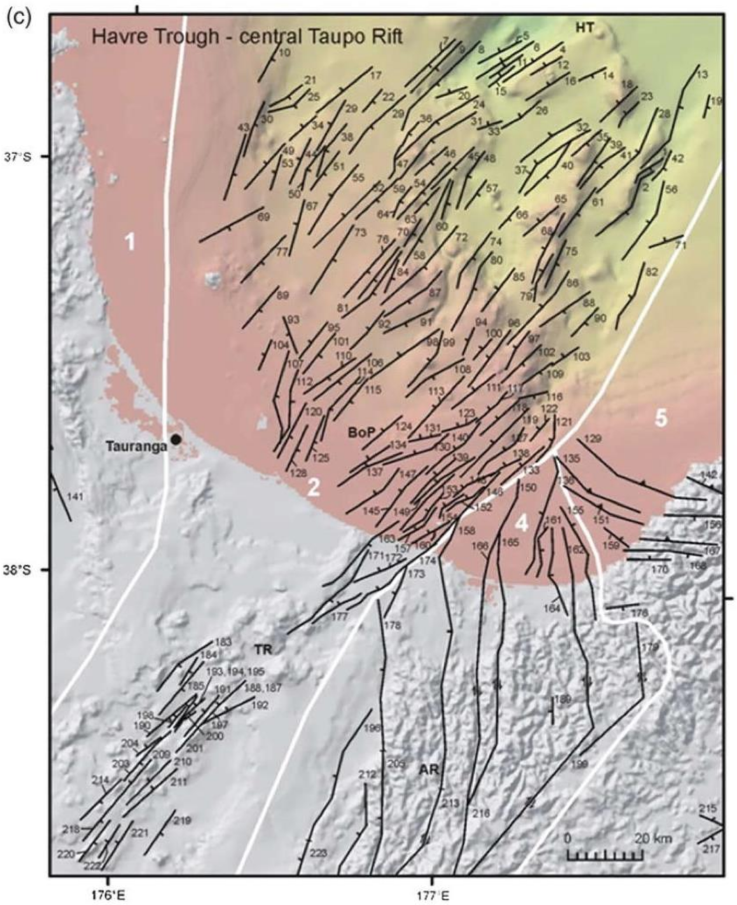


Figure 2-1: Active faults in the Bay of Plenty and Taupo Rift. The fault sources are shown as black lines and Area 2, which is bounded by the white lines, identifies the Bay of Plenty and Taupo Rift. Reproduced from "National Hazard Seismic Model for New Zealand: 2010 Update"

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[5] Leonard, G.S., Begg, J.G., Wilson, C.J.J. (compilers) 2010. "Geology of the Rotorua area." Institute of Geological & Nuclear Sciences 1:250 000 geological map 5. 1 sheet + 102 p. Lower Hutt, New Zealand. GNS Science.

[6] Clark KJ, Vilamor P, and Ries WF. 2017. "Active Fault Mapping for Western Bay of Plenty Growth Areas." GNS Science consultancy report; 2017/97. Lower Hutt, New Zealand. GNS Science.

[7] Stirling, M., et al., 2012. "National Hazard Seismic Model for New Zealand: 2010 Update." Bulletin of the Seismological Society of America, 102 (4), pp. 1514-1542.

The majority of the mapped active faults in the Bay of Plenty are north of the study area (in the Bay of Plenty) and in the Taupo Rift to the south and southeast. The closest active fault is identified as Fault No. 128 which is about 10 km north east of the study area, is capable of a moment magnitude (M_w) of 6.3 and has an average recurrence interval of 1,360 years. Larger faults further away in the Waikato basin and Taupo volcanic zone also contribute to the seismic hazard of the area.

2.2 Geotechnical investigations

The following geotechnical investigations were carried out in the Te Tumu Urban Growth Area and were used for the purposes of assessing liquefaction and lateral spreading vulnerability:

1. Twenty Cone Penetration Tests (CPTs) carried out on 24 and 25 February 2016 by Perry Geotech Ltd[8].
2. Thirty-three CPTs carried out on 12 to 14 June 2017 by Perry Geotech Ltd.
3. Five boreholes (BHs) carried out on 19 to 22 June 2017 by Perry Geotech Ltd.
4. Lab testing comprising of plasticity index and fines content tests carried out on samples retrieved from the BHs by Geotechnics Ltd.

The investigations were evenly distributed across the study area. The following factors were considered when determining the CPT and BH locations:

- Approval from land owners;
- Ecological areas;
- Archaeological areas;
- Location of services (electrical lines, stormwater pipes, etc.); and
- Ease of the CPT and drilling rig access.

The geotechnical investigation locations are shown in Figure A1 in Appendix A and the CPT and BH results are presented in Appendix B.

2.3 Geotechnical model

Table 2.1 below presents the generalised soil profile in the upper 20 m inferred from the 5 BHs and 53 CPTs.

Table 2.1: Generalised soil profile in upper 20 m

Layer No.	Unit	Depth to top (m)	Depth to bottom (m)	Description
1	Upper Sand	0	8.5	Loose to medium dense clean to gravelly sand. Very soft sandy silt close to the Kaituna River.
2	Lower Sand	8.5	20	Medium dense to very dense clean to gravelly sand. The lower sand deposit comprises interbedded very soft to stiff volcanic and estuarine silts at a depth below - 14.5 mRL (Moturiki 1953).

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[8] These CPTs were not part of the scope of this project. They were undertaken for the purpose of the high-level liquefaction assessment of Wairakei/Te Tumu in 2016.

3 Groundwater

A median groundwater surface level was created for the purpose of undertaking the liquefaction and lateral spreading assessment. The use of the median model is considered appropriate because using an alternate groundwater surface level (i.e. higher or lower) will alter the return period of the liquefaction assessment[9].

3.1 Source data

The source data used to create the median groundwater surface level was obtained from TCC in early June 2017 and has been referenced against the Moturiki Vertical Datum 1953 (MVD 1953). The model was created using the mean seal level and records from groundwater monitoring wells between October 2016 and May 2017. The locations of the monitoring wells are shown in all figures in Appendix C.

3.2 Modelling methodology

The median model is created using the median depth to groundwater record at each of the monitoring wells and the mean sea level. The median groundwater level is the level which is exceeded for 50% of the monitoring period. The median groundwater surface level (Figure C2) was then developed by contouring between the points and a series of assumptions were applied in order to create the model. Information about the method and the assumptions is presented in Appendix C.

3.3 Incorporating sea level rise

In order to assess the potential increase in liquefaction vulnerability as a result of sea level rise, two scenarios of sea level rise were applied to the median model (1.25 m and 1.9 m), as requested by TCC. These levels are in accordance with local sea level rise projection scenarios provided in a recent NIWA study.[10] The sea level rise projection of 1.25 m represents a 100 year timeframe as required by BOP RPS Policy NH11B.[11] The sea level rise projection of 1.9 m represents an upper bound scenario for the purpose of stress testing green field development.

The complexities associated with how sea level rise would influence the hydrological mechanics of the region are largely unknown. Given the site's proximity to the coast, the inland damping effects of sea level rise are expected to be minimal. Therefore, to model sea level rise, the median groundwater surface level was simply raised by a constant of 1.25 m and 1.9 m. These changes in groundwater surface level are presented in Figures C3 and C4 respectively in Appendix C.

3.4 Models used for liquefaction assessment

Two median depth to groundwater surface levels were created for the purpose of the liquefaction and lateral spreading assessment. One is the difference between the existing 2015 LiDAR DEM (Figure A3) and the median groundwater level surface (Figure C2) and the other is the difference between the proposed DEM (i.e. the proposed design surface Figure A4) and the median groundwater level surface (Figure C2).

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[9] Tonkin + Taylor, 2015. "Canterbury Earthquake Sequence: Increased Liquefaction Vulnerability Methodology". Retrieved from http://www.eqc.govt.nz/ILV-engineering-assessment-methodology

[10] NIWA, 2017. "Tauranga Harbour extreme sea level analysis." NIWA Project: BOP17202. Hamilton, New Zealand. National Institute of Water & Atmospheric Research Ltd.

[11] Bay of Plenty Regional Council, 2016. "Operative Regional Policy Statement for the Bay of Plenty." Retrieved from https://www.boprc.govt.nz/plans-policies-and-resources/policies/operative-regional-policy-statement/

Depth to groundwater figures accounting for 1.25m and 1.9m of sea level rise were also created for both the existing 2015 LiDAR DEM and the proposed DEM. These can be found in Figures C6, C7, C9 and C10.

It is important to note that the groundwater levels are likely to change following the earthworks proposed for the purpose of urban development. However, the complexities associated with how earthworks would influence the hydrological mechanics of the region and to what extent are largely unknown. Therefore, the same median groundwater level surface pre and post earthworks has been assumed. Qualitative observation indicates that development of the Papamoa/Wairakei area, located adjacent to and west of the Te Tumu area, did not cause any significant response to the monitored groundwater levels.

4 Seismic shaking hazard

4.1 Seismic site subsoil class

The seismic subsoil class in accordance with NZS 1170.5:2004 (Section 3.1.3) for the site is considered to be 'Class D – Deep or Soft Soil Sites' due to the large depth to bedrock at the site.

Further investigations and assessment of subsoil class (e.g. deep borehole or microtremor testing) are unlikely to modify the conclusion of Class D.

4.2 Ground shaking hazard

The liquefaction assessment has been undertaken using the criteria set out in Appendix L in the BOP RPS. In accordance with the natural hazard provisions of the BOP RPS, the liquefaction hazard for the study area was examined at 0.2%, 0.1% and 0.033% annual exceedance probabilities (AEP). These AEP correspond to 500, 1000 and 3030 year return period earthquake events.

The seismic shaking hazard in terms of peak ground acceleration (PGA) and magnitude (M_{eff}) for the area has been assessed based on the NZTA Bridge Manual[12]. Table 4.1 presents the return periods, PGAs and corresponding earthquake magnitudes. The PGAs were determined using building importance level 2 (single storey family residential dwelling)[13] given the expected use of the land.

Table 4.1: Ground seismic hazard

BOP RPS AEP (%)	Return period (years)	PGA (g)	Magnitude (M_{eff})
0.2	500	0.27	6.0
0.1	1000	0.35	6.0
0.033	3030	0.53	6.0

Note:

PGA and M_{eff} has been assessed based on the Bridge Manual SP/M/022 Third Edition for the following:

Building design life	50 years
Building importance level	2 (NZS 1170.0:2004, Table 3.2) – single family residential dwellings
Return period factor, Ru	1.0 for 500yr; 1.3 for 1000yr; 1.8 for 3030yr return period (NZS 1170.5:2004, Table 3.5)
Subsoil class	D (Deep soil) – refer Section 4.1
Return period PGA coefficient, $C_{0,1000}$	0.35 (Bridge Manual Figure 6.1(b))
Site subsoil class factor, f	1.0 (Bridge Manual Section 6.2)
PGA	$C_{0,1000}$ x Ru/1.3 x f x g (Bridge Manual Section 6.2)
Effective Magnitude, M_{eff}	6.0 (Bridge Manual Table 6.2(d))

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[12] As outlined in the latest New Zealand Geotechnical Society (NZGS) and Ministry of Business Innovation & Employment (MBIE) guidelines for Earthquake geotechnical Practice in New Zealand (March 2016).

[13] Standards New Zealand, 2004. "NZS1170.5:2004 Structural Design Actions Part 5: Earthquake actions - New Zealand". Standards New Zealand. Retrieved from https://www.standards.govt.nz/

5 Liquefaction susceptibility, triggering and consequence

5.1 Liquefaction process

It can be readily observed that dry, loose sands and silts contract in volume if shaken. However, if the loose sand is saturated, the soil's tendency to contract causes the pressure in the water between the sand grains (known as "pore water") to increase. The increase in pore water pressure causes the soil's effective grain-to-grain contact stress (known as "effective stress") to decrease. The soil softens and loses strength as this effective stress is reduced. This process is known as liquefaction.

The elevation in pore water pressure can result in the flow of water in the liquefied soil. This water can collect under a lower permeability soil layer and if this capping layer cracks, can rush to the surface bringing sediment with it. This process causes ground failure and with the removal of water and soil, a reduction in volume and hence subsidence of the ground surface.

The surface manifestation of the liquefaction process is the water, sand and silt ejecta that can be seen flowing up to 2 hours following an earthquake. The path for the ejecta can be a geological discontinuity or a man-made penetration, such as a fence post, which extends down to the liquefying layer to provide a preferential path for the pressurised water. The sand often forms a cone around the ejecta hole. With the dissipation of the excess pore-water pressure, the liquefied soil regains its pre-earthquake strength and stiffness.

The surface expression of liquefaction, water and sand depends on a number of characteristics of the soil and the geological profile. If there is a thick crust of non-liquefiable soil such as a clay, or sand that is too dense to liquefy during the particular level of shaking of the earthquake, then water fountains and sand ejecta may not be seen on the surface. The amount of ground surface subsidence is generally dependent on the density of the sand layers as well as how close the liquefying layers are to the surface. Ground surface subsidence increases with increasing looseness in the soil packing. The ground rarely subsides uniformly resulting in differential settlement of buildings and foundations.

Figure 5-1 summarises the process of liquefaction with a schematic representation.

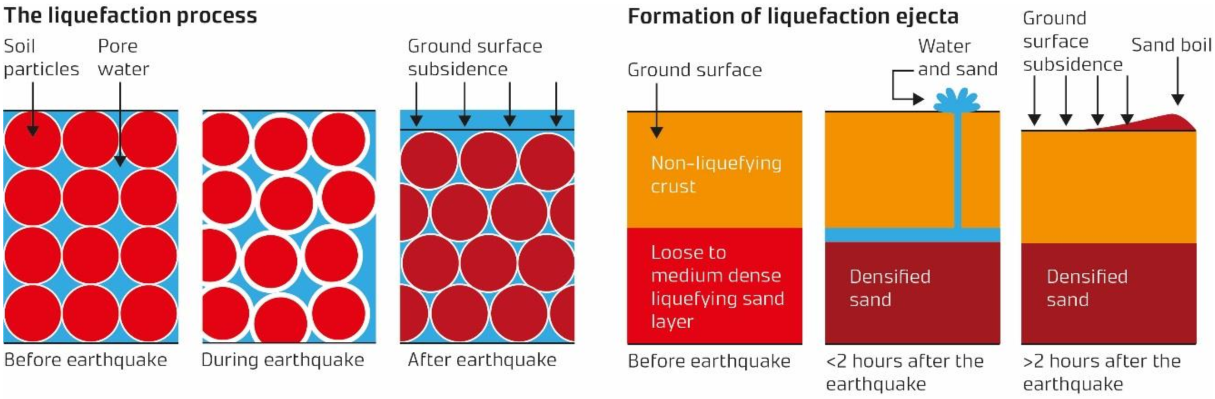

Figure 5-1: Schematic representation of the process of liquefaction and the manifestation of liquefaction ejecta

5.2 Liquefaction susceptibility and triggering

Liquefaction only occurs in some soil types. These are typically soils which are saturated, non-cohesive, and low to moderate permeability. Soil types which are susceptible to liquefaction are listed below:

- Sands and low plasticity/non-plastic silts[14]
- Fine grained low to non-plastic soils with a high moisture content[15,16]
- Young, typically Holocene-aged (≤12,000 years old) deposits

Susceptible soils require a certain level of earthquake shaking in order to trigger liquefaction. Denser soils require more intense and/or longer duration of shaking than those that are less dense.

The trigger level earthquake shaking (in terms of peak ground acceleration (PGA) and magnitude (M)) for each soil layer identified as being susceptible to liquefaction has been assessed by the method proposed by Boulanger and Idriss (2014)[17]. This method is based on the empirical relationship between the CPT tip resistance (q_c) and soil fines content. The trigger PGA and magnitude which has been used is aligned with the site's assessed seismic shaking hazard as described in Section 4.2.

In the Te Tumu Urban Growth Area, the majority of the soils below the groundwater table are susceptible to liquefaction because they are predominantly loose to medium dense sands. The conclusions of the assessment are presented in Section 6 and 7 and the results of the supporting liquefaction and lateral spreading analyses are presented in Appendix D and E.

5.3 Liquefaction consequence

Liquefaction can cause significant damage to land, buildings and infrastructure. A summary of main potential consequences of liquefaction is provided in Table 5.1.While the immediate effects of liquefaction relate primarily to land, building and infrastructure damage, liquefaction can also have a significant social, economic and environmental impact. For example, there is the potential for contamination from ejected soils to present a risk to human health, for the discharge of sediments into waterways, and for community disruption and displacement.

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[14] Bray, J., et al, 2014, "Liquefaction effects on buildings in Central Business District of Christchurch", Earthquake Spectra, 30 (1), 85-109.

[15] Bray J.D. and Sancio R.B., 2006, "Assessment of the liquefaction susceptibility of fine-graded soils", Journal of Geotechnical and Geoenvironmental Engineering, 132 (9), 1165–1177.

[16] Boulanger R.W. and Idriss I.M., 2006, "Liquefaction Susceptibility Criteria for Silts and Clays", Journal of Geotechnical and Geoenvironmental Engineering, 132 (11), 1412–1426.

[17] Boulanger, R.W and Idriss, I.M., 2014. "CPT and SPT based liquefaction triggering procedures." Report No. UCD/CGM-14/01, Center for Geotechnical Modelling, Department of Civil and Environmental Engineering, University of California, Davis, CA, 134 pp.

Table 5.1: Consequences of liquefaction.

Phenomenon	**Description**
Differential settlement	A difference in ground settlement between two points which can cause damage to foundations, services and roads.
Sand and water ejected to the surface (sand boils)	This exacerbates differential settlement, can result in damage to paved and other ground surfaces, reduce clearances under buildings, ingress and block buried pipes, etc.
Reduced support to foundations bearing above the liquefied soil	Bearing capacity of the soil could be reduced resulting in subsidence of foundations.
Buoyancy effects	Liquefaction can result in upward movement (floatation) of manholes, tanks and other buried vessels being subject to buoyancy effects.
Lateral spread	Land above the liquefied soil layer moving either down slope or toward a free edge such as a stream channel. This total and differential lateral movement can cause severe damage to buildings and infrastructure.

5.4 Liquefaction and lateral spreading vulnerability indicators

The vulnerability of land to liquefaction and lateral spreading damage is dependent on the depth to groundwater (i.e. crust thickness), the thickness of liquefiable soils, the level of earthquake shaking, the slope of the ground surface and the proximity to the river edge. The closer the liquefiable soils are to the ground surface, the more vulnerable the land is to damage due to liquefaction. Also, the more sloping the land and the nearer to a river edge the more vulnerable the land is to damage due to lateral spreading.

The vulnerability indicators which have been evaluated to assess the vulnerability of land as a result of liquefaction and lateral spreading at the site is summarised in Table 5.2.

Table 5.2: Liquefaction and lateral spreading vulnerability indicators

Vulnerability Indicator	**Comments and observations from past events**
Depth to groundwater	Observations from Christchurch and Japan indicate that the greater the thickness of the non-liquefying crust the less damage is likely to be reflected at the ground surface. Examples of sand boils and damaging differential settlement are very few for sites with a crust thickness greater than 3 m[18].
Calculated volumetric one dimensional free field settlement (S_{V1D})[19]	In Christchurch, land for proposed residential subdivision development is being delineated into technical categories (TC1 to TC3) depending on its expected performance in the event of liquefaction. Calculated free field settlement is being applied as a parameter to be considered in this delineation. While this guideline is not applicable outside of Christchurch, it can be referred to for indicative purposes. ULS calculated settlement of <25mm implies TC1 and >100 mm implies TC3 foundation solutions for Christchurch.
Liquefaction Severity Number (LSN)[20]	LSN is a parameter which characterises the vulnerability of land to damage due to liquefaction for a given level of shaking and a given groundwater level. This parameter has been correlated with evidence of surface ground damage in Christchurch. A higher LSN value indicates a greater likelihood of surface ground damage. LSN of 0-15 indicates a high likelihood of little to no expression of liquefaction at the ground surface whereas LSN of 16 to 25 indicates a high likelihood of minor to moderate expression of liquefaction at the ground surface and LSN greater than 25 indicates a high likelihood of moderate to severe expression of liquefaction at the ground surface.
Lateral Displacement Index (LDI)[21]	LDI is an index value that can be derived from either CPT or SPT data. While the units are reported in mm, it is intended only to provide an index to quantify potential lateral displacements for a given soil profile, soil properties and earthquake shaking. The actual magnitude of lateral displacement depends on both LDI and geometric parameters that characterise the geometry of the ground.
Lateral Displacements (LD)	LD is an estimate of the expected lateral displacement at the ground surface due to lateral spreading and/or lateral stretch. The magnitude of LD is dependent on the geometric parameters that characterise geometry of the ground and LDI. It has a reported degree of accuracy ranging between 50% and 200%[22] although recent studies have indicated greater uncertainty depending on the local geomorphic conditions[23]. Because it is based on a single CPT point location, the method does not account for the spatial variability of the surrounding land which is a significant source of uncertainty.

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[18] Ishihara, K., 1985. “Stability of natural soil deposits during earthquakes”. International Conference on Soil Mechanics and Foundation Engineering, San Francisco: 321-376.

[19] Zhang, G., Robertson, P. and Brachman, R., 2002. “Estimating liquefaction-induced ground settlements from CPT for level ground”. Canadian Geotechnical Journal, 39(5): 1168-1180.

[20] van Ballegooy, S. et al., 2014. “Assessment of liquefaction-induced land damage for residential Christchurch”. Earthquake Spectra, 30(1): 31-35.

[21] Zhang, G., Robertson, P. K. & Brachman, R. W. I., 2004. “Estimating Liquefaction-Induced Lateral Displacements Using the Standard Penetration Test of Cone Penetration Test”. Journal of Geotechnical and Geoenvironmental Engineering, 8(130): 861-871.

[22] National Academies of Sciences, Engineering, and Medicine, 2016. “State of the Art and Practice in the Assessment of Earthquake-Induced Soil Liquefaction and Its Consequences”. Washington, DC: The National Academies Press.

[23] Russell, J. et al., 2017. “Influence of geometric, geologic, geomorphic and subsurface ground conditions on the accuracy of empirical models for prediction of lateral spreading”. 3rd International Conference on Performance-based Design in Earthquake Geotechnical Engineering, Vancouver.

5.5 Liquefaction-induced land damage

In order to relate land damage to potential building stock damage for the purpose of this assessment, we have referred to Section 2.4 in the newly published MBIE Liquefaction Guidelines[24] and a paper published by Russell et al. (2015)[25]. How the degree of liquefaction-induced land damage relates to LSN is summarised in Table 5.3.

Table 5.3: Degrees of liquefaction-induced land damage and characteristic LSN values

Degree of liquefaction-induced land damage	**Characteristics of liquefaction and its consequences**	**Characteristic LSN**
None to Minor	• None to minor signs of ejected liquefied material at the ground surface. • None or minor differential settlement of the ground surface (e.g. undulations <25mm in height). • No apparent lateral spreading ground movement. • Liquefaction causes no or only cosmic damage to buildings and infrastructure.	<16
Minor to Moderate	• Minor to moderate quantities of ejected material at the ground surface; and/or • Moderate differential settlement of the ground surface (e.g. undulations 25-100mm in height). • No significant lateral spreading ground movement (e.g. ground cracks <50mm and primarily caused by ground oscillation or settlement rather than lateral spreading). • Liquefaction causes moderate but typically repairable damage to buildings and infrastructure.	16-25
Moderate to Severe	• Large quantities of ejected material at the ground surface; and/or • Moderate to severe differential settlement of the ground surface (e.g. undulations >100mm in height); and/or • Significant lateral spreading ground movement (e.g. ground cracks >50mm and primarily caused movement downslope or towards a free-face). • Liquefaction causes substantial damage and disruptions to buildings and infrastructure. Repair may be difficult or uneconomical.	>25

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[24] Ministry of Business Innovation & Employment (MBIE), 2017. "Planning and engineering guidance for potentially liquefaction-prone land". Retrieved from https://www.building.govt.nz/building-code-compliance/b-stability/b1-structure/planning-engineering-liquefaction-land/

[25] Russell, J., et al., 2015. "The Effect of Subsidence on Liquefaction Vulnerability Following the 2010 – 2011 Canterbury Earthquake Sequence". 6th International Conference on Earthquake Geotechnical Engineering, Christchurch.

6 Liquefaction assessment

For a plan change required to inform urban residential development, where liquefaction damage is possible, a calibrated desktop assessment is recommended.[26] The geotechnical investigation density undertaken for this site is consistent with the minimum investigation density requirement for changes to proposed land use (i.e. the investigation density is consistent with a Level B calibrated desktop assessment).

The liquefaction assessment for this report has been undertaken predominantly by analysing the CPT data within the Te Tumu Growth Area. The CPT analysis includes the calculation of LSN, S_{V1D} and the groundwater depth liquefaction vulnerability indicators at each CPT location.

To enable spatial interpretation of the CPT analyses, a series of nine maps was produced showing the calculated liquefaction vulnerability indicators at each CPT location for each combination of earthquake shaking (i.e. 0.2%, 0.1% and 0.033% AEP) and sea level condition (i.e. median GW, 1.25m SLR and 1.9m SLR). These nine maps are presented in Appendix D and the combination of earthquake shaking and sea level rise scenario and their corresponding Figure reference is shown in Table 6.1.

Table 6.1: Figure reference for CPT analysis maps by earthquake return period and sea level rise scenario (refer to Appendix D)

		Sea level Rise		
		Median GW	**1.25m SLR**	**1.9m SLR**
Earthquake return period	**0.2% AEP (500 yr)**	Figure D2	Figure D3	Figure D4
	0.1% AEP (1,000 yr)	Figure D5	Figure D6	Figure D7
	0.033% AEP (3,030 yr)	Figure D8	Figure D9	Figure D10

For presentation purposes the liquefaction vulnerability indicators at each CPT location on the maps in Appendix D have been grouped into bands representing low, medium and high values. These low medium and high bands are coloured green, yellow and red respectively. Further details about each of liquefaction vulnerability indices shown in Appendix D are provided in Table 5.2 and Table 5.3.

The CPT analysis maps have been produced for each combination of earthquake shaking and sea level rise. However, as requested by TCC, the interpretation of these CPT analyses has been undertaken using the proposed ground surface level for only the following five scenarios:

1. 0.2% AEP (i.e. 500yr) using current median groundwater levels (Figure D2)
2. 0.2% AEP (i.e. 500yr) using median groundwater with 1.25 m of sea level rise (Figure D5)
3. 0.2% AEP (i.e. 500yr) using median groundwater with 1.9 m of sea level rise (Figure D8)
4. 0.1% AEP (i.e. 1,000yr) using median groundwater with 1.25 m of sea level rise (Figure D6)
5. 0.033% AEP (i.e. 3,030yr) using median groundwater with 1.9 m of sea level rise (Figure D10)

To achieve the proposed ground surface levels, the existing ground surface will need to be re-levelled. The liquefaction and lateral spreading assessments presented below are based on the assumption that the fill material will be carefully selected and compacted to ensure it is not susceptible to liquefaction. If liquefiable fill is used, then the liquefaction and lateral spreading

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[26] Ministry of Business Innovation & Employment (MBIE), 2017. “Planning and engineering guidance for potentially liquefaction-prone land”. Retrieved from https://www.building.govt.nz/building-code-compliance/b-stability/b1-structure/planning-engineering-liquefaction-land/

assessments would need to be reassessed. Similarly, if the proposed ground surface levels were to change, then the liquefaction and lateral spreading assessments would also need to be reassessed.

The liquefaction assessment results have been presented for each of the landowner blocks identified in Figure A2. Since landowner blocks 'C' and 'H' are very small, no CPT have been obtained within them. As the geology and elevations are similar to landowner block 'B', they have been analysed as part of landowner block 'B'. For the same reasons, landowner block 'G' has been analysed in conjunction with landowner block 'F'. Areas within the Te Tumu Urban Growth Area which are not expected to be developed have not been assessed. Therefore, in total the assessment has been undertaken for five areas.

While these landowner blocks are a suitable and convenient scale for the purposes of this risk assessment, the ground conditions are likely to vary within each block. Therefore, for more detailed assessments (e.g. studies to support sub-division or building consents) consideration of blocks of land that are representative of consistent ground conditions and therefore likely performance should be considered.

6.1 Results

The results in Table 6.2 reflect the expected liquefaction-induced land damage interpreted from the liquefaction vulnerability indices presented on the maps in Appendix D for the five scenarios for each of the five landowner blocks. Where fill is required to attain the desired design ground surface level, the assumption that the fill is non-liquefiable has been made when undertaking the liquefaction assessment.

The presence of a non-liquefying crust at the ground surface is very important in the assessment of liquefaction vulnerability. Observations from Christchurch and Japan demonstrate that the greater the thickness of the non-liquefying crust, the less damage is likely to occur at the ground surface. Within the available literature there are very few case histories of the surface expression of liquefaction ejecta and differential settlement that is damaging to low rise (i.e. 2 storeys or less) residential dwellings for sites with a crust thickness greater than 3 m[27]. In sandy soils that are susceptible to liquefaction, such as those encountered at the site, the thickness of the non-liquefying crust is largely controlled by the depth to the groundwater such that deeper groundwater results in a thicker crust and vice versa.

Some key observations from Table 6.2 are that unsurprisingly, the expected liquefaction-induced land damage of the five blocks increases when the levels of earthquake shaking increase and also when groundwater levels are increased as a result of sea level rise. Landowner block 'F' is the least vulnerable to liquefaction as it has 'none to minor' expected liquefaction-induced land damage for all five scenarios. Landowner block 'D' and 'E' 'none to minor' vulnerability to liquefaction at 500 year levels of earthquake shaking but the vulnerability increases slightly at 1,000 year and 3,030 year levels of earthquake shaking. It is important to note that there are no CPT within these landowner block so only limited CPT around these block have been used for the assessment. Since the groundwater level is generally quite deep in landowner blocks 'D', 'E' and 'F' (i.e. more than 3m below the ground surface) the non-liquefying crust is thicker and the estimated LSN values are generally low in these areas, indicating the surface expression of liquefaction ejecta is unlikely, particularly for 500 year levels of earthquake shaking (i.e. Scenarios 1, 2 and 3). Whereas landowner blocks 'A' and 'B' have shallower groundwater and correspondingly a thinner non-liquefying crust and this is reflected in their greater expected liquefaction-induced land damage, particularly at higher levels of earthquake shaking (i.e. Scenario 4 and 5).

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[27] Ishihara, K., 1985. "Stability of natural soil deposits during earthquakes". International Conference on Soil Mechanics and Foundation Engineering, San Francisco: 321-376.

Table 6.2: Expected liquefaction-induced land damage for the five scenarios.

Liquefaction Assessment Area	Scenario 1 (500yr; no SLR)	Scenario 2 (500yr; 1.25m SLR)	Scenario 3 (500yr; 1.9m SLR)	Scenario 4 (1000yr; 1.25m SLR)	Scenario 5 (3030yr; 1.9m SLR)	Comments
Landowner Block 'A'	None to Minor	None to Minor/ Minor to Moderate	Minor to Moderate	Minor to Moderate	Minor to Moderate/ Moderate to Severe	Shallow groundwater level in parts (i.e. 1m below ground surface); S_{V1D} is up to 150 mm; LSN values for some CPT greater than 25 for Scenario 5.
Landowner Block 'B' (and 'C' and 'H')	None to Minor	None to Minor/ Minor to Moderate	Minor to Moderate	Minor to Moderate	Minor to Moderate/ Moderate to Severe	Shallow groundwater level in parts (i.e. 1.5m below ground surface); S_{V1D} is up to 150 mm; LSN values for some CPT greater than 25 for Scenario 5.
Landowner Block 'D'	None to Minor	None to Minor	None to Minor	None to Minor	None to Minor/ Minor to Moderate	Deeper groundwater levels (i.e. >2.5m below ground surface even with 1.9 m SLR); S_{V1D} is up to 100 mm; LSN values for some CPT greater than 16 for Scenario 5. No CPT have been undertaken within these landowner blocks so the CPT adjacent to these blocks have been used to estimate the adopted LSN values.
Landowner Block 'E'	None to Minor	None to Minor	None to Minor/ Minor to Moderate	None to Minor/ Minor to Moderate	None to Minor/ Minor to Moderate	Deep groundwater levels (i.e. >4m below ground surface even with 1.9 m SLR); potential for global settlement and consolidation at depth due to presence of soft soils; LSN values for some CPT greater than 16 for Scenario 5.
Landowner Block 'F' (and 'G')	None to Minor	None to Minor	None to Minor	None to Minor	None to Minor	Deep groundwater levels (i.e. >3m below ground surface even with 1.9 m SLR); S_{V1D} is up to 120 mm; LSN values for some CPT greater than 16 for Scenario 5. Low-lying land in/around the stream has been excluded from this assessment as assumption is that no development will take place there.

6.2 Options to mitigate the effects of liquefaction at the ground surface

There are various ways in which the effects of liquefaction can be mitigated at the ground surface and three possible options are presented below. The first is to undertake appropriate robust detailing for design of buildings and infrastructure (e.g. MBIE TC2 or TC3 type foundations[28] for buildings and flexible polyethylene for pipelines). The second and third are to undertake ground improvements either locally (i.e. under a building footprint) or on an area wide basis. These three possible options are presented below.

6.2.1 Option 1 – robust foundation design

For this option, a site-specific assessment should be undertaken to estimate potential ground deformation, with buildings designed accordingly. It is important to note that while TC2 or TC3 type equivalent foundations may result in significantly lower differential settlements and hence lower expected building consequence levels, the expected liquefaction-induced land damage would remain 'minor to moderate' or 'moderate to severe' and this would likely result in liquefaction-related damage to surrounding horizontal infrastructure (e.g. roads, sewers, water supply, etc.). Constructing more robust horizontal infrastructure needs to be considered in parallel with enhancements to building foundations. Resilient detailing of buried infrastructure would provide the ability to tolerate moderate ground deformation (e.g. flexible connections between pipelines and buildings), but might not be sufficient to ensure services remain operational at the upper range of expected ground deformations.

T+T understands that the difference in cost between a slab-on-grade and TC2 type equivalent foundation is minimal and this type of foundation is routinely constructed by large building companies operating in the Bay of Plenty Region. Therefore, on land where *liquefaction damage is possible*[29], we recommend that foundations are built using no less than a TC2 type equivalent foundation.

Conversely, the difference in cost between a slab-on-grade and TC3 type equivalent foundation is significant so further assessments should be undertaken to determine whether the additional cost is acceptable to the landowner (the costs of infrastructure also need to be considered).

6.2.2 Option 2 – site-specific ground improvement

For this option, site-specific ground improvements would be undertaken under the building footprint to reduce building differential settlements. The type, depth and extent of ground improvement would be specifically designed to suit each location. The presence of ground improvement means a less robust foundation option could be suitable. However, the requirements for building foundation type and infrastructure will depend on the target building consequence level.

As with Option 1, while ground improvements may result in significantly lower differential settlements and hence lower expected building consequence levels, the expected liquefaction-induced damage to the surrounding land would remain 'minor to moderate' or 'moderate to severe' and this would likely result in liquefaction-related damage to surrounding horizontal infrastructure (e.g. roads, sewers, water supply etc.). Hence, more robust horizontal infrastructure needs to be considered in parallel with enhancements to building foundations.

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[28] Ministry of Business Innovation & Employment (MBIE), 2012. "Repairing and rebuilding houses affected by the Canterbury earthquakes". New Zealand.

[29] "Liquefaction damage is possible" is one of the performance criteria for the categorisation of land damage MBIE guidance document *Repairing and rebuilding houses affected by the Canterbury earthquakes.* Refer to Section 4.5.2 and Table 4.4 of that document for further discussion about recommended performance criteria for liquefaction vulnerability.

6.2.3 Option 3 – area wide ground improvement

For this option, shallow ground improvement would be undertaken across a large area, with a typical depth of between 3 – 6 m. The type of ground improvement used would be selected to suit the specific circumstances, but given the large areas to be treated this would likely need to be a lower-cost higher-speed improvement technique such as dynamic compaction. Some types of ground improvement result in a significant lowering of the ground level (e.g. by up 0.5 m) due to compaction of the underlying soil, meaning that a greater volume of fill material would be required to raise the land to the target finished level.

Similarly to Option 2, the presence of ground improvement means a less robust foundation option could be suitable but once again, the requirements for building foundation type and infrastructure will depend on the target building consequence level.

6.3 Alternate liquefaction mitigation options

The liquefaction mitigation options presented above are preliminary estimates based on the ground investigations and analysis undertaken to date. They are included as part of this risk assessment to demonstrate possible solutions that could be used to mitigate liquefaction hazard at the site. Alternate liquefaction mitigation options may be suitable for the site and the specific requirements in each part of the Te Tumu Urban Growth Area will need to be confirmed following more detailed investigation and assessment at the subdivision and building design stages.

7 Lateral spreading assessment

The lateral spreading assessment has been undertaken in accordance with the method presented in Zhang et al. (2004)[30] and the case studies presented in Cubrinovski (2015)[31]. The Zhang (2004) methodology involves the calculation of the Lateral Displacement Index (LDI) and estimation of lateral displacement. The Cubrinovski (2015) case studies provide an insight into the likely failure mechanism and likely extent of lateral spreading by characterising and comparing the soil profiles with existing case studies of lateral spreading.

The potential for earthquake-induced lateral spreading to occur is typically greatest for land adjacent to free-faces such as riverbanks and terrace edges. The proposed finished ground surface for the Te Tumu Urban Growth Area includes five such areas. The areas susceptible to lateral spreading are identified in Figure 7-1 and Figure E1 in Appendix E and are referred to herein as:

- River Plain – the low lying river plain directly north of the Kaituna River
- River Fill – the edge of the fill north of the Kaituna River
- Stream – Wairakei stream which runs parallel to Papamoa Beach
- Pond (west) – the pond located in the western part of the site
- Pond (east) – the pond located in the eastern part of the site

Figure 7-1: Map showing the potential lateral spread areas. *Source: Google Earth*

Away from these identified locations, there are some areas within the Te Tumu Urban Growth Area where gentle slopes in the proposed finished ground level have the potential to cause minor lateral

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[30] Zhang, G., Robertson, P. K. & Brachman, R. W. I., 2004. "Estimating Liquefaction-Induced Lateral Displacements Using the Standard Penetration Test of Cone Penetration Test". Journal of Geotechnical and Geoenvironmental Engineering, 8(130): 861-871.

[31] Cubrinovski, M. & Robinson, K., 2015. "Lateral spreading: evidence and interpretation from the 2010-2011 Christchurch earthquakes". 6th International Conference on Earthquake Geotechnical Engineering, Christchurch.

ground movements in an earthquake. The proposed DEM provided to us indicates that the variation in finished ground level is typically small (in the order of 1 to 2 m) with the groundwater depth significantly deeper (on average about 4 m below the ground surface). Because of this, the consequences are likely to be minor (i.e. the magnitude of ground stretch is expected to be within the deformation tolerance of robust foundation and infrastructure options). Therefore, these areas of potential minor ground stretching have specifically been excluded as part of this lateral spreading assessment, however the potential for these ground movements to occur reinforces the importance of specifying appropriately robust detailing for buildings and infrastructure.

In a similar manner to the maps presented in Appendix D and discussed in Section 6, the maps presented in Appendix E have been prepared to enable spatial interpretation of the CPT analysis undertaken for the lateral spreading assessment. These maps present LDI and LD values at each CPT location grouped into bands representing low, medium and high values. These low medium and high bands are coloured green, yellow and red respectively. Further details about the LDI and LD liquefaction vulnerability indices are provided in Table 5.2.

As requested by TCC, the lateral spreading assessment has been undertaken using the proposed ground surface level for the following five scenarios:

1 0.2% AEP (i.e. 500yr) using current median groundwater levels (Figure E3)

2 0.2% AEP (i.e. 500yr) using median groundwater with 1.25 m of sea level rise (Figure E4)

3 0.2% AEP (i.e. 500yr) using median groundwater with 1.9 m of sea level rise (Figure E5)

4 0.1% AEP (i.e. 1,000yr) using median groundwater with 1.25 m of sea level rise (Figure E6)

5 0.033% AEP (i.e. 3030yr) using median groundwater with 1.9 m of sea level rise (Figure E7)

It is important to note that the 3,030 year return period earthquake event (i.e. PGA = 0.53g and M = 6) has a comparable intensity of shaking to the 22 February 2011 Christchurch earthquake and therefore, case studies from this event provide useful insights into the likely performance during Scenario 5.

7.1 Results

A summary of the lateral spreading assessment for the five scenarios and for the five areas identified as having the most significant potential for earthquake-induced lateral spreading is presented in Table 7.1. More detailed result tables for each of the scenarios are also presented in Appendix E. The LDI values have been calculated at the CPT locations while the LD values have been calculated at 50 m, 100 m and 150 m offsets from the free-face. The maps presenting the lateral spreading assessment results can also be found in Appendix E.

Table 7.1: Lateral spreading assessment results for the five scenarios.

Area Susceptible to Lateral Spread	Description	Scenario 1		Scenario 2		Scenario 3		Scenario 4		Scenario 5	
		LDI[32] Range	LDI Median	LDI Range	LDI Median	LDI Range	LDI Median	LDI Range	LDI Median	LDI Range	LDI Median
River Plain	Very shallow groundwater level (i.e. within 0.5 m of the ground surface); some silty/organic soils in upper 2-3 m of soil profile; height of free-face is between 4.5-6 m.	430-1030	600	430-1030	600	470-1030	600	530-1140	650	640-1230	730
River Fill	Groundwater level is between 3-4.5 m below ground surface; soil profile consists of proposed new fill in the upper 2-4 m with clean sand below it; height of free-face is between 4.5-6 m.	40-360	180	40-590	240	40-690	290	40-760	360	60-920	530
Stream	Groundwater level ranges between 0.5-3 m below ground surface; soil profile is clean sand; height of free-face is between 5-7.5 m.	90-820	220	110-1060	350	110-1130	460	150-1180	550	200-1360	730
Pond (west)	Groundwater level is about 2 m below ground surface; soil profile is clean sand; height of free-face is between 5.5-6.5 m.	130-350	200	190-630	300	260-760	370	280-780	470	460-980	650
Pond (east)	Groundwater level ranges between 3.5-4 m below ground surface; soil profile consists 0-5 m of fill with clean sand below it; height of free-face is between 5.5-7.5 m.	80-270	110	90-370	210	110-370	230	160-490	380	350-630	530

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[32] LDI is an index value that can be derived from either CPT or SPT data. While the units are reported in mm, it is intended only to provide an index to quantify potential lateral displacements for a given soil profile, soil properties and earthquake shaking. The actual magnitude of lateral displacement depends on both LDI and geometric parameters that characterise the geometry of the ground.

While the LDI and LD values indicate that the areas are vulnerable to lateral spreading, it is important to note that there are substantial uncertainties involved in predicting the extent and magnitude of lateral spreading. Recent publications have collated observations from various earthquakes and demonstrated that the actual lateral spread displacements typically range between 50% and 200% of the magnitude predicted using current semi-empirical correlations[33]. They also highlight that these correlations have been developed based on a limited number of case studies, which can restrict their range of applicability. Preliminary findings from Russell et al. (2017) indicate a higher degree of uncertainty and that geomorphology is a significant factor in the accuracy of the Zhang (2004) method[34].

To help address some of these limitations with calculation-based predictions of lateral spreading, we have also undertaken a qualitative assessment which compares the soil profiles across the site with comparable case studies presented in Cubrinovski (2015).

The results in Table 7.1 indicate that all five areas are vulnerable to lateral spreading for all five scenarios using both the Zhang et al. (2004) and Cubrinovski (2015) approaches. Four of the areas (River Fill, Steam, Pond (west) and Pond (east)) all have very similar sub-surface profiles. The River Plain has a slightly different sub-surface profile because there are silty and organic soils present close to the ground surface and the groundwater table is very close to the ground surface.

The River Fill, Stream, Pond (west) and Pond (east) areas all have clean sand profiles and a thick non-liquefying cap which consists of either clean sand or fill, both of which are not expected to be cohesive. A comparison with case studies from the 2010 – 2011 Canterbury earthquakes presented in Cubrinovski (2015) suggests that in the event of a large earthquake, lateral spreading in these areas is mainly expected to result in moderate displacement[35]. This is because the soil profiles in these four lateral spread areas are most consistent with the soil profiles of the case studies which experienced moderate lateral spread displacements. They have a continuous liquefiable layer below the groundwater level with dense non liquefiable sand at depth. The main difference between the soil profiles in the Te Tumu area and those in Christchurch is the thickness of the non-liquefiable crust. Te Tumu will have a much thicker non-liquefiable crust, predominantly consisting of fill. The crust is expected to be non-cohesive and hence reduce the likelihood for large lateral spread displacements resulting from formation of water film layers.

The LDI and LD results for the River Fill, Steam, Pond (west) and Pond (east) areas are in the same order of magnitude for each scenario (refer to Tables E1 to E5 in Appendix E). While the LDI and LD values are lower for Scenarios 1 to 3 than they are for Scenarios 4 and 5, the liquefaction assessment for all five scenarios indicates a continuous liquefiable layer close to the bottom of the free-face. This continuous liquefiable layer is likely to cause lateral spreading towards the free-face. Figure 7-2 shows a simplified example of a cross section of Wairakei Stream where the continuous liquefiable layer can be inferred from the CPT analyses.

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[33] National Academies of Sciences, Engineering, and Medicine, 2016. “State of the Art and Practice in the Assessment of Earthquake-Induced Soil Liquefaction and Its Consequences”. Washington, DC: The National Academies Press.

[34] Russell, J. et al., 2017. “Influence of geometric, geologic, geomorphic and subsurface ground conditions on the accuracy of empirical models for prediction of lateral spreading”. 3rd International Conference on Performance-based Design in Earthquake Geotechnical Engineering, Vancouver.

[35] See Figure 8 of Cubrinovski, M. & Robinson, K., 2015. “Lateral spreading: evidence and interpretation from the 2010-2011 Christchurch earthquakes”. 6th International Conference on Earthquake Geotechnical Engineering, Christchurch.

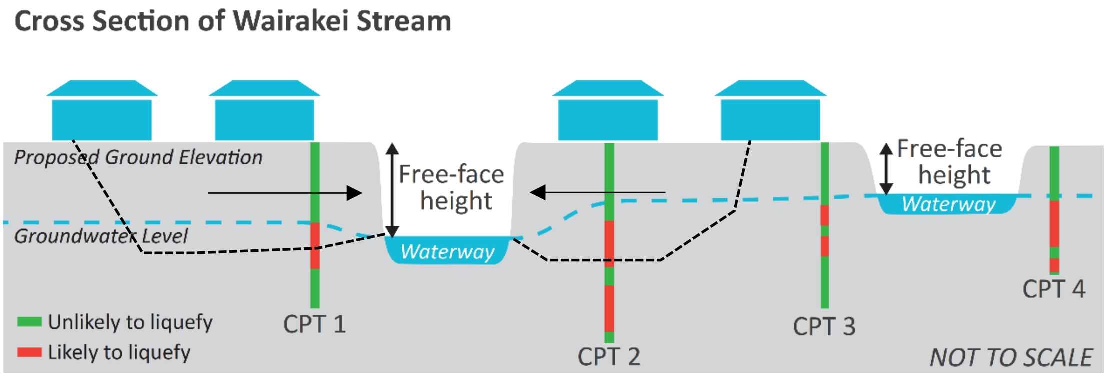

Figure 7-2: Cross section of Wairakei Stream showing example of lateral spreading assessment results.

The example CPTs in Figure 7-2 all show a layer of material below the groundwater table and close to the bottom of the free-face which is likely to liquefy. Given the similarity between all of the soil profiles inferred from the CPTs in the Te Tumu Urban Growth Area, it is reasonable to assume that a continuous liquefiable layer exists at depth across the site.

To check whether or not the failure mechanisms as a result of lateral spreading were realistic for the given the soil conditions, sliding block analyses of representative cross-sections were undertaken. The results from the CPTs with the highest LDI values were used to verify if the order of magnitude of displacement estimated using the Zhang et al. method (2004) were appropriate. The checks confirmed that moderate lateral displacements are expected following the five scenarios assessed above.

7.2 Options to mitigate the effects of lateral spreading

There are various ways in which the effects of lateral spreading can be mitigated. This can be done by applying a large (conservative) setback distance from the free-face, applying a medium setback with appropriate robust detailing for design of buildings and infrastructure, undertaking ground improvements or filling the ponds and/or stream. Five possible options are presented below.

7.2.1 Option 1 – large setback

For this option, a setback of approximately 150 m from the edge of the free-faces would be established. Beyond this setback distance, lateral ground stretch following a large seismic event is expected to be less than 100 mm over a distance of 20 m. This magnitude of ground stretch is likely to be readily accommodated by appropriately robust detailing for design of buildings and infrastructure (e.g. MBIE TC2 type foundations[36] for buildings and flexible polyethylene for pipelines). This option is presented in Figure 7-3.

Within the setback distance consideration of how to appropriately manage the effects of ground deformation will be required and specific design for buildings and infrastructure will likely be necessary. Possible management approaches might include accepting the risk of damage due to ground deformation; providing robust readily-repairable detailing to limit the consequences of ground deformation; or implementing localised measures to limit the ground deformation.

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[36] Ministry of Business Innovation & Employment (MBIE), 2012. “Repairing and rebuilding houses affected by the Canterbury earthquakes”. New Zealand.

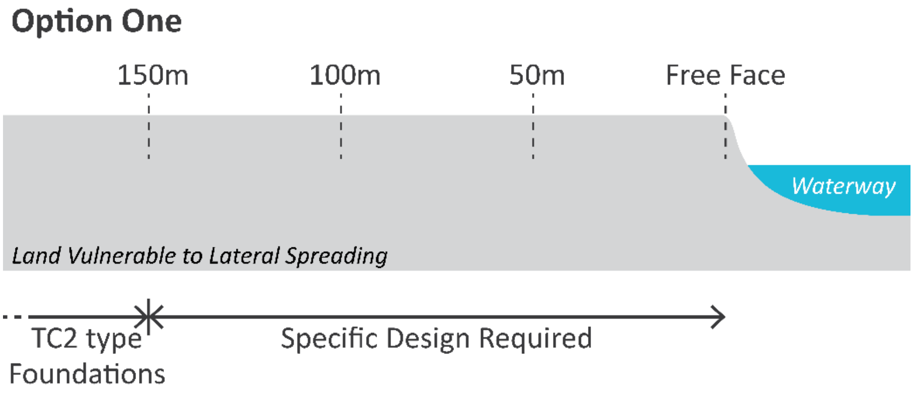

Figure 7-3: Lateral spreading mitigation Option 1 involves applying a large set-back distance.

7.2.2 Option 2 – medium setback with deformation-tolerant design

For this option, all buildings and infrastructure would be located with a setback of approximately 100m from the edge of the free-faces, with design requirements varying depending on the distance from the edge (see Figure 7-4).

Between 100 and 150 m from the edge of the free-face, a site-specific assessment would need to be undertaken to estimate potential ground deformation, with buildings and infrastructure designed accordingly. Depending on the specific details at each location, predicted lateral ground stretch following a large seismic event might typically range between 100 and 500 mm over a distance of 20 m.

This magnitude of ground deformation is within the design limits for several MBIE TC3 type foundation options. Resilient detailing of buried infrastructure would provide the ability to tolerate moderate ground stretching (e.g. flexible connections between pipelines and buildings), but might not be sufficient to ensure services remain operational at the upper range of expected ground deformations. When comparing the merits of the various options, it should be recognised that while this approach of using robust readily-repairable detailing to tolerate ground deformations satisfies Building Code requirements, it presents greater potential for short and long-term community disruption than alternative options which seek to avoid or reduce ground deformations altogether.

Beyond 150 m from the edge, the same requirements would apply as outlined for Option 1 above. It is recommended that major roads and infrastructure lines be located beyond this 150 m setback where possible.

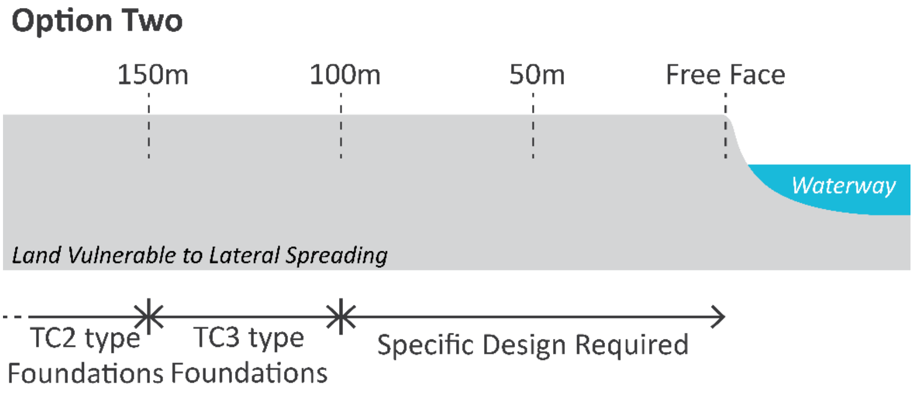

Figure 7-4: Lateral spreading mitigation Option 2 involves applying a medium set-back distance.

7.2.3 Option 3 – deep perimeter ground improvement

For this option, deep ground improvement would be undertaken along a strip of ground beside the free-face (see Figure 7-5). This block of strengthened ground helps to resist lateral spreading forces imposed by the adjacent ground and thus reduces ground deformations.

The type, depth and extent of ground improvement would be specifically designed to suit each location. Where this approach has been adopted previously elsewhere around New Zealand, the ground improvement block is typically between 6 – 12 m deep and 15 – 40 m wide.

The requirements for buildings and infrastructure will depend on the target performance adopted for design of the ground improvement. If the design aims to limit ground displacements to a small magnitude (e.g. less than 100 mm at the free-face) then MBIE TC2 type foundations might be appropriate. If a less stringent target performance is adopted (e.g. 300 mm displacement at the free-face), then more robust foundations and/or a larger setback would likely be required.

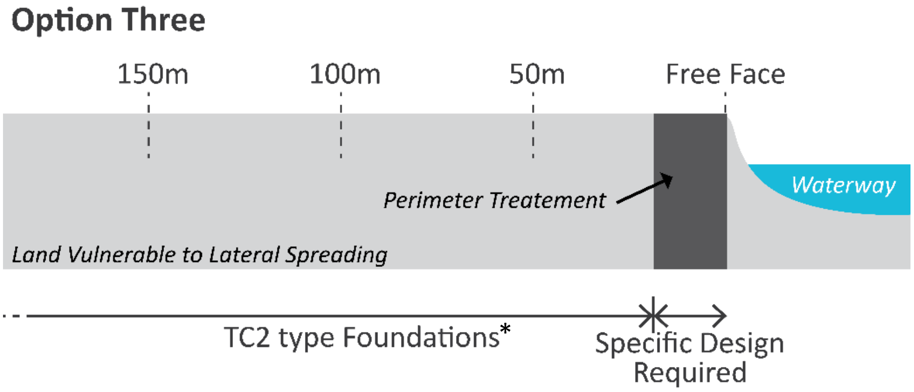

*Figure 7-5: Lateral spreading mitigation Option 3 involves undertaking deep perimeter ground improvement. *Indicating TC2 foundations assumes that the ground treatment is designed to limit ground deformations to values appropriate for TC2 foundations. Alternatively, ground treatment could be designed to a higher or lesser standard and other foundation types adopted.*

Within the zone of perimeter treatment specific design would be required for any foundation systems adopted. The entire footprint of any buildings or infrastructure constructed within the vicinity of the perimeter treatment should preferably be contained either entirely within the area of perimeter treatment or entirely outside of the area of perimeter treatment. Buildings or infrastructure should not be constructed such that they straddle the boundary of the treated area, unless they are specifically designed to tolerate the differential ground settlement and lateral stretch that could occur.

7.2.4 Option 4 – area wide ground improvement

For this option, shallow ground improvement would be undertaken across a large area. Depending on the specific details of the design, this might comprise either a very wide strip adjacent to the free-face (e.g. 150 m wide) or improvement across the entire site, with a typical depth of between 3 – 6 m. This option is presented in Figure 7-6.

The type of ground improvement used would be selected to suit the specific circumstances, but given the large areas to be treated this would likely need to be a lower-cost higher-speed improvement technique such as dynamic compaction. Some types of ground improvement result in a significant lowering of the ground level (e.g. by up 0.5 m) due to compaction of the underlying soil, meaning that a greater volume of fill material would be required to raise the land to the target finished level.

Similarly to Option 3, the design requirements and setbacks for buildings and infrastructure will depend on the target performance adopted for design of the ground improvement.

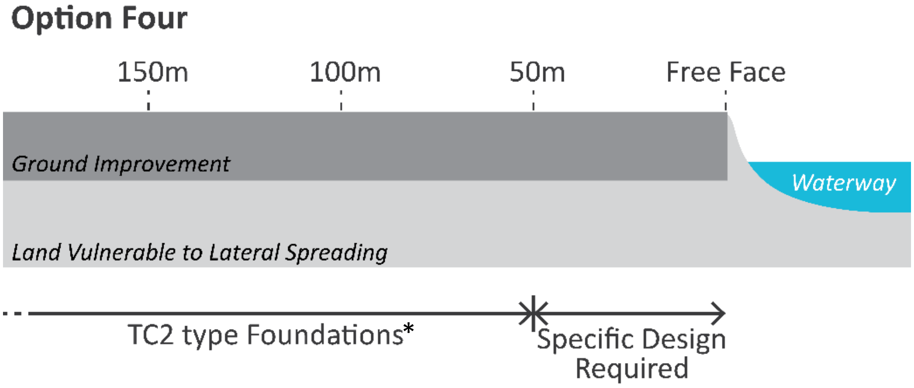

*Figure 7-6: Lateral spreading mitigation Option 4 involves undertaking area wide ground improvement. *Indicating TC2 foundations assumes that the ground treatment is designed to limit ground deformations to values appropriate for TC2 foundations. Alternatively, ground treatment could be designed to a higher or lesser standard and other foundation types adopted.*

7.2.5 Option 5 – fill ponds and/or stream

For this option, the ponds and/or streams would be filled, removing the presence of a free-face. The fill would need to be designed appropriately to ensure it performs in a consistent manner with adjacent land under earthquake shaking. Ground improvements, similar to those described in Option 4, may still be required to mitigate the potential effects of liquefaction.

7.2.6 General requirements for all options

For each of the options described, it is recommended that drainage blankets be installed at the base of the fill. In the event of an earthquake, this would help to reduce the build-up of excess pore water pressure which creates a water film layer. This water film layer provides a plane of weakness which increases the likelihood of lateral spread occurring.

7.3 Summary of lateral spread mitigation options

Table 7.2 below presents our preliminary assessment of the foundation requirements expected to generally apply for each of the lateral spread mitigation options listed above (Sections 7.2.1 to 7.2.5) and a given set-back distance. The matrix has been prepared by considering a lightweight (both cladding and roofing material) residential dwelling 1 – 2 storeys in height.

Specific design, which will likely result in the adoption of a more robust foundation solution, will be required for other building types such as: heavy weight residential dwellings; residential dwellings greater than 2 storeys in height; multi-unit buildings (e.g. terraced houses); and non-residential (e.g. commercial/educational/recreational) buildings.

Note that this matrix has been prepared as a preliminary land use planning tool to assist TCC with their assessment of the proposed Te Tumu development. It does not present the final foundation options for the site and more detailed engineering assessment will be required as the development progresses through subdivision and building consent stages.

Table 7.2: Foundation matrix for lightweight 1-2 storey residential building[1]

Lateral Spread Mitigation Option	0 - 50 m set-back distance	50 - 100 m set-back distance	100 - 150 m set-back distance	Greater than 150 m set-back distance
Option 1 – large set back	Specific foundation design	Specific foundation design	Specific foundation design	TC2 foundation
Option 2 – medium set back with deformation tolerant design	Specific foundation design	Specific foundation design	TC3 foundation	TC2 foundation
Option 3 – deep perimeter ground improvement	TC2 foundation[2 3]	TC2 foundation[3]	TC2 foundation	TC2 foundation
Option 4 –area wide ground improvement	Specific foundation design	TC2 foundation[3]	TC2 foundation	TC2 foundation
Option 5 – fill ponds and/or stream	TC2 foundation	TC2 foundation	TC2 foundation	TC2 foundation

[1] As an alternative to the foundation options presented specific foundation design can be undertaken to suit the specific site conditions.

[2] With deep perimeter treatment it is possible to build up to the free face. However, this would be limited by the need to ensure that dwellings are not constructed partially on and partially off the zone of perimeter treatment. Differential settlement may occur in future earthquakes if dwellings are allowed to straddle this area. Either the zone of perimeter treatment needs to be sufficiently wide to cover the first row of properties adjacent to the free face or the set-back distance should be the width of the perimeter treatment with a small buffer distance (typically 2 m).

[3] Indicating TC2 foundations assumes that the ground treatment is designed to limit ground deformations to values appropriate for TC2 foundations. Alternatively, ground treatment could be designed to a higher or lesser standard and other foundation types adopted.

7.4 Alternate lateral spread mitigation options

The setback distances, ground displacement estimates and foundation solutions outlined for the various lateral spread mitigation options above are preliminary estimates based on the ground investigations and analysis undertaken to date. They are included as part of this risk assessment to demonstrate possible solutions that could be used to mitigate lateral spread hazard at the site. Alternate lateral spread mitigation options may be suitable for the site and the specific requirements in each part of the Te Tumu Urban Growth Area will need to be confirmed following more detailed investigation and assessment at the subdivision and building design stages.

8 Risk assessment in accordance with BOP RPS

8.1 General

The results generated from the liquefaction and lateral spreading assessments presented in Sections 6 and 7 respectively have been used to undertake a natural hazard risk assessment in accordance the natural hazard provisions of the BOP RPS[37], Appendix L. In Appendix L a method is presented whereby the risk exposure of a particular area to a given hazard can be evaluated. This risk assessment has been undertaken for residential buildings with some additional commentary on lifeline utilities and health and safety.

For this study the risk associated with liquefaction and lateral spread hazards in the Te Tumu Urban Growth Area has been assessed for each of the different landowner blocks. The extent of the each of the different landowner parcels within Te Tumu is shown in in Figure A2 of Appendix A. While these landowner blocks provide a suitable and convenient scale for the purposes of this risk assessment, the ground conditions are likely to vary within each block. Therefore, for more detailed assessments (e.g. studies to support sub-division or building consents) consideration of blocks of land that are representative of consistent ground conditions and therefore likely performance should be considered.

T+T understands that the proposed DEM for the Te Tumu area has been modified since the analyses presented in the draft report dated August 2017 were undertaken. Changes to that DEM may have an impact on the validity of the liquefaction and lateral spread analyses undertaken and this may also impact on the risk assessment. T+T's liquefaction and lateral spread analyses and the associated risk assessment are only valid for the DEM provided by TCC (dated 17 May 2015). We would be happy to review the DEM once finalised and provide commentary about the implications of these changes on the liquefaction and lateral spread analyses and the corresponding risk assessments. The work completed to date provides an excellent framework to undertake this review.

8.2 Event likelihood

Table 8.1 below is taken from the RPS Natural Hazards Risk Assessment User Guide[38] and shows that earthquake events with annual exceedance probabilities of 0.1, 0.2 and 0.033 percent (1,000 year ARI, 500 year ARI and 3,300 year ARI, respectively), should be considered in a risk based assessment. In total five scenarios, as described in Section 6, have been considered for this risk assessment which include allowances for sea level rise as described in Section 3.3.

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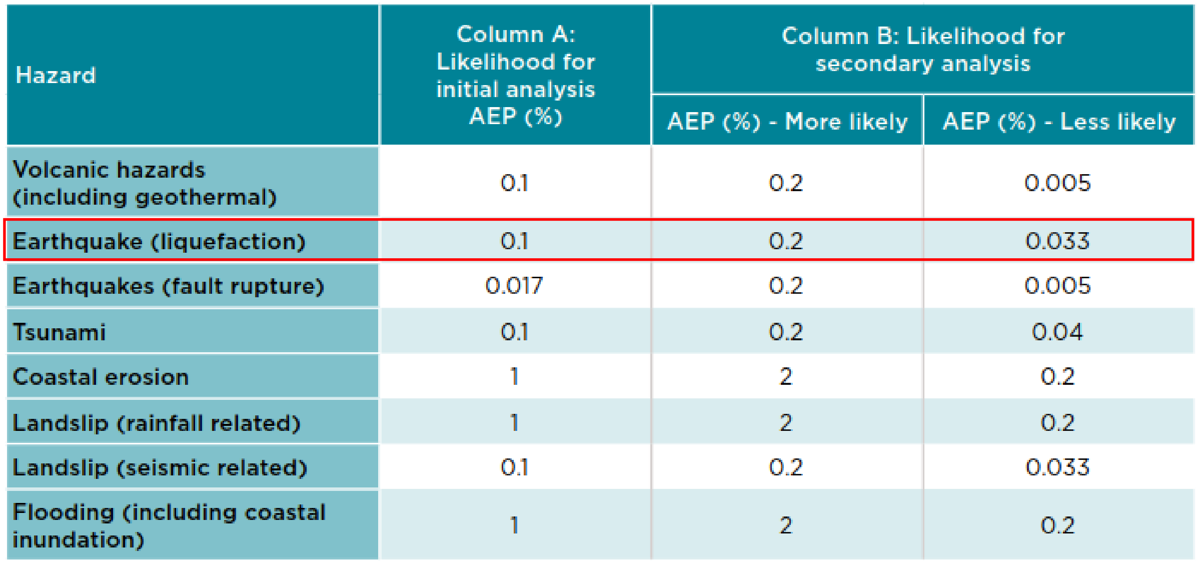
[37] Bay of Plenty Regional Council, 2016. "Operative Regional Policy Statement for the Bay of Plenty." Retrieved from https://www.boprc.govt.nz/plans-policies-and-resources/policies/operative-regional-policy-statement/

[38] Bay of Plenty Regional Council, 2016. "Natural Hazard Risk Assessment User Guide." Retrieved from https://www.boprc.govt.nz/plans-policies-and-resources/policies/operative-regional-policy-statement/

Table 8.1: Event Probabilities for Analysis (taken from RPS Natural Hazards Risk Assessment User Guide)



Hazard	Column A: Likelihood for initial analysis AEP (%)	Column B: Likelihood for secondary analysis	
		AEP (%) - More likely	AEP (%) - Less likely
Volcanic hazards (including geothermal)	0.1	0.2	0.005
Earthquake (liquefaction)	0.1	0.2	0.033
Earthquakes (fault rupture)	0.017	0.2	0.005
Tsunami	0.1	0.2	0.04
Coastal erosion	1	2	0.2
Landslip (rainfall related)	1	2	0.2
Landslip (seismic related)	0.1	0.2	0.033
Flooding (including coastal inundation)	1	2	0.2

8.3 Hazard Susceptibility Area (HSA)

The Hazard Susceptibility Area (HSA) is defined as the maximum spatial extent of a particular hazard. For this liquefaction and lateral spreading risk assessment this was defined as the entire extent of the post-developed terrain because the majority of the soils underlying the site are susceptible to liquefaction (refer to Section 5).

8.4 Building risk assessment

This building risk assessment follows the method presented for Primary Analysis (Steps 1-4) of the BOP RPS. It does not include the method presented for Secondary Analysis (Step 5) which incorporates the calculation of Annual Individual Fatality Risk (AIFR). The commentary on health and safety provided in Section 8.6 discusses the likelihood of death and injury associated with liquefaction and lateral spreading hazards.

8.4.1 Compromised functionality

In order to undertake a risk assessment as described in Appendix L of the BOP RPS, consideration needs to be given to the definition of "functionally compromised." In the context of buildings the BOP RPS provides some guidance when it defines "functionally compromised" as "…will generally occur when a building cannot continue to be used for its intended use immediately after an event". The methodology then allows for judgement as to the nature and duration of loss of functioning.

The New Zealand Building Code establishes a similar concept through objective B1.1(b) that a building is to have a low probability of "loss of amenity" during its life. Amenity is defined in the Code as "…an attribute of a building which contributes to the health, physical independence and well-being of the building's user but which is not associated with disease or a specific illness."

The MBIE guidance document "Repairing and rebuilding houses affected by the Canterbury earthquakes" [39]defines loss of amenity as the exceedance of the following tolerable impact:

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[39] Ministry of Business Innovation & Employment (MBIE), 2012. "Repairing and rebuilding houses affected by the Canterbury earthquakes". New Zealand.

"All parts of the structure shall remain functional so that the building can continue to perform its intended purpose. Minor damage to structure. Some damage to building contents, fabric and lining. Readily repairable. Building accessible and safe to occupy. No loss of life. No injuries..."

For the purposes of this assessment we have considered "functionally compromised" as synonymous with "loss of amenity" as defined above.

One of the key performance measures in the definition above is the terminology of "readily repairable." The MBIE guidance document defines this as "…repairable without relocation of occupants for more than four weeks." Therefore, with respect to the duration of loss of functionality, we have assumed that a "functionally compromised" building will be damaged beyond a "readily repairable" state i.e. it will require relocation of the occupants for more than four weeks to undertake necessary repair.

It is important to note that for this risk assessment we have only considered the performance of the residential buildings, and not the lifelines and utilities associated with the building. There are instances where the building consequence levels could be deemed insignificant or minor, but due to poor performance of the surrounding lifelines and utilities the functionality of the building could be compromised. These instances have not been accounted for as part of this assessment. Refer to Section 8.5 for further commentary on lifelines and utilities.

8.4.2 Building density

TCC have asked T+T to compare the effect on risk levels of assuming two different levels of building density; specifically 15 and 24 buildings per hectare. However, unlike other hazards such as flood and tsunami, the density of buildings typically does not have a significant and measurable impact on the level of risk provided that the same building type is constructed for each case.

For this risk assessment we have made the following assumptions about the buildings constructed on the site:

1. The buildings will be no more than 2 stories high and constructed of lightweight materials (e.g. timber cladding and frame and steel roof)
2. The buildings will be freestanding (i.e. not large multi-unit buildings)

The first assumption is important because it minimises the weight of the building. Experience in Christchurch following the Canterbury Earthquake Sequence (CES) is that under the same ground conditions heavier buildings are more likely than lightweight buildings to sustain damage by settling into the ground either uniformly or differentially. A guiding principle of the MBIE guidance document is that *"…to mitigate the effects of liquefaction…it is preferable to build using lightweight materials rather than heavy materials."*[40]

The second assumption is important because free standing dwellings with relatively small footprints are less susceptible to the effects of lateral stretch than multi-unit buildings with relatively large footprints. This is because the comparatively large area of a multi-unit building means that a larger magnitude of lateral stretch is likely to occur across the building footprint. As a result, it is more likely for significant cracking to occur within the foundation of a multi-unit building in ground where lateral stretching occurs.

For the lower building density of 15 buildings per hectare it seems reasonable to assume that both of these conditions will be able to be met. However, for the higher building density of 24 buildings per hectare it may be difficult to achieve these conditions. If these conditions cannot be met, it will

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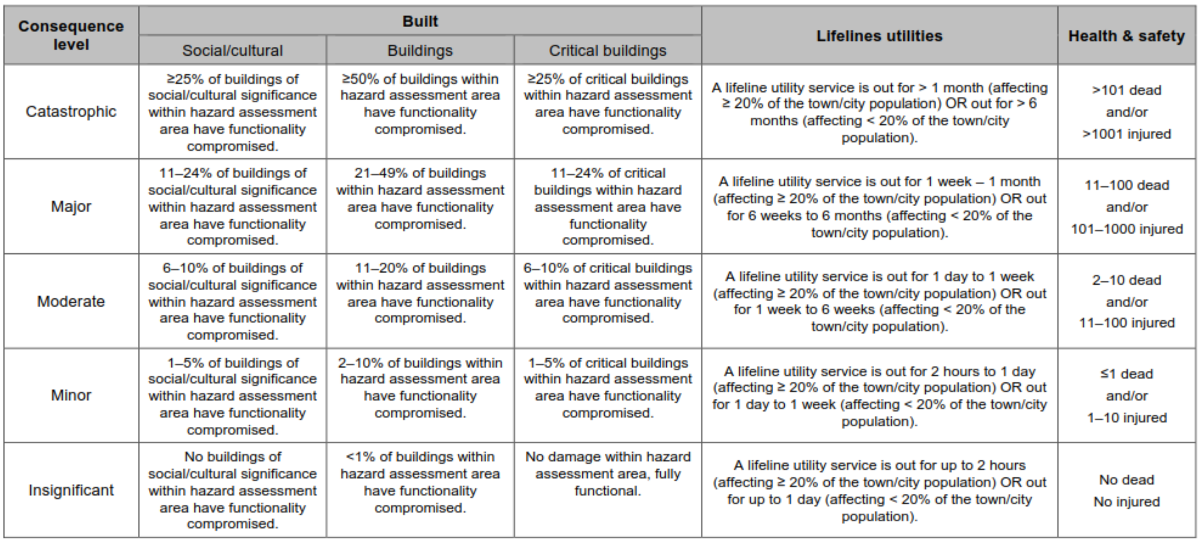
[40] Ministry of Business Innovation & Employment (MBIE), 2012. "Repairing and rebuilding houses affected by the Canterbury earthquakes". New Zealand.

impact on the validity of this risk assessment and the process should be revisited with more detail about the proposed design of the buildings to be constructed.

8.4.3 Liquefaction risk assessment

The liquefaction vulnerability of the five sites needs to be considered in accordance with the liquefaction hazard risk assessment presented in the BOP RPS and more specifically, the consequence table (Table 21 in Appendix L of the BOP RPS) represented in Figure 8-1 below. Given the Te Tumu Urban Growth Area is intended to be re-zoned to 'Residential', the consequence levels have only been considered for residential dwellings and not critical buildings or buildings of social/cultural importance.



Consequence level	Built			Lifelines utilities	Health & safety
	Social/cultural	Buildings	Critical buildings		
Catastrophic	≥25% of buildings of social/cultural significance within hazard assessment area have functionality compromised.	≥50% of buildings within hazard assessment area have functionality compromised.	≥25% of critical buildings within hazard assessment area have functionality compromised.	A lifeline utility service is out for > 1 month (affecting ≥ 20% of the town/city population) OR out for > 6 months (affecting < 20% of the town/city population).	>101 dead and/or >1001 injured
Major	11–24% of buildings of social/cultural significance within hazard assessment area have functionality compromised.	21–49% of buildings within hazard assessment area have functionality compromised.	11–24% of critical buildings within hazard assessment area have functionality compromised.	A lifeline utility service is out for 1 week – 1 month (affecting ≥ 20% of the town/city population) OR out for 6 weeks to 6 months (affecting < 20% of the town/city population).	11–100 dead and/or 101–1000 injured
Moderate	6–10% of buildings of social/cultural significance within hazard assessment area have functionality compromised.	11–20% of buildings within hazard assessment area have functionality compromised.	6–10% of critical buildings within hazard assessment area have functionality compromised.	A lifeline utility service is out for 1 day to 1 week (affecting ≥ 20% of the town/city population) OR out for 1 week to 6 weeks (affecting < 20% of the town/city population).	2–10 dead and/or 11–100 injured
Minor	1–5% of buildings of social/cultural significance within hazard assessment area have functionality compromised.	2–10% of buildings within hazard assessment area have functionality compromised.	1–5% of critical buildings within hazard assessment area have functionality compromised.	A lifeline utility service is out for 2 hours to 1 day (affecting ≥ 20% of the town/city population) OR out for 1 day to 1 week (affecting < 20% of the town/city population).	≤1 dead and/or 1–10 injured
Insignificant	No buildings of social/cultural significance within hazard assessment area have functionality compromised.	<1% of buildings within hazard assessment area have functionality compromised.	No damage within hazard assessment area, fully functional.	A lifeline utility service is out for up to 2 hours (affecting ≥ 20% of the town/city population) OR out for up to 1 day (affecting < 20% of the town/city population).	No dead No injured

Figure 8-1: Consequence table with qualitative and quantitative descriptions (Source: Table 21, Appendix L, BOP RPS)

In order to relate liquefaction land damage to the risk assessment outlined in the BOP RPS and more specifically the consequence levels for residential dwelling, the estimated liquefaction-induced land damage results from Table 6.2 have been correlated with the building consequence levels in the BOP RPS. The correlation between expected land performance and expected building performance is dependent on the dwelling foundations assumed. Therefore, the correlation has been presented for three different types of foundations:

- TC1 concrete "Slab-on-grade" (commonly referred to as 'Type C foundation', which represents the predominant foundation of the current nation-wide building stock)
- Foundation equivalent to a TC2 type foundation
- Foundation equivalent to a TC3 type foundation[41]

The choice of foundation type for a residential dwelling can have a significant impact on the expected building consequence level. For example, for 'moderate to severe' expected liquefaction-induced land damage, a TC1 concrete slab-on-grade foundation is expected to perform very poorly and a TC2 type equivalent foundation is expected to perform considerably better. A more robust TC3 type equivalent foundation is expected to perform better than both slab-on-grade and TC2 foundations. Not only are TC3 type foundation expected to perform better, they are also readily repairable.

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[41] Ministry of Business Innovation & Employment (MBIE), 2012. "Repairing and rebuilding houses affected by the Canterbury earthquakes". New Zealand.

In order to convert from the expected land damage for each landowner block (shown in Table 6.2) to the consequence level listed in Figure 8-1, we have developed the matrix presented in Table 8.2. This matrix has been developed based on T+T's experience following the CES.

Table 8.2: Consequence conversion matrix for land damage and foundation type

Land Damage Category	Foundation Type		
	Slab-on-grade	**TC2**	**TC3**
None-to-minor	Minor	Insignificant	Insignificant
None-to-minor / Minor-to-moderate	Minor to Moderate	Insignificant to Minor	Insignificant
Minor to Moderate	Moderate	Minor	Insignificant to Minor
Minor to Moderate / Moderate-to-severe	Major	Minor to Moderate	Insignificant to Minor
Moderate-to-severe	Major to Catastrophic	Moderate to Major	Minor to Moderate

The results of the applying the consequence conversion matrix in Table 8.2 to the estimated liquefaction-induced land damage results from Table 6.2 for the five different scenarios are presented in Table 8.3 for each of the landowner blocks.

It is important to note that while the Landowner Blocks provide a suitable and convenient scale for the purposes of this risk assessment, the ground conditions are likely to vary within each block and as a result the consequence levels described in Table 8.3 are also likely to vary (refer to Section 8.1). Therefore, for more detailed assessments (e.g. studies to support sub-division or building consents) consideration of blocks of land that are representative of consistent ground conditions and therefore likely performance should be considered.

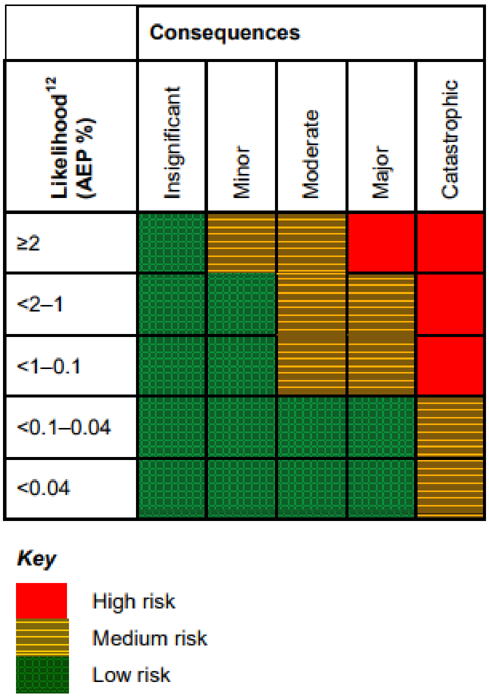
The outcomes presented in Table 8.3 indicate that in landowner blocks 'A' and 'B', the estimated residential building consequence level could be as high as 'major' for the scenario with the greatest degree of consequential land damage (i.e. Scenario 5) if the dwellings are built using a standard TC1 concrete slab-on-grade foundation. Further, a consequence level of 'moderate' for a 500 year return period earthquake with 1.9 m of sea level rise (i.e. Scenario 3) is possible. Alternatively, the estimated residential building consequence level could be limited to 'insignificant to minor' for large return period earthquake events if the dwellings are built using a robust TC3 type equivalent foundation.

The residential building consequence levels for landowner blocks 'D' and 'E' are estimated to be 'minor to moderate' for Scenario 5 if the dwellings are built using a standard TC1 concrete slab-on-grade foundation. However, these consequence levels can be reduced to 'insignificant or minor' for all scenarios if the dwellings are built using a TC2 type equivalent foundation or 'insignificant' if the dwellings are built using a robust TC3 type equivalent foundation. While the consequence levels suggest TC1 concrete-slab-on-grade foundations could be appropriate, some TC2 type foundations provide significant improvements for a relatively small additional cost. Furthermore, these foundation options will provide greater resilience than non-robust NZS3604 foundations to other geotechnical influences and earthquake effects (e.g. settlement of near surface soils, variations in bearing capacity, and effects of strong earthquake shaking).

Table 8.3: Summary of derived building related consequence levels for the five landowner blocks

Landowner Block	Foundation type	Consequence Level				
		Scenario 1 (500yr; no SLR)	Scenario 2 (500yr; 1.25m SLR)	Scenario 3 (500yr; 1.9m SLR)	Scenario 4 (1,000yr; 1.25m SLR)	Scenario 5 (3,030yr; 1.9m SLR)
Landowner Block 'A'	Slab-on-grade	Minor	Minor to Moderate	Moderate	Moderate	Major
	TC2 type	Insignificant	Insignificant to Minor	Minor	Minor	Minor to Moderate
	TC3 type	Insignificant	Insignificant	Insignificant to Minor	Insignificant to Minor	Insignificant to Minor
Landowner Block 'B'	Slab-on-grade	Minor	Minor to Moderate	Moderate	Moderate	Major
	TC2 type	Insignificant	Insignificant to Minor	Minor	Minor	Minor to Moderate
	TC3 type	Insignificant	Insignificant	Insignificant to Minor	Insignificant to Minor	Insignificant to Minor
Landowner Block 'D'	Slab-on-grade	Minor	Minor	Minor	Minor	Minor to Moderate
	TC2 type	Insignificant	Insignificant	Insignificant	Insignificant	Insignificant to Minor
	TC3 type	Insignificant	Insignificant	Insignificant	Insignificant	Insignificant
Landowner Block 'E'	Slab-on-grade	Minor	Minor	Minor to Moderate	Minor to Moderate	Minor to Moderate
	TC2 type	Insignificant	Insignificant	Insignificant to Minor	Insignificant to Minor	Insignificant to Minor
	TC3 type	Insignificant	Insignificant	Insignificant	Insignificant	Insignificant
Landowner Block 'F'	Slab-on-grade	Minor	Minor	Minor	Minor	Minor
	TC2 type	Insignificant	Insignificant	Insignificant	Insignificant	Insignificant
	TC3 type	Insignificant	Insignificant	Insignificant	Insignificant	Insignificant

Landowner block 'F' is the least vulnerable to liquefaction-induced land damage and for all scenarios, the consequence levels are estimated to be 'minor' if the dwellings are built using a standard TC1 concrete slab-on-grade foundations and 'insignificant' if the dwellings are built using either a TC2 type foundation or a robust TC3 type equivalent foundation. The results in Table 8.3 highlight the importance of the foundation type(s) of the building stock when assessing the expected building consequence level.



	Consequences				
Likelihood[12] (AEP %)	Insignificant	Minor	Moderate	Major	Catastrophic
≥2	🟩	▨	▨	🟥	🟥
<2–1	🟩	🟩	▨	▨	🟥
<1–0.1	🟩	🟩	▨	▨	🟥
<0.1–0.04	🟩	🟩	🟩	🟩	▨
<0.04	🟩	🟩	🟩	🟩	▨

Key

🟥	High risk
▨	Medium risk
🟩	Low risk

Figure 8-2: BOP RPS risk screening matrix

The next step in the BOP RPS Risk Assessment process is to determine the risk level. Figure 8-2 shows the matrix provided in the BOP RPS to determine the risk level for a given likelihood of occurrence and consequence level. Table 8.4 shows the result of applying the risk level matrix to the consequence levels in Table 8.3.

Inspection of Table 8.4 shows that the assessed risk level for the majority of the foundation options is low. The exceptions to this are the medium assessed risk level for slab-on-grade foundations in both Landowner Block B (scenarios 2, 3 and 4) and Landowner Block E (scenarios 3 and 4). For both TC2 and TC3 foundation types the risk level for all landowner blocks (for each of the five scenarios) is assessed as low. As with the consequence assessment, while the risk levels indicate that TC1 concrete-slab-on-grade foundations could be appropriate, some TC2 type foundations provide significant improvements for a relatively small additional cost.

Table 8.4: Summary of derived building related risk levels for the five landowner blocks

Landowner Block	Foundation type	Risk Level				
		Scenario 1 (500yr; no SLR)	Scenario 2 (500yr; 1.25m SLR)	Scenario 3 (500yr; 1.9m SLR)	Scenario 4 (1000yr; 1.25m SLR)	Scenario 5 (3030yr; 1.9m SLR)
Landowner Block 'A'	Slab-on-grade	Low	Medium	Medium	Medium	Low
	TC2 type	Low	Low	Low	Low	Low
	TC3 type	Low	Low	Low	Low	Low
Landowner Block 'B'	Slab-on-grade	Low	Medium	Medium	Medium	Low
	TC2 type	Low	Low	Low	Low	Low
	TC3 type	Low	Low	Low	Low	Low
Landowner Block 'D'	Slab-on-grade	Low	Low	Low	Low	Low
	TC2 type	Low	Low	Low	Low	Low
	TC3 type	Low	Low	Low	Low	Low
Landowner Block 'E'	Slab-on-grade	Low	Low	Medium	Medium	Low
	TC2 type	Low	Low	Low	Low	Low
	TC3 type	Low	Low	Low	Low	Low
Landowner Block 'F'	Slab-on-grade	Low	Low	Low	Low	Low
	TC2 type	Low	Low	Low	Low	Low
	TC3 type	Low	Low	Low	Low	Low

8.4.4 Lateral spreading risk assessment

The results of the lateral spreading assessment are presented in Section 7.1. Given the River Fill, Stream, Pond (west) and Pond (east) areas all have similar lateral spreading vulnerabilities, the same conclusions and mitigation options have been drawn for all four areas. If left untreated, land up to approximately 150 m from the free-faces in the four areas is considered vulnerable to lateral spreading (based on the currently proposed finished ground surface topography) for each of the five scenarios considered. Maps showing 150 m of setback from the free-faces are presented in Figures E2 and E3. If lateral spreading mitigation measures are not adopted, buildings and infrastructure constructed on this land are expected to have compromised functionality (refer to Section 8.4) should one of the five scenarios considered occur. T+T has recommended the lateral spreading mitigation options presented in Section 7.2 be considered for design purposes. No conclusions have been drawn for the River Plain area as it is not intended to be developed (see Figure A2).

This binary impact of lateral spreading makes the risk assessment relatively straight forward. For areas outside of the 150 m set back, the consequence level for lateral spreading is considered "insignificant" and therefore the corresponding risk level is "low" for each of the 5 scenarios. Similarly, if one of the lateral spreading mitigation options presented in Section 7.2 is adopted, the consequence level of lateral spreading of land within the 150m set-back is also considered to be "insignificant" and therefore the corresponding risk level is also "low". T+T does not recommend the construction of buildings on land within the 150 m set-back without the adoption of an appropriate mitigation option. Note that this risk level only applies to lateral spreading and a particular area may be assessed as higher risk of liquefaction related land damage as evaluated in Section 8.4.3.

Therefore, the adoption of one of the lateral spreading mitigation options described in Section 7.2 does not impact on the outcome of the risk assessment. It does however have a significant impact on the area of land available and therefore the number of buildings that can be built. As shown on Figure E1 the 150 m set back significantly reduces the area of land available for development. However comparison with Figure E8, shows that considerably more land is available for development if Mitigation Option 4 is implemented. Table 8.5 compares the difference in building yield between adopting a 150 m set back and assuming Mitigation Option 4 is implemented.

Mitigation Option 4 is presented as an example. T+T have also assessed Mitigation Option 3 through a separate assessment for TCC.

Table 8.5: Summary of the effect of lateral spreading Mitigation Option 4 on building yield

	No Mitigation – 150m set back			Mitigation Option 4 – 50m set back with shallow ground improvement		
Landowner Block	**Land area available for development (ha)**	**Building count (15 buildings/ha)**	**Building count (24 buildings/ha)**	**Land area available for development (ha)**	**Building count (15 buildings/ha)**	**Building count (24 buildings/ha)**
Landowner Block 'A'	96	1,440	2,304	140	2,100	3,360
Landowner Block 'B'	50	750	1,200	88	1,320	2,112
Landowner Block 'D'	9	135	216	19	285	456
Landowner Block 'E'	0	0	0	2	30	48
Landowner Block 'F'	69	1,035	1,656	137	2,055	3,288
Total	224	3,360	5,376	386	5,790	9,264

Table 8.5 demonstrates that there is a significant difference in the building yield if Mitigation Option 4 is adopted. For 15 buildings per hectare approximately 2,400 additional buildings may be able to be built and for 24 buildings per hectare approximately 3,900 additional may be able to be built. A technical evaluation and a cost benefit analysis on the different mitigation options would provide a more complete picture however this simple calculation demonstrates one of the benefits of treating the effects of lateral spreading.

8.5 Lifelines and utilities

As noted in Section 8.4.1, this risk assessment has focussed on the performance of buildings when exposed to liquefaction and lateral spreading hazards. For the purposes of this risk assessment the definition of a "functionally compromised" building specifically excluded the loss of functionality due to damage of the lifelines and utilities associated with building.

Lifelines and utilities should be appropriately designed to mitigate the consequences of liquefaction and lateral spreading that are anticipated for the local ground conditions. Where practical in areas where moderate-to-severe liquefaction damage is possible or within lateral spreading set back areas the construction of critical lifelines and utilities should be avoided. Utilities should be designed such that they are readily repairable should damage be sustained. Particular attention should be given to the detailing of utility connections with buildings as the differential settlement of buildings relative to the surrounding ground can significantly compromise the functionality of utilities even when the majority of the network is relatively undamaged. Standard designs for lifelines and utilities are likely to be suitable where liquefaction and lateral spreading related land damage is not anticipated.

8.6 Health and safety

Despite the potential to cause significant damage to buildings and other infrastructure, the experience in the Christchurch area following the CES is that liquefaction and lateral spreading do not pose a significant risk to health and safety. While 185 people lost their lives as a result the

February 2011 earthquake 130 of these deaths occurred as a result of the collapse of two office buildings due to structural failure induced by severe ground shaking and the remaining deaths were as a result of either collapsed walls, falling masonry or falling rocks. None of these deaths were associated with either liquefaction or lateral spreading.

However it is important to note that lateral spreading as a result of the CES did cause significant damage to a small number of buildings such that they were close to complete collapse. As such there is some health and safety risk associated with this form of land damage and it is conceivable that injury or death could occur.

Therefore based on this experience and our understanding of the mechanisms through which the consequences of liquefaction and lateral spreading are manifest, we preliminarily consider the health and safety consequence level for both of liquefaction and lateral spreading as minor for all five of the scenarios considered. Inspection of the BOP RPS risk matrix presented in Figure 8-2 indicates that this consequence level translates to a low risk for health and safety.

Note that this assessment considers only the primary effects of liquefaction and lateral spreading on health and safety. We have not allowed for secondary effects on health and safety such as respiratory diseases caused by damp homes due to liquefaction ejecta being manifest under the buildings foundations.

9 Conclusions

The liquefaction assessment of the Te Tumu Urban Growth Area indicates that the land is vulnerable to liquefaction but is likely to be suitable for urban development purposes using the proposed ground elevations. While the sub-surface soil profiles in all landowner blocks are similar, the blocks have different vulnerabilities to liquefaction. Landowner blocks ‘A’ and ‘B’ are more vulnerable to liquefaction as the groundwater level is closer to the design ground surface than in landowner blocks ‘D’, ‘E’ and ‘F’. This is especially the case for higher levels of earthquake shaking.

The lateral spreading assessment of the Te Tumu Urban Growth Area indicates that there are significant areas within the landowner blocks which are vulnerable to lateral spreading. These are generally confined to areas within certain distances from a free-face.

TCC and the land owners can choose to accept the building consequence levels (which have been determined in accordance with the BOP RPS) as they are. Alternatively, the building consequence levels can be reduced by building using enhanced foundations, robust infrastructure and setting the dwellings and infrastructure back a set distance from the free-faces. Alternatively, ground improvements could be used to mitigate the potential effects of liquefaction and/or lateral spread damage and hence reduce the building consequence levels. Given the site is currently a greenfield site, area wide ground improvements could be an economical option. If the mitigation measures proposed are adopted the risk assessment undertaken in accordance with the BOP RPS indicates that the risk of liquefaction and lateral spreading to buildings is low.

If the Te Tumu Urban Growth Area is going to be developed for residential purposes, it is recommended that TCC and/or the land developers undertake the following works:

- A more detailed liquefaction assessment that includes consideration of 100 year return period levels of earthquake shaking to inform subdivision consenting (e.g. a Level C detailed area wide assessment[42]). This is because much of the land around New Zealand has the potential for liquefaction damage at 500 year levels of shaking, but only areas of particularly challenging land tend to show the potential for damage at 100 year levels of shaking. So to distinguish between areas of land with high and moderate liquefaction risk it is useful to consider this shorter return period event.

  The MBIE liquefaction guidelines[42] recommend that for land use planning purposes it is most appropriate to consider 1 in 500 year return period events. This is because once the land use is established it is likely to continue in perpetuity and it is difficult to withdraw from the area and therefore the longer return period events, which may result in more severe consequences, become more relevant.

  However, to inform decisions about the type of structures to be built on the land it is necessary to consider shorter return period events (e.g. 1 in 100 year) that are more likely to occur within the design life of the structure. For this reason that guidance document recommends both 100 year and 500 year return period events be considered for sub division consenting purposes on a development of the size and scale as that proposed at Te Tumu. More detailed geotechnical investigations to inform foundation design and building consent applications (in accordance with the MBIE liquefaction guidelines[35]).
- Reassess the liquefaction vulnerability using design profiles prior to or following any earthworks design or liquefaction and lateral spreading mitigations works (i.e. changes to the soil properties and/or site topography are likely to impact the liquefaction vulnerability of the site).

---

[42] Ministry of Business Innovation & Employment (MBIE), 2017. “Planning and engineering guidance for potentially liquefaction-prone land”. Retrieved from https://www.building.govt.nz/building-code-compliance/b-stability/b1-structure/planning-engineering-liquefaction-land/

- Ensure the fill is non-liquefiable and correctly layered and compacted to avoid long term consolidation of the fill.
- Continue to closely monitor groundwater levels in existing monitoring wells particularly if earthworks are expected to take place. Monitoring groundwater during and after earthworks is important to ensure groundwater does not rise significantly, reducing the thickness of the non-liquefying crust or fall significantly, increasing the likelihood of settlement resulting in potential ground surface deformation. If there is movement in groundwater levels, further analysis is recommended to better understand the impact this has on the liquefaction vulnerability of the site.

10 Applicability

This report has been prepared for the exclusive use of our client Tauranga City Council, 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.

Recommendations and opinions in this report are based on data from CPT and borehole locations. The nature and continuity of subsoil away from these locations are inferred and it must be appreciated that actual conditions could vary from the assumed model.

The susceptibility analyses carried out represent probabilistic analyses of empirical liquefaction databases under various earthquakes. Earthquakes are unique and impose different levels of shaking in different directions on different sites. The results of the liquefaction susceptibility analyses and the estimates of consequences presented within this document are based on regional seismic demand and published analysis methods, but it is important to understand that the actual performance may vary from that calculated.

Tonkin & Taylor Ltd

Report prepared by:	Report reviewed by:
....	....
James Russell	Mike Jacka
Geotechnical Engineer	Senior Geotechnical Engineer

Authorised for Tonkin & Taylor Ltd by:

....

Peter Cochrane

Project Director

JICR
t:\tauranga\projects\1002034\1002034.2000\workingmaterial\reporting\20180709.te tumu liquefaction assessment report final.docx

Appendix A: General figures

Notes: Bay of Plenty 0.4m Rural Aerial Photos (2010 - 2012)
soureсd from LINZ under CC-BY 3.0

A4 SCALE 1:25,000

0 0.25 0.5 0.75 1 1.25 (km)

N

Tonkin+Taylor

105 Carlton Gore Rd, Newmarket, Auckland
www.tonkintaylor.co.nz

DRAWN	DXLR	Aug.17
CHECKED	VL	Aug.17
APPROVED	PRC	Jul.18

ARCFILE
1002034-001.mxd

SCALE (AT A4 SIZE)
1:25,000

PROJECT No.
102034.2000

TAURANGA CITY COUNCIL

TE TUMU URBAN GROWTH AREA

CPT and BH Locations Overlaid on Aerial Imagery

FIGURE No.
Figure A1

Rev.
0

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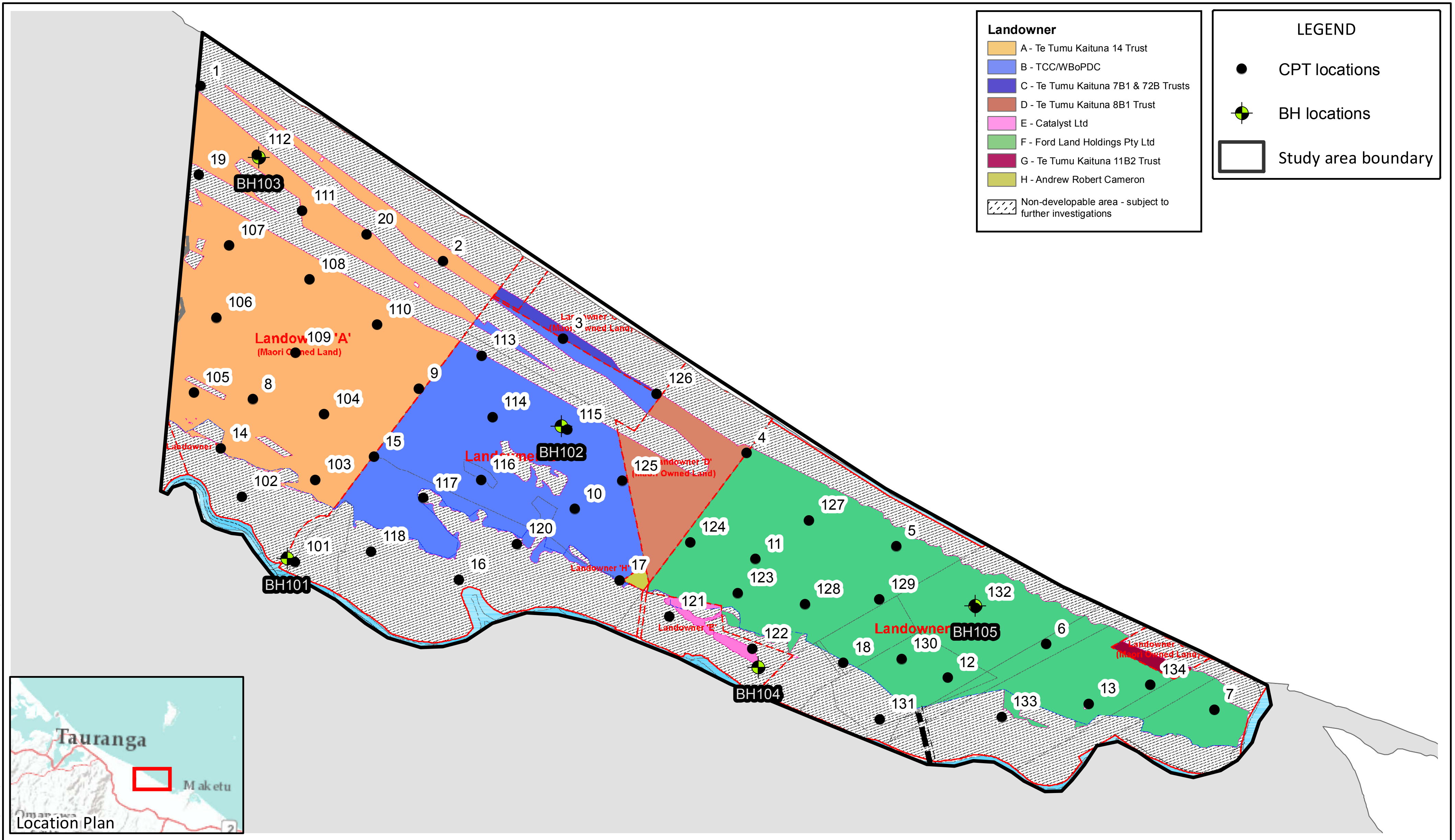

Notes: The background map showing the proposed future growth of Te Tumu was obtained from Tauranga City Council and is indicative only.

A4 SCALE 1:25,000

0 0.25 0.5 0.75 1 1.25 (km)

N

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DRAWN	DXLR	Aug.17
CHECKED	VL	Aug.17
APPROVED	PRC	Jul.18

ARCFILE
1002034-025.mxd

SCALE (AT A4 SIZE)
1:25,000

PROJECT No.
102034.2000

TAURANGA CITY COUNCIL
TE TUMU URBAN GROWTH AREA
CPT and BH Locations Overlaid on Landowner Blocks

FIGURE No.
Figure A2

Rev.
0

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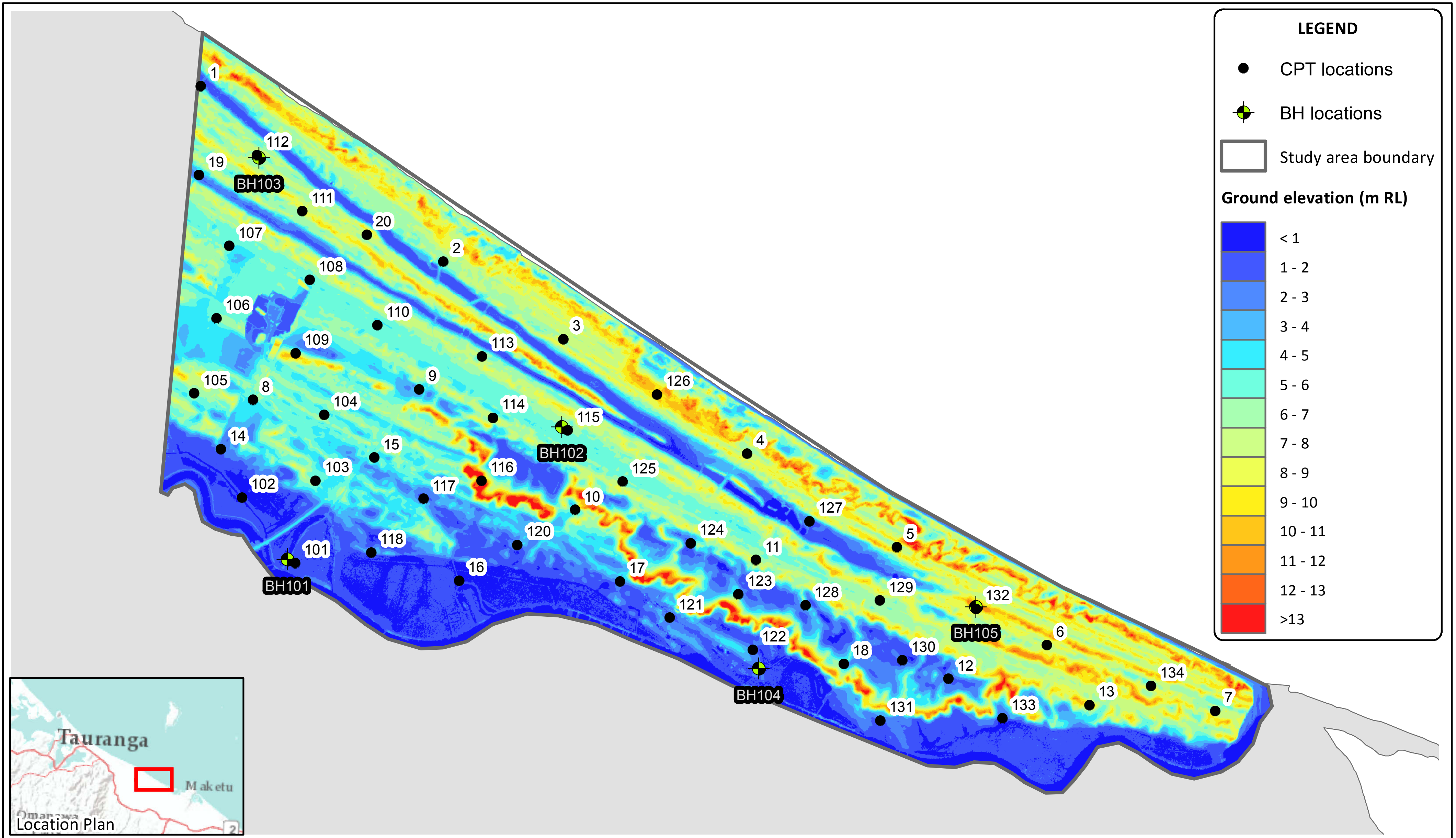

Notes:

A4 SCALE 1:25,000

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N

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105 Carlton Gore Rd, Newmarket, Auckland
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DRAWN	DXLR	Aug.17
CHECKED	VL	Aug.17
APPROVED	PRC	Jul.18

ARCFILE
1002034-002.mxd

SCALE (AT A4 SIZE)
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PROJECT No.
102034.2000

TAURANGA CITY COUNCIL

TE TUMU URBAN GROWTH AREA

CPT and BH Locations Overlaid on Existing 2015 LiDAR DEM

FIGURE No. Figure A3

Rev. 0

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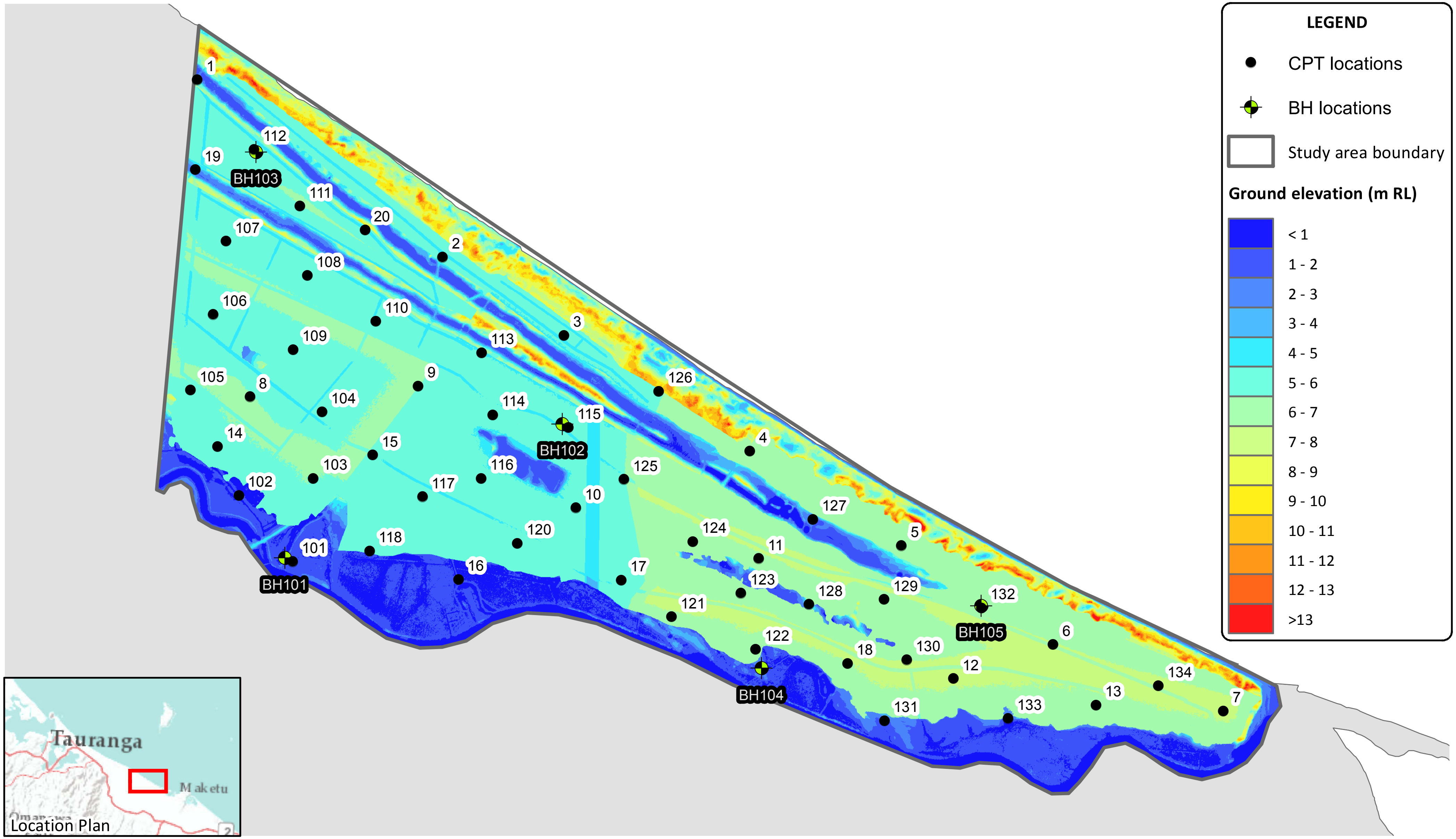

Notes:

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N

Tonkin+Taylor

105 Carlton Gore Rd, Newmarket, Auckland
www.tonkintaylor.co.nz

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CHECKED	VL	Aug.17
APPROVED	PRC	Jul.18

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SCALE (AT A4 SIZE)
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PROJECT No.
102034.2000

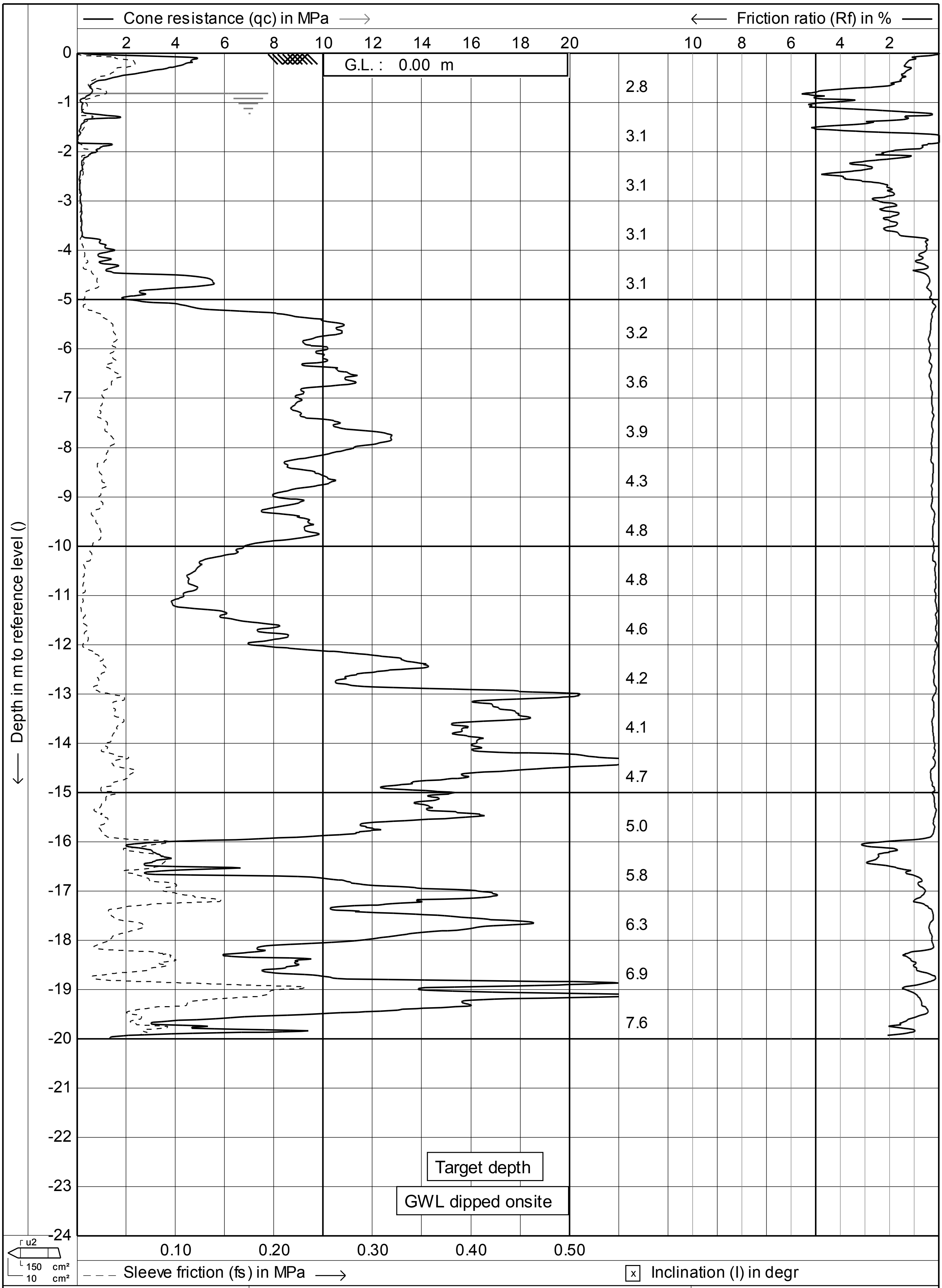
TAURANGA CITY COUNCIL
TE TUMU URBAN GROWTH AREA
CPT and BH Locations Overlaid on Proposed DEM

FIGURE No.
Figure A4

Rev.
0

Appendix B : Ground investigation results

- **CPT log results (CPT 101 to 118 and 120 to 134)**
- **BH log results (BH 101 to 105)**
- **Lab testing results**



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PERRY GEOTECH

Test according A.S.T.M Standard D 5778-12

Project : **Site Investigations**

Location: **Bell Rd - Papamoa**

Position: **0, 0 RD**

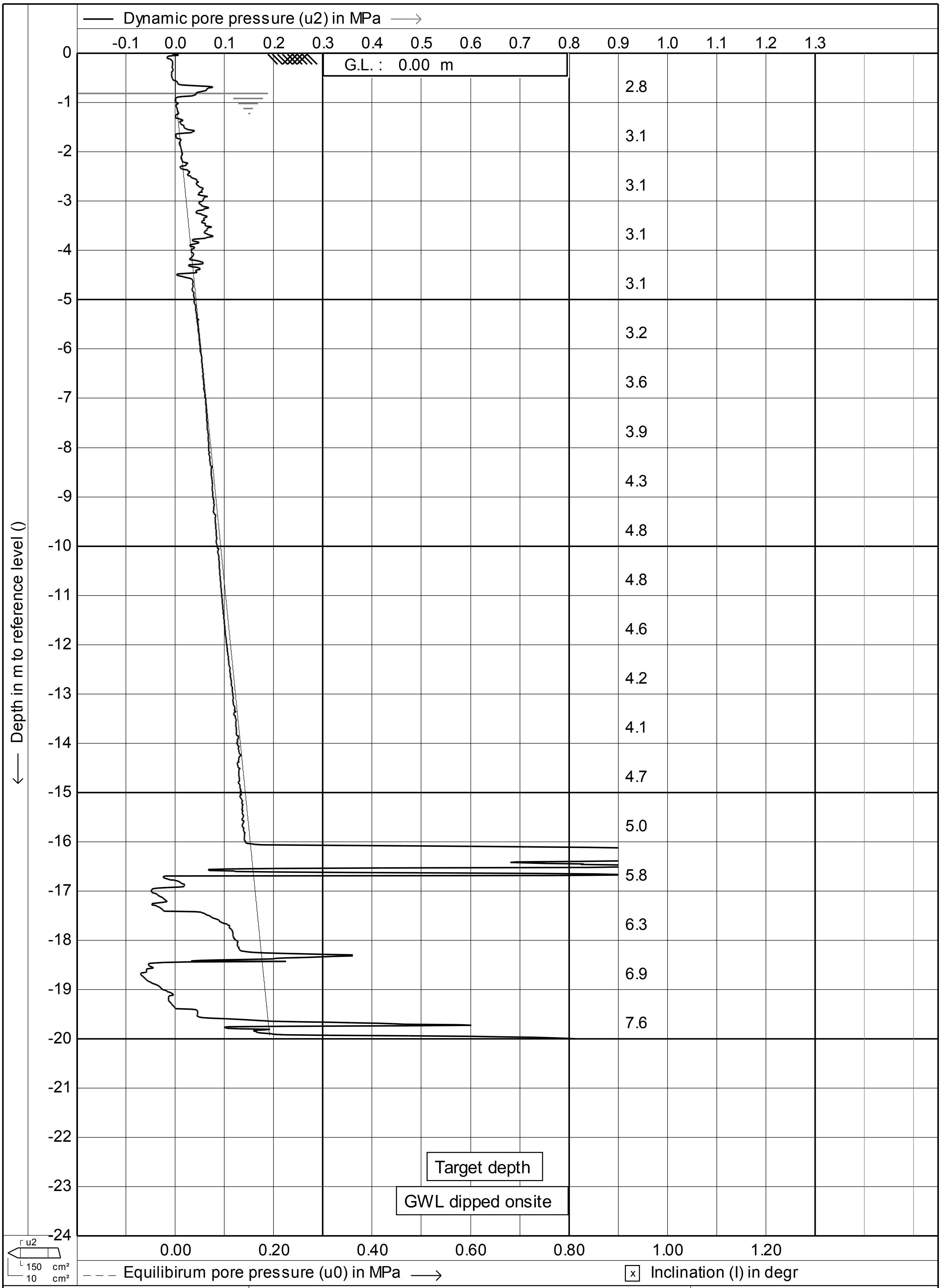
Date : **9/06/2017**

Cone no. : **C10CFIIP.C13068**

Project no. : **05TT4**

CPT no. : **101**

1/14



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Location: **Bell Rd - Papamoa**

Position: **0, 0 RD**

Date : **9/06/2017**

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Project no. : **05TT4**

CPT no. : **101**

2/14

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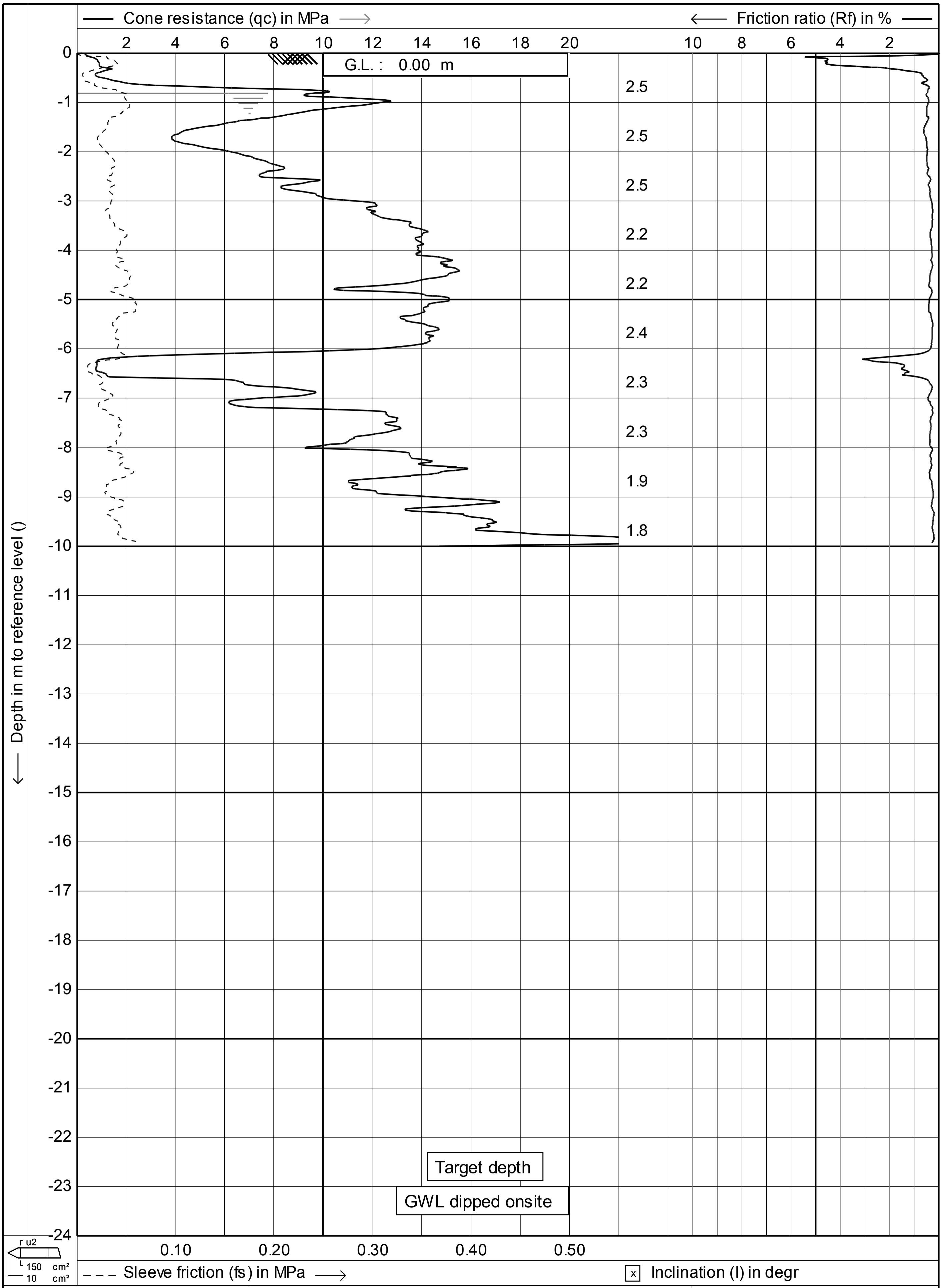

PERRY
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Project no. : **05TT4**

CPT no. : **102**

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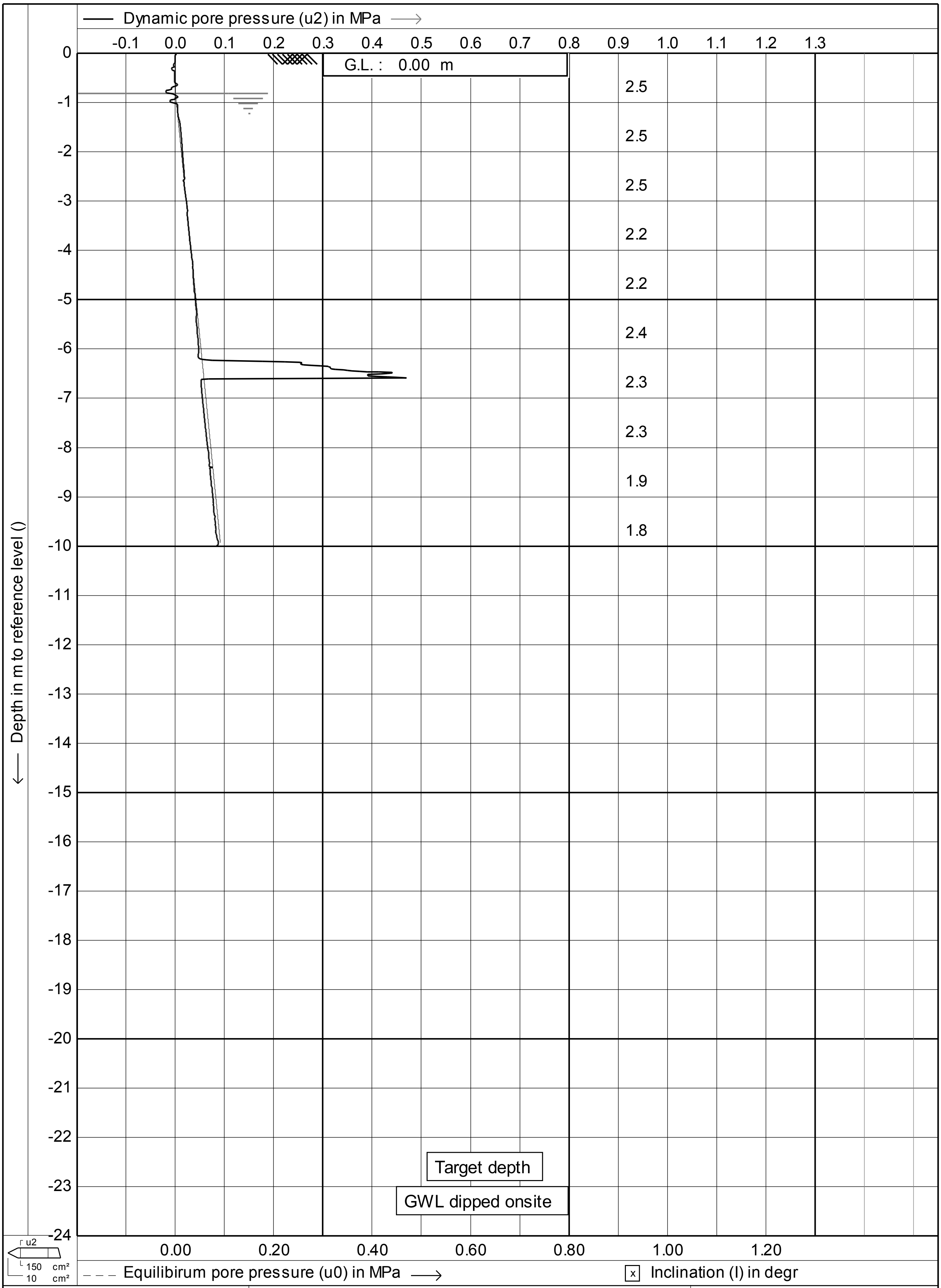

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Project no. : **05TT4**

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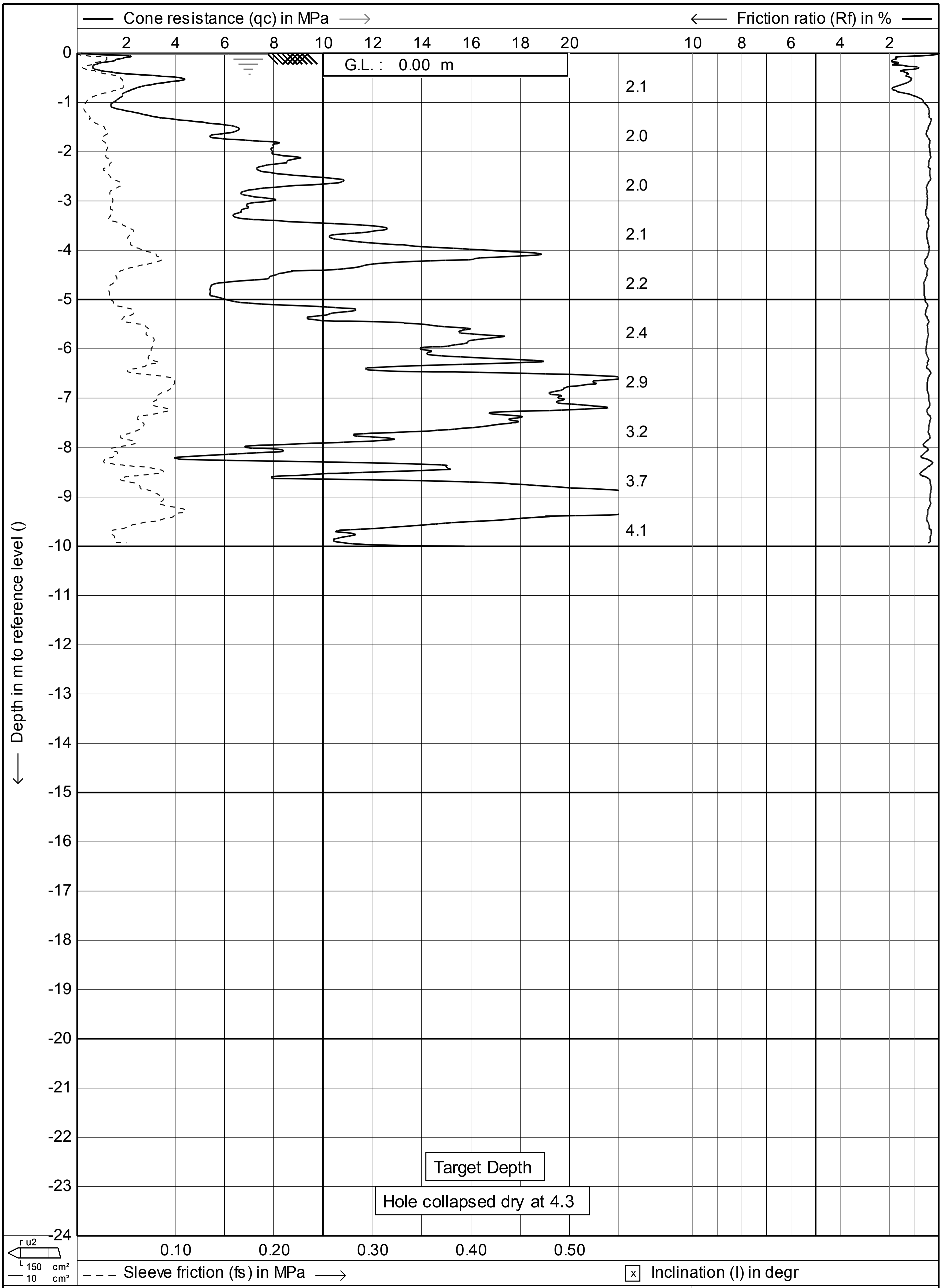
2/14



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Project no. : **05TT4**

CPT no. : **103**

1/14

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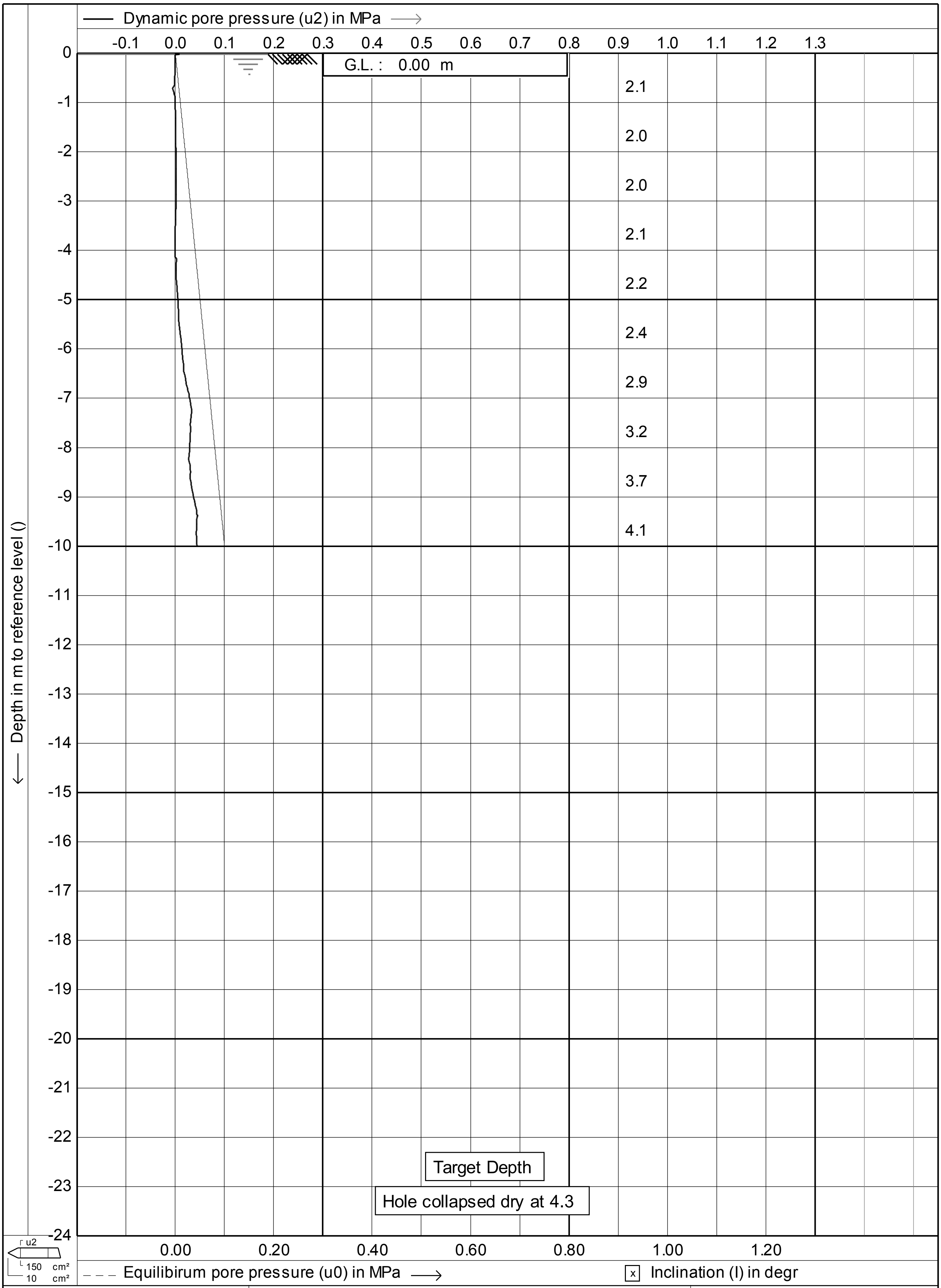

Target Depth

Hole collapsed dry at 4.3

PERRY GEOTECH

Test according A.S.T.M Standard D 5778-12

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Location: **Bell Rd - Papamoa**
Position: **0, 0 RD**

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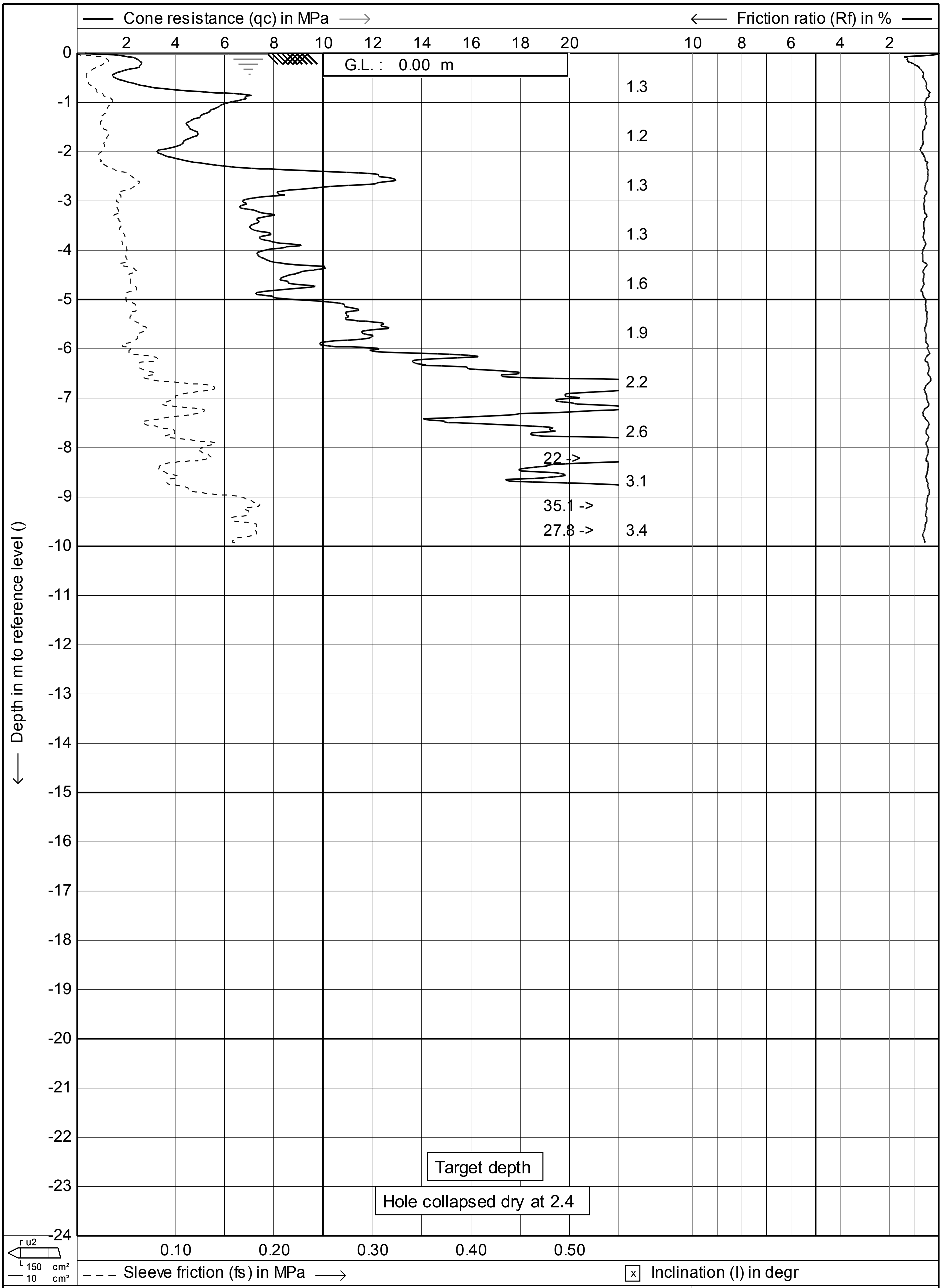

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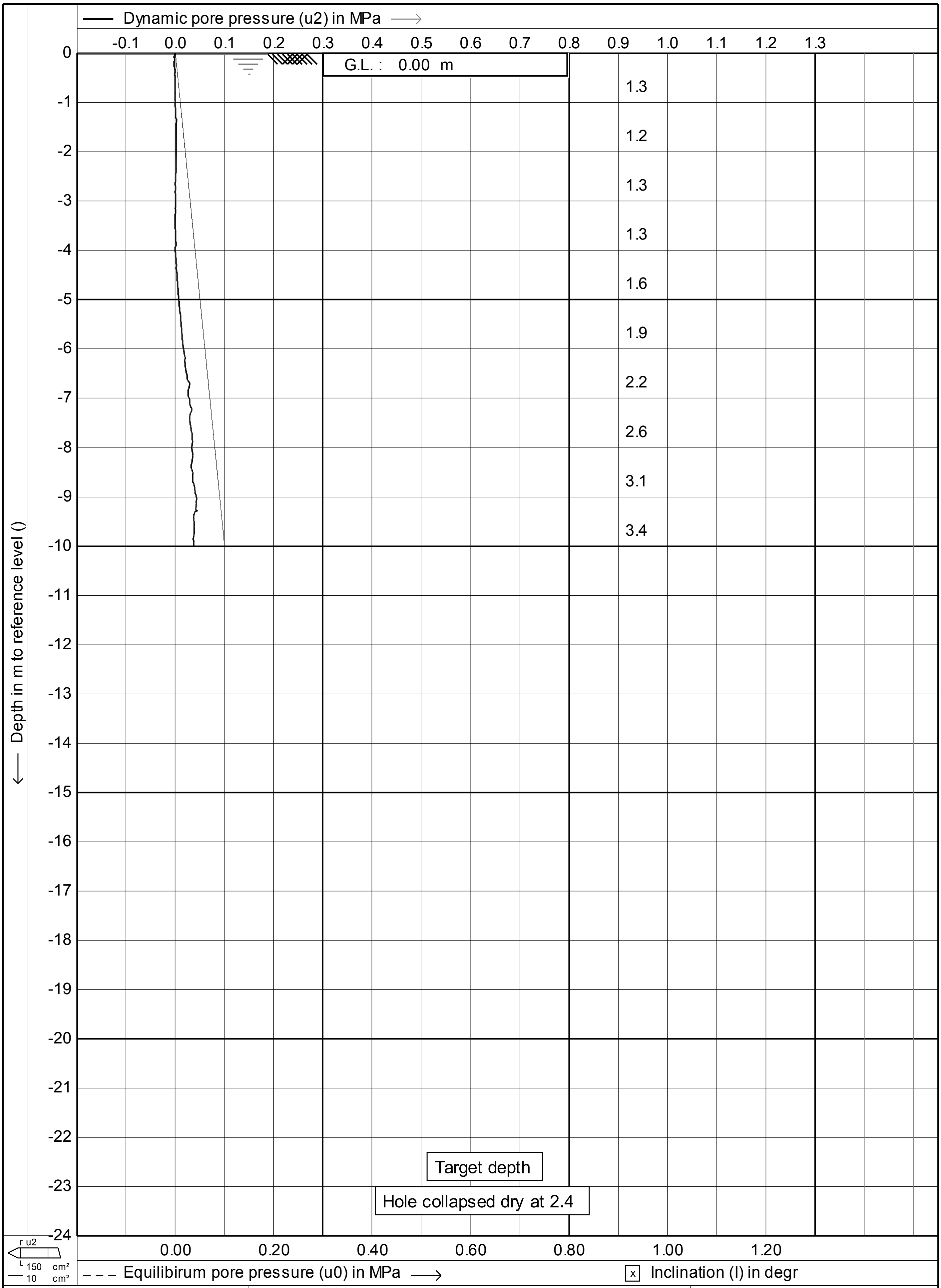
Project no.	: **05TT4**
CPT no.	: **104**

1/14

1.43



Target depth

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PERRY GEOTECH

Test according A.S.T.M Standard D 5778-12

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Location: **Bell Rd - Papamoa**
Position: **0, 0 RD**

Date : **9/06/2017**
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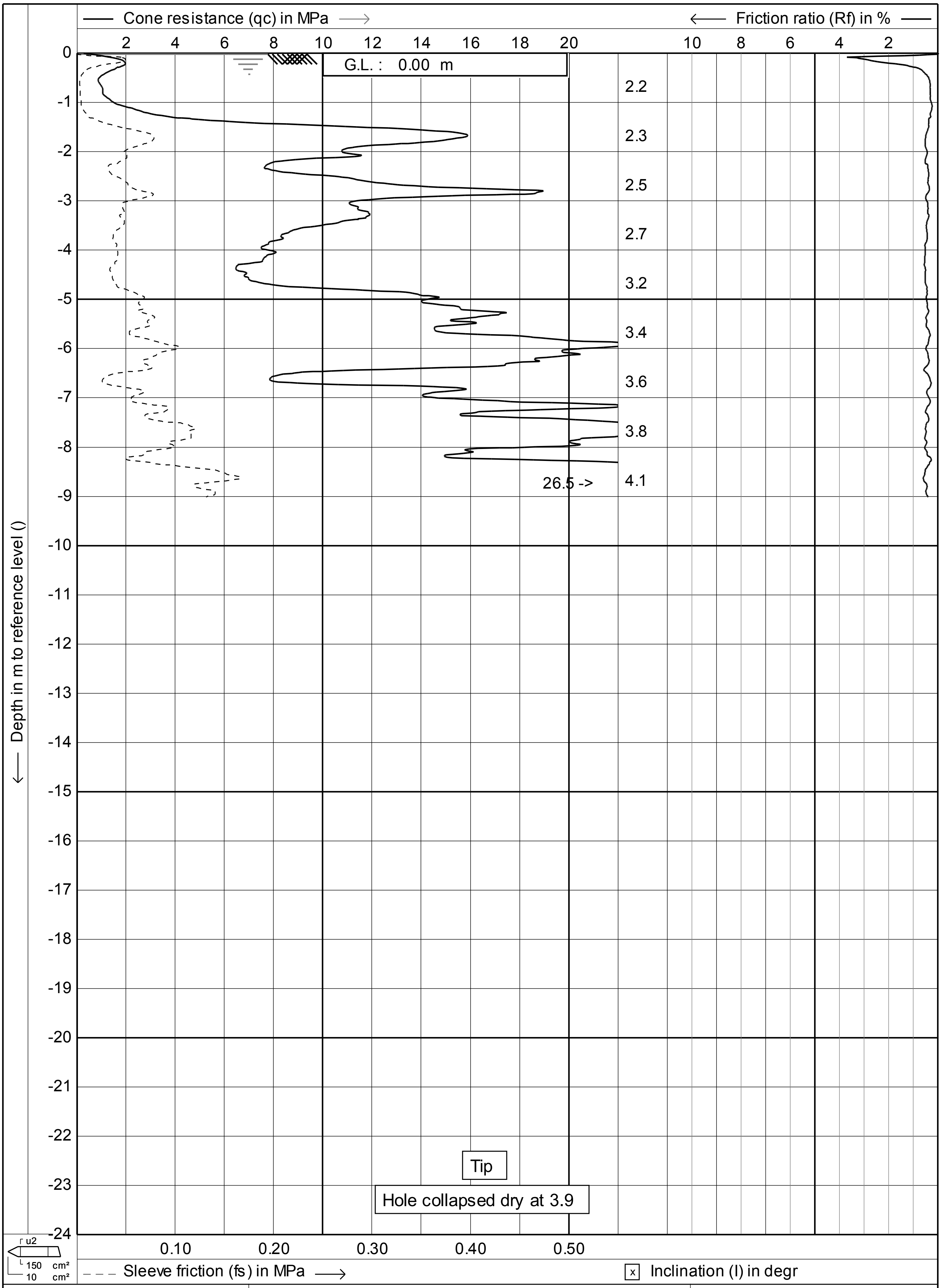
Project no. : **05TT4**
CPT no. : **104**

2/14

1.43



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Position: **0, 0 RD**

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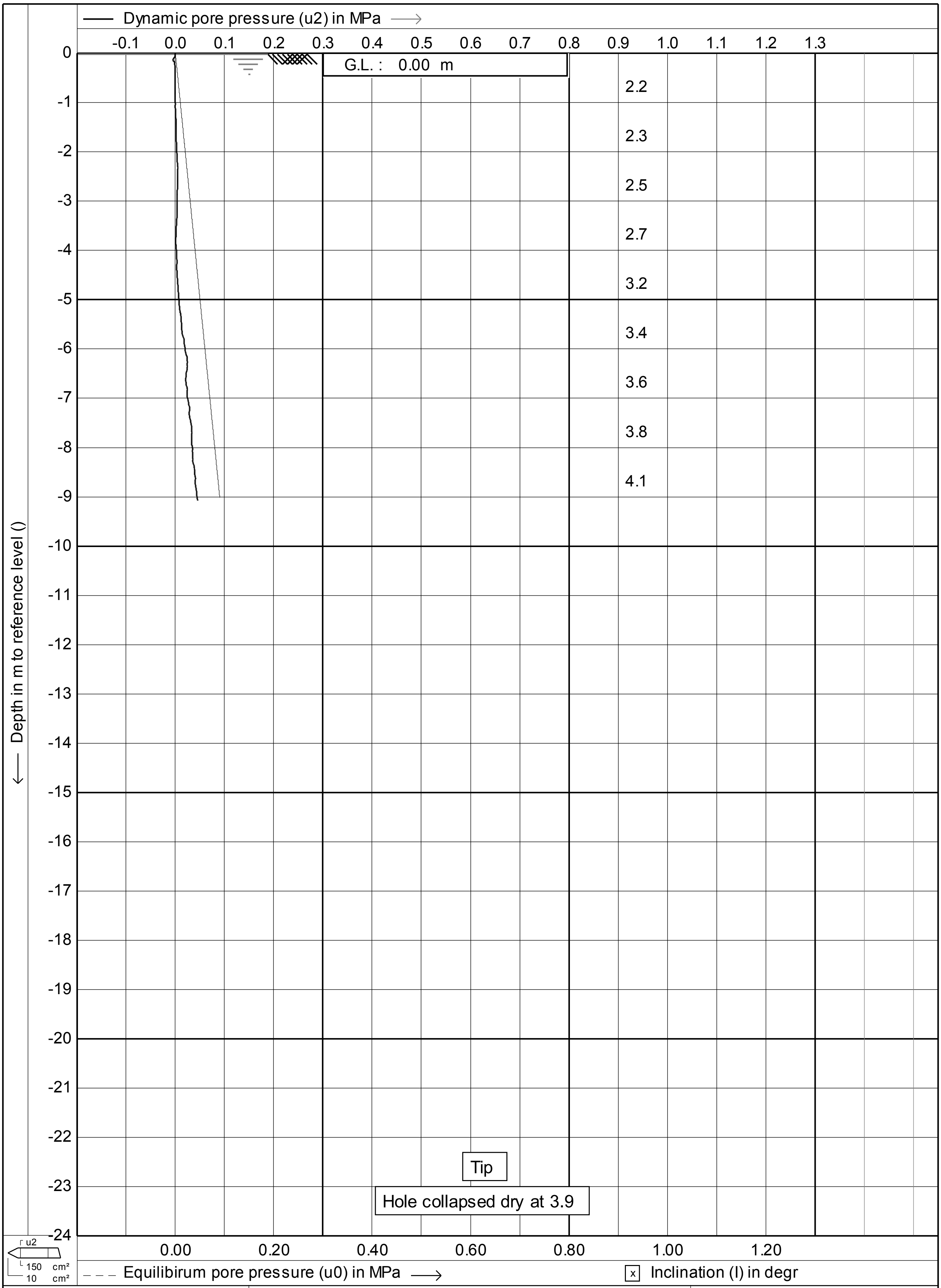
Project no. : **05TT4**

CPT no. : **105**

1/14

1.43



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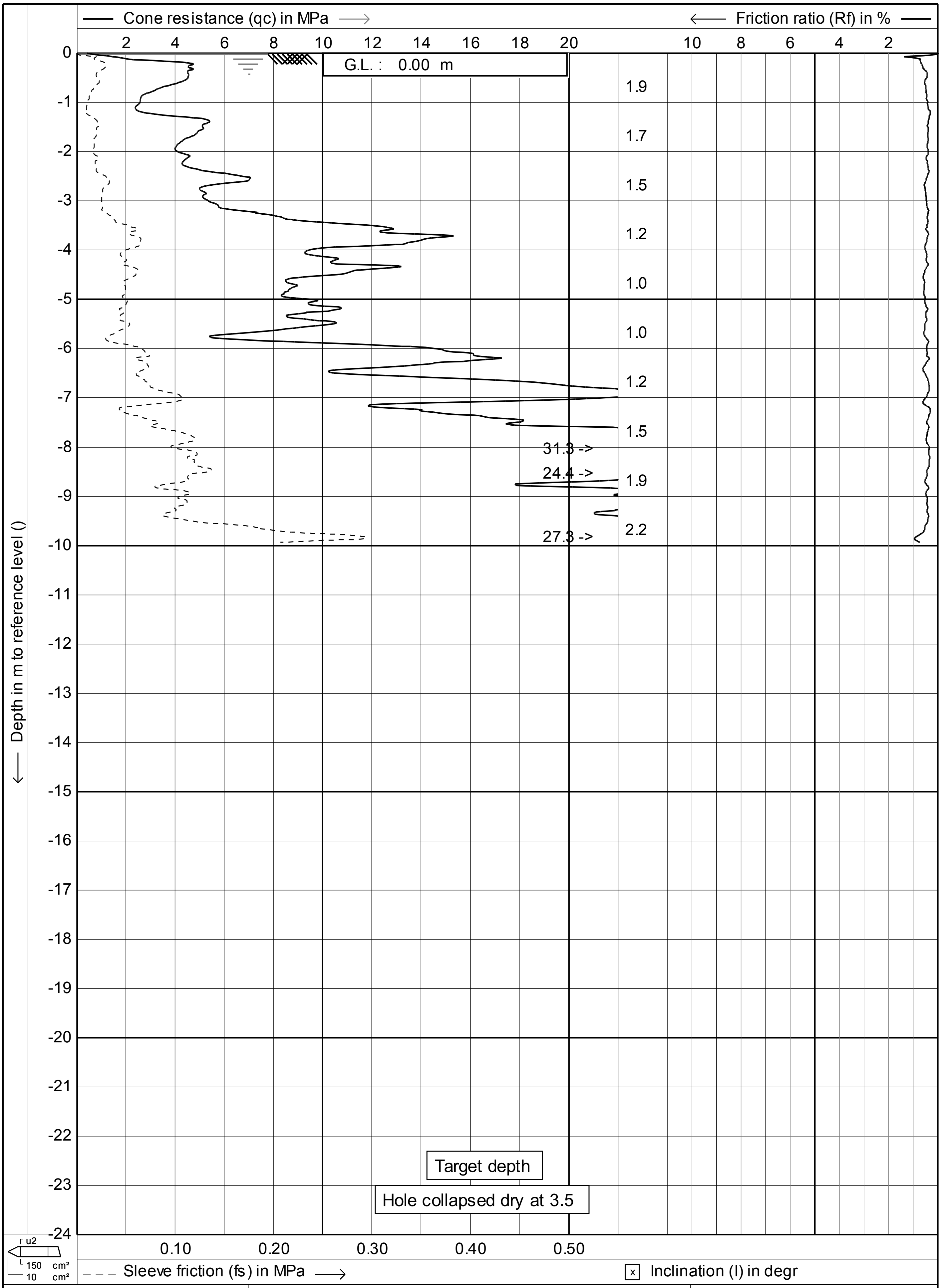

Target depth

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Position: **0, 0 RD**

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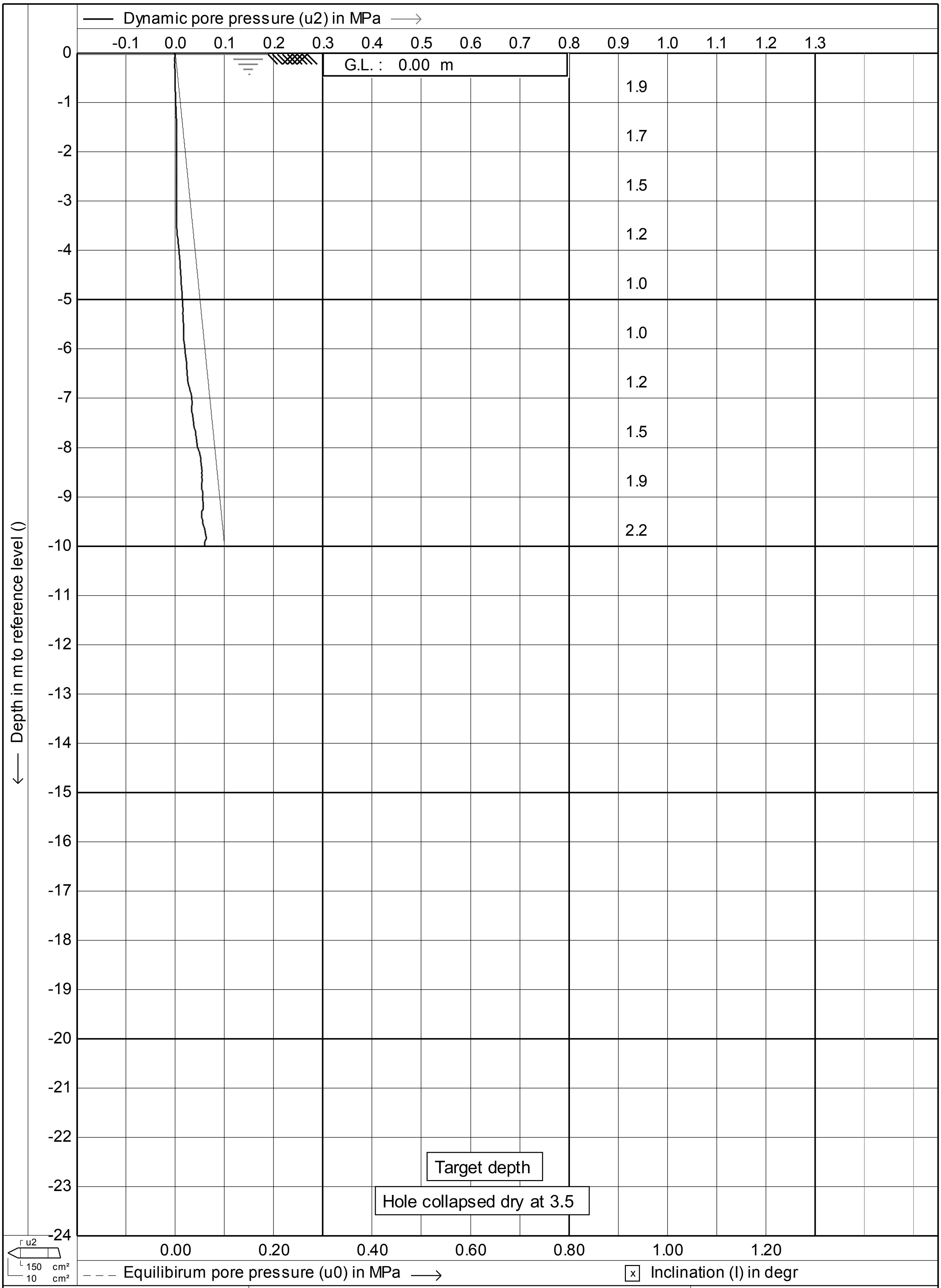
Project no. : **05TT4**
CPT no. : **106** **1/14**



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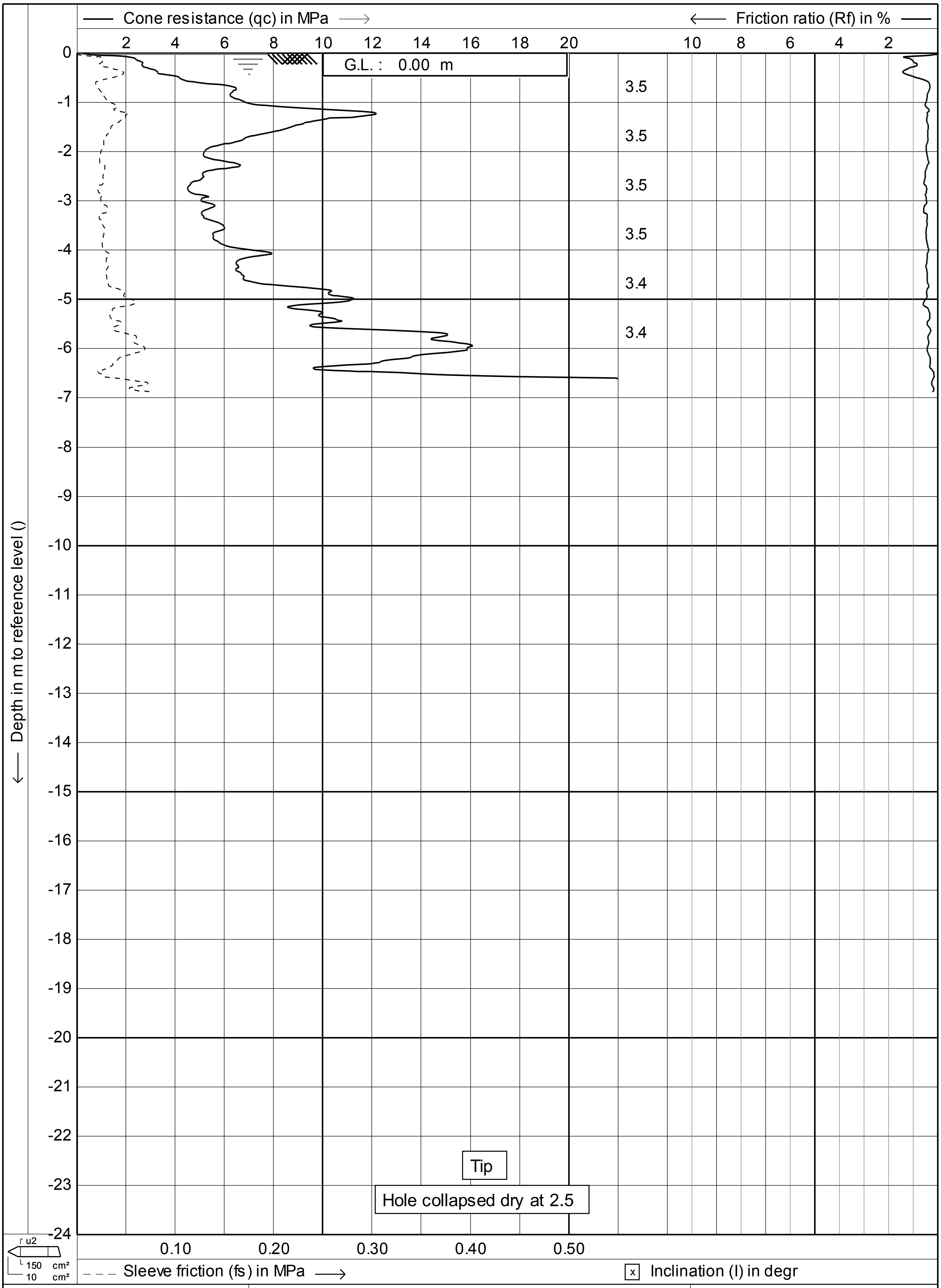
Project no. : **05TT4**
CPT no. : **106**

2/14

1.43



PERRY GEOTECH

Test according A.S.T.M Standard D 5778-12

Project : **Site Investigations**

Location: **Bell Rd - Papamoa**

Position: **0, 0 RD**

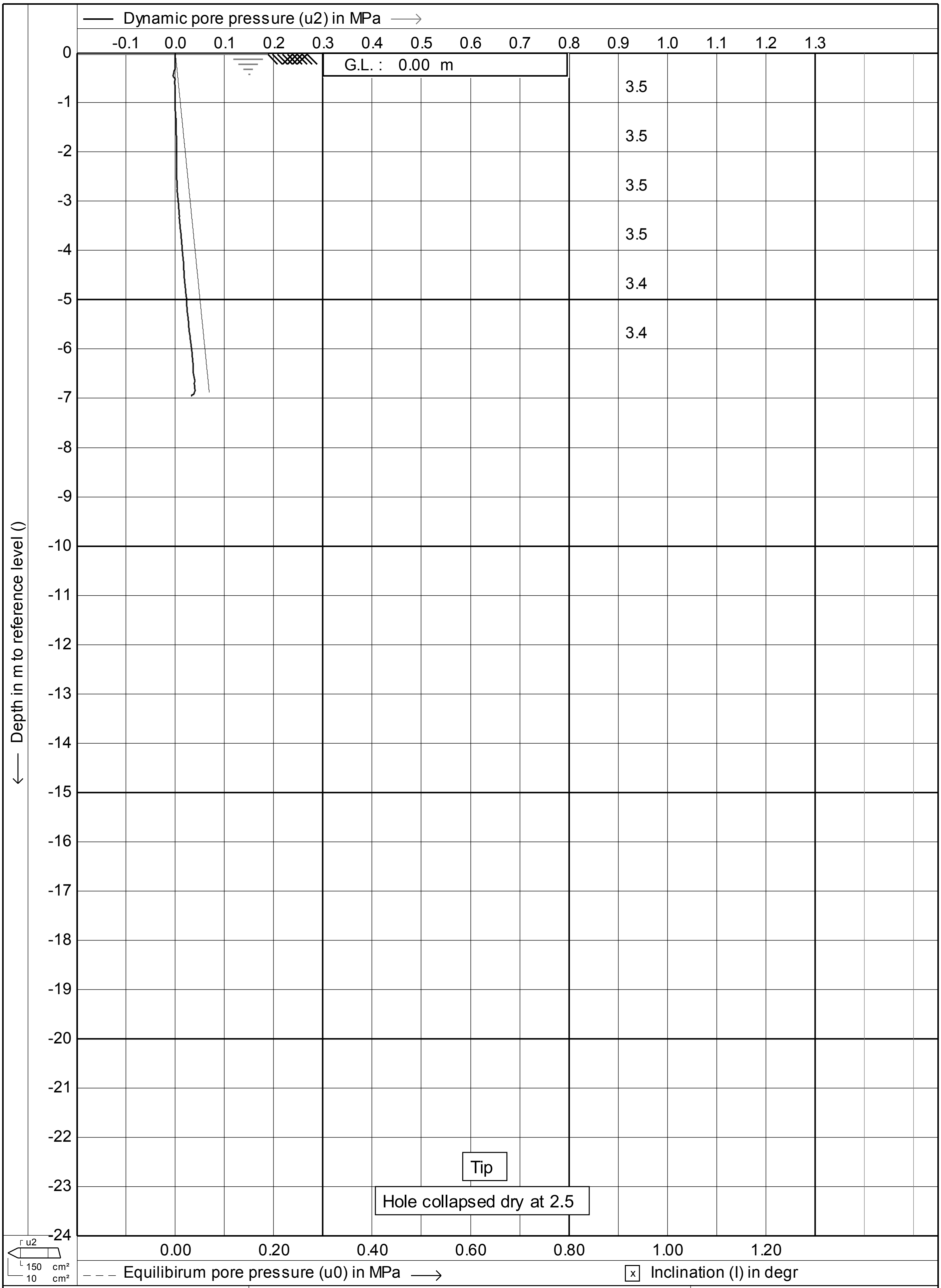
Date : **9/06/2017**

Cone no. : **C10CFIIP.C13068**

Project no. : **05TT4**

CPT no. : **107**

1/14



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Test according A.S.T.M Standard D 5778-12

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Location: **Bell Rd - Papamoa**
Position: **0, 0 RD**

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Cone no. : **C10CFIIP.C13068**
Project no. : **05TT4**
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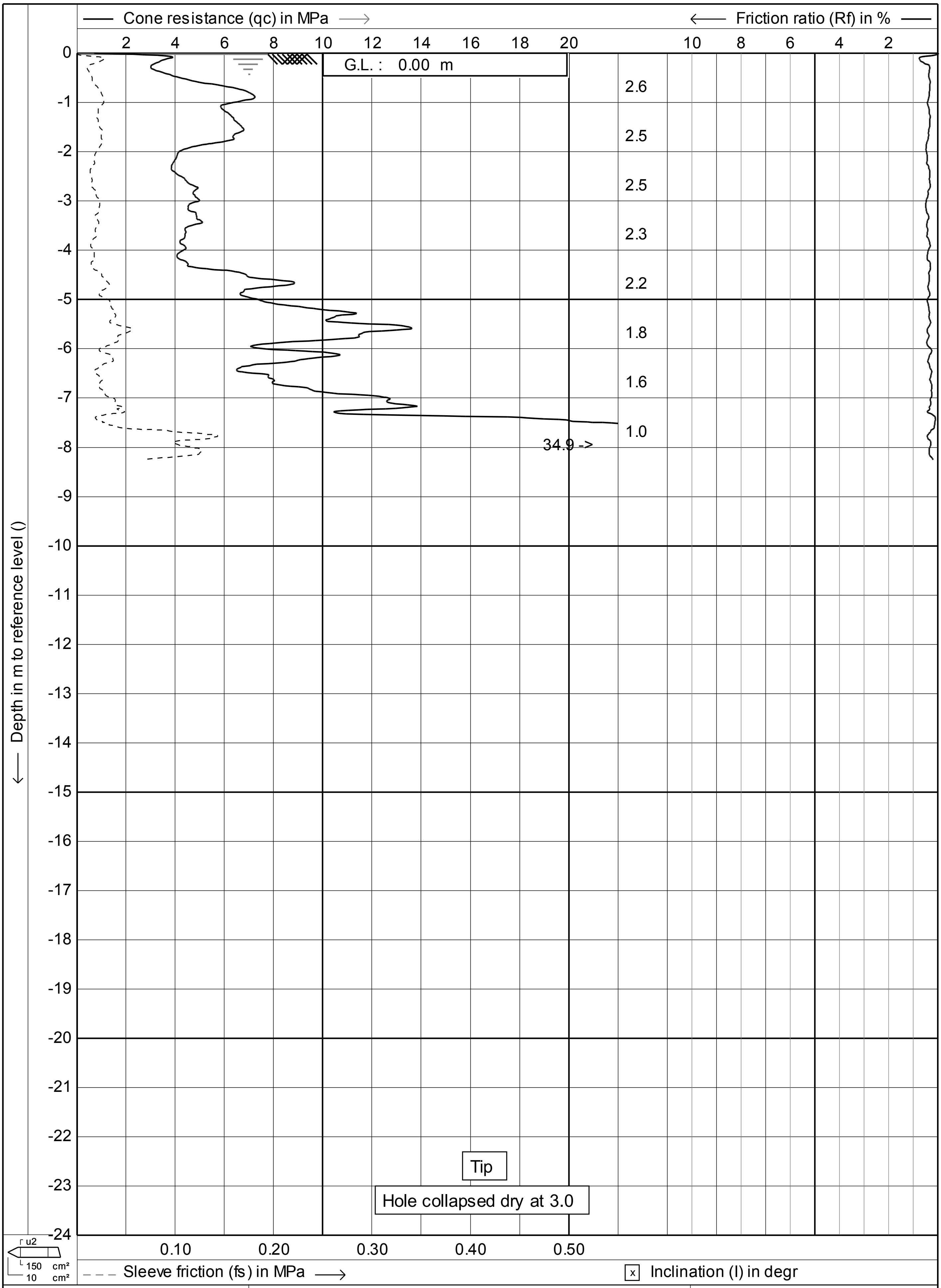


PERRY GEOTECH

Test according A.S.T.M Standard D 5778-12

Project : **Site Investigations**

Location: **Bell Rd - Papamoa**

Position: **0, 0 RD**

Date : **9/06/2017**

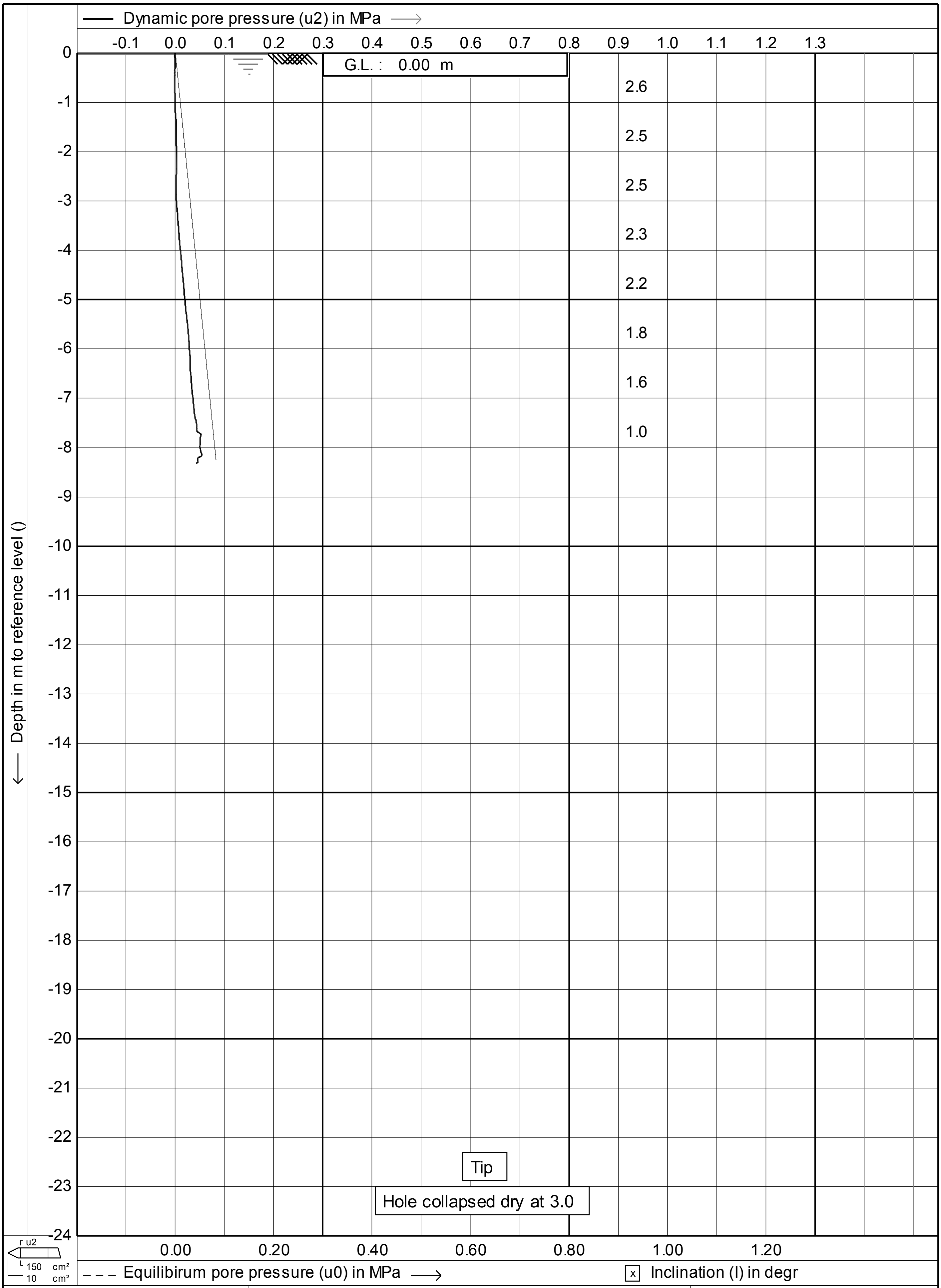
Cone no. : **C10CFIIP.C13068**

Project no. : **05TT4**

CPT no. : **108**

1/14

1.43



PERRY GEOTECH

Test according A.S.T.M Standard D 5778-12

Project : **Site Investigations**

Location: **Bell Rd - Papamoa**

Position: **0, 0 RD**

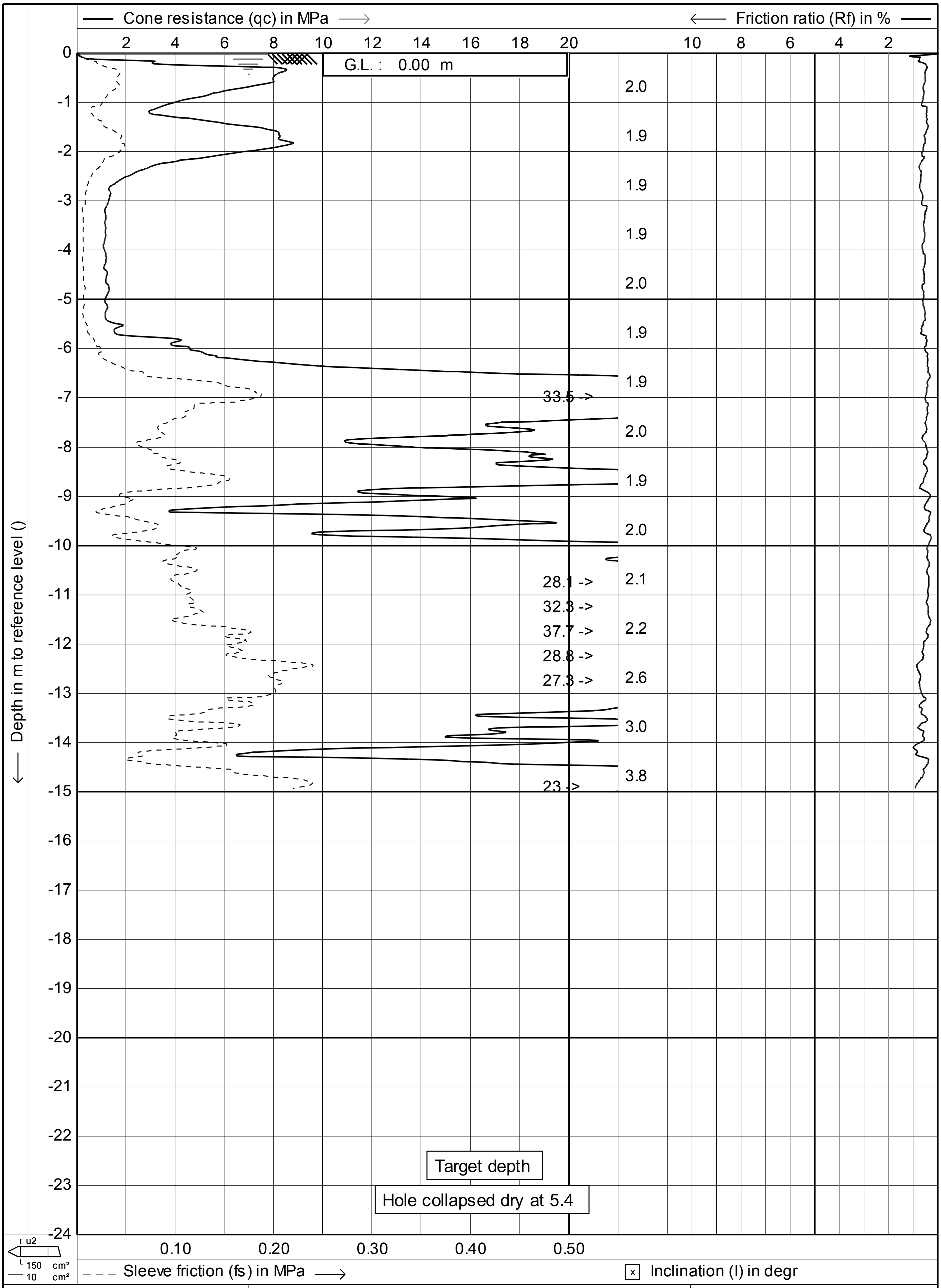
Date : **9/06/2017**

Cone no. : **C10CFIIP.C13068**

Project no. : **05TT4**

CPT no. : **108** **2/14**

1.43



Target depth

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PERRY GEOTECH

Test according A.S.T.M Standard D 5778-12

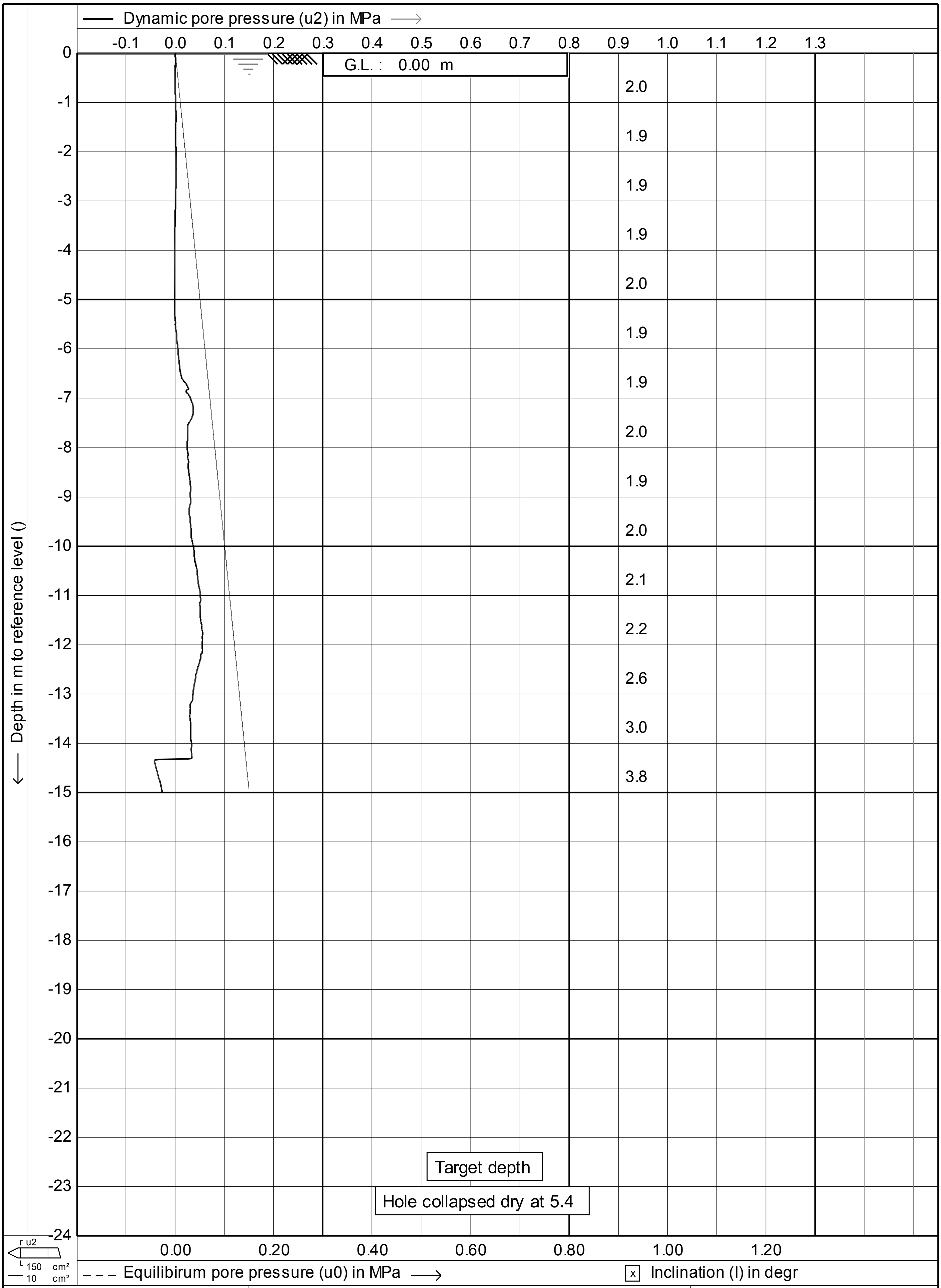
Project : **Site Investigations**

Location: **Bell Rd - Papamoa**

Position: **0, 0 RD**

Date	: **9/06/2017**
Cone no.	: **C10CFIIP.C13068**
Project no. :	**05TT4**
CPT no.	: **109**
	1/14

1.43



PERRY GEOTECH

Test according A.S.T.M Standard D 5778-12

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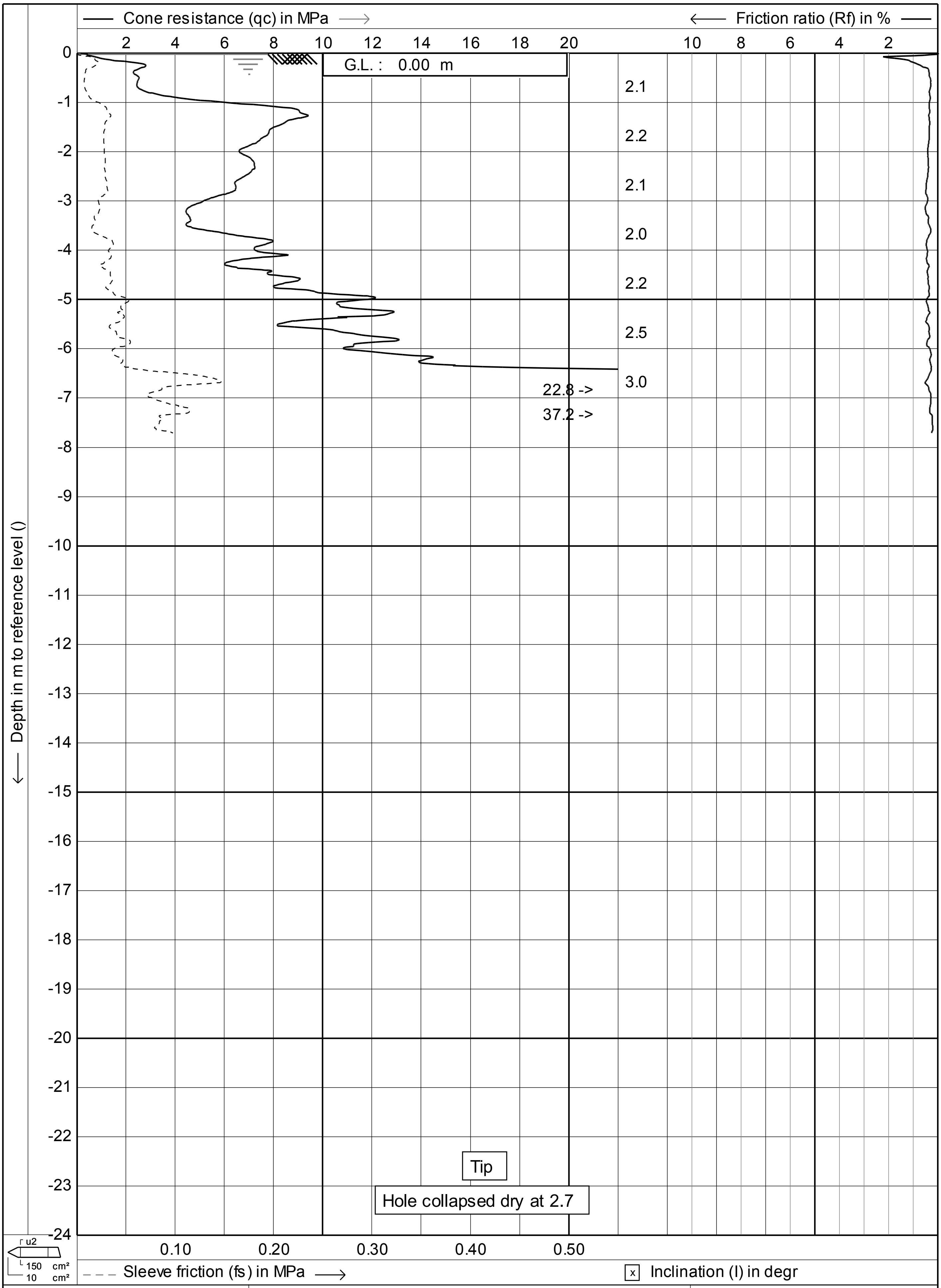
Cone no. : **C10CFIIP.C13068**
Project no. : **05TT4**
CPT no. : **109**

2/14



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Test according A.S.T.M Standard D 5778-12	
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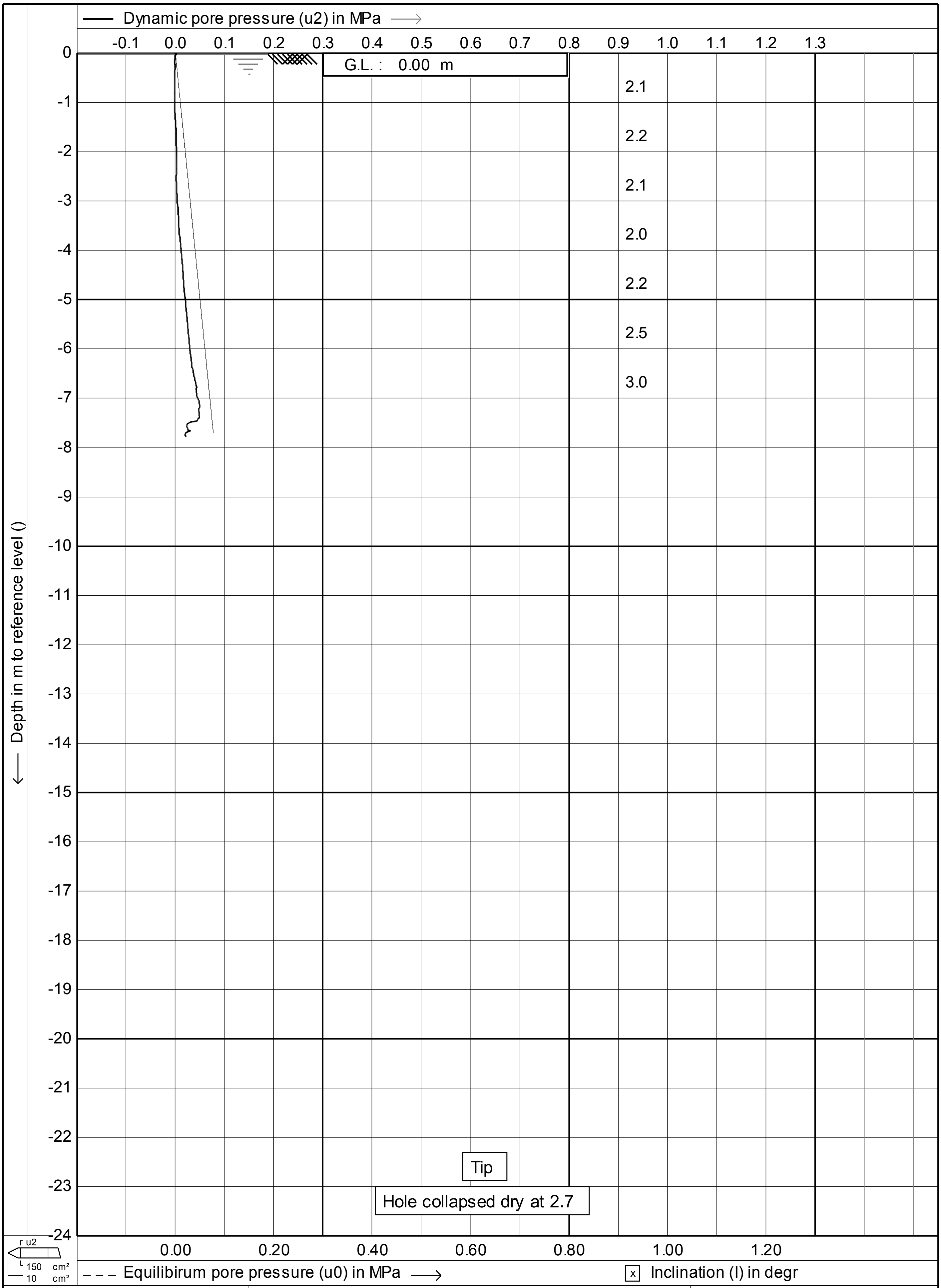
Position: **0, 0 RD**	Project no. : **05TT4**
	CPT no. : **110** 1/14



G.L. : 0.00 m

Tip

Hole collapsed dry at 2.7

PERRY GEOTECH

Test according A.S.T.M Standard D 5778-12

Project : **Site Investigations**

Location: **Bell Rd - Papamoa**

Position: **0, 0 RD**

Date : **9/06/2017**

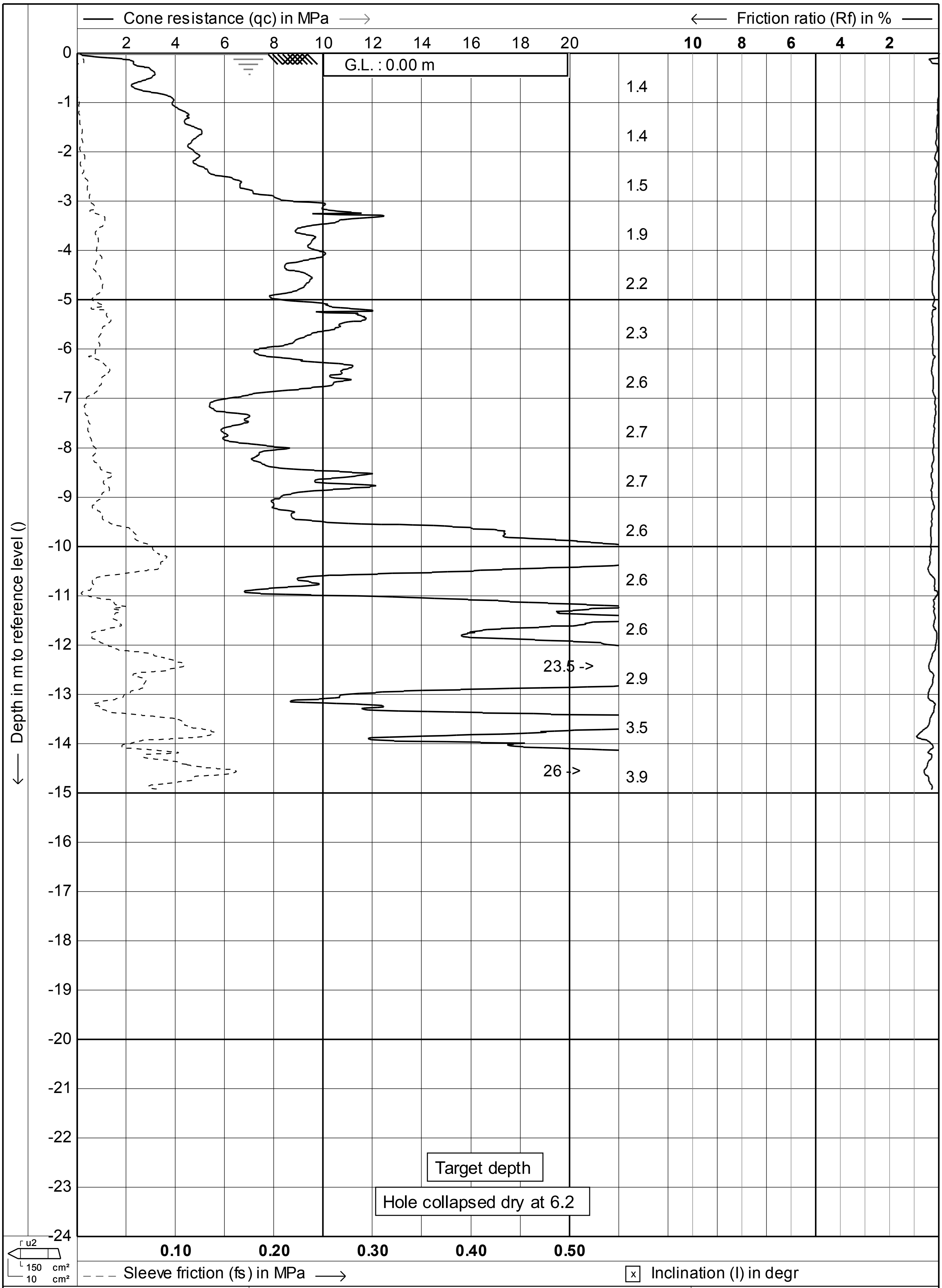
Cone no. : **C10CFIIP.C13068**

Project no. : **05TT4**

CPT no. : **110**

2/14

1.43



CPTask V1.33

PERRY GEOTECH

Test according A.S.T.M. Standard D 5778-12

Project : **Site Investigation**

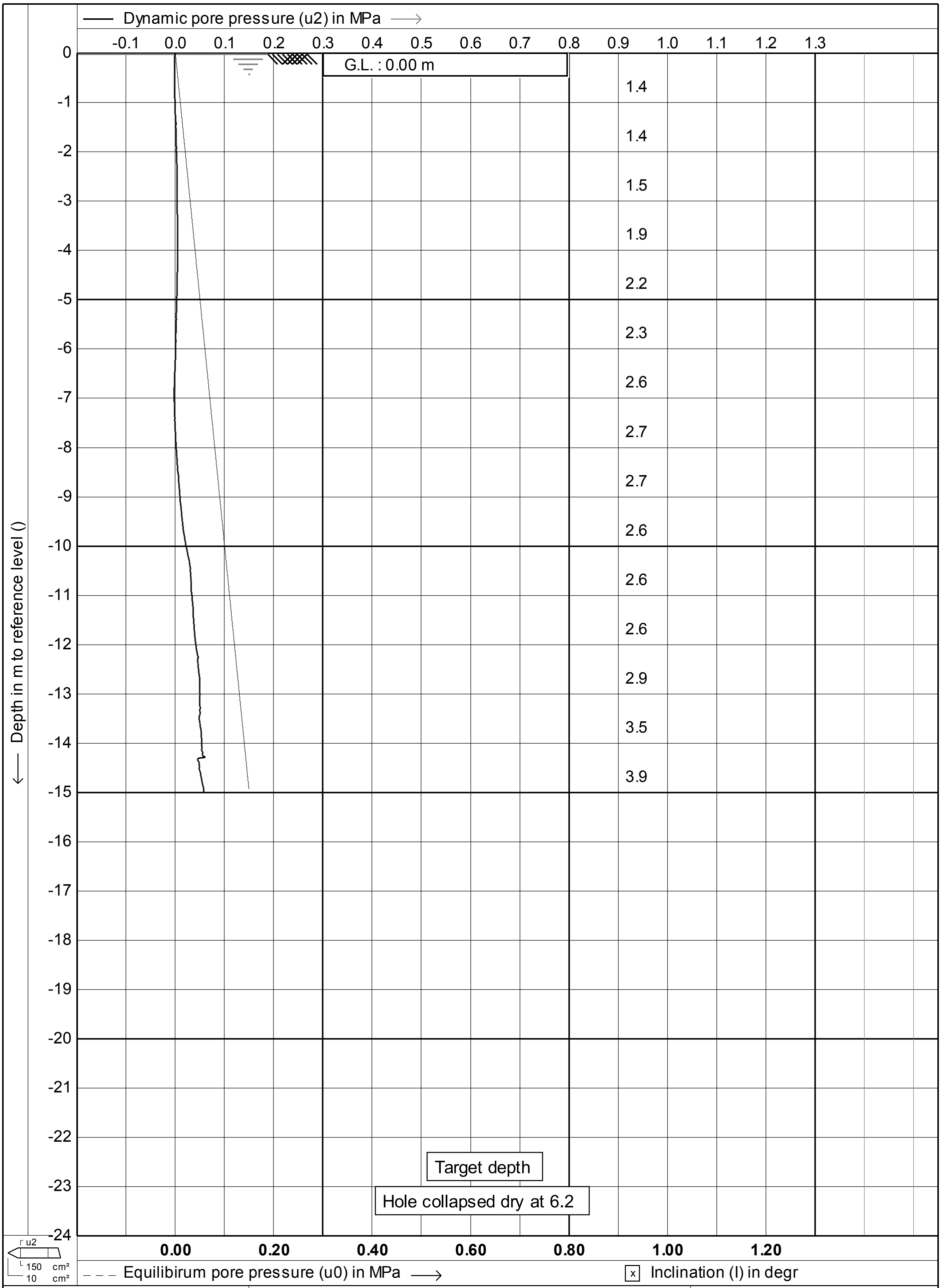
Location: **Bell rd - Papamoa**

Date : **12-6-2017**

Cone no. : **C10CFIIP.C15212**

Project no. : **02TT06**

CPT no. : **111** **1/14**



Target depth

Hole collapsed dry at 6.2

CPTask V1.33

PERRY
GEOTECH

Test according A.S.T.M. Standard D 5778-12

Project : **Site Investigation**

Location: **Bell rd - Papamoa**

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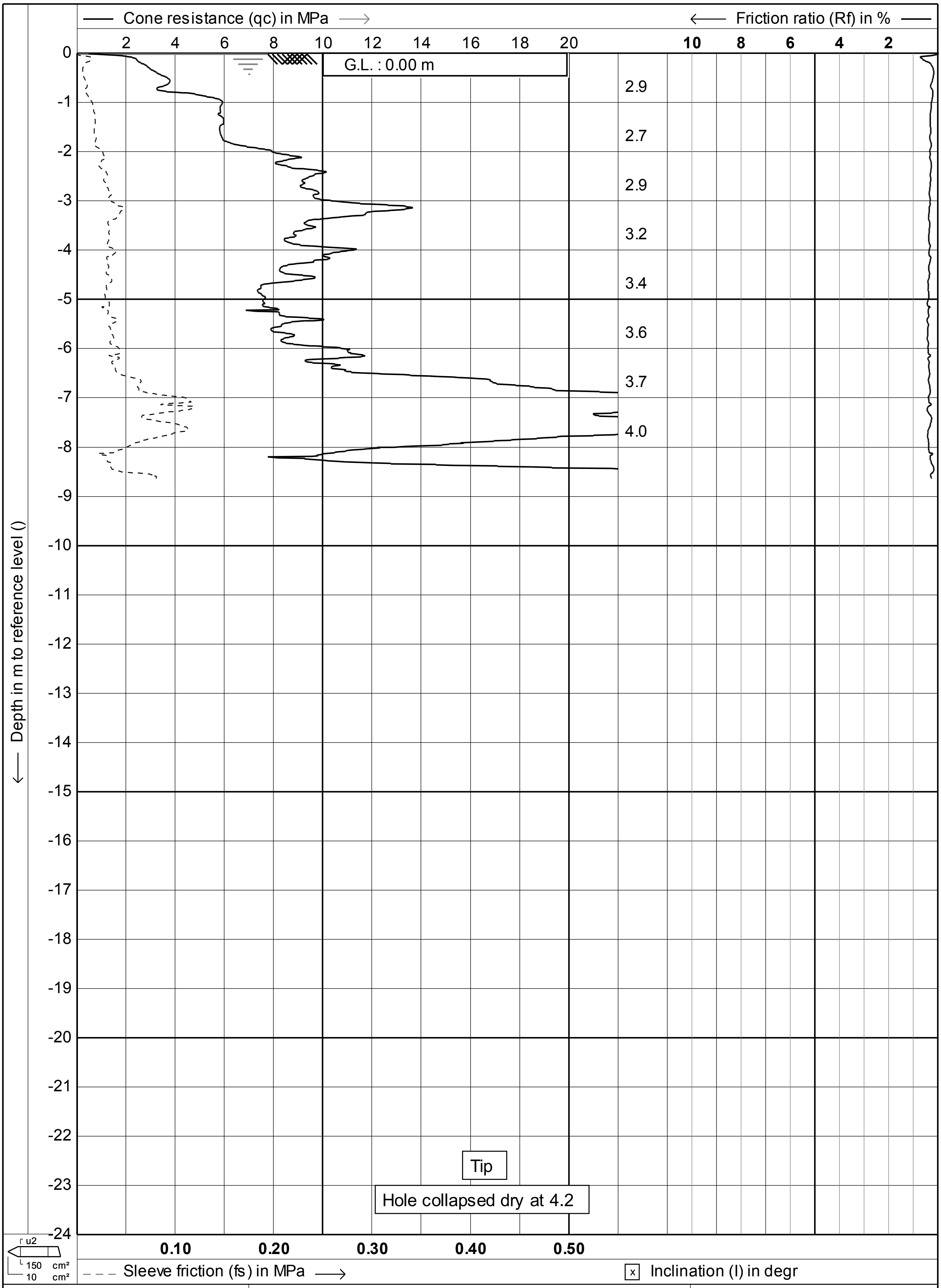
2/14



PERRY GEOTECH

Test according A.S.T.M. Standard D 5778-12

Project : **Site Investigation**

Location: **Bell rd - Papamoa**

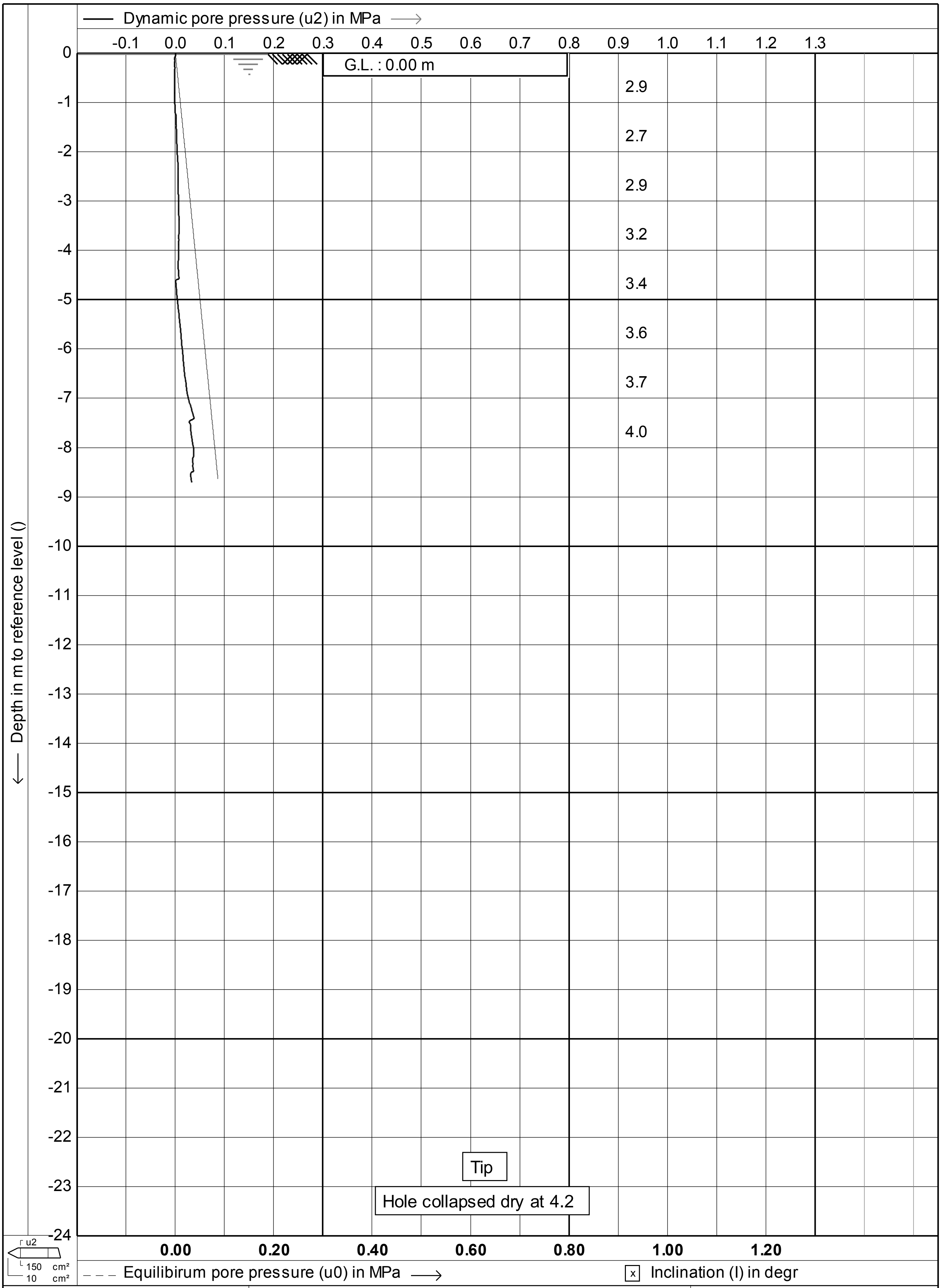
Date : **12-6-2017**

Cone no. : **C10CFIIP.C15212**

Project no. : **02TT06**

CPT no. : **112** **1/14**

CPTask V1.33



CPTask V1.33

PERRY GEOTECH

Test according A.S.T.M. Standard D 5778-12

Project : **Site Investigation**

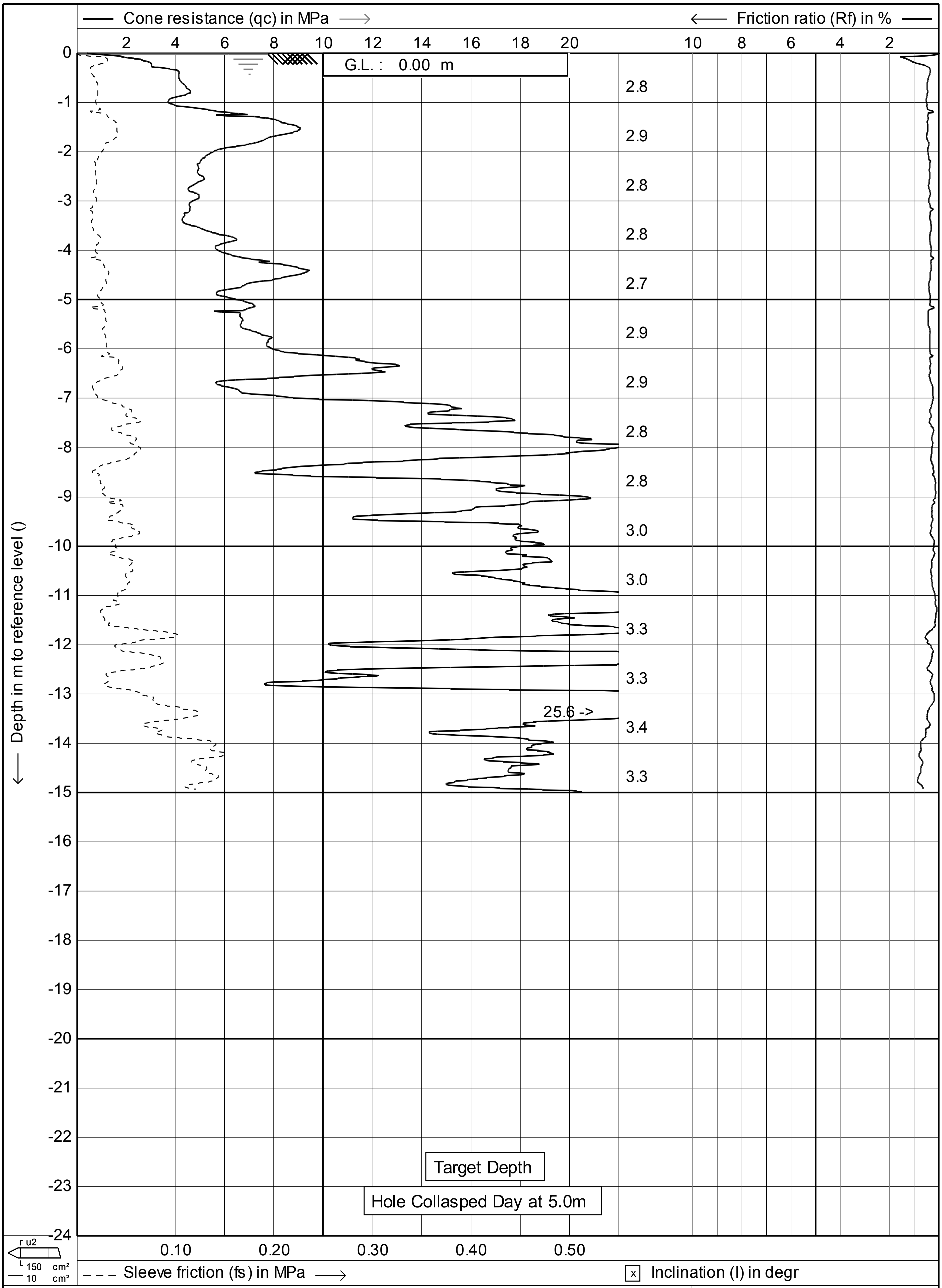
Location: **Bell rd - Papamoa**

Date : **12-6-2017**

Cone no. : **C10CFIIP.C15212**

Project no. : **02TT06**

CPT no. : **112**



Target Depth

Hole Collasped Day at 5.0m

PERRY GEOTECH

1.47

Test according A.S.T.M. Standard D 5778-12

Project : **Site Investigation**

Location: **Bell rd - Papamoa**

Position: **0, 0**

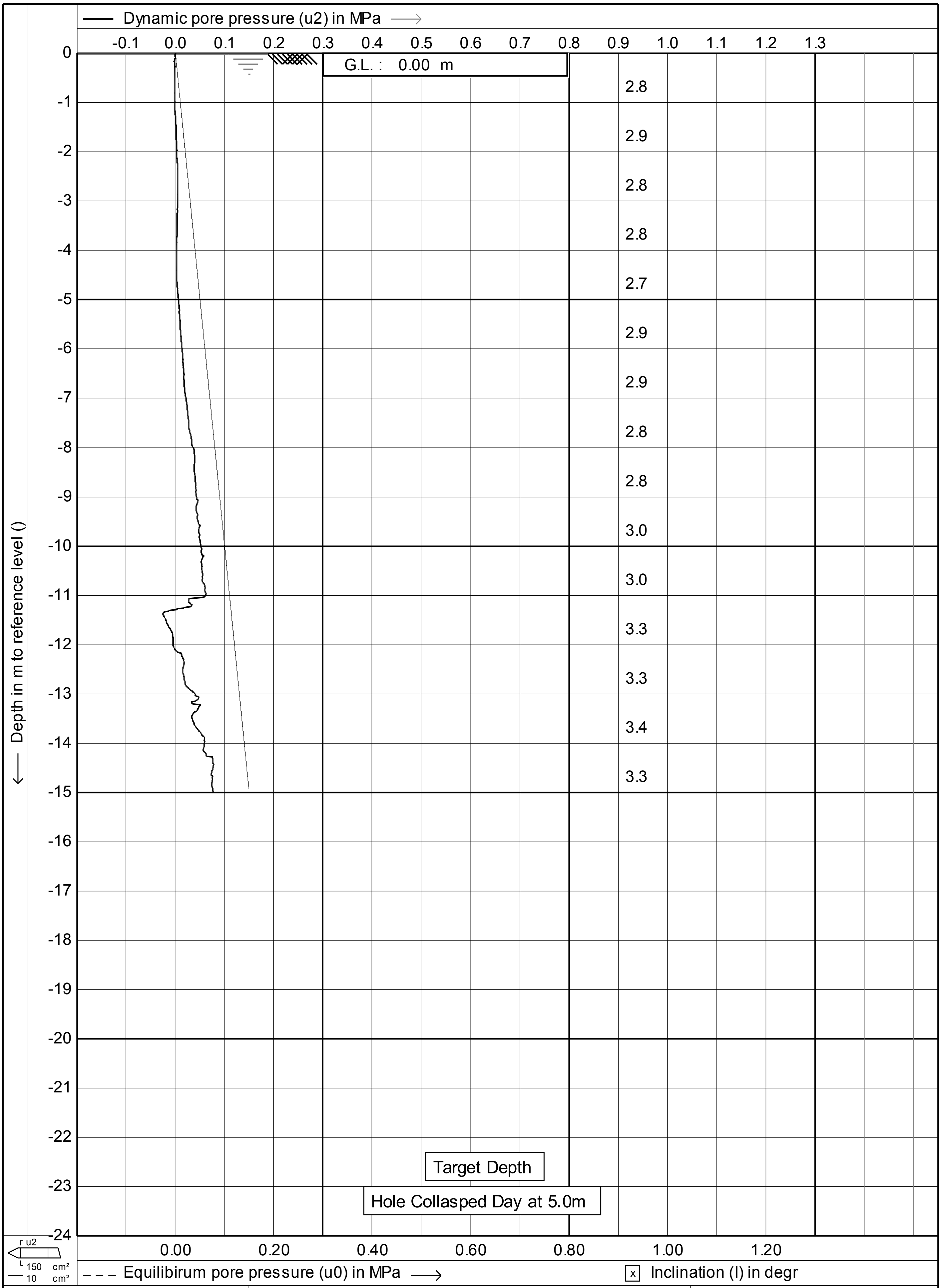
Date : **6/14/2017**

Cone no. : **C10CFIIP.C15212**

Project no. : **02TT06**

CPT no. : **113**

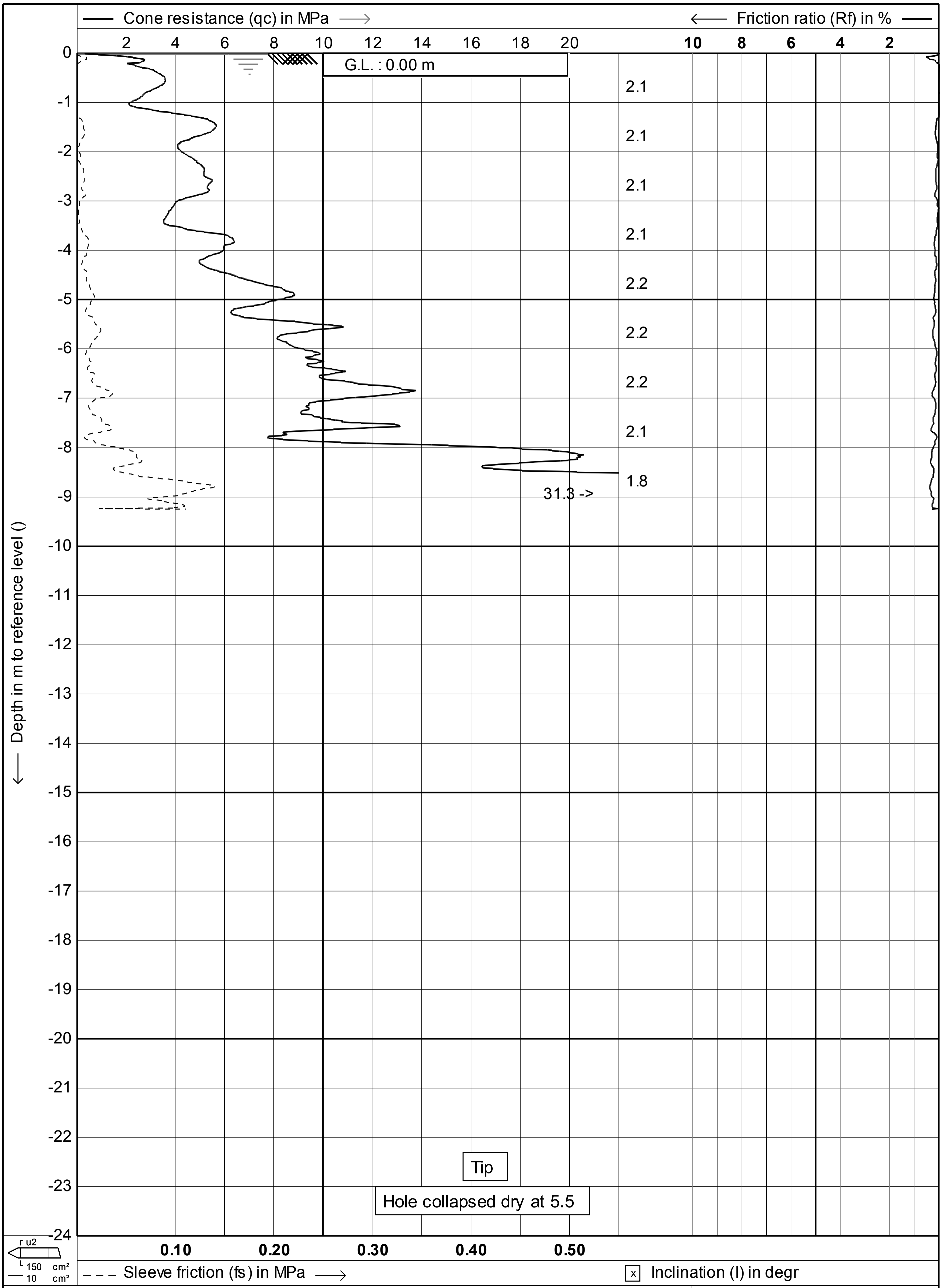
1/14



Test according A.S.T.M. Standard D 5778-12

Project : **Site Investigation**
Location: **Bell rd - Papamoa**
Position: **0, 0**

Date	: **6/14/2017**
Cone no.	: **C10CFIIP.C15212**
Project no. :	**02TT06**
CPT no.	: **113**



PERRY GEOTECH

Test according A.S.T.M. Standard D 5778-12

Project : **Site Investigation**

Location: **Bell rd - Papamoa**

Date : **13-6-2017**

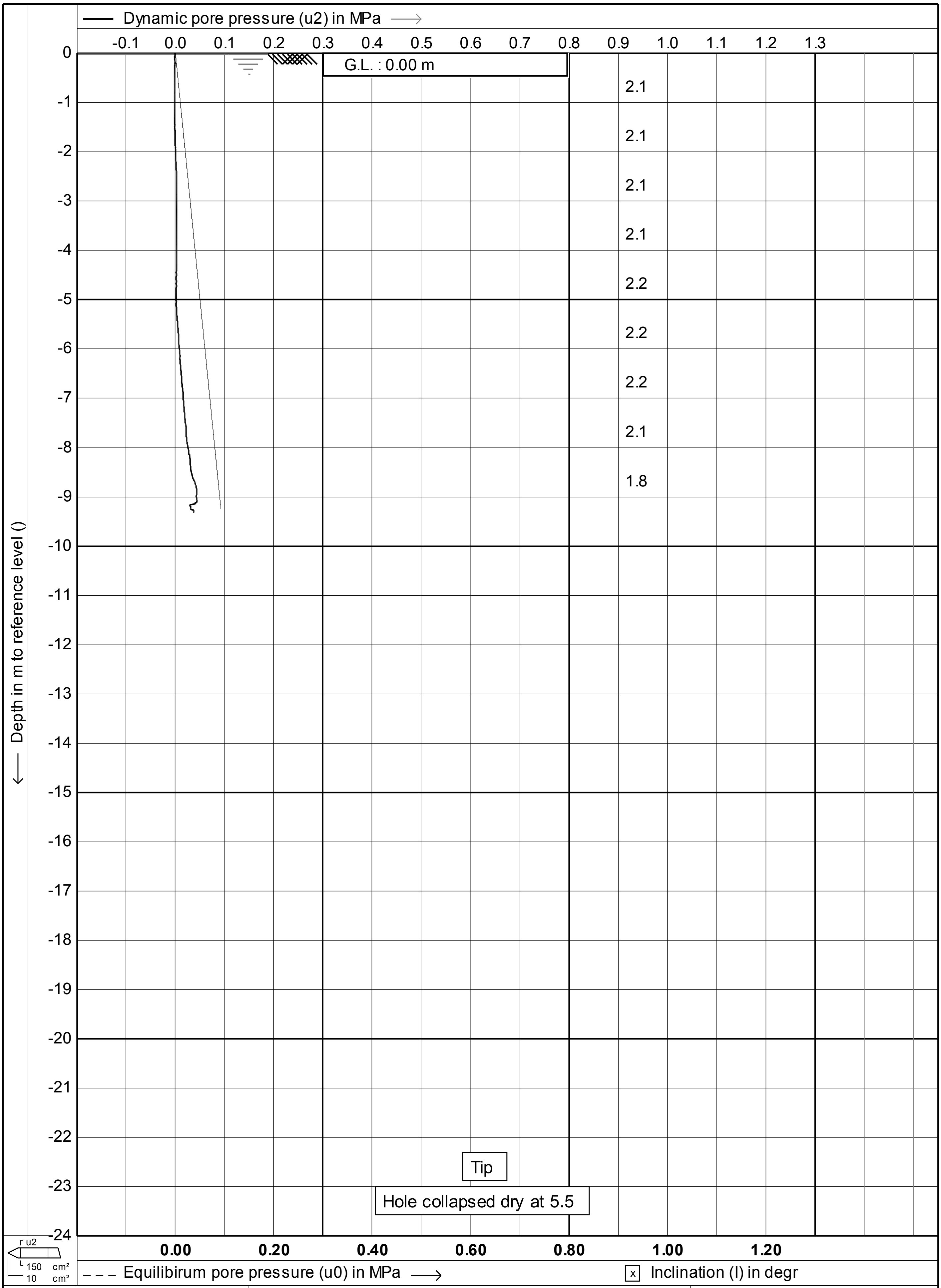
Cone no. : **C10CFIIP.C15212**

Project no. : **02TT06**

CPT no. : **114**

1/14

CPTask V1.33



Hole collapsed dry at 5.5

PERRY GEOTECH

Test according A.S.T.M. Standard D 5778-12

Project : **Site Investigation**

Location: **Bell rd - Papamoa**

Date : **13-6-2017**

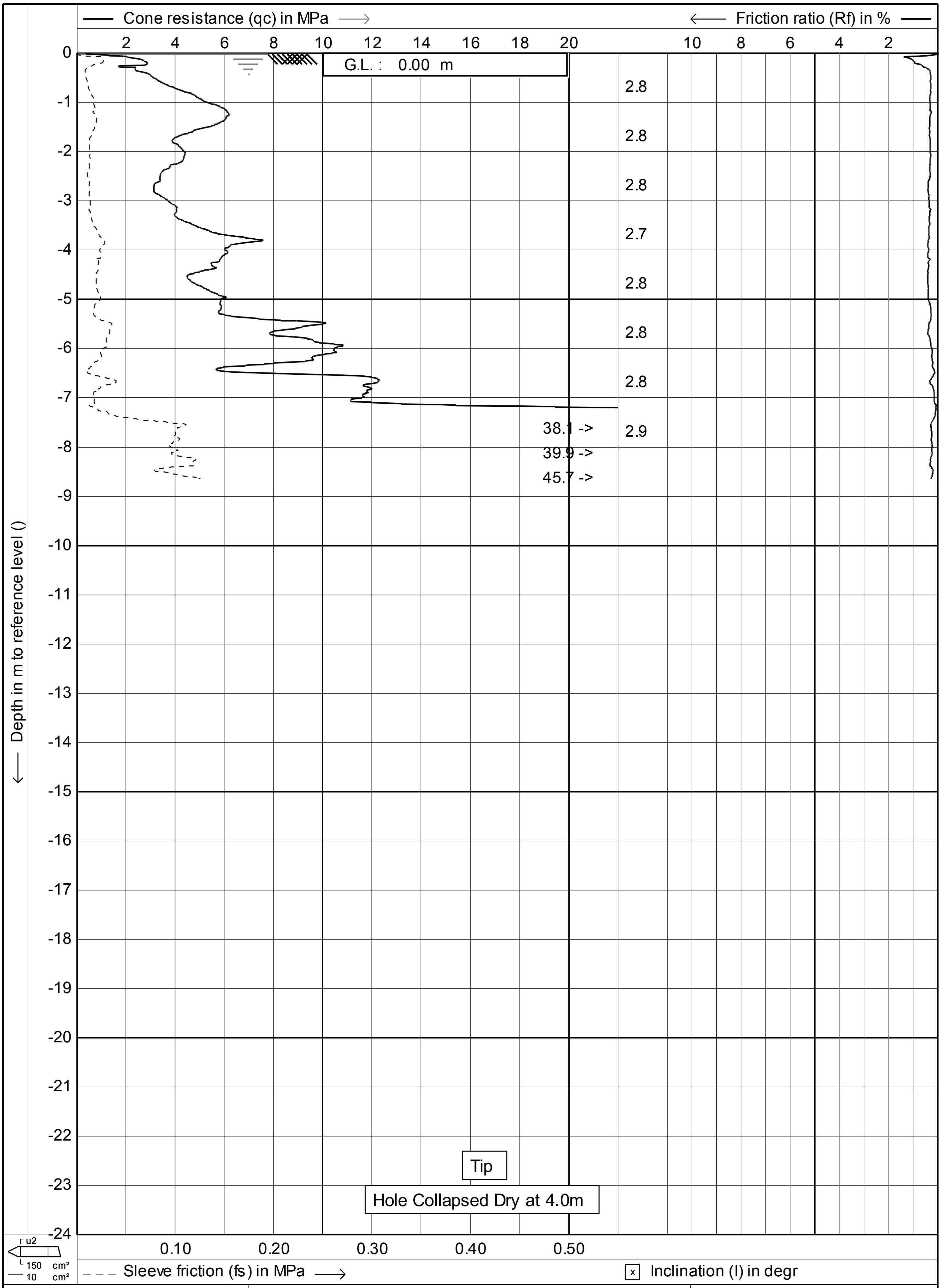
Cone no. : **C10CFIIP.C15212**

Project no. : **02TT06**

CPT no. : **114**

2/14

CPTask V1.33



1.47

PERRY GEOTECH

Test according A.S.T.M. Standard D 5778-12

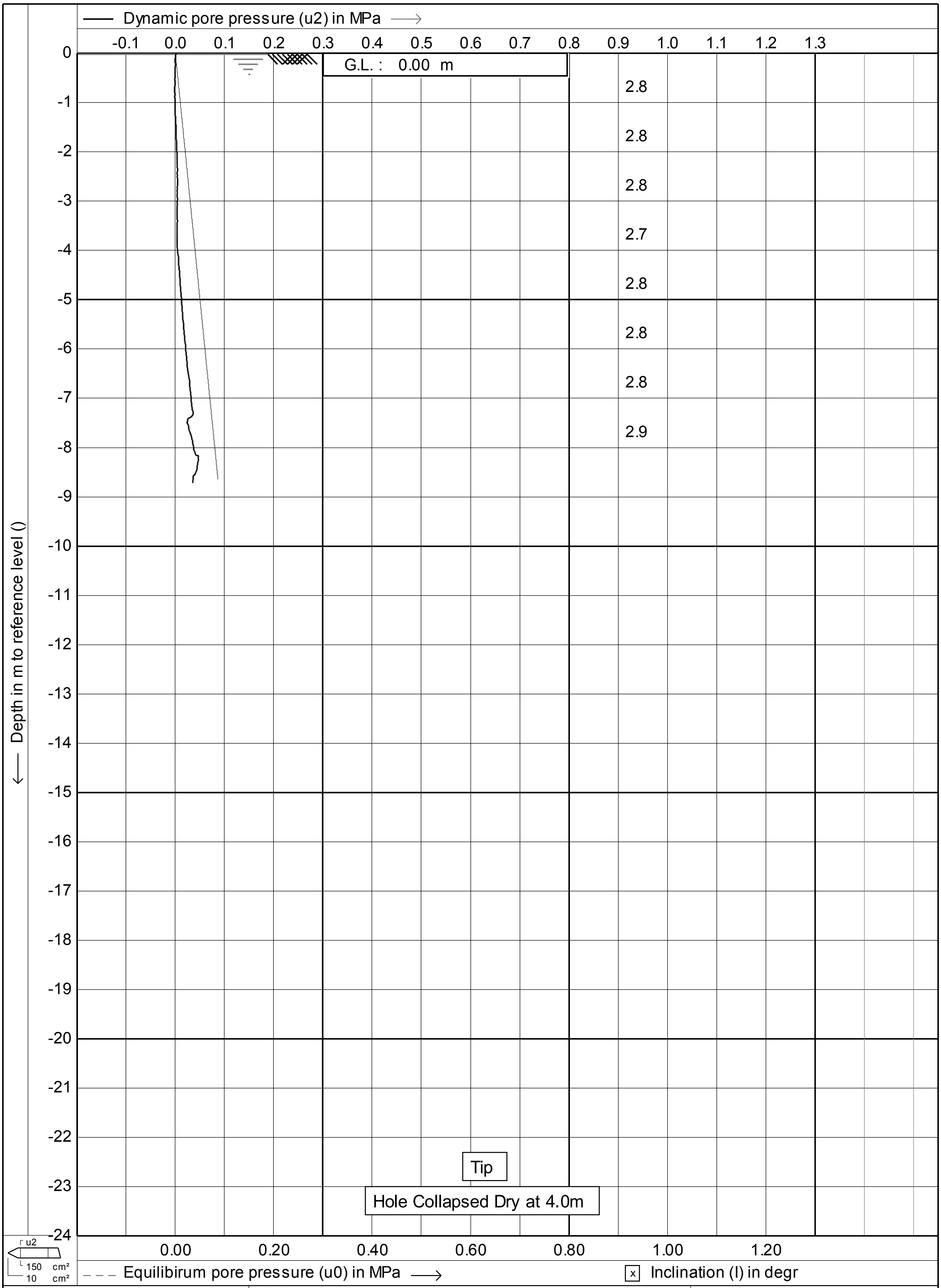
Project : **Site Investigation**

Location: **Bell rd - Papamoa**

Position: **0, 0**

Date	: **6/14/2017**
Cone no.	: **C10CFIIP.C15212**
Project no. :	**02TT06**
CPT no.	: **115a**

1/14



PERRY
GEOTECH

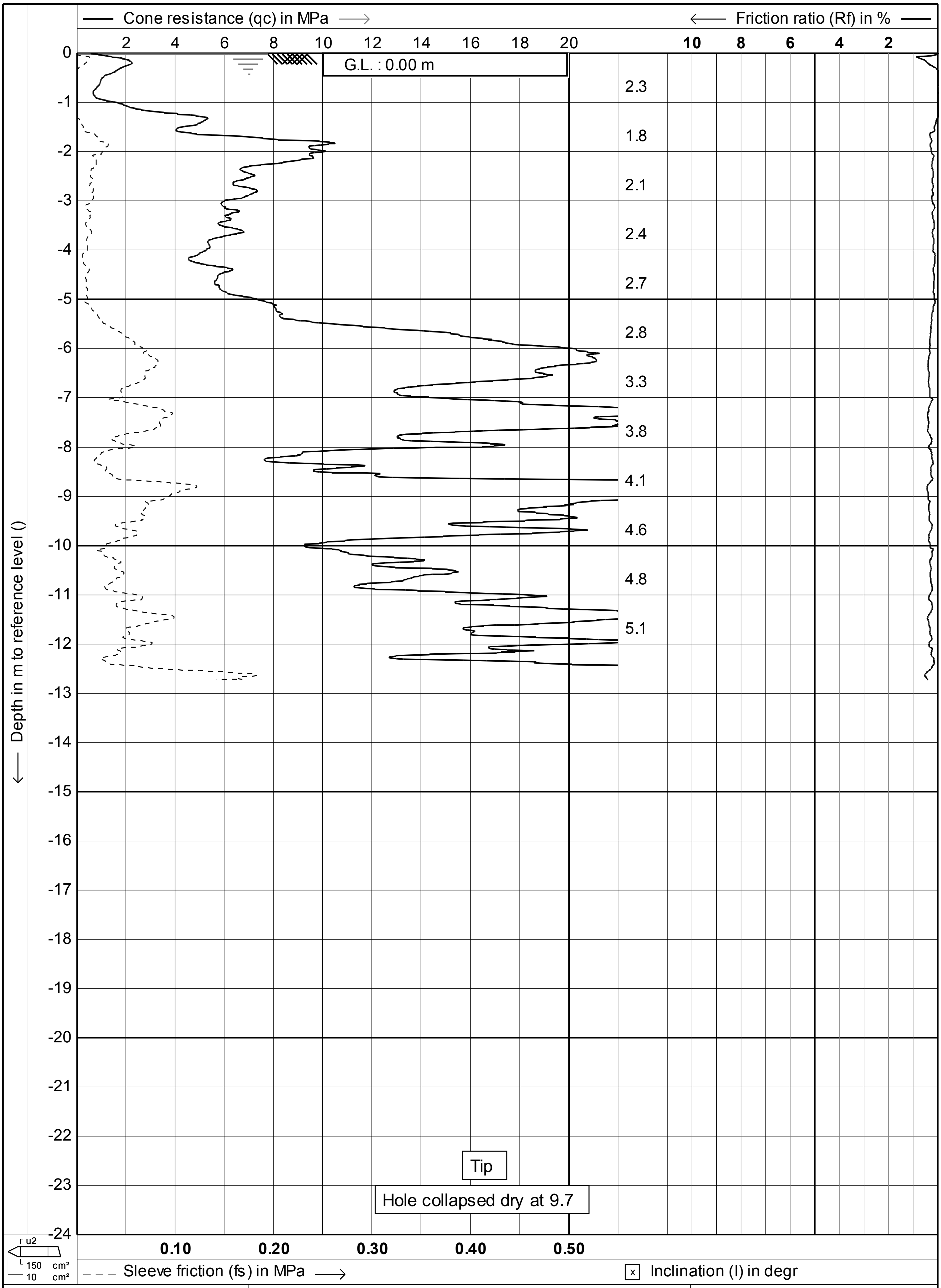
Test according A.S.T.M. Standard D 5778-12

Project : **Site Investigation**
Location: **Bell rd - Papamoa**
Position: **0, 0**

Date : **6/14/2017**
Cone no. : **C10CFIIP.C15212**
Project no. : **02TT06**
CPT no. : **115a**

2/14

1.47



PERRY GEOTECH

Test according A.S.T.M. Standard D 5778-12

Project : **Site Investigation**

Location: **Bell rd - Papamoa**

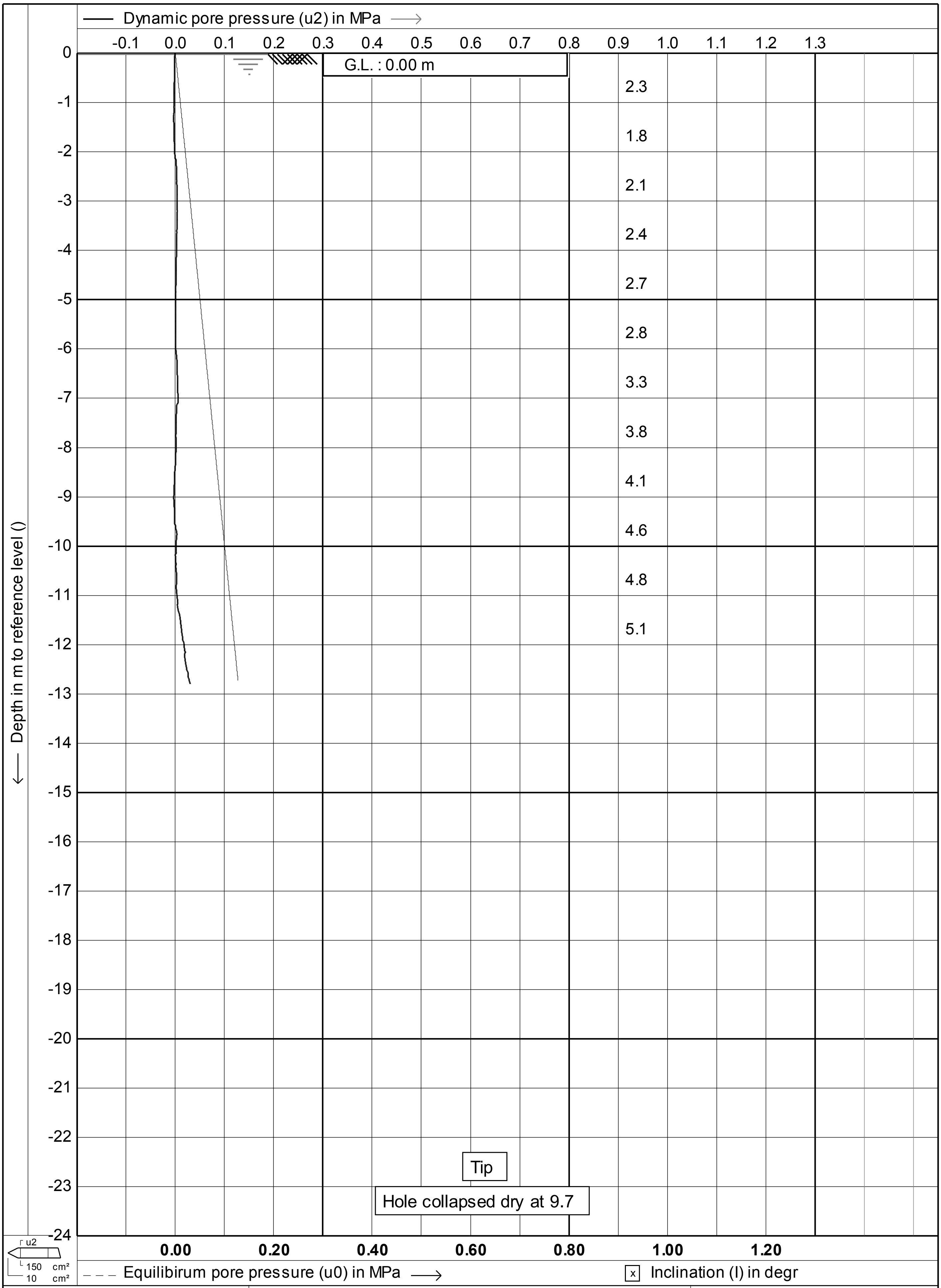
Date : **13-6-2017**

Cone no. : **C10CFIIP.C15212**

Project no. : **02TT06**

CPT no. : **116**

1/14



CPTask V1.33

PERRY GEOTECH

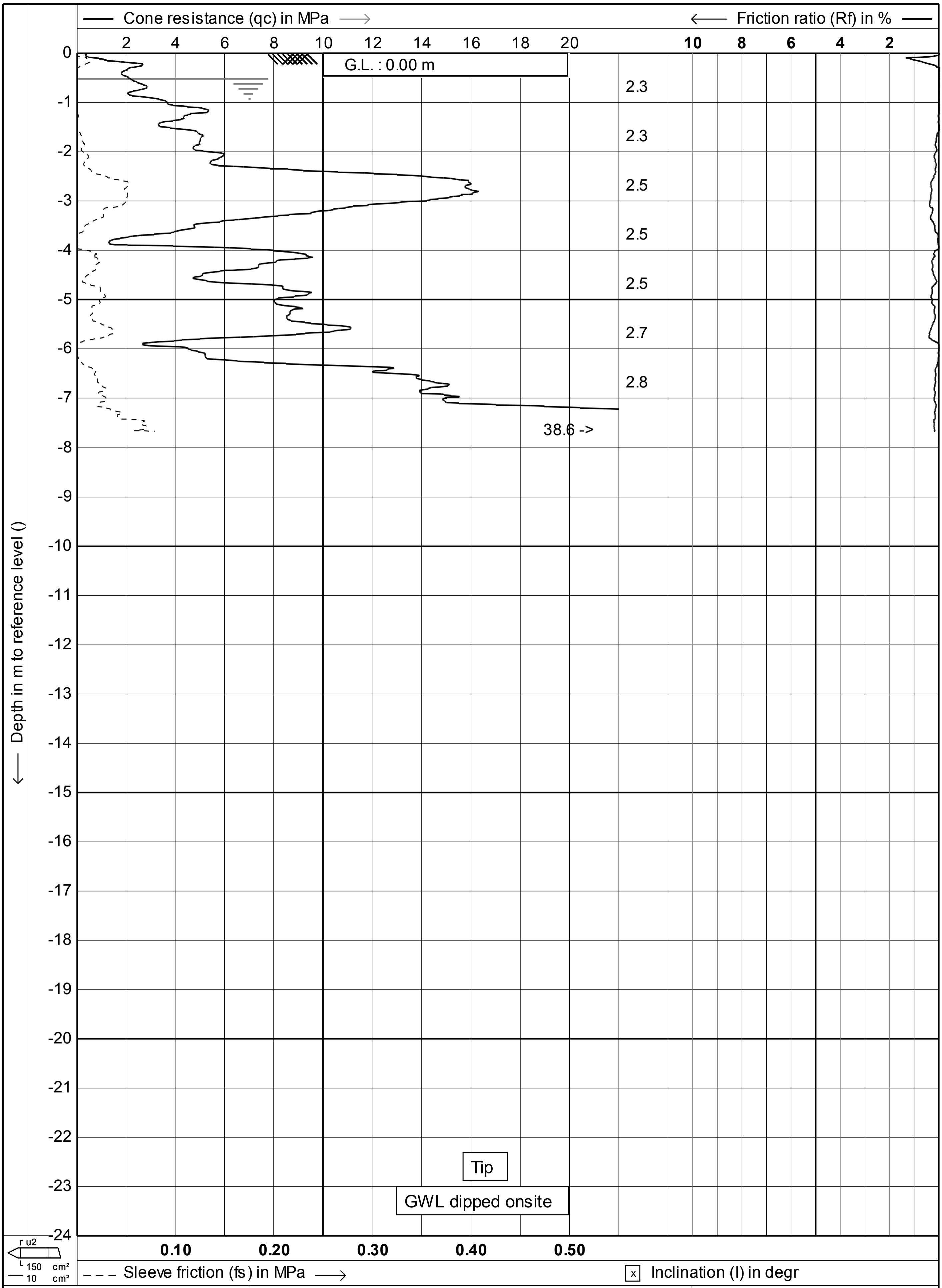
Test according A.S.T.M. Standard D 5778-12

Project : **Site Investigation**

Location: **Bell rd - Papamoa**

Date : **13-6-2017**
Cone no. : **C10CFIIP.C15212**
Project no. : **02TT06**
CPT no. : **116**

2/14



CPTask V1.33

PERRY GEOTECH

Test according A.S.T.M. Standard D 5778-12

Project : **Site Investigation**

Location: **Bell rd - Papamoa**

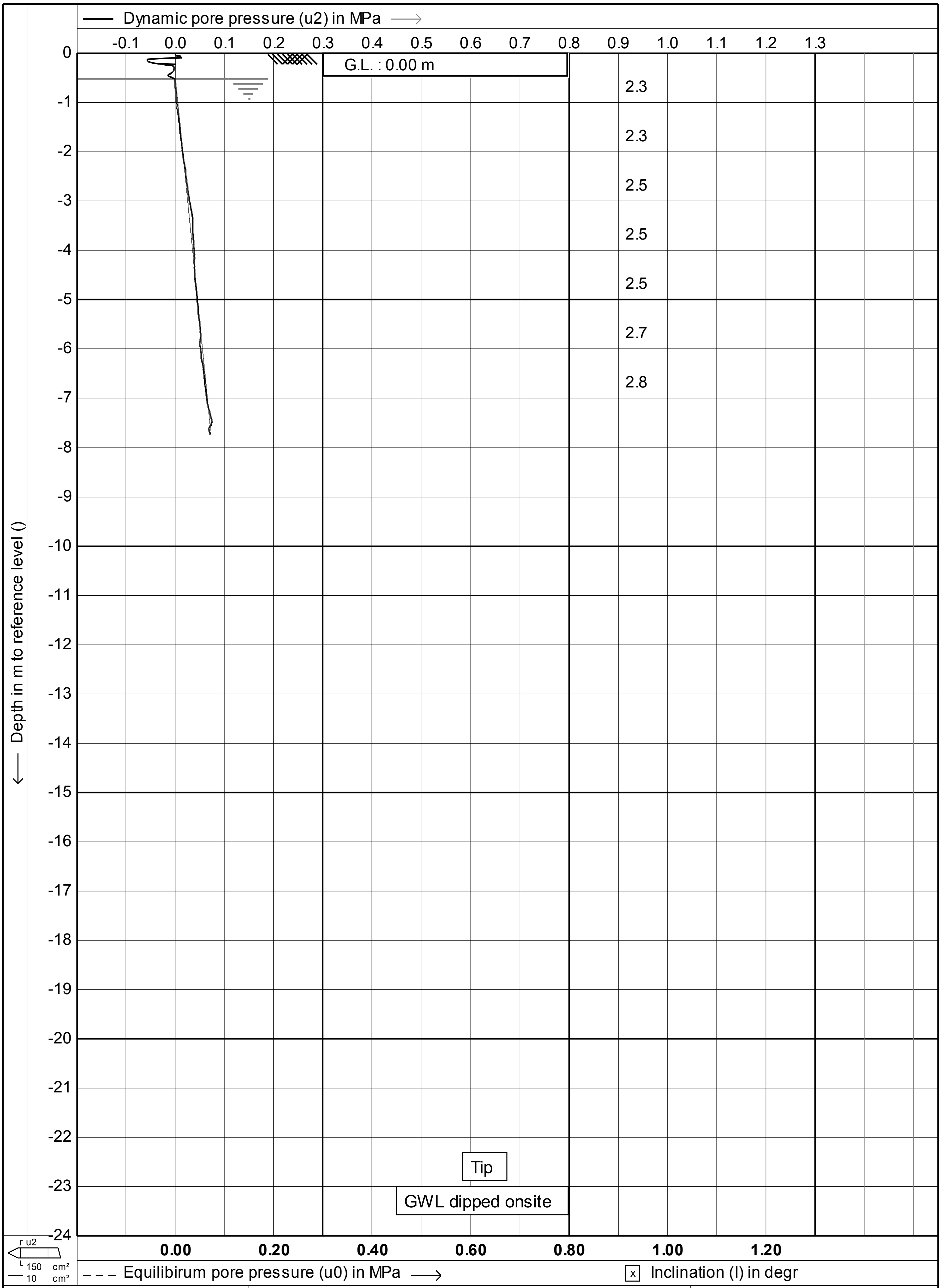
Date : **13-6-2017**

Cone no. : **C10CFIIP.C15212**

Project no. : **02TT06**

CPT no. : **117**

1/14



CPTask V1.33

PERRY GEOTECH

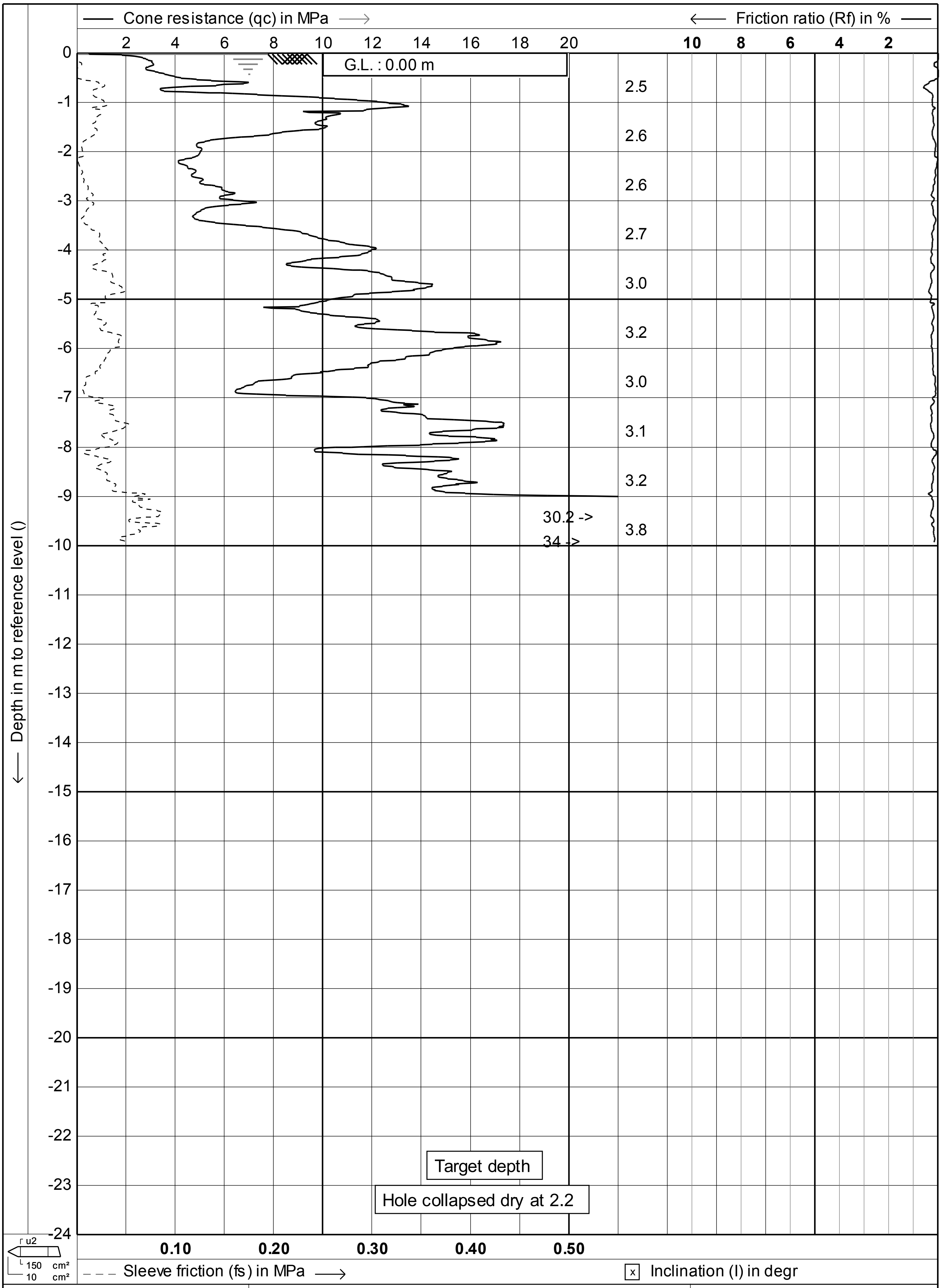
Test according A.S.T.M. Standard D 5778-12

Project : **Site Investigation**

Location: **Bell rd - Papamoa**

Date : **13-6-2017**
Cone no. : **C10CFIIP.C15212**
Project no. : **02TT06**
CPT no. : **117**

2/14



Target depth

Hole collapsed dry at 2.2

CPTask V1.33

PERRY GEOTECH

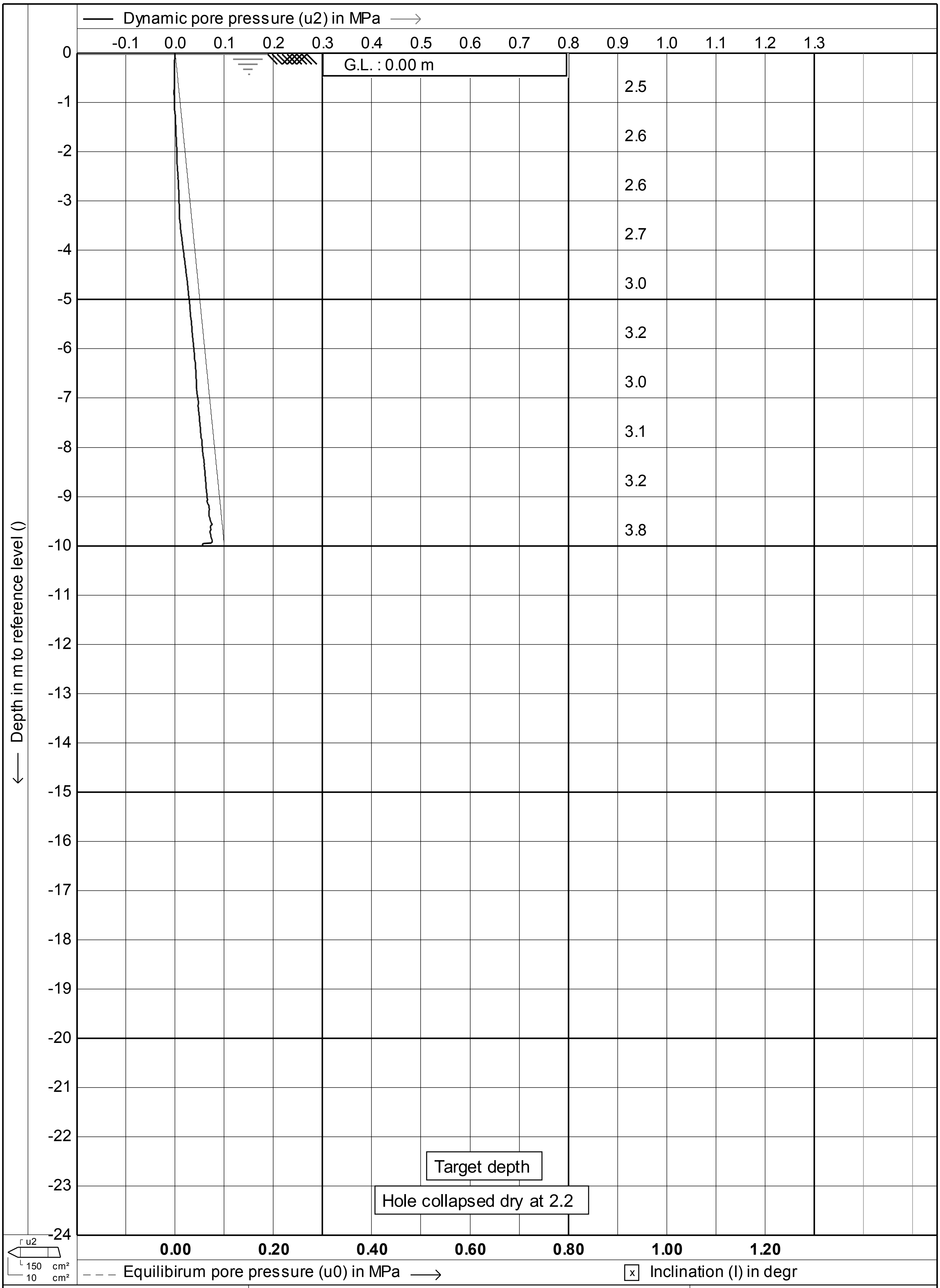
Test according A.S.T.M. Standard D 5778-12

Project : **Site Investigation**

Location: **Bell rd - Papamoa**

Date	: **13-6-2017**
Cone no.	: **C10CFIIP.C15212**
Project no. :	**02TT06**
CPT no.	: **118**

1/14



Target depth

Hole collapsed dry at 2.2

CPTask V1.33

PERRY GEOTECH

Test according A.S.T.M. Standard D 5778-12

Project : **Site Investigation**

Location: **Bell rd - Papamoa**

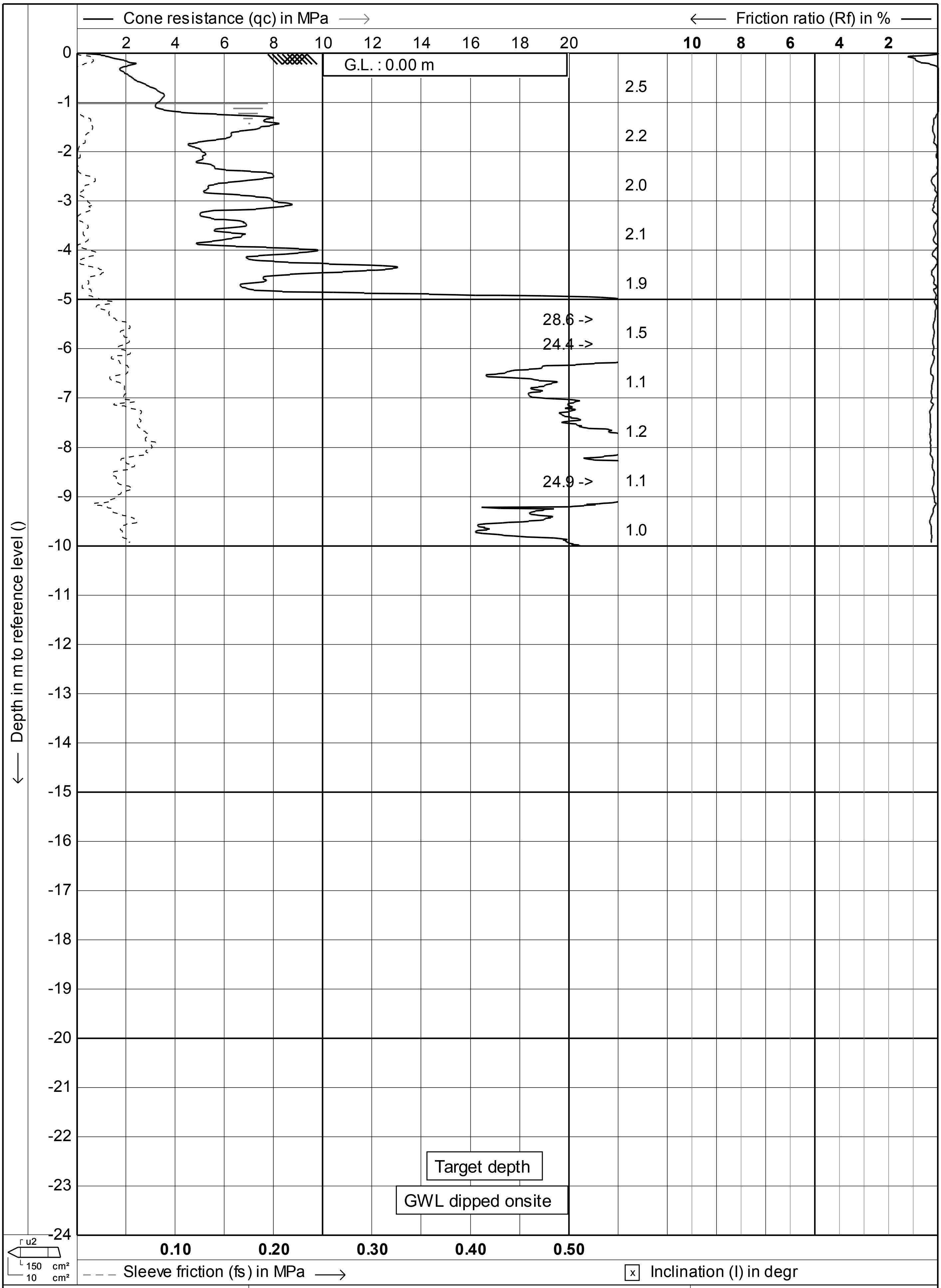
Date : **13-6-2017**

Cone no. : **C10CFIIP.C15212**

Project no. : **02TT06**

CPT no. : **118**

2/14



CPTask V1.33

PERRY
GEOTECH

Test according A.S.T.M. Standard D 5778-12

Project : **Site Investigation**

Location: **Bell rd - Papamoa**

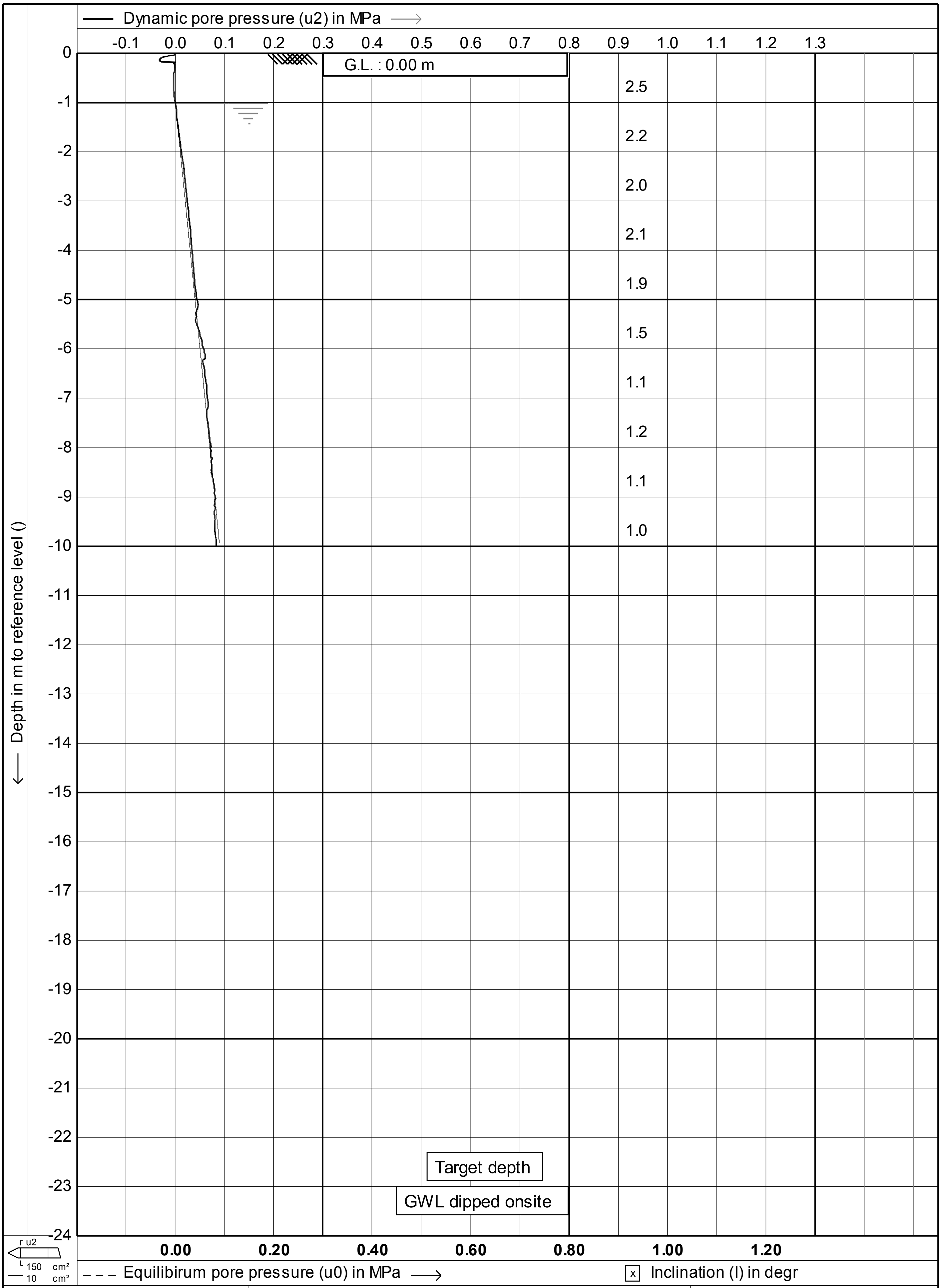
Date : **13-6-2017**

Cone no. : **C10CFIIP.C15212**

Project no. : **02TT06**

CPT no. : **120**

1/14



CPTask V1.33

PERRY
GEOTECH

Test according A.S.T.M. Standard D 5778-12

Project : **Site Investigation**

Location: **Bell rd - Papamoa**

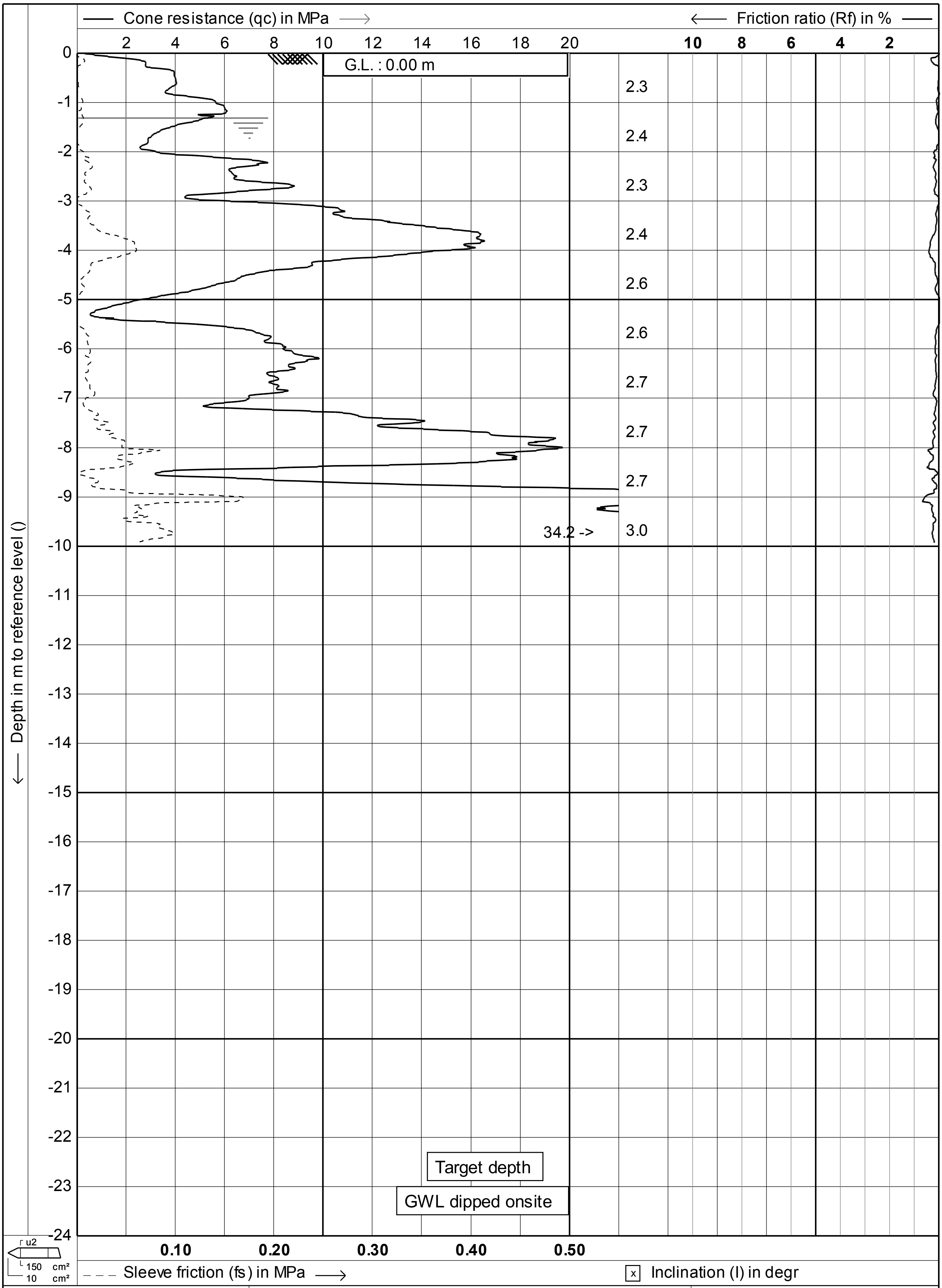
Date : **13-6-2017**

Cone no. : **C10CFIIP.C15212**

Project no. : **02TT06**

CPT no. : **120**

2/14



CPTask V1.33

PERRY GEOTECH

Test according A.S.T.M. Standard D 5778-12

Project : **Site Investigation**

Location: **Bell rd - Papamoa**

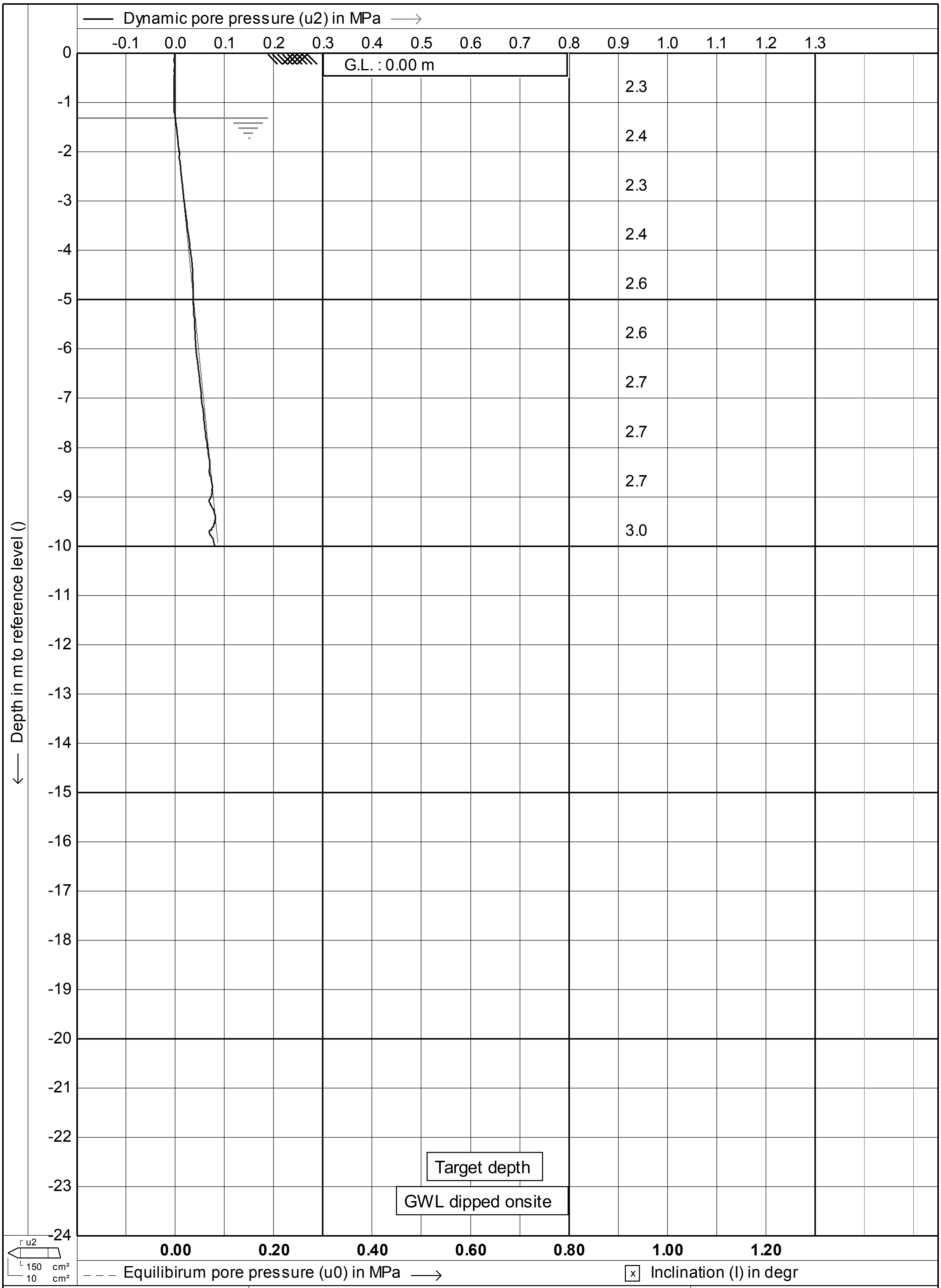
Date : **13-6-2017**

Cone no. : **C10CFIIP.C15212**

Project no. : **02TT06**

CPT no. : **121**

1/14



PERRY GEOTECH

Test according A.S.T.M. Standard D 5778-12

Project : **Site Investigation**

Location: **Bell rd - Papamoa**

Date : **13-6-2017**

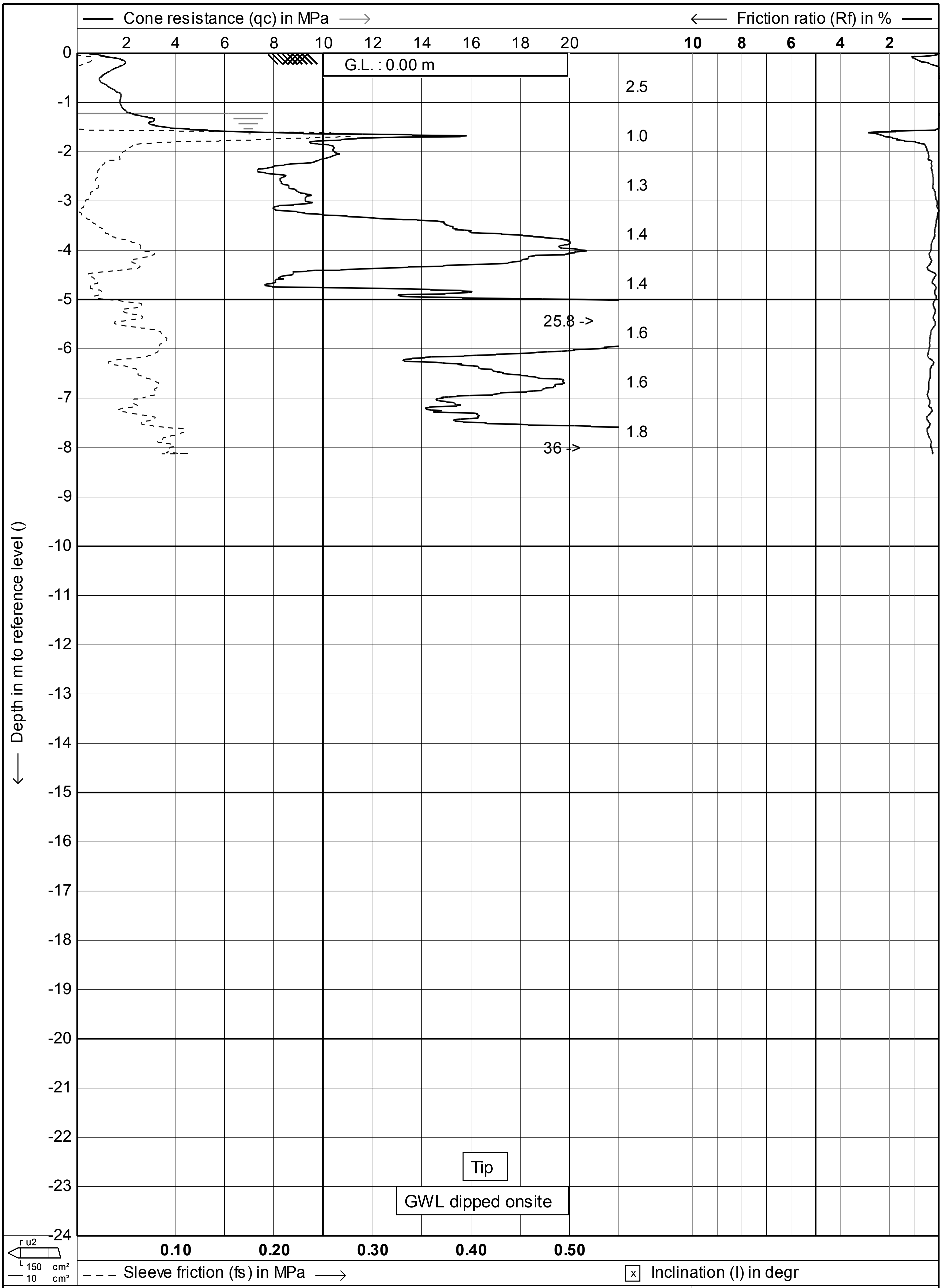
Cone no. : **C10CFIIP.C15212**

Project no. : **02TT06**

CPT no. : **121**

2/14

CPTask V1.33



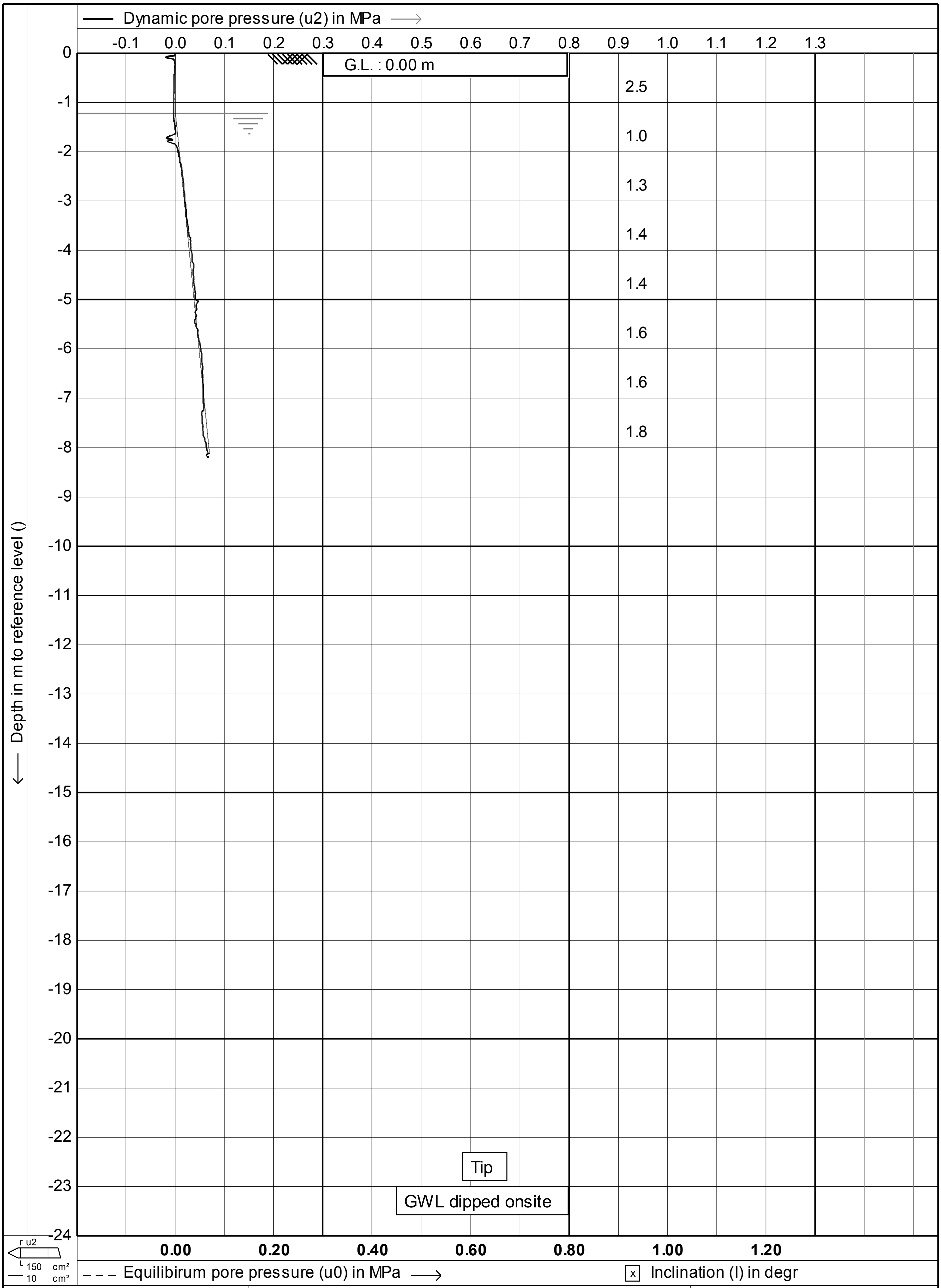
Test according A.S.T.M. Standard D 5778-12

Project : **Site Investigation**

Location: **Bell rd - Papamoa**

Date : **13-6-2017**
Cone no. : **C10CFIIP.C15212**
Project no. : **02TT06**
CPT no. : **122**
1/14

CPTask V1.33



CPTask V1.33

PERRY
GEOTECH

Test according A.S.T.M. Standard D 5778-12

Project : **Site Investigation**

Location: **Bell rd - Papamoa**

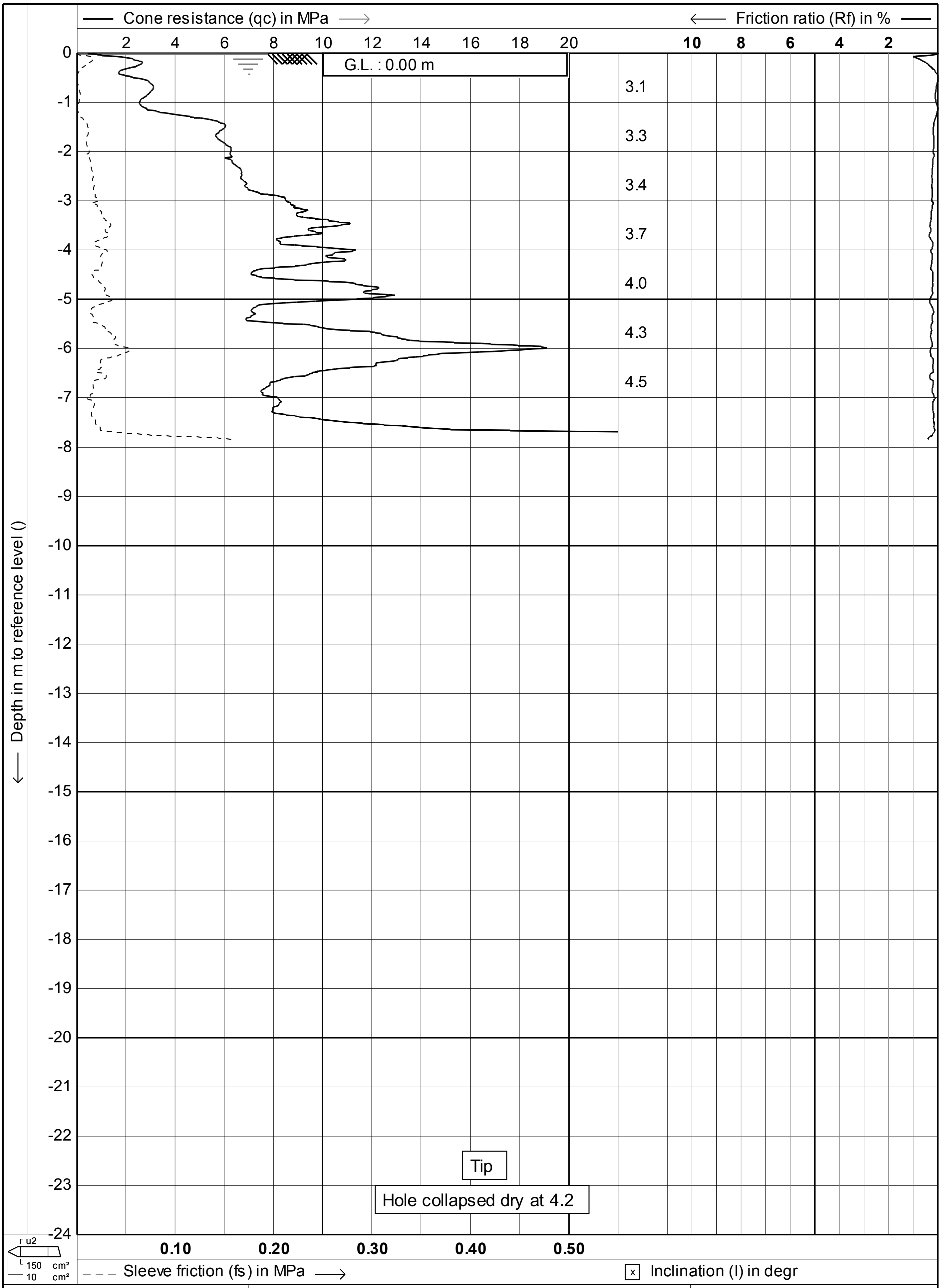
Date : **13-6-2017**

Cone no. : **C10CFIIP.C15212**

Project no. : **02TT06**

CPT no. : **122**

2/14



CPTask V1.33

PERRY GEOTECH

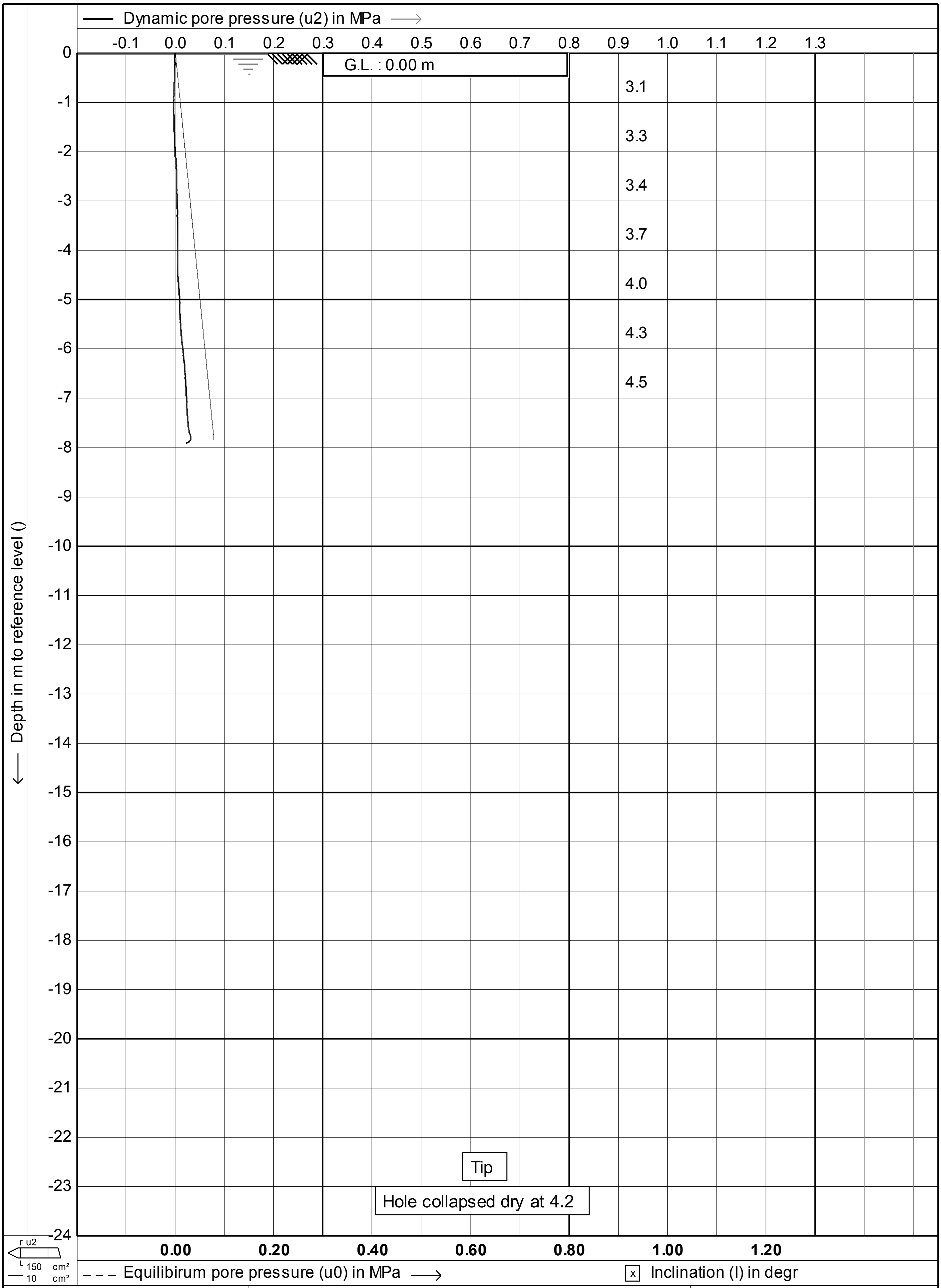
Test according A.S.T.M. Standard D 5778-12

Project : **Site Investigation**

Location: **Bell rd - Papamoa**

Date	: **12-6-2017**
Cone no.	: **C10CFIIP.C15212**
Project no. :	**02TT06**
CPT no.	: **123**

1/14



CPTask V1.33

PERRY GEOTECH

Test according A.S.T.M. Standard D 5778-12

Project : **Site Investigation**

Location: **Bell rd - Papamoa**

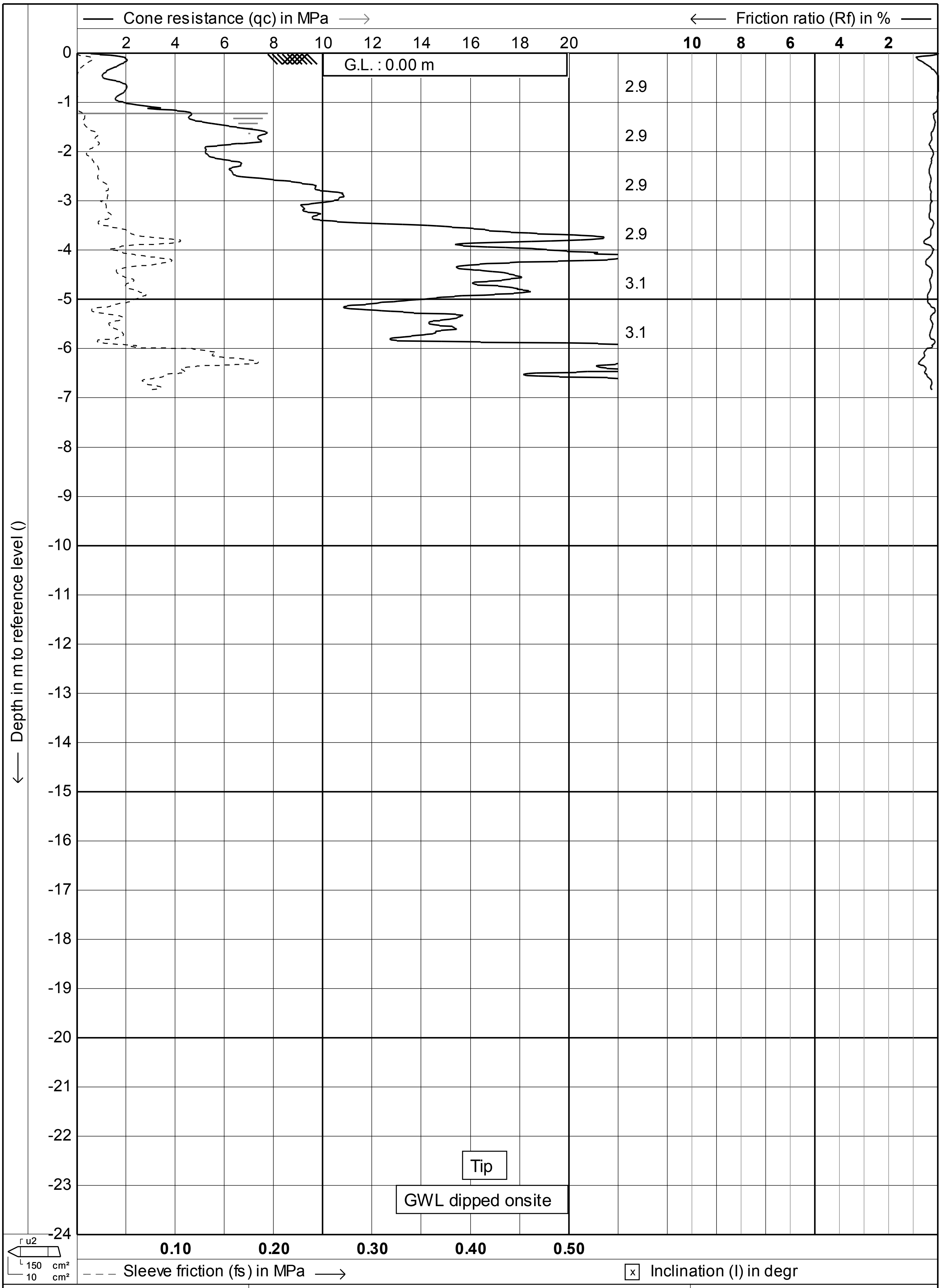
Date : **12-6-2017**

Cone no. : **C10CFIIP.C15212**

Project no. : **02TT06**

CPT no. : **123**

2/14



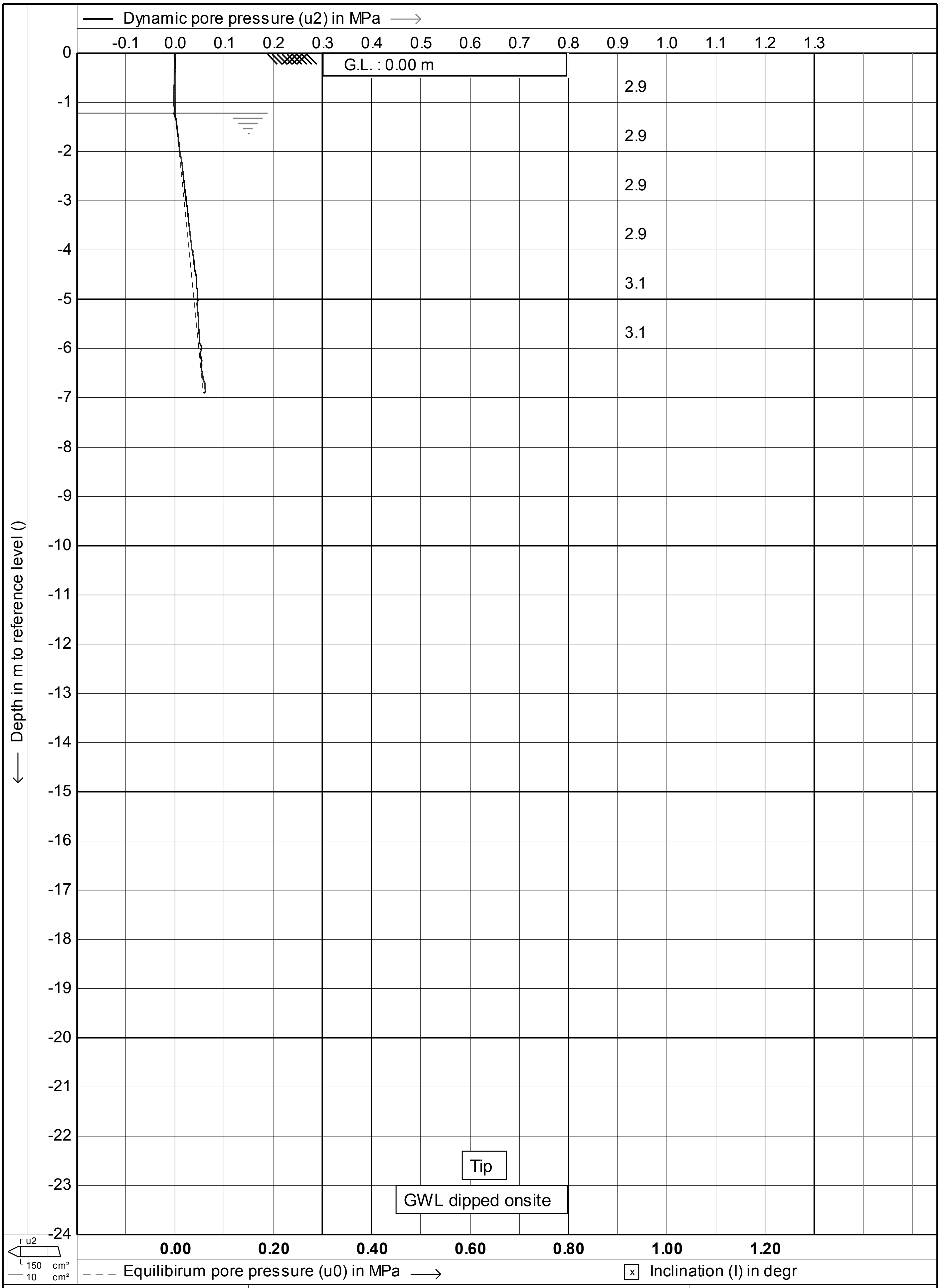
Test according A.S.T.M. Standard D 5778-12

Project : **Site Investigation**

Location: **Bell rd - Papamoa**

Date	: **12-6-2017**
Cone no.	: **C10CFIIP.C15212**
Project no. :	**02TT06**
CPT no.	: **124** **1/14**

CPTask V1.33



CPTask V1.33

PERRY GEOTECH

Test according A.S.T.M. Standard D 5778-12

Project : **Site Investigation**

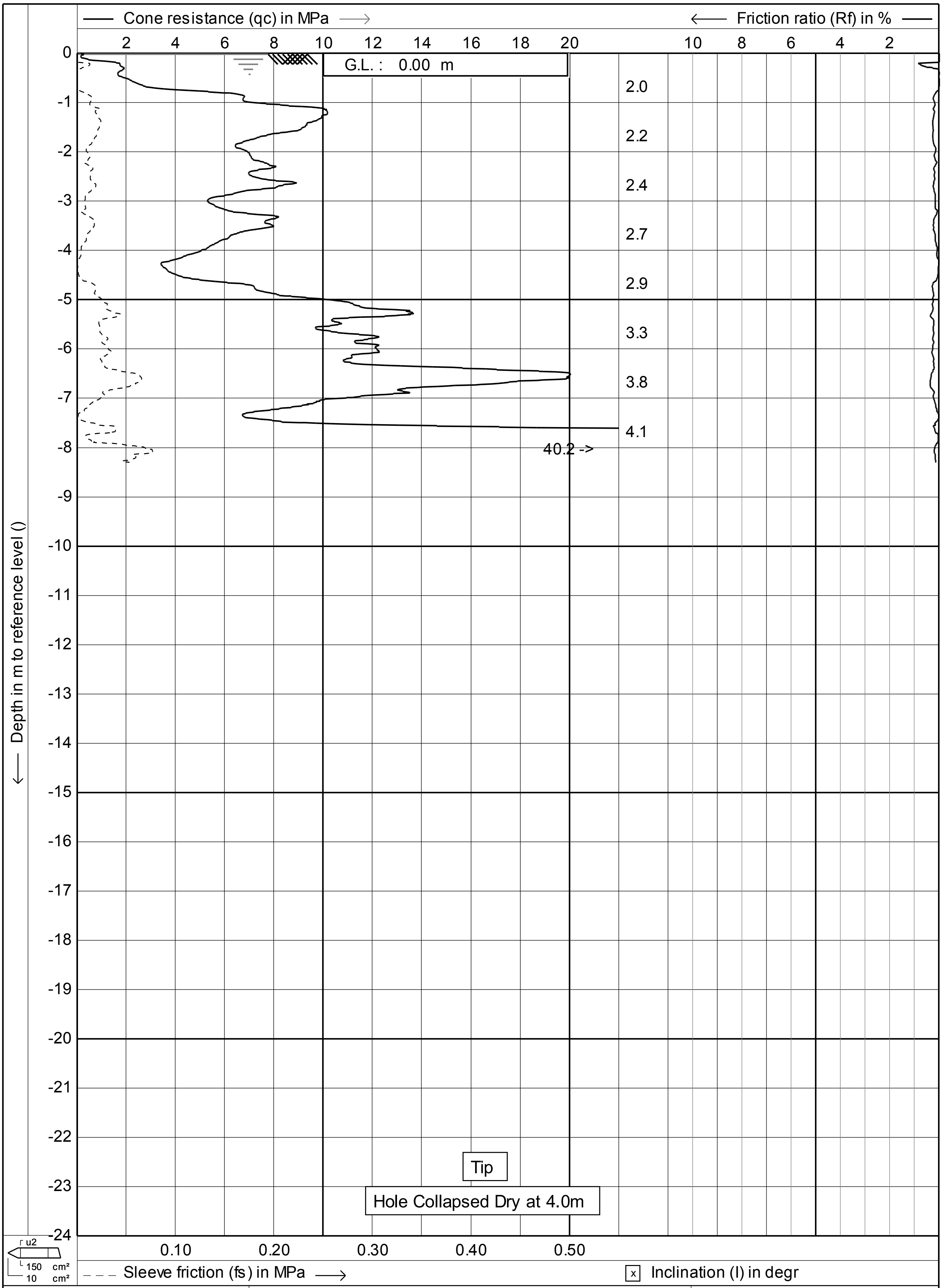
Location: **Bell rd - Papamoa**

Date : **12-6-2017**

Cone no. : **C10CFIIP.C15212**

Project no. : **02TT06**

CPT no. : **124**



1.47

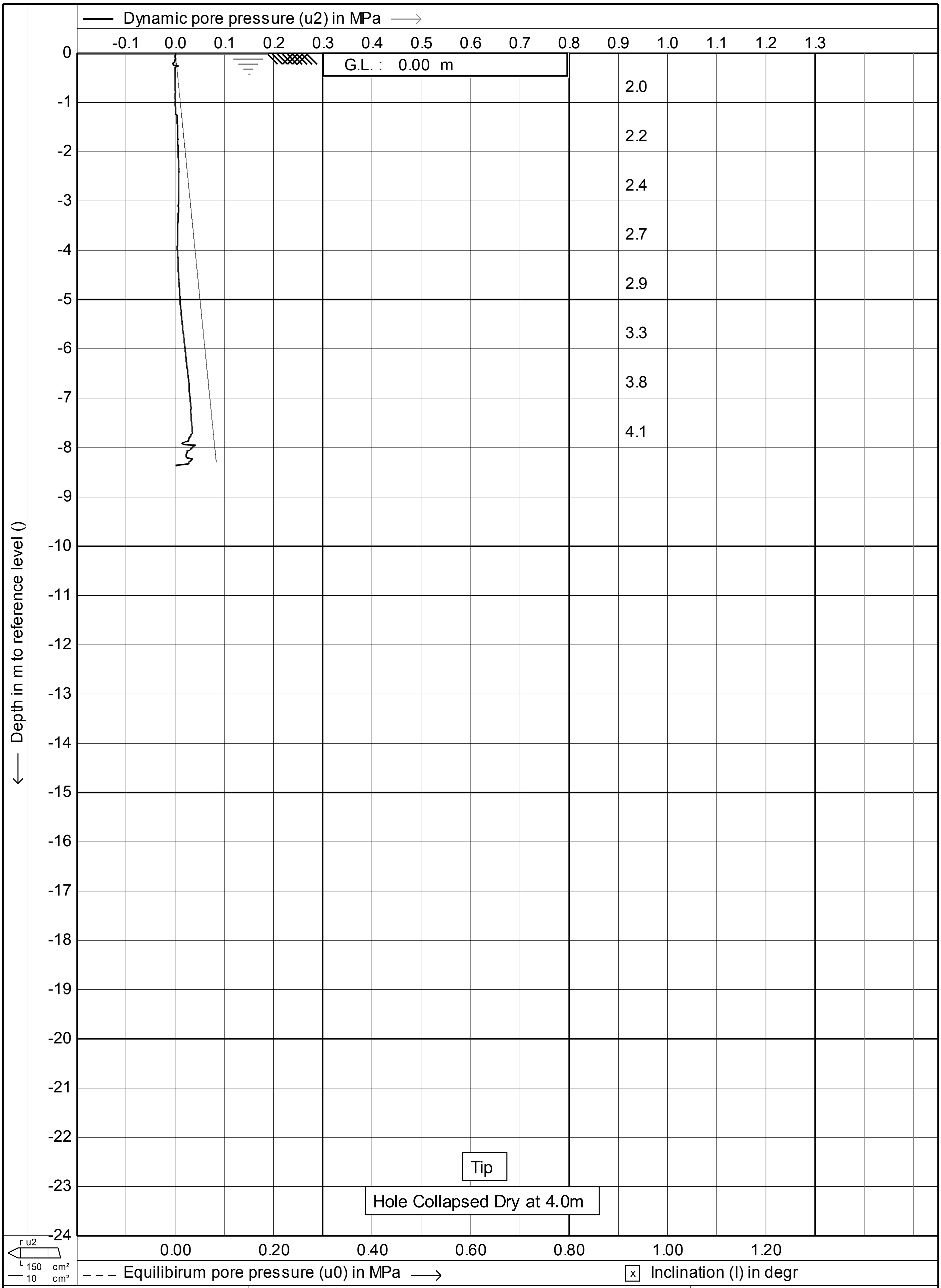
PERRY GEOTECH

Test according A.S.T.M. Standard D 5778-12

Project : **Site Investigation**
Location: **Bell rd - Papamoa**
Position: **0, 0**

Date : **6/14/2017**
Cone no. : **C10CFIIP.C15212**
Project no. : **02TT06**
CPT no. : **125**

1/14



PERRY GEOTECH

1.47

Test according A.S.T.M. Standard D 5778-12

Project : **Site Investigation**

Location: **Bell rd - Papamoa**

Position: **0, 0**

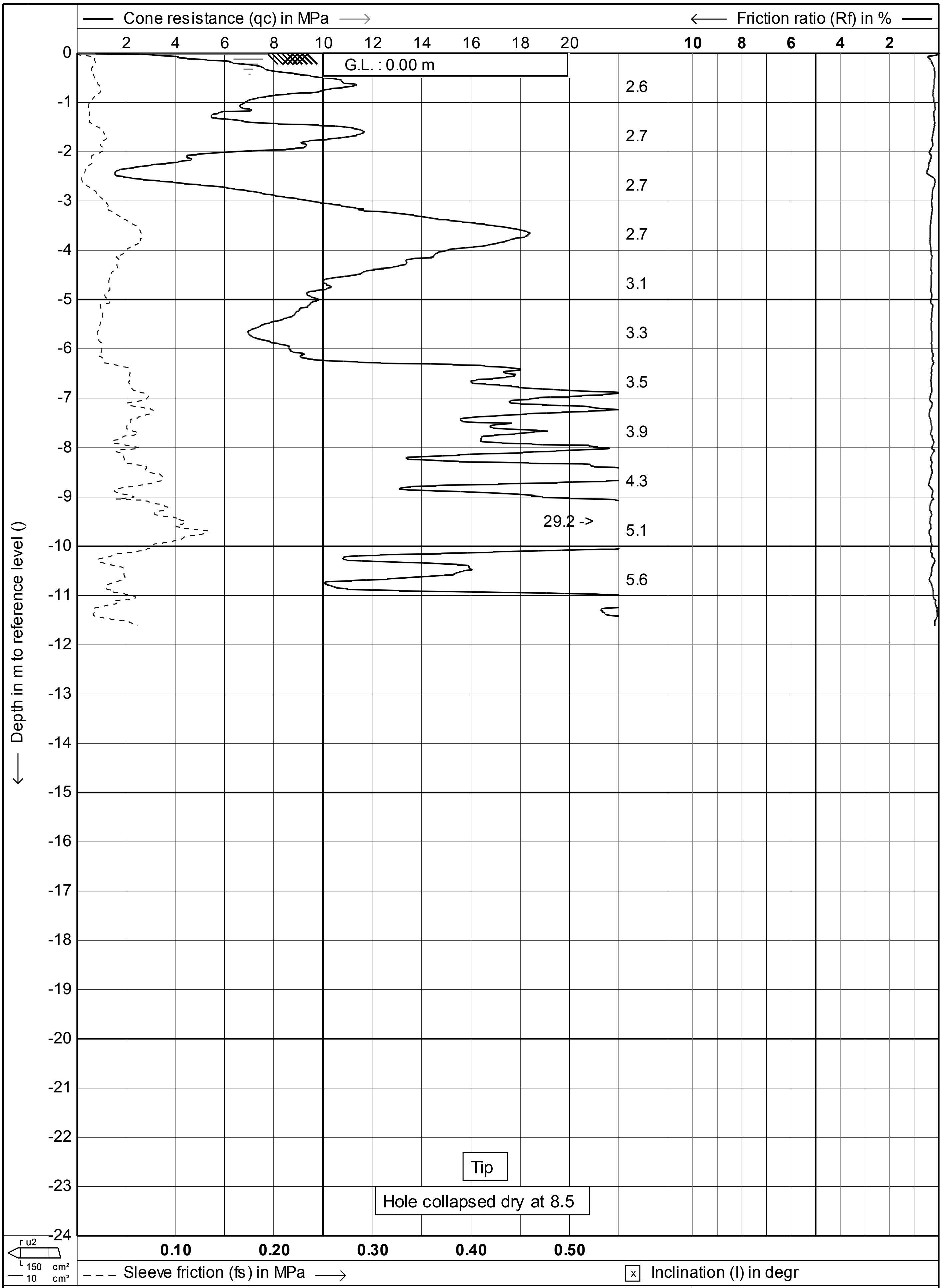
Date : **6/14/2017**

Cone no. : **C10CFIIP.C15212**

Project no. : **02TT06**

CPT no. : **125**

2/14



Test according A.S.T.M. Standard D 5778-12

Project : **Site Investigation**

Location: **Bell rd - Papamoa**

Date : **12-6-2017**

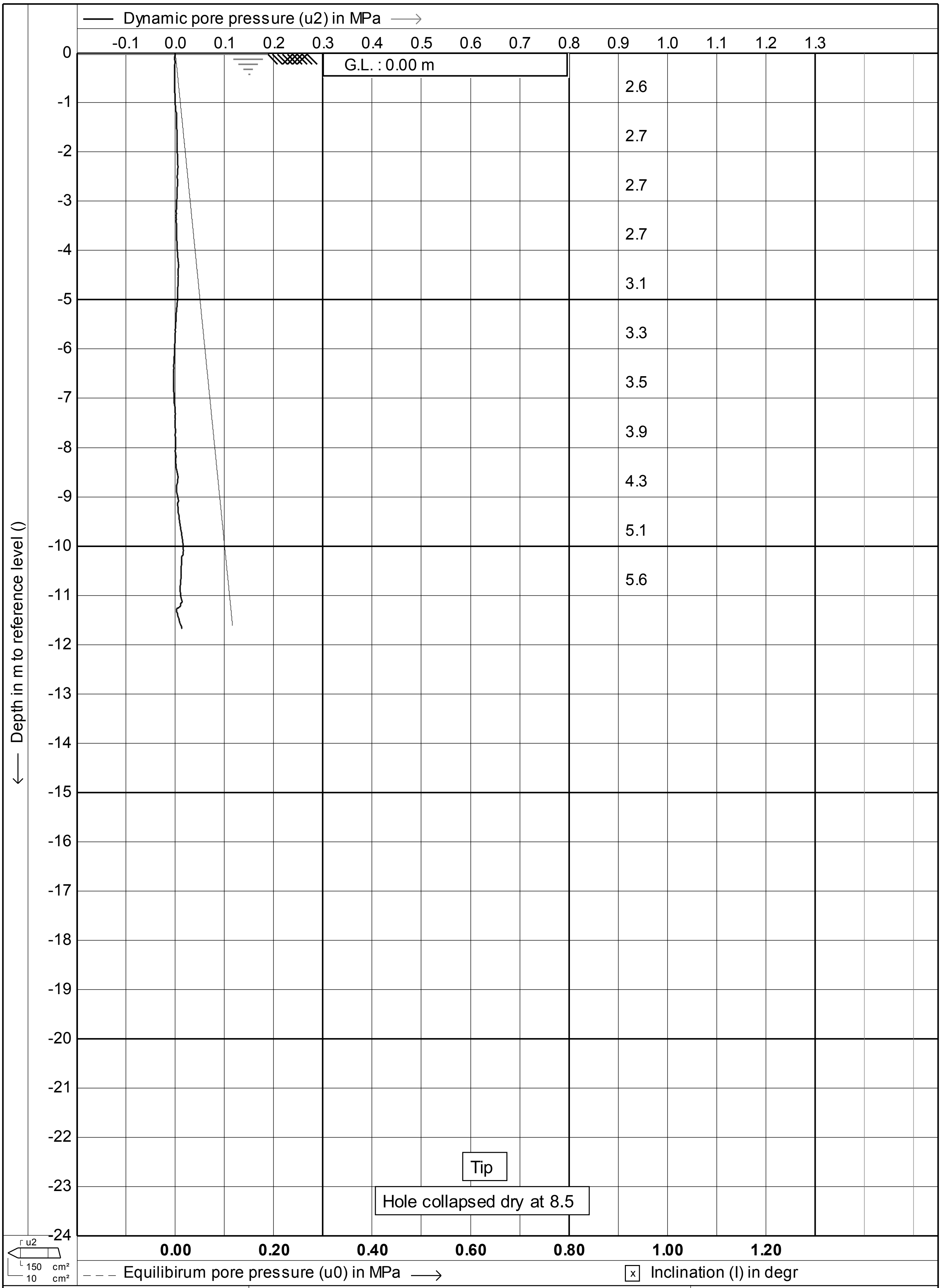
Cone no. : **C10CFIIP.C15212**

Project no. : **02TT06**

CPT no. : **126**

1/14

CPTask V1.33



CPTask V1.33

PERRY GEOTECH

Test according A.S.T.M. Standard D 5778-12

Project : **Site Investigation**

Location: **Bell rd - Papamoa**

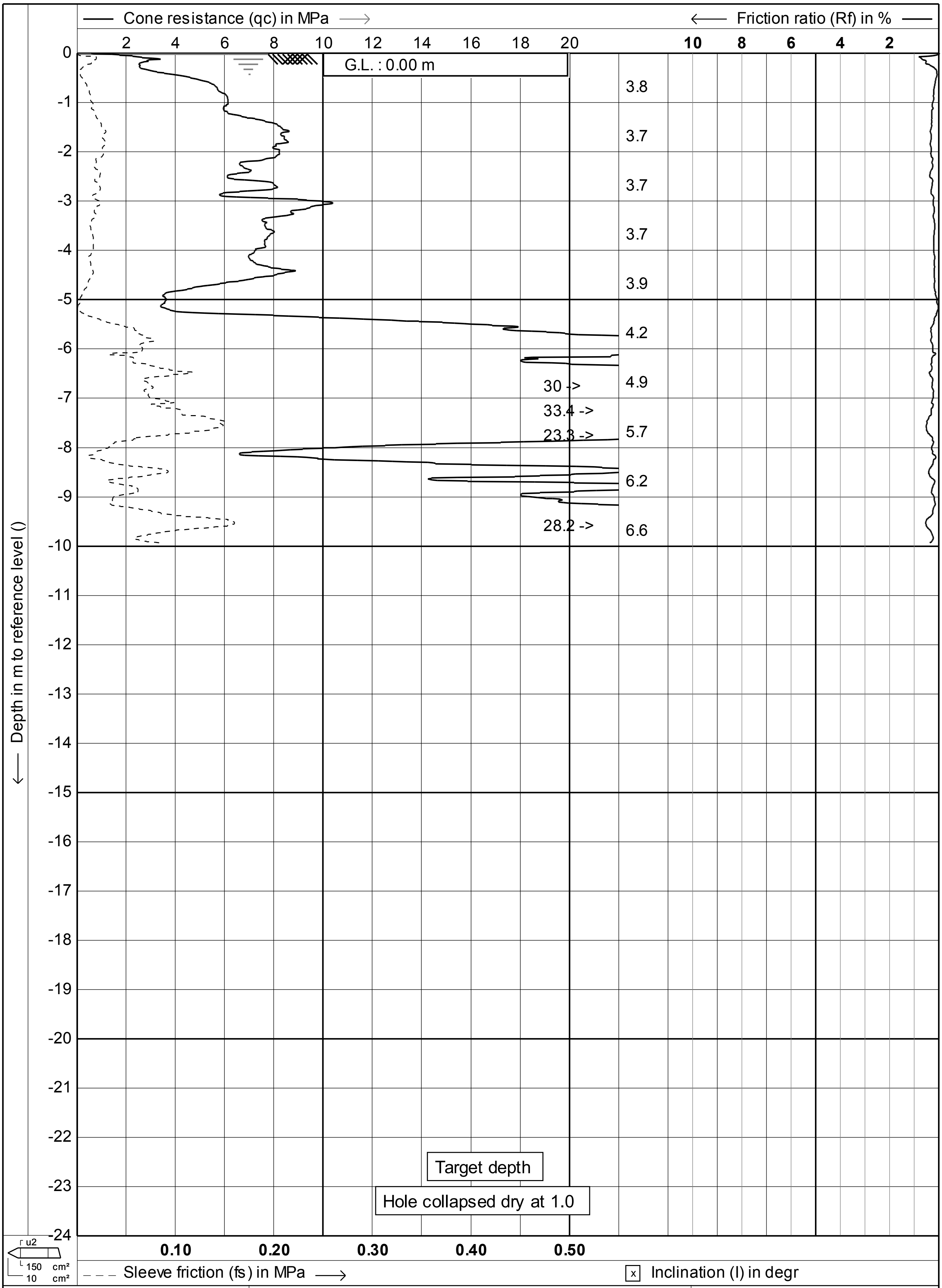
Date : **12-6-2017**

Cone no. : **C10CFIIP.C15212**

Project no. : **02TT06**

CPT no. : **126**

2/14



CPTask V1.33

PERRY
GEOTECH

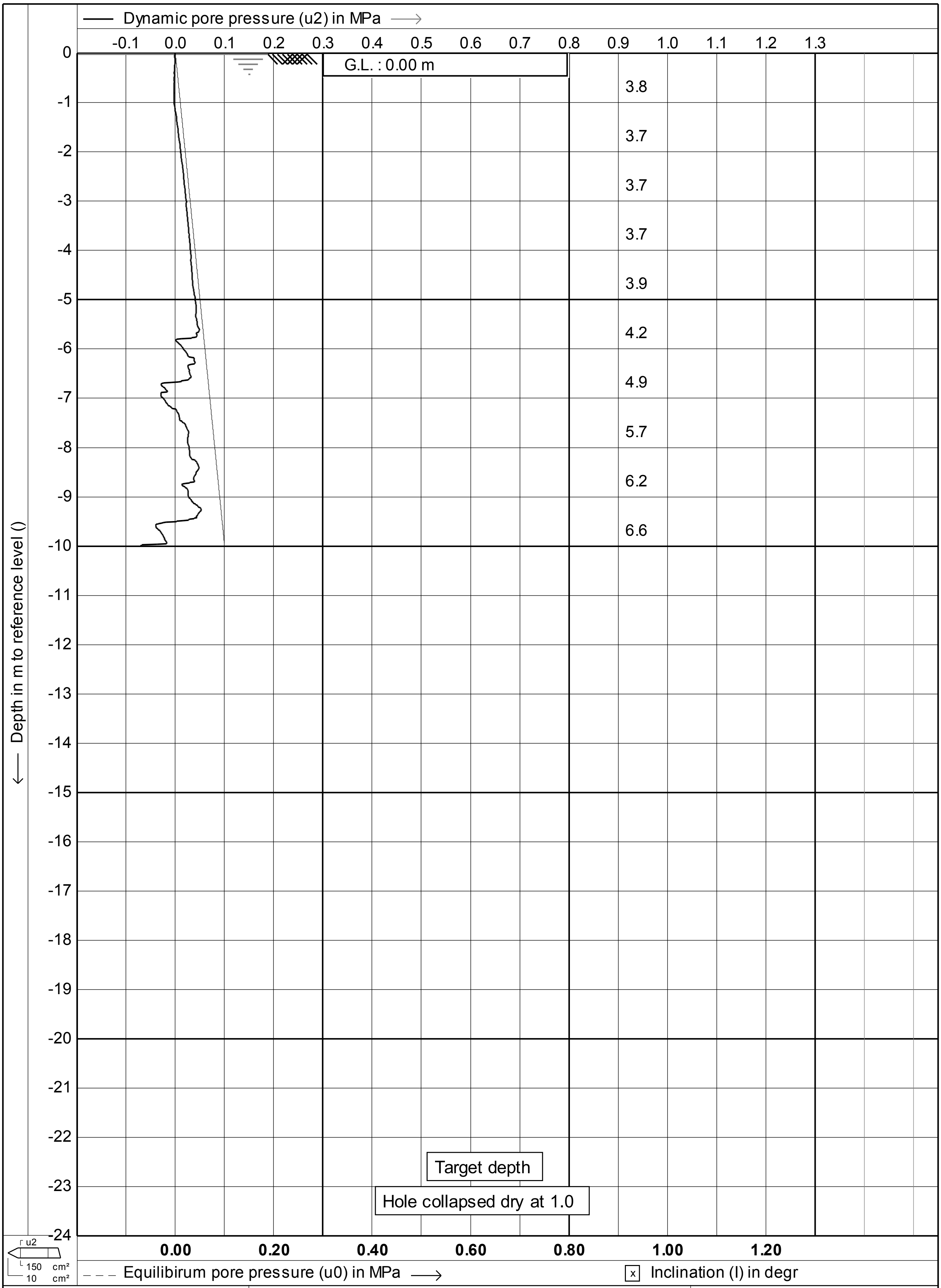
Test according A.S.T.M. Standard D 5778-12

Project : **Site Investigation**

Location: **Bell rd - Papamoa**

Date : **12-6-2017**
Cone no. : **C10CFIIP.C15212**
Project no. : **02TT06**
CPT no. : **127**

1/14



CPTask V1.33

PERRY GEOTECH

Test according A.S.T.M. Standard D 5778-12

Project : **Site Investigation**

Location: **Bell rd - Papamoa**

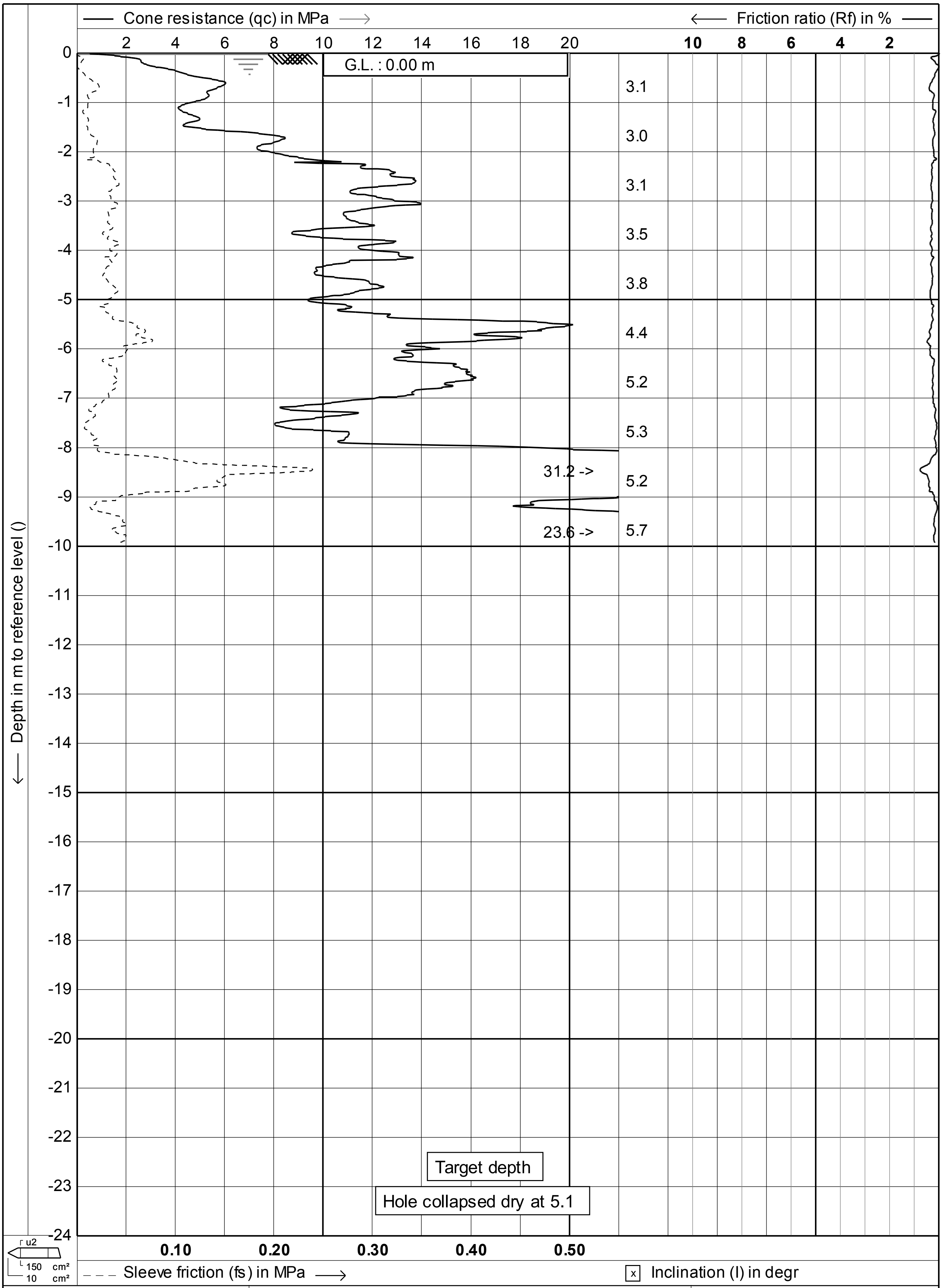
Date : **12-6-2017**

Cone no. : **C10CFIIP.C15212**

Project no. : **02TT06**

CPT no. : **127**

2/14



CPTask V1.33

PERRY
GEOTECH

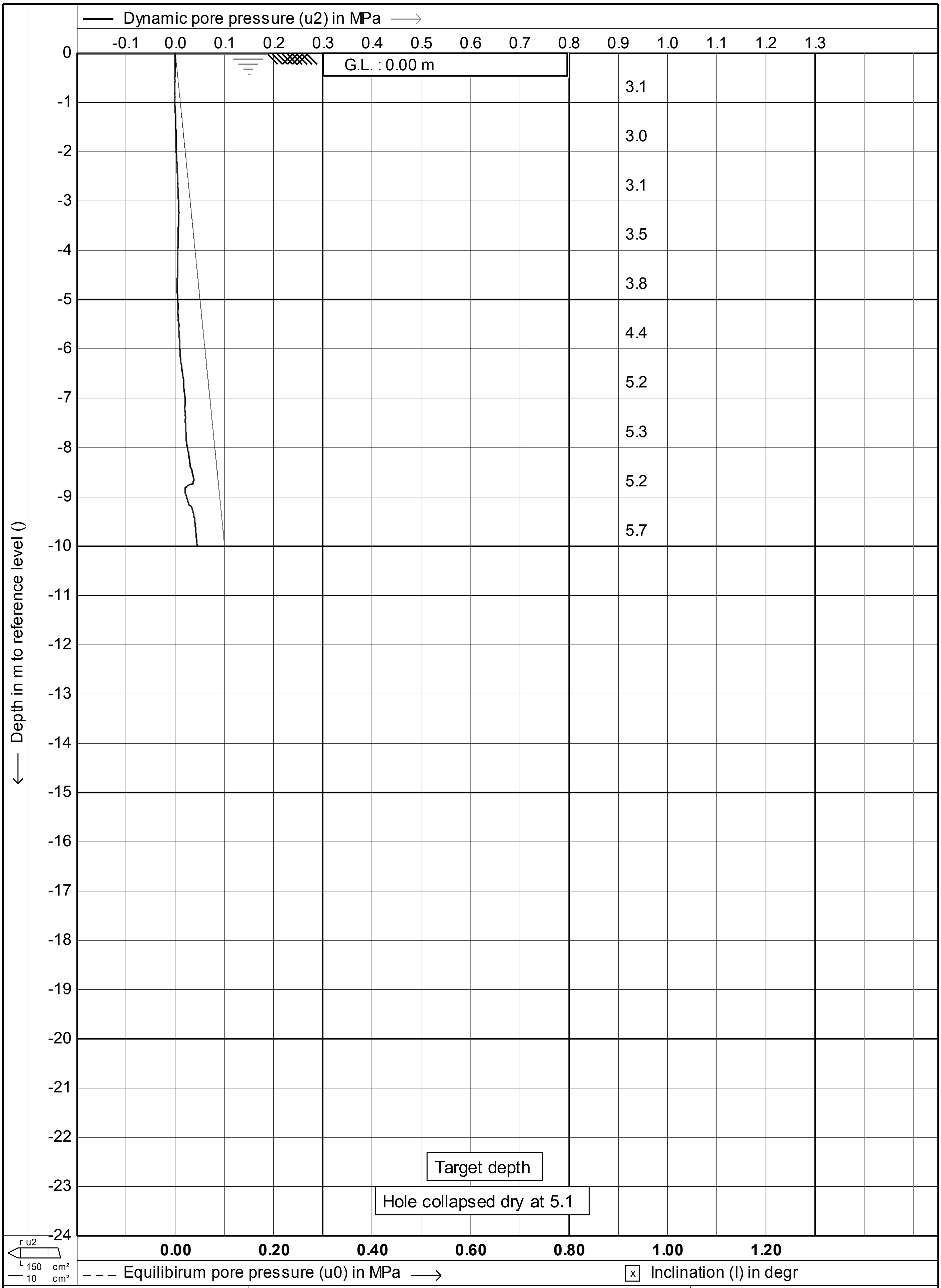
Test according A.S.T.M. Standard D 5778-12

Project : **Site Investigation**

Location: **Bell rd - Papamoa**

Date	: **12-6-2017**
Cone no.	: **C10CFIIP.C15212**
Project no. :	**02TT06**
CPT no.	: **128**

1/14



CPTask V1.33

PERRY GEOTECH

Test according A.S.T.M. Standard D 5778-12

Project : **Site Investigation**

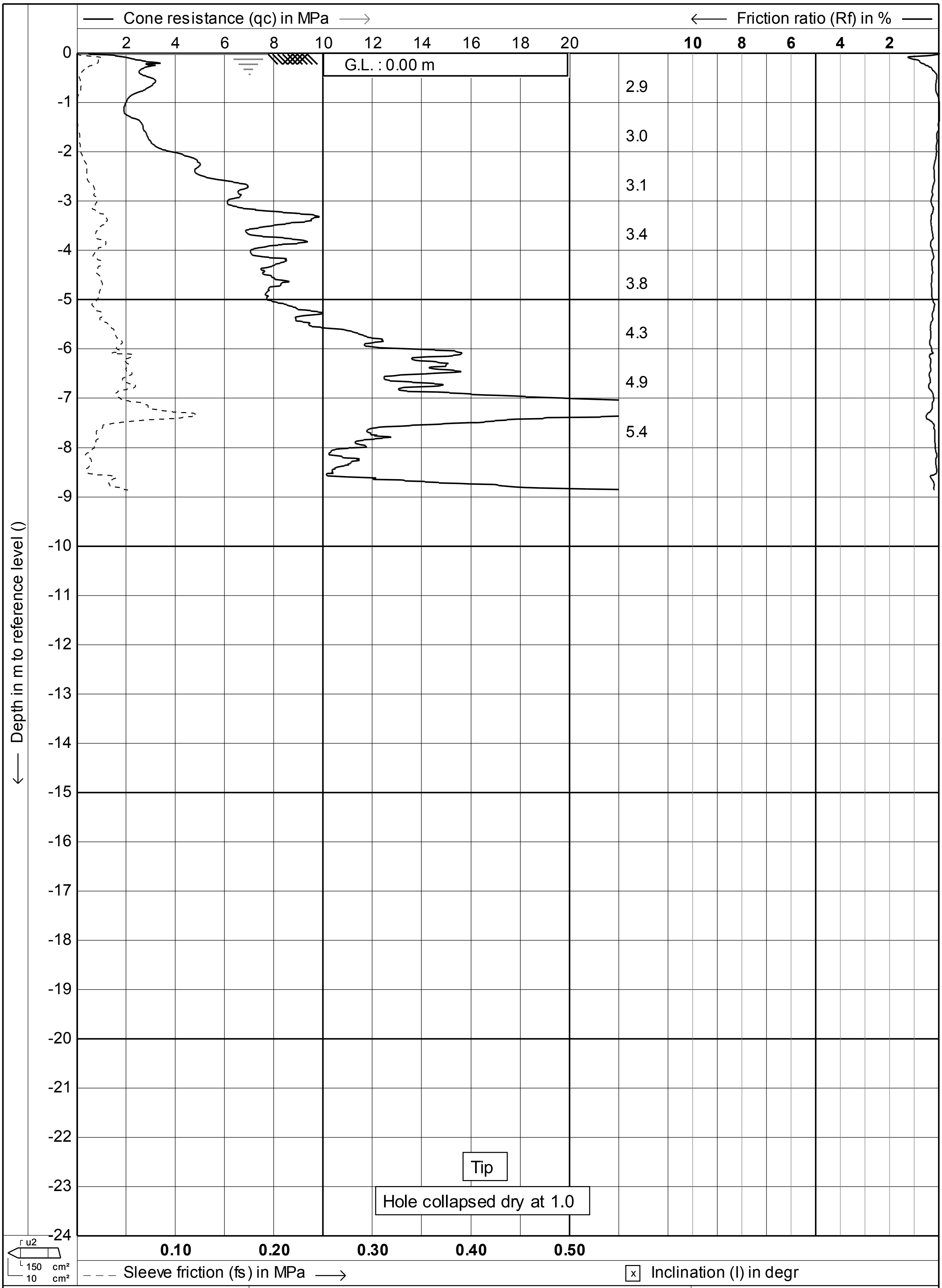
Location: **Bell rd - Papamoa**

Date : **12-6-2017**

Cone no. : **C10CFIIP.C15212**

Project no. : **02TT06**

CPT no. : **128**



CPTask V1.33

PERRY GEOTECH

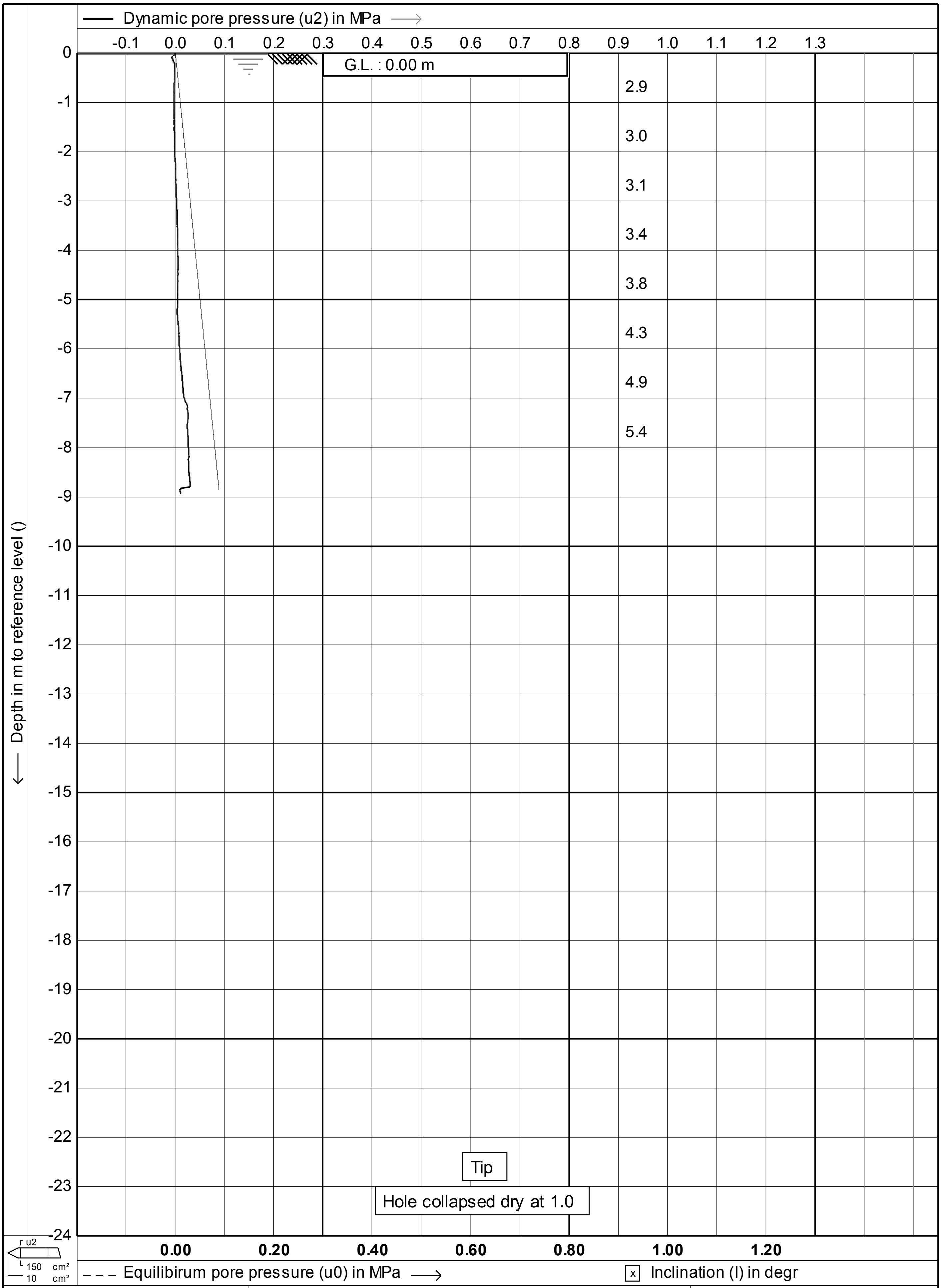
Test according A.S.T.M. Standard D 5778-12

Project : **Site Investigation**

Location: **Bell rd - Papamoa**

Date	: **12-6-2017**
Cone no.	: **C10CFIIP.C15212**
Project no. :	**02TT06**
CPT no.	: **129**

1/14



G.L. : 0.00 m

Tip

Hole collapsed dry at 1.0

CPTask V1.33

PERRY GEOTECH

Test according A.S.T.M. Standard D 5778-12

Project : **Site Investigation**

Location: **Bell rd - Papamoa**

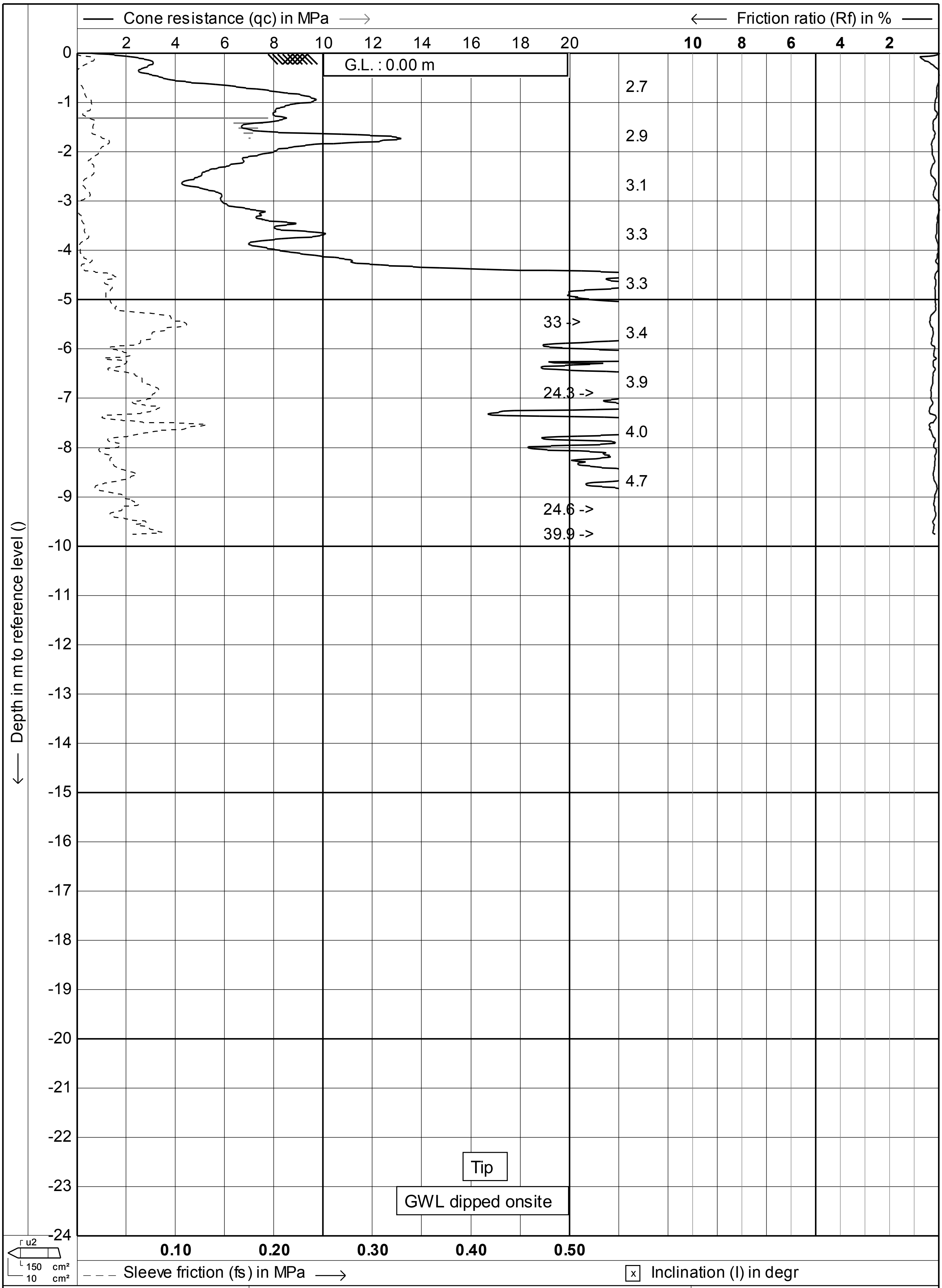
Date : **12-6-2017**

Cone no. : **C10CFIIP.C15212**

Project no. : **02TT06**

CPT no. : **129**

2/14



CPTask V1.33

PERRY GEOTECH

Test according A.S.T.M. Standard D 5778-12

Project : **Site Investigation**

Location: **Bell rd - Papamoa**

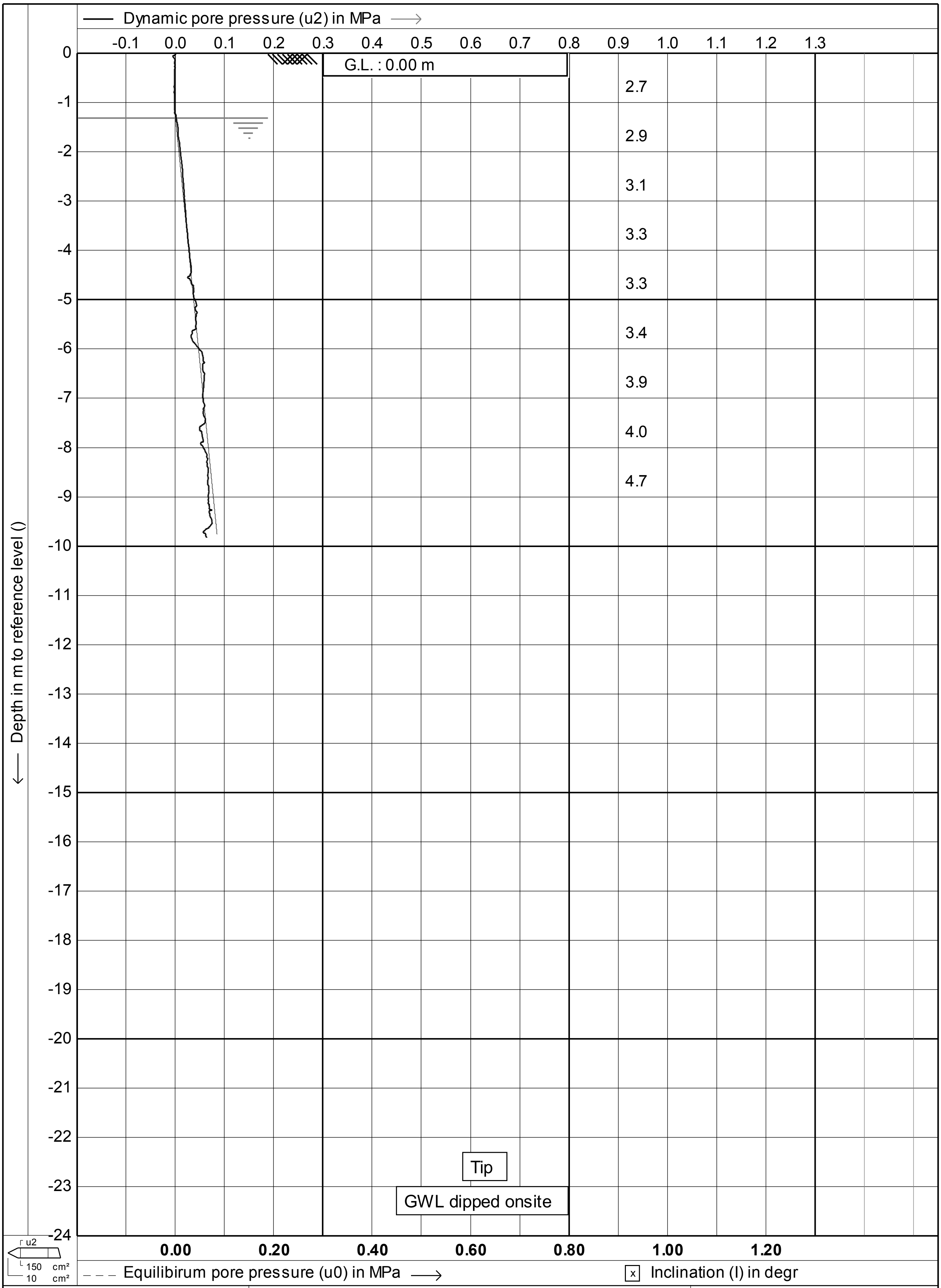
Date : **13-6-2017**

Cone no. : **C10CFIIP.C15212**

Project no. : **02TT06**

CPT no. : **130**

1/14



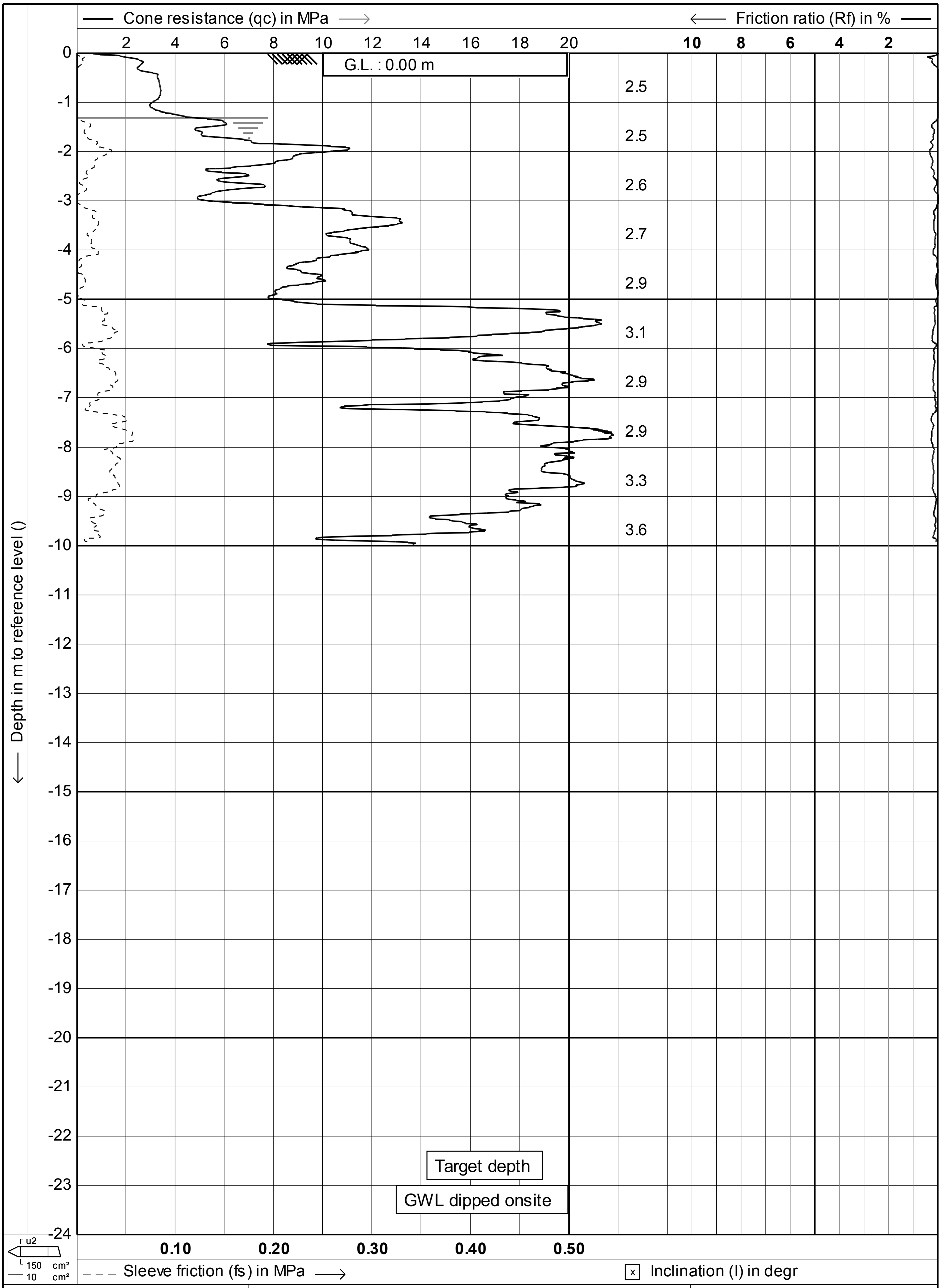
PERRY GEOTECH

Test according A.S.T.M. Standard D 5778-12

Project : **Site Investigation**

Location: **Bell rd - Papamoa**

Date : **13-6-2017**
Cone no. : **C10CFIIP.C15212**
Project no. : **02TT06**
CPT no. : **130**



PERRY GEOTECH

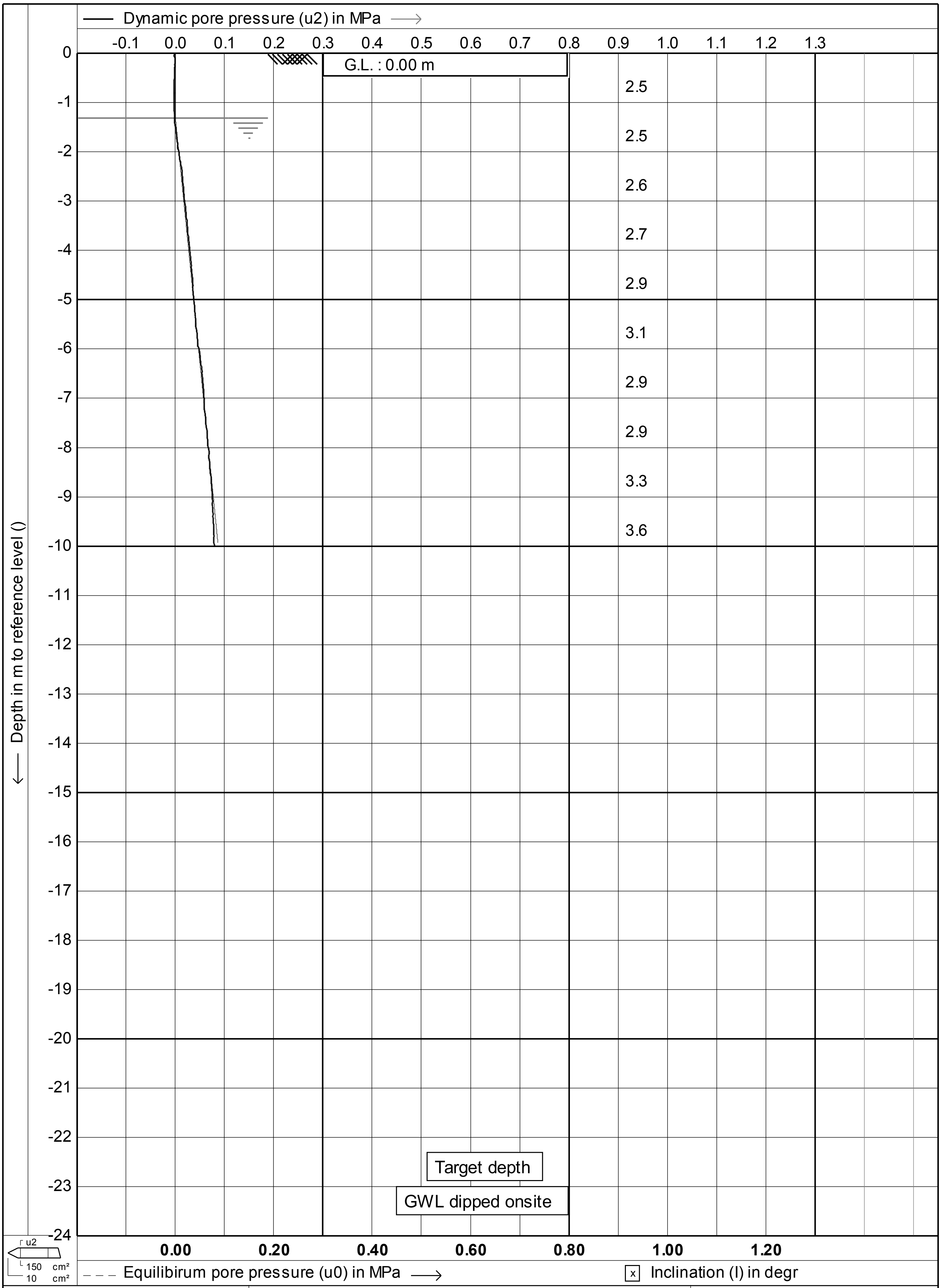
Test according A.S.T.M. Standard D 5778-12

Project : **Site Investigation**

Location: **Bell rd - Papamoa**

Date	: **13-6-2017**	
Cone no.	: **C10CFIIP.C15212**	
Project no. :	**02TT06**	
CPT no.	: **131**	**1/14**

CPTask V1.33



CPTask V1.33

PERRY GEOTECH

Test according A.S.T.M. Standard D 5778-12

Project : **Site Investigation**

Location: **Bell rd - Papamoa**

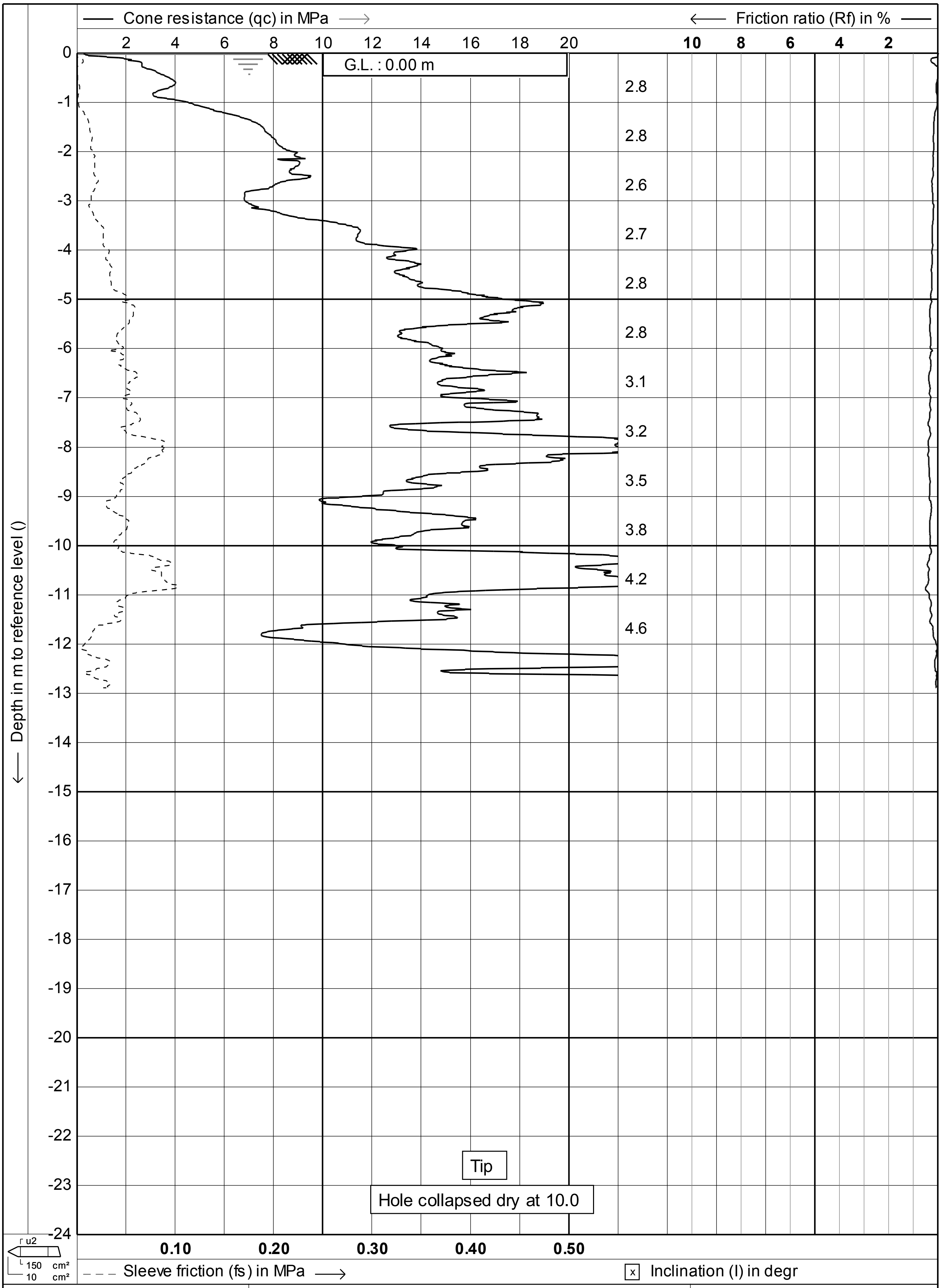
Date : **13-6-2017**

Cone no. : **C10CFIIP.C15212**

Project no. : **02TT06**

CPT no. : **131**

2/14



PERRY
GEOTECH

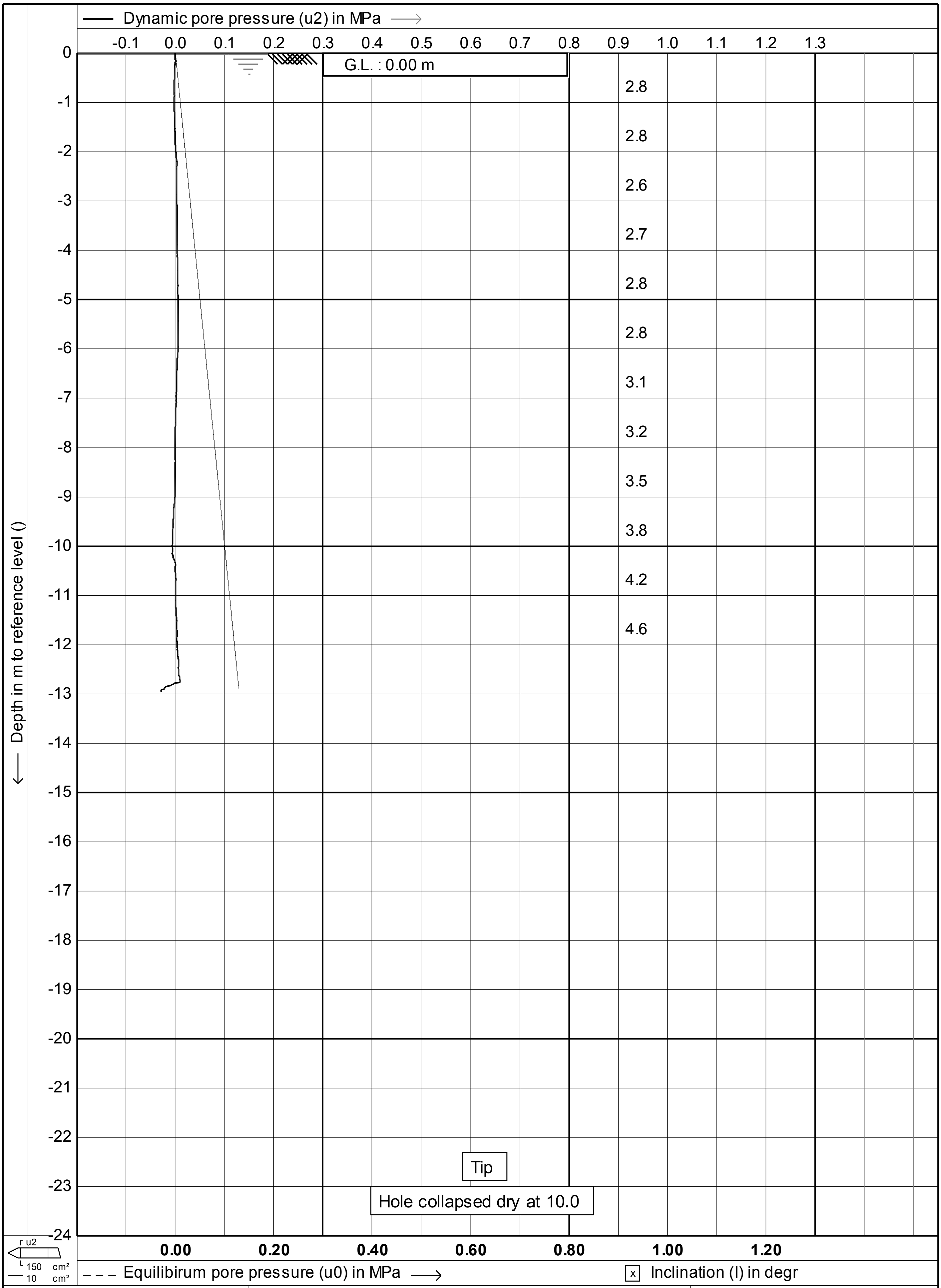
Test according A.S.T.M. Standard D 5778-12

Project : **Site Investigation**

Location: **Bell rd - Papamoa**

Date	: **12-6-2017**
Cone no.	: **C10CFIIP.C15212**
Project no. :	**02TT06**
CPT no.	: **132** **1/14**

CPTask V1.33



Hole collapsed dry at 10.0

PERRY GEOTECH

Test according A.S.T.M. Standard D 5778-12

Project : **Site Investigation**

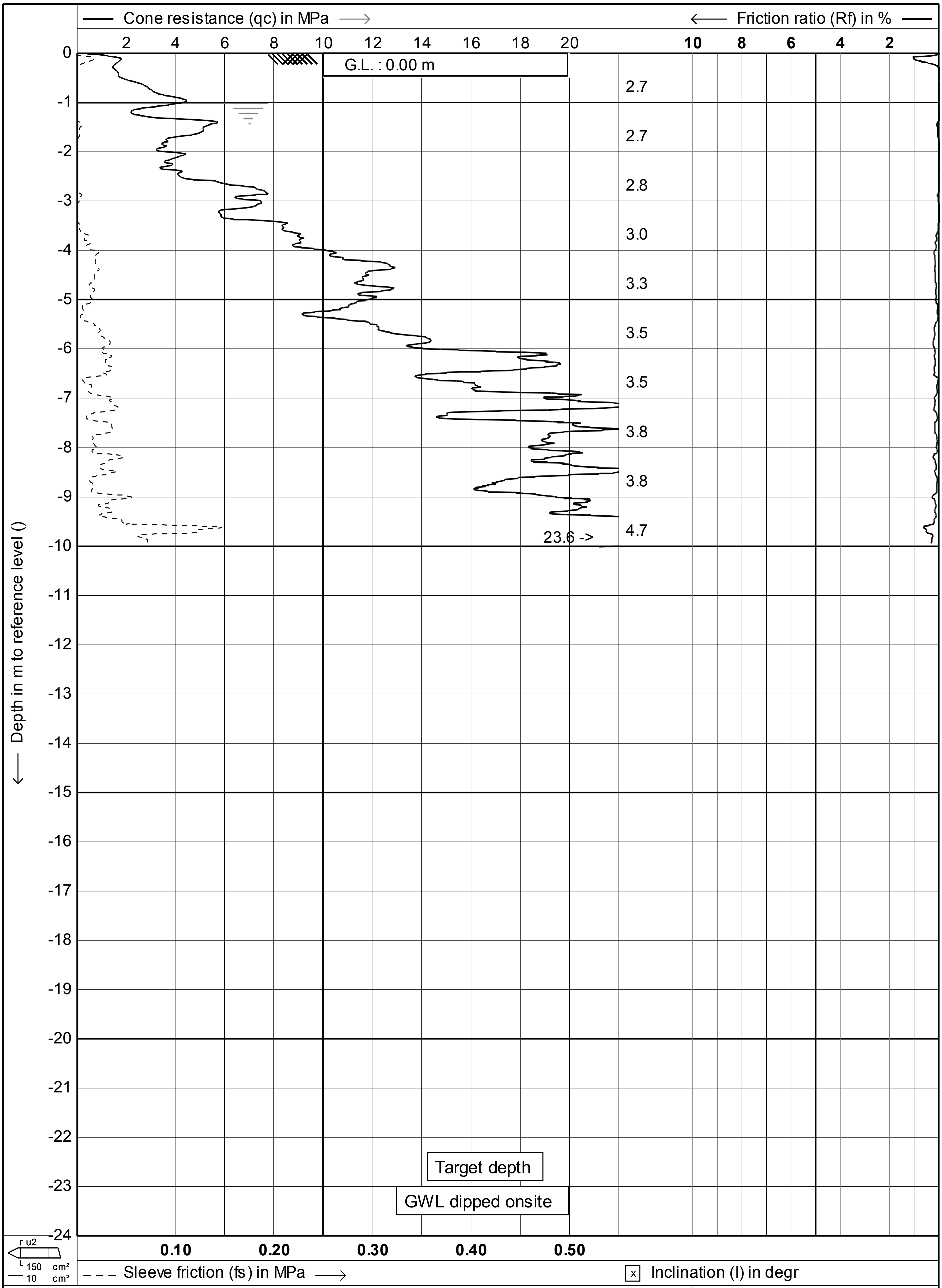
Location: **Bell rd - Papamoa**

Date : **12-6-2017**

Cone no. : **C10CFIIP.C15212**

Project no. : **02TT06**

CPT no. : **132**



CPTask V1.33

PERRY GEOTECH

Test according A.S.T.M. Standard D 5778-12

Project : **Site Investigation**

Location: **Bell rd - Papamoa**

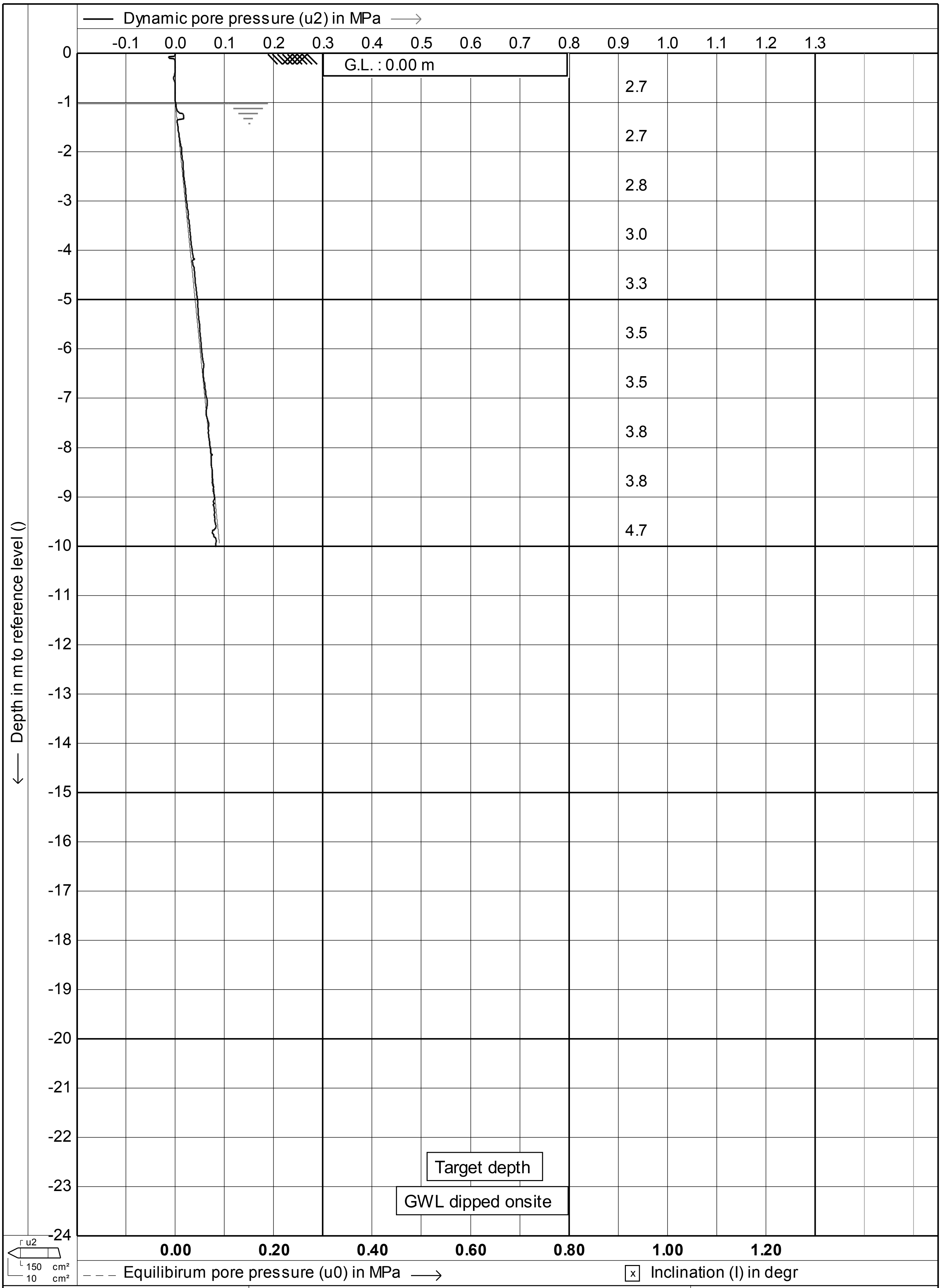
Date : **13-6-2017**

Cone no. : **C10CFIIP.C15212**

Project no. : **02TT06**

CPT no. : **133a**

1/14



CPTask V1.33

Test according A.S.T.M. Standard D 5778-12

Project : **Site Investigation**

Location: **Bell rd - Papamoa**

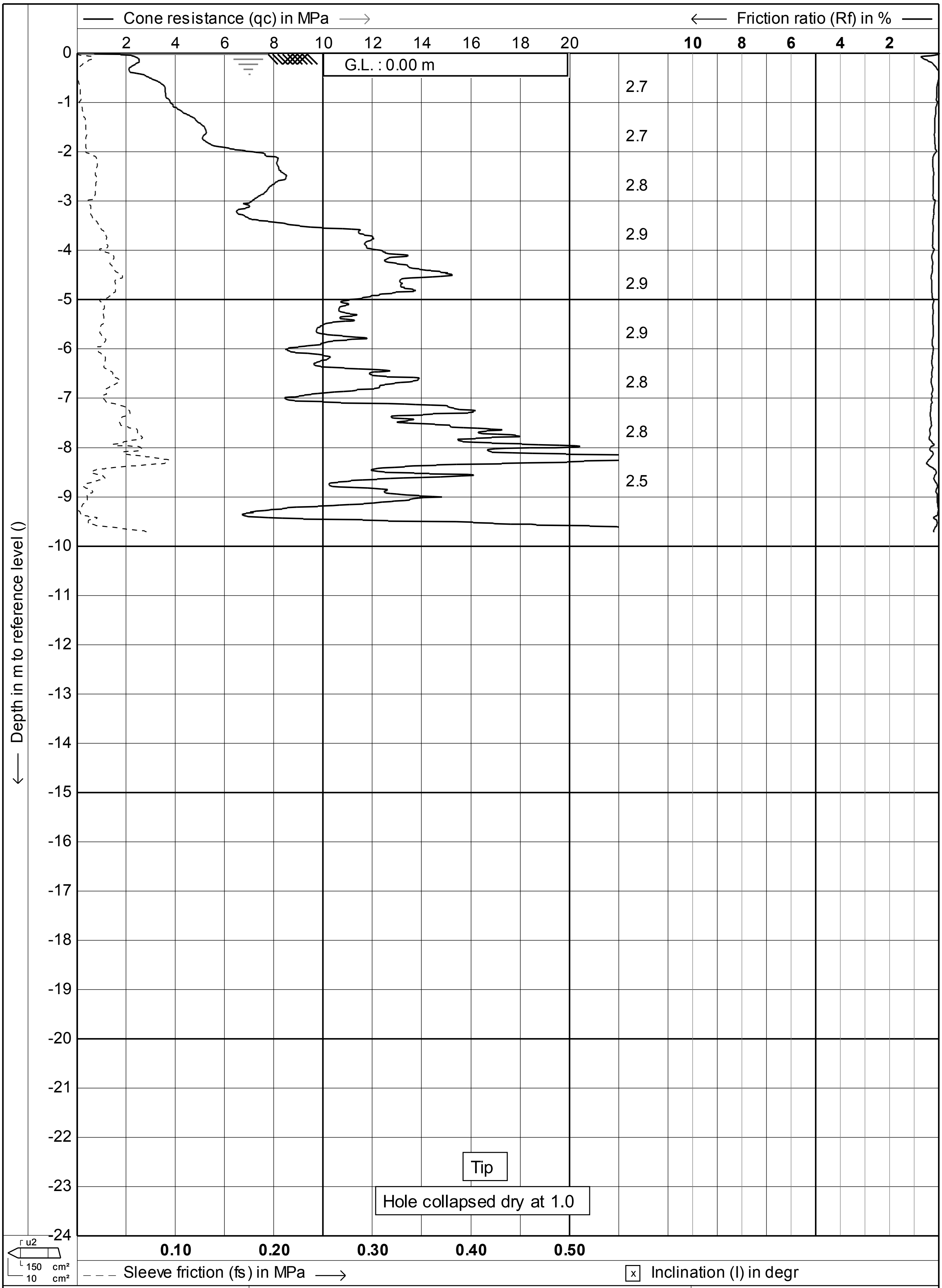
Date : **13-6-2017**

Cone no. : **C10CFIIP.C15212**

Project no. : **02TT06**

CPT no. : **133a**

2/14



G.L. : 0.00 m

Tip

Hole collapsed dry at 1.0

CPTask V1.33

PERRY GEOTECH

Test according A.S.T.M. Standard D 5778-12

Project : **Site Investigation**

Location: **Bell rd - Papamoa**

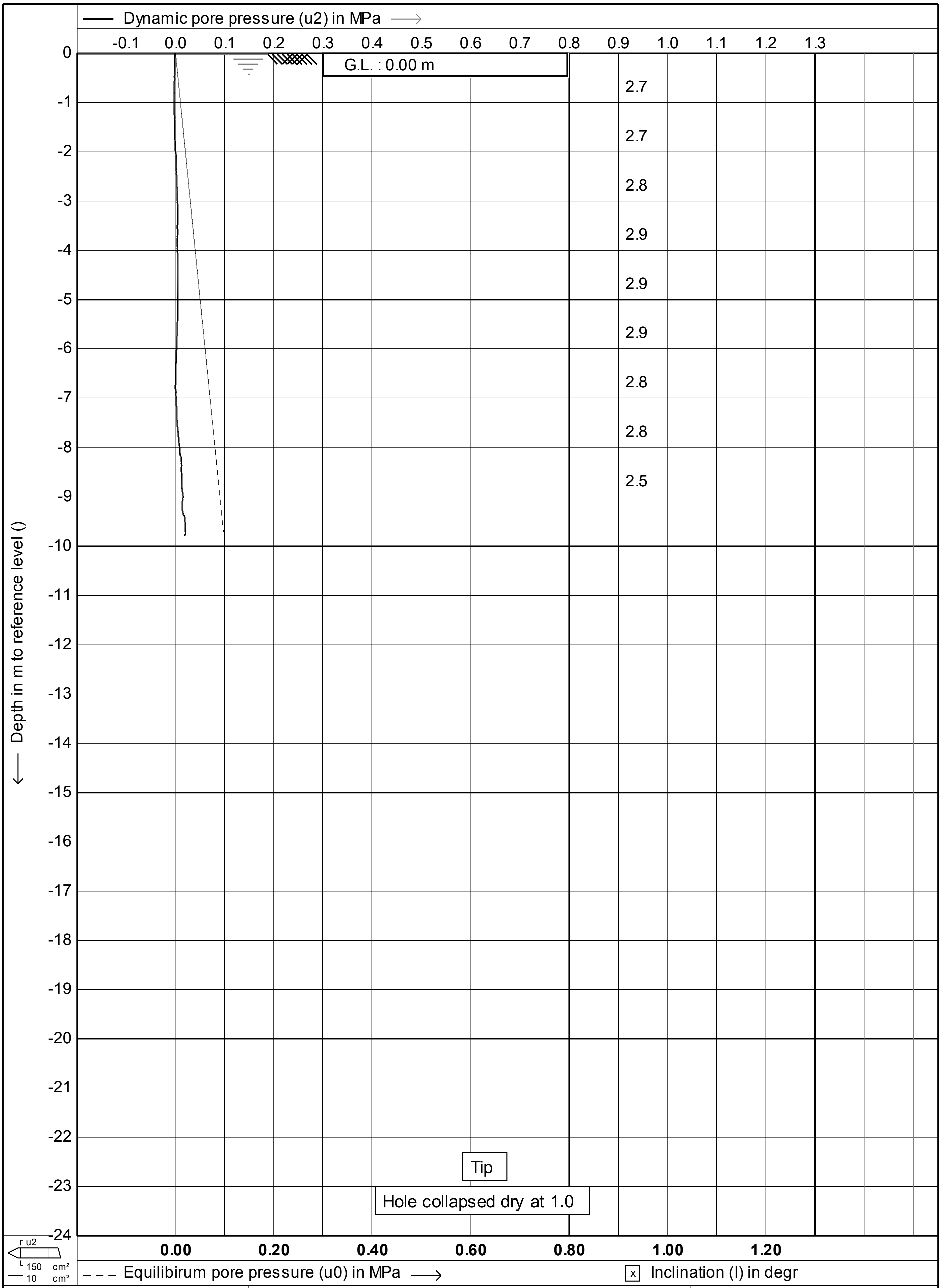
Date : **12-6-2017**

Cone no. : **C10CFIIP.C15212**

Project no. : **02TT06**

CPT no. : **134**

1/14



CPTask V1.33

PERRY GEOTECH

Test according A.S.T.M. Standard D 5778-12

Project : **Site Investigation**

Location: **Bell rd - Papamoa**

Date : **12-6-2017**

Cone no. : **C10CFIIP.C15212**

Project no. : **02TT06**

CPT no. : **134**

2/14

Tonkin+Taylor

BOREHOLE LOG

BOREHOLE No.:
BH101
SHEET: 1 OF 4

PROJECT: Te Tumu TCC	CO-ORDINATES: (NZTM) 5817292 mN 1896131 mE
JOB No.: 1002034.2000	DIRECTION: N/A
LOCATION: Bell Road	ANGLE FROM HORIZ.: -90°

R.L. GROUND: 33.35m
R.L. COLLAR: 33.35m
DATUM: Moturiki 1953
SURVEY: Handheld GPS

DRILLED BY: JK/SM
LOGGED BY: HU
CHECKED: RWOT
START DATE: 19/06/2017
FINISH DATE: 19/06/2017
CONTRACTOR: Perry Drilling Ltd

GEOLOGICAL UNIT | DESCRIPTION OF CORE — SOIL: Classification, colour, consistency / density, moisture, plasticity; ROCK: Weathering, colour, fabric, name, strength, cementation | Rock Weathering (UW SW MW HW CW) | Rock Strength (ES VS S MS W VW EW) | Sampling Method | Core Recovery (%) | Testing | RL (m) | Depth (m) | Graphic Log | ROCK DEFECTS: Defect Log, Fracture Spacing (mm) (2000 600 200 60 20), RQD (%), Description & Additional Observations | Fluid Loss (%) (25 50 75) | Water Level | Casing | Installation | Core Box No

Core loss 0.0-0.1m

Organic fine to medium SAND, with trace rootlets; dark brown. Loose; moist; sand, poorly graded (Topsoil).

Sandy SILT; dark brown. Very soft, wet, high plasticity, trace rootlets; sand, fine to medium.

Organic sandy SILT; dark grey. Very soft, wet, low plasticity; sand, fine to medium.

- 1.95m: sand changes to fine, with trace rootlets.

Gravelly fine to coarse SAND; light grey. Very loose, wet, well graded, trace shell fragments (~5%); gravel, fine, sub-angular to sub-rounded; pumiceous.

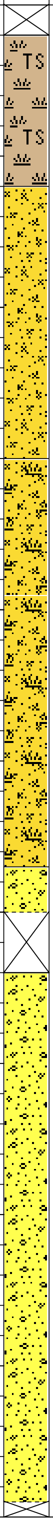
Core loss 3.0-3.2m

Gravelly fine to coarse SAND, as above

Sampling Method	Core Recovery (%)	Testing
HQ3	93	1 @ 0.4m
SPT	100	1/0 0/0 0/0 **N=0**
HQ3	100	2 @ 2.8m
SPT	55	1/0 0/1 0/1 **N=2**
HQ3	100	
SPT	100	1/1 2/1 2/2 **N=7**

RL (m): 33, 32, 31, 30, 29

Depth (m): 1, 2, 3, 4



Water Level: 19/06/2017

Core Box No: Box 1, 0.0-4.1m

COMMENTS: Static water level recorded 19/06/2017 at 1.6mbgl

Hole Depth
19.95m

Scale 1:25

Rev.: A

Tonkin+Taylor

BOREHOLE LOG

BOREHOLE No.: **BH101**

SHEET: 2 OF 4

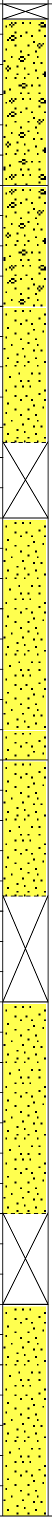
DRILLED BY: JK/SM
LOGGED BY: HU
CHECKED: RWOT
START DATE: 19/06/2017
FINISH DATE: 19/06/2017
CONTRACTOR: Perry Drilling Ltd

PROJECT: Te Tumu TCC
JOB No.: 1002034.2000
LOCATION: Bell Road

CO-ORDINATES: (NZTM) 5817292 mN 1896131 mE
DIRECTION: N/A
ANGLE FROM HORIZ.: -90°

R.L. GROUND: 33.35m
R.L. COLLAR: 33.35m
DATUM: Moturiki 1953
SURVEY: Handheld GPS

GEOLOGICAL UNIT	DESCRIPTION OF CORE SOIL: Classification, colour, consistency / density, moisture, plasticity ROCK: Weathering, colour, fabric, name, strength, cementation	Sampling Method	Core Recovery (%)	Testing	RL (m)	Depth (m)
	Core loss 4.95-5.05m					
	Gravelly fine to coarse SAND; light grey. Loose, wet, well graded, trace rootlets and trace shell fragments (~5%); gravel, fine to medium, sub-angular to sub-rounded; pumiceous.	HQ3	90		28	
	Fine to coarse SAND, with some gravel; dark grey. Loose, saturated, well graded; gravel, fine, sub-angular to sub-rounded.					
	- 6.0m: SAND changes to fine to medium, trace fine gravel	SPT	100	1/2 2/3 4/4 **N=13**	27	6
	Core loss 6.45-6.7m					
	SAND, as above - 7.4m: trace silt, changes to light grey	HQ3	76		26	7
	Fine to coarse SAND, with minor gravel; dark grey. Medium dense, saturated, well graded, trace shell fragments (~5%); gravel, fine, sub-angular to sub-rounded; shell fragments up to 40mm.	SPT	100	2/2 3/3 4/5 **N=15**		
	Core loss 7.95-8.3m					8
	SAND, as above	HQ3	66		25	
	Core loss 9.0-9.3m	SPT	33	1/1 3/4 4/5 **N=16**		9
	SAND, as above - 9.3m: shell fragments changes to around 15%				24	



Rock Weathering: RS EW HW MW SW UW; Rock Strength: EW VW W MS S VS ES; Fracture Spacing (mm): 2000 600 200 60 20; Fluid Loss (%): 25 50 75

Core Box No: Box 2, 4.1-8.6m

COMMENTS: Static water level recorded 19/06/2017 at 1.6mbgl

Hole Depth 19.95m

Scale 1:25

Rev.: A

BOREHOLE LOG

BOREHOLE No.:

BH101

SHEET: 3 OF 4

DRILLED BY: JK/SM
LOGGED BY: HU
CHECKED: RWOT
START DATE: 19/06/2017
FINISH DATE: 19/06/2017
CONTRACTOR: Perry Drilling Ltd

PROJECT: Te Tumu TCC
JOB No.: 1002034.2000
LOCATION: Bell Road

CO-ORDINATES: (NZTM) 5817292 mN
1896131 mE
DIRECTION: N/A
ANGLE FROM HORIZ.: -90°

R.L. GROUND: 33.35m
R.L. COLLAR: 33.35m
DATUM: Moturiki 1953
SURVEY: Handheld GPS

DESCRIPTION OF CORE SOIL: Classification, colour, consistency / density, moisture, plasticity ROCK: Weathering, colour, fabric, name, strength, cementation	Sampling Method	Core Recovery (%)	Testing
Fine to coarse SAND, with minor gravel; dark grey. Medium dense, saturated, well graded, some shell fragments (~15%); gravel, fine, sub-angular to sub-rounded; shell fragments up to 40mm. - 10.2m: SAND changes to fine to medium, trace shell fragments	HQ3	100	3 @ 10.4m
Core loss 10.5-10.8m	SPT	33	1/2 3/4 4/6 **N=17**
SAND, as above			
Core loss 10.95-11.25m	HQ3	66	
Fine to coarse SAND, with minor gravel; dark grey. Medium dense, saturated, well graded, some shell fragments (~15%); gravel, fine, sub-angular to sub-rounded; shell fragments up to 40mm. - 11.8m: minor shell fragments			
Core loss 12.0-12.3m	SPT	33	2/3 4/4 3/3 **N=14**
SAND, as above			
Core loss 12.45-12.75m	HQ3	71	
Fine to coarse SAND, with minor gravel; dark grey. Medium dense, saturated, well graded, some shell fragments (~15%); gravel, fine, sub-angular to sub-rounded; shell fragments up to 40mm. - 13.45-13.5m: trace grey silt lens			4 @ 13.2m
Core loss 13.5-13.65m	SPT	66	2/3 4/4 6/6 **N=20**
SAND, as above			
Core loss 13.95-14.2m	HQ3	76	
SAND, as above - 14.4m: Shell fragments up to 35mm, whole shells up to 20mm, gravel changes to fine to medium, sub-rounded			

RL (m): 23, 22, 21, 20, 19
Depth (m): 11, 12, 13, 14

GEOLOGICAL UNIT | Rock Weathering (UW SW MW HW CW) | Rock Strength (ES VS S MS W VW EW) | Graphic Log | ROCK DEFECTS: Defect Log | Fracture Spacing (mm) (2000 600 200 60 20) | RQD (%) | Description & Additional Observations | Fluid Loss (%) (25 50 75) | Water Level | Casing | Installation | Core Box No

Core Box No: Box 3, 8.6-13.2m

COMMENTS: Static water level recorded 19/06/2017 at 1.6mbgl

Hole Depth
19.95m

Scale 1:25

Rev.: A

Tonkin+Taylor

BOREHOLE LOG

BOREHOLE No.:

BH101

SHEET: 4 OF 4

PROJECT: Te Tumu TCC	CO-ORDINATES: (NZTM) 5817292 mN 1896131 mE	R.L. GROUND: 33.35m	DRILLED BY: JK/SM
JOB No.: 1002034.2000	DIRECTION: N/A	R.L. COLLAR: 33.35m	LOGGED BY: HU
LOCATION: Bell Road	ANGLE FROM HORIZ.: -90°	DATUM: Moturiki 1953	CHECKED: RWOT
		SURVEY: Handheld GPS	START DATE: 19/06/2017
			FINISH DATE: 19/06/2017
			CONTRACTOR: Perry Drilling Ltd

DESCRIPTION OF CORE

SOIL: Classification, colour, consistency / density, moisture, plasticity

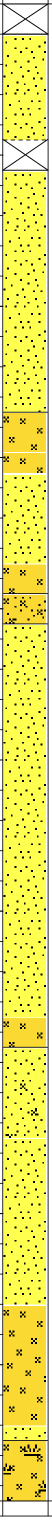
ROCK: Weathering, colour, fabric, name, strength, cementation

Columns: GEOLOGICAL UNIT; Rock Weathering (UW SW MW HW CW); Rock Strength (ES VS S MS W VW EW); Sampling Method; Core Recovery (%); Testing; RL (m); Depth (m); Graphic Log; ROCK DEFECTS: Defect Log, Fracture Spacing (mm) (2000 600 200 60 20), RQD (%), Description & Additional Observations; Fluid Loss (%) (25 50 75); Water Level; Casing; Installation; Core Box No

Description of core	Sampling Method	Core Recovery (%)	Testing
Core loss 15.0-15.1m	SPT	77	2/2 3/2 3/3 **N=11**
Fine to coarse SAND, with minor gravel; dark grey. Medium dense, saturated, well graded, trace shell fragments (~5%); gravel, fine to medium, sub-rounded.			
Core loss 15.45-15.55m	HQ3	90	5 @ 16.3m
SAND, as above			
SILT; light greyish green. Very stiff, moist, low plasticity. - 16.48m: SILT changes to light grey - 16.55m: 300 mm lens - Fine to medium SAND; light grey. Medium dense, wet, pumiceous.	SPT	100	2/2 4/6 5/6 **N=21**
Sandy SILT; light greenish grey. Firm, wet, low plasticity; sand, fine.	HQ3	100	
Fine to medium SAND with trace silt; light grey. Medium dense, wet, low plasticity, pumiceous. - 18.35m: 100mm lens - SILT; light greenish grey. Firm, wet, low plasticity.	SPT	100	4/2 2/1 2/2 **N=7**
Fine to coarse SAND; white grey. Loose, moist, well graded, pumiceous. - 18.55m: 200mm lens - silty fine to medium SAND, light grey. Loose, moist, well graded. - 19.3m: 400mm lens of SILT; light green grey. Stiff, moist, low plasticity.	HQ3	100	6 @ 19.3m
Organic SILT; dark blackish brown. Very soft, moist, high plasticity, trace rootlets.	SPT	100	1/2 2/0 1/0 **N=3**
19.95m: END OF BOREHOLE			

RL (m): 18, 17, 16, 15, 14

Depth (m): 16, 17, 18, 19



Core Box No: Box 4, 13.2-17.3m; Box 5, 17.3-20.0m

COMMENTS: Static water level recorded 19/06/2017 at 1.6mbgl

Hole Depth
19.95m

Scale 1:25

Rev.: A

BOREHOLE LOG

BOREHOLE No.:
BH102
SHEET: 1 OF 4

DRILLED BY: JK/SM
LOGGED BY: HU
CHECKED: RWOT
START DATE: 19/06/2017
FINISH DATE: 20/06/2017
CONTRACTOR: Perry Drilling Ltd

PROJECT: Te Tumu TCC
JOB No.: 1002034.2000
LOCATION: CPT 115

CO-ORDINATES: (NZTM) 5817925 mN 1897495 mE
DIRECTION: N/A
ANGLE FROM HORIZ.: -90°

R.L. GROUND: 35.95m
R.L. COLLAR: 35.95m
DATUM: Moturiki 1953
SURVEY: Handheld GPS

GEOLOGICAL UNIT

DESCRIPTION OF CORE
SOIL: Classification, colour, consistency / density, moisture, plasticity
ROCK: Weathering, colour, fabric, name, strength, cementation

Rock Weathering: UW SW MW HW CW
Rock Strength: ES VS S MS W VW EW
Sampling Method
Core Recovery (%)
Testing
RL (m)
Depth (m)
Graphic Log

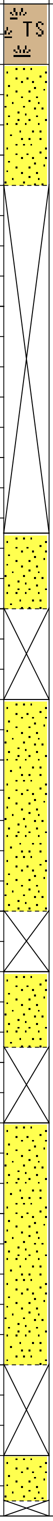
ROCK DEFECTS
Defect Log
Fracture Spacing (mm): 2000 600 200 60 20
RQD (%)
Description & Additional Observations

Fluid Loss (%): 25 50 75
Water Level
Casing
Installation
Core Box No

DESCRIPTION OF CORE
Silty fine SAND; dark brown. Soft, moist, low plasticity (Topsoil).
Fine to medium SAND; dark orange brown. Loose, moist, poorly graded.
Core loss 0.6-1.75m
- 1.75m - SAND changes to light brown with orange mottling
Core loss 2.0-2.3m
Fine to medium SAND; light brown with orange mottling. Loose, moist, poorly graded.
Core loss 3.0-3.2m
Fine to medium SAND; light brown with orange mottling. Loose, moist, poorly graded.
Core loss 3.45-3.7m
SAND, as above - 3.8-4.0m - trace rootlets
Core loss 4.5-4.8m
SAND, as above

Sampling Method	Core Recovery (%)	Testing
HQ3	40	
SPT	44	1/1 2/1 1/1 **N=5**
HQ3	66	
SPT	55	1/1 1/1 1/1 **N=4**
HQ3	76	1 @ 4.1m
SPT	33	1/0 1/1 1/1 **N=4**

RL (m)	Depth (m)
35	1
34	2
33	3
32	4
31	



Water Level: 20/06/2017

COMMENTS: Static water level recorded 20/06/2017 at 4.0mbgl

Hole Depth
19.95m

Scale 1:25

Rev.: A

Tonkin+Taylor

BOREHOLE LOG

BOREHOLE No.:
BH102
SHEET: 2 OF 4

PROJECT:	Te Tumu TCC
JOB No.:	1002034.2000
LOCATION:	CPT 115
CO-ORDINATES: (NZTM)	5817925 mN 1897495 mE
DIRECTION:	N/A
ANGLE FROM HORIZ.:	-90°
R.L. GROUND:	35.95m
R.L. COLLAR:	35.95m
DATUM:	Moturiki 1953
SURVEY:	Handheld GPS
DRILLED BY:	JK/SM
LOGGED BY:	HU
CHECKED:	RWOT
START DATE:	19/06/2017
FINISH DATE:	20/06/2017
CONTRACTOR:	Perry Drilling Ltd

GEOLOGICAL UNIT | DESCRIPTION OF CORE | Rock Weathering (UW SW MW HW CW) | Rock Strength (ES VS S MS W VW EW) | Sampling Method | Core Recovery (%) | Testing | RL (m) | Depth (m) | Graphic Log | ROCK DEFECTS: Defect Log, Fracture Spacing (mm) (2000 600 200 60 20), RQD (%), Description & Additional Observations | Fluid Loss (%) (25 50 75) | Water Level | Casing | Installation | Core Box No

SOIL: Classification, colour, consistency / density, moisture, plasticity

ROCK: Weathering, colour, fabric, name, strength, cementation

Core loss 4.95-5.2m

Fine to medium SAND; light brown with orange mottling. Loose, wet, poorly graded.

Fine to coarse SAND with trace gravel; light brown with orange mottling. Loose, saturated, well graded; gravel, fine, sub-rounded.

Core loss 6.0-6.15m

SAND, as above

- 6.45m: some fine gravel, grey brown

Sandy fine to medium GRAVEL; dark grey. Medium dense, wet, well graded, sub-rounded; sand, fine to coarse.

- 6.8m: Minor shell fragments (~10%)

Fine to coarse SAND, with some gravel; brownish grey. Medium dense to dense, saturated, well graded, trace shell fragments (~5%); gravel, fine, sub-rounded; shell fragments up to 15mm.

Gravelly fine to coarse SAND; brownish grey. Dense, saturated, well graded, trace shell fragments (~5%); gravel, fine, sub-rounded.

Core loss 9.0-9.2m

Gravelly SAND, as above

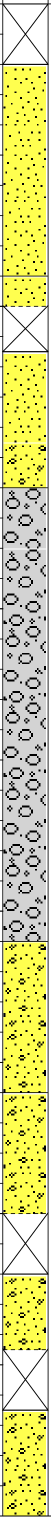
Core loss 9.45-9.65m

Gravelly SAND, as above

Sampling Method	Core Recovery (%)	Testing
HQ3	76	
SPT	66	2/2 1/2 2/2 **N=7**
HQ3	100	
SPT	100	6/7 7/6 8/9 **N=30**
HQ3	100	2 @ 8.0m
SPT	55	10/11 12/11 12/12 **N=47**

RL (m)	Depth (m)
30	6
29	7
28	8
27	9
26	

Core Box No: Box 1, 0.0-6.0m; Box 2, 6.0-8.9m



COMMENTS: Static water level recorded 20/06/2017 at 4.0mbgl

Hole Depth
19.95m

Scale 1:25

Rev.: A

General Log - 27/07/2017 12:37:01 PM - Produced with Core-GS by GeRoc

BOREHOLE LOG

BOREHOLE No.:

BH102

SHEET: 3 OF 4

PROJECT:	Te Tumu TCC
JOB No.:	1002034.2000
LOCATION:	CPT 115
CO-ORDINATES: (NZTM)	5817925 mN 1897495 mE
DIRECTION:	N/A
ANGLE FROM HORIZ.:	-90°
R.L. GROUND:	35.95m
R.L. COLLAR:	35.95m
DATUM:	Moturiki 1953
SURVEY:	Handheld GPS
DRILLED BY:	JK/SM
LOGGED BY:	HU
CHECKED:	RWOT
START DATE:	19/06/2017
FINISH DATE:	20/06/2017
CONTRACTOR:	Perry Drilling Ltd

GEOLOGICAL UNIT | DESCRIPTION OF CORE (SOIL: Classification, colour, consistency / density, moisture, plasticity; ROCK: Weathering, colour, fabric, name, strength, cementation) | Rock Weathering (UW SW MW HW CW) | Rock Strength (ES VS S MS W VW EW) | Sampling Method | Core Recovery (%) | Testing | RL (m) | Depth (m) | Graphic Log | ROCK DEFECTS: Defect Log, Fracture Spacing (mm) (2000 600 200 60 20), RQD (%), Description & Additional Observations | Fluid Loss (%) (25 50 75) | Water Level | Casing | Installation | Core Box No

DESCRIPTION OF CORE

Gravelly fine to coarse SAND; brownish grey. Dense, saturated, well graded, trace shell fragments (~5%); gravel, fine, sub-rounded.

Fine to medium SAND with trace gravel; grey. Very dense, saturated, poorly graded, trace shell fragments (~5%); gravel, fine, sub-rounded.

Core loss 10.5-10.65m

SAND, as above

Core loss 10.95-11.05m

SAND, as above

Fine to coarse SAND with minor gravel; grey. Medium dense, saturated, well graded, trace shell fragments (~5%); gravel, fine, sub-rounded.

- 12.70m: minor fine gravel, changes to dark grey.

Core loss 13.5-13.65m

SAND, as above

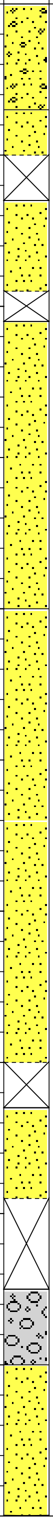
Core loss 13.95-14.25m

Sandy fine to medium GRAVEL; dark grey. Very dense, saturated, well graded, minor shell fragments (~10%); sand, fine to medium; gravel, sub-rounded.

Fine to medium SAND; dark grey. Very dense, saturated, well graded.

Sampling Method	Core Recovery (%)	Testing
HQ3	80	
SPT	73	4/8 12/15 16/7 for 30mm **N>=50**
HQ3	87	
SPT	100	3/2 3/6 6/6 **N=21**
HQ3	100	
SPT	77	4/10 9/8 10/12 **N=39**
HQ3	71	

RL (m)	Depth (m)
25	11
24	12
23	13
22	14
21	



Core Box No: Box 3, 8.9-13.0m

COMMENTS: Static water level recorded 20/06/2017 at 4.0mbgl

Hole Depth
19.95m

Scale 1:25

Rev.: A

Tonkin+Taylor

BOREHOLE LOG

BOREHOLE No.:
BH102
SHEET: 4 OF 4

PROJECT: Te Tumu TCC
JOB No.: 1002034.2000
LOCATION: CPT 115

CO-ORDINATES: (NZTM) 5817925 mN 1897495 mE
DIRECTION: N/A
ANGLE FROM HORIZ.: -90°

R.L. GROUND: 35.95m
R.L. COLLAR: 35.95m
DATUM: Moturiki 1953
SURVEY: Handheld GPS

DRILLED BY: JK/SM
LOGGED BY: HU
CHECKED: RWOT
START DATE: 19/06/2017
FINISH DATE: 20/06/2017
CONTRACTOR: Perry Drilling Ltd

DESCRIPTION OF CORE
SOIL: Classification, colour, consistency / density, moisture, plasticity
ROCK: Weathering, colour, fabric, name, strength, cementation

DESCRIPTION OF CORE	Sampling Method	Core Recovery (%)	Testing	RL (m)	Depth (m)	Core Box No
Core loss 15.0-15.1m	SPT	77	4/6 5/6 5/5 **N=21**			
Fine to coarse SAND; dark grey. Medium dense, saturated, well graded, trace shell fragments (~5%).						
	HQ3	100	3 @ 16.0m	20	16	
Core loss 16.5-16.65m	SPT	66	3/3 2/2 4/5 **N=13**			
SAND, as above						Box 4, 13.0-17.0m
Core loss 16.95-17.1m				19	17	
SAND, as above	HQ3	85		18		
Core loss 18.0-18.15m	SPT	66	5/8 7/6 9/10 **N=32**		18	
Fine to coarse SAND; dark grey. Medium dense, saturated, well graded, trace shell fragments (~5%).						
Core loss 18.45-18.85m	HQ3	61				
SAND, as above				17	19	
Core loss 19.5-19.65m	SPT	66	3/3 4/5 6/7 **N=22**			
SAND, as above						
19.95m: END OF BOREHOLE				16		Box 5, 17.0-20.0m

COMMENTS: Static water level recorded 20/06/2017 at 4.0mbgl

Hole Depth
19.95m

General Log - 27/07/2017 12:37:01 PM - Produced with Core-GS by GeRoc

Tonkin+Taylor

BOREHOLE LOG

BOREHOLE No.:

BH103

SHEET: 1 OF 5

DRILLED BY: JK/SM
LOGGED BY: HU
CHECKED: RWOT
START DATE: 20/06/2017
FINISH DATE: 20/06/2017
CONTRACTOR: Perry Drilling Ltd

PROJECT: Te Tumu TCC
JOB No.: 1002034.2000
LOCATION: CPT 112

CO-ORDINATES: (NZTM) 5819238 mN 1896006 mE
DIRECTION: N/A
ANGLE FROM HORIZ.: -90°

R.L. GROUND: 36.38m
R.L. COLLAR: 36.38m
DATUM: Moturiki 1953
SURVEY: Handheld GPS

GEOLOGICAL UNIT

DESCRIPTION OF CORE

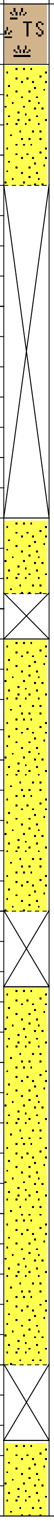
SOIL: Classification, colour, consistency / density, moisture, plasticity
ROCK: Weathering, colour, fabric, name, strength, cementation

Rock Weathering: UW SW MW HW CW EW
Rock Strength: ES VS S MS W VW EW
Sampling Method | Core Recovery (%) | Testing | RL (m) | Depth (m) | Graphic Log
ROCK DEFECTS: Defect Log | Fracture Spacing (mm): 2000 600 200 60 20 | RQD (%) | Description & Additional Observations
Fluid Loss (%): 25 50 75 | Water Level | Casing | Installation | Core Box No

DESCRIPTION OF CORE
Sandy SILT with trace rootlets; dark brown. Soft, wet, low plasticity, quick; sand, fine to medium (Topsoil).
Fine to medium SAND; light brown. Loose, wet, poorly graded.
Core loss 0.6-1.7m
SAND, as above
Core loss 1.95-2.1m
Fine to medium SAND; light brown. Loose, wet, poorly graded.
Core loss 3.0-3.25m
SAND, as above
Core loss 4.5-4.75m
SAND, as above

Sampling Method	Core Recovery (%)	Testing
HQ3	53	
SPT	55	1/1 2/2 3/3 **N=10**
HQ3	85	
SPT	44	2/1 1/2 2/1 **N=6**
HQ3	100	
SPT	44	3/2 2/2 2/3 **N=9**

RL (m)	Depth (m)
36	
	1
35	
	2
34	
	3
33	
	4
32	



Core Box No: Box 1, 0.0-5.0m

COMMENTS: No water level recorded

Hole Depth
21m

General Log - 27/07/2017 12:37:14 PM - Produced with Core-GS by GeRoc

Tonkin+Taylor

BOREHOLE LOG

BOREHOLE No.:
BH103
SHEET: 2 OF 5

DRILLED BY: JK/SM
LOGGED BY: HU
CHECKED: RWOT
START DATE: 20/06/2017
FINISH DATE: 20/06/2017
CONTRACTOR: Perry Drilling Ltd

PROJECT: Te Tumu TCC
JOB No.: 1002034.2000
LOCATION: CPT 112

CO-ORDINATES: 5819238 mN
(NZTM) 1896006 mE
DIRECTION: N/A
ANGLE FROM HORIZ.: -90°

R.L. GROUND: 36.38m
R.L. COLLAR: 36.38m
DATUM: Moturiki 1953
SURVEY: Handheld GPS

GEOLOGICAL UNIT | DESCRIPTION OF CORE: SOIL: Classification, colour, consistency / density, moisture, plasticity; ROCK: Weathering, colour, fabric, name, strength, cementation | Rock Weathering (UW SW MW HW CW) | Rock Strength (ES VS S MS W VW EW) | Sampling Method | Core Recovery (%) | Testing | RL (m) | Depth (m) | Graphic Log | ROCK DEFECTS: Defect Log | Fracture Spacing (mm) (2000 600 200 60 20) | RQD (%) | Description & Additional Observations | Fluid Loss (%) (25 50 75) | Water Level | Casing | Installation | Core Box No

Fine to medium SAND; light brown. Loose, saturated, poorly graded.

Core loss 6.0-6.2m

SAND, as above

Fine to coarse SAND; brown with dark orange mottling. Loose, saturated, well graded.

Core loss 7.5-7.65m

SAND, as above, changes to medium dense

Fine to coarse SAND with trace gravel; dark grey. Medium dense, saturated, well graded; gravel, fine, sub-rounded.

- 8.75m: trace shell fragments (~5%)

- 8.8m: 100mm lens - Gravelly fine to coarse SAND; dark grey. Medium dense, saturated, well graded; gravel, fine to medium, sub-rounded.

Fine to coarse SAND with trace gravel; dark grey. Very dense, saturated, well graded; gravel, fine, sub-rounded.

- 9.6m - 100mm lens - Shelly SAND, shell fragments

Sampling Method	Core Recovery (%)	Testing
HQ3	100	Sample 1 @ 5.0m
SPT	55	1/2 2/3 2/2 **N=9**
HQ3	100	
SPT	66	1/1 3/4 4/5 **N=16**
HQ3	100	
SPT	100	6/8 11/15 24 for 5mm **N>=50**

RL (m): 31, 30, 29, 28, 27
Depth (m): 6, 7, 8, 9

Core Box No: Box 2, 5.0-8.3m

COMMENTS: No water level recorded

Hole Depth
21m

Scale 1:25

Rev.: A

BOREHOLE LOG

BOREHOLE No.:

BH103

SHEET: 3 OF 5

DRILLED BY: JK/SM
LOGGED BY: HU
CHECKED: RWOT
START DATE: 20/06/2017
FINISH DATE: 20/06/2017
CONTRACTOR: Perry Drilling Ltd

PROJECT: Te Tumu TCC
JOB No.: 1002034.2000
LOCATION: CPT 112

CO-ORDINATES: (NZTM) 5819238 mN 1896006 mE
DIRECTION: N/A
ANGLE FROM HORIZ.: -90°

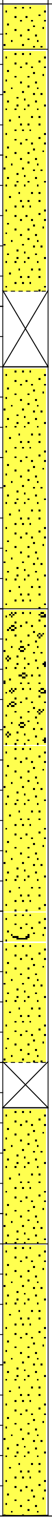
R.L. GROUND: 36.38m
R.L. COLLAR: 36.38m
DATUM: Moturiki 1953
SURVEY: Handheld GPS

GEOLOGICAL UNIT	DESCRIPTION OF CORE SOIL: Classification, colour, consistency / density, moisture, plasticity ROCK: Weathering, colour, fabric, name, strength, cementation	Rock Weathering (UW SW MW HW CW)	Rock Strength (ES VS S MS W VW EW)
	- 10.0m: 150mm lens - fine to medium SAND		
	Fine to coarse SAND with minor gravel; dark grey. Very dense, saturated, well graded, trace shell fragments (~5%); gravel, fine, sub-rounded.		
	Core loss 10.95-11.2m		
	SAND, as above - 11.2m: changes to trace fine gravel		
	Fine to coarse SAND with some gravel; dark grey. Dense, saturated, well graded, trace shell fragments (~5%); gravel, fine, sub-rounded. - 12.45m: changes to minor gravel - 13.0m: 50mm lens - some shell fragments (~15%)		
	Core loss 13.5-13.65m		
	SAND, as above		
	Fine to coarse SAND; dark grey. Dense, wet, well graded, trace shell fragments (~5%).		

Sampling Method	Core Recovery (%)	Testing
HQ3	93	
SPT	100	12/15 18/21 11 for 30mm **N>=50**
HQ3	73	
SPT	100	8/11 11/9 10/16 **N=46**
HQ3	100	Sample 2 @ 12.5m
SPT	66	2/3 6/8 11/11 **N=36**
HQ3	100	

RL (m): 26, 25, 24, 23, 22

Depth (m): 11, 12, 13, 14



ROCK DEFECTS: Defect Log	Fracture Spacing (mm) (2000 600 200 60 20)	RQD (%)	Description & Additional Observations	Fluid Loss (%) (25 50 75)	Water Level	Casing	Installation	Core Box No
								Box 3, 8.3-11.0m
								Box 4, 11.0-14.3m

COMMENTS: No water level recorded

Hole Depth
21m

Scale 1:25

Rev.: A

BOREHOLE LOG

BOREHOLE No.: **BH103**

SHEET: 4 OF 5

DRILLED BY: JK/SM
LOGGED BY: HU
CHECKED: RWOT
START DATE: 20/06/2017
FINISH DATE: 20/06/2017
CONTRACTOR: Perry Drilling Ltd

PROJECT: Te Tumu TCC
JOB No.: 1002034.2000
LOCATION: CPT 112

CO-ORDINATES: (NZTM) 5819238 mN 1896006 mE
DIRECTION: N/A
ANGLE FROM HORIZ.: -90°

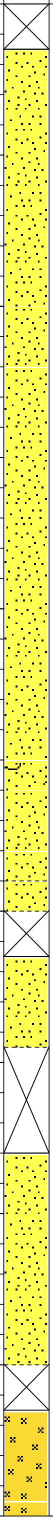
R.L. GROUND: 36.38m
R.L. COLLAR: 36.38m
DATUM: Moturiki 1953
SURVEY: Handheld GPS

GEOLOGICAL UNIT | DESCRIPTION OF CORE: SOIL: Classification, colour, consistency / density, moisture, plasticity; ROCK: Weathering, colour, fabric, name, strength, cementation | Rock Weathering (UW SW MW HW CW) | Rock Strength (ES VS S MS W VW EW) | Sampling Method | Core Recovery (%) | Testing | RL (m) | Depth (m) | Graphic Log | ROCK DEFECTS: Defect Log, Fracture Spacing (mm) (2000 600 200 60 20), RQD (%), Description & Additional Observations | Fluid Loss (%) (25 50 75) | Water Level | Casing | Installation | Core Box No

Depth (m)	Description of core	Sampling Method	Core Recovery (%)	Testing
15.0–15.15	Core loss 15.0-15.15m	SPT	66	3/6 8/9 10/12 **N=39**
15.15	Fine to medium SAND; dark grey. Dense, wet, poorly graded, trace shell fragments (~5%).			
15.45–16.5		HQ3	100	
16.0	-16.0m: changes to minor shell fragments (~5-10%)			
16.5–16.95		SPT	100	7/7 7/6 7/6 **N=26**
16.95–18.0		HQ3	100	
17.5	- 17.5m: 100mm lens - some shell fragments (~15%)			
17.8	-17.8m: 100mm lens - Fine to coarse SAND with minor gravel; dark grey. Dense, saturated, well graded, trace shell fragments (~5%); gravel, fine to medium, sub-rounded.			
18.0–18.15	Core loss 18.0-18.15m	SPT	66	8/9 11/11 14/13 **N=49**
18.15	Fine to medium SAND; dark grey. Dense, wet, poorly graded, trace shell fragments (~5%).			
18.45–18.8	Core loss 18.45-18.8m	HQ3	57	
18.8	SAND, as above			
19.5–19.65	Core loss 19.5-19.65m	SPT	66	0/0 0/0 0/0 **N=0**
19.65	SILT; dark greenish grey. Very soft, saturated, high plasticity, trace shell fragments (~5%).			

RL (m): 21, 20, 19, 18, 17

Depth (m): 16, 17, 18, 19



Core Box No: Box 5, 14.3-17.2m

COMMENTS: No water level recorded

Hole Depth 21m

Scale 1:25

Rev.: A

General Log - 27/07/2017 12:37:15 PM - Produced with Core-GS by GeRoc

Tonkin+Taylor

BOREHOLE LOG

BOREHOLE No.:
BH103
SHEET: 5 OF 5

DRILLED BY: JK/SM
LOGGED BY: HU
CHECKED: RWOT
START DATE: 20/06/2017
FINISH DATE: 20/06/2017
CONTRACTOR: Perry Drilling Ltd

PROJECT: Te Tumu TCC
JOB No.: 1002034.2000
LOCATION: CPT 112

CO-ORDINATES: (NZTM) 5819238 mN
1896006 mE
DIRECTION: N/A
ANGLE FROM HORIZ.: -90°

R.L. GROUND: 36.38m
R.L. COLLAR: 36.38m
DATUM: Moturiki 1953
SURVEY: Handheld GPS

GEOLOGICAL UNIT	DESCRIPTION OF CORE SOIL: Classification, colour, consistency / density, moisture, plasticity ROCK: Weathering, colour, fabric, name, strength, cementation	Rock Weathering UW SW MW HW CW	Rock Strength ES VS S MS W VW EW	Sampling Method	Core Recovery (%)	Testing	RL (m)	Depth (m)	Graphic Log	ROCK DEFECTS: Defect Log	ROCK DEFECTS: Fracture Spacing (mm) 2000 600 200 60 20	ROCK DEFECTS: RQD (%)	ROCK DEFECTS: Description & Additional Observations	Fluid Loss (%) 25 50 75	Water Level	Casing	Installation	Core Box No
	SILT; dark greenish grey. Very soft, saturated, high plasticity, trace shell fragments (~5%). - 20.1m: 100 mm diameter tree root			HQ3	100	Sample 3 @ 20.9m	16	21										Box 6, 17.2-21.0m
	21m: END OF BOREHOLE						15 14 13 12	22 23 24										

COMMENTS: No water level recorded

Hole Depth
21m

Scale 1:25

Rev.: A

Tonkin+Taylor

BOREHOLE LOG

BOREHOLE No.:

BH104

SHEET: 1 OF 4

DRILLED BY: TG/SM
LOGGED BY: HU
CHECKED: RWOT
START DATE: 21/06/2017
FINISH DATE: 21/06/2017
CONTRACTOR: Perry Drilling Ltd

PROJECT: Te Tumu TCC
JOB No.: 1002034.2000
LOCATION: 581D Bell Road

CO-ORDINATES: (NZTM) 5816779 mN 1898414 mE
DIRECTION: N/A
ANGLE FROM HORIZ.: -90°

R.L. GROUND: 34.00m
R.L. COLLAR: 34.00m
DATUM: Moturiki 1953
SURVEY: Handheld GPS

GEOLOGICAL UNIT	DESCRIPTION OF CORE SOIL: Classification, colour, consistency / density, moisture, plasticity ROCK: Weathering, colour, fabric, name, strength, cementation	Rock Weathering UW SW MW HW CW	Rock Strength ES VS S MS W VW EW	Sampling Method	Core Recovery (%)	Testing
	Organic fine to medium SAND with minor silt and trace rootlets; dark brown. Loose, moist, low plasticity (Topsoil).			HQ3	66	
	Fine to medium SAND with trace rootlets; dark brown. Loose, moist, poorly graded.					
	Fine to coarse SAND; light brown. Loose, moist, well graded.					
	Core loss 1.0-1.5m					
	SAND, as above			SPT	100	1/2 1/2 1/2 **N=6**
				HQ3	100	
	Fine to coarse SAND with minor gravel; light brown. Loose, wet, well graded; gravel, fine, sub-rounded.					
	Gravelly fine to coarse SAND; orange brown. Loose, wet, well graded; gravel, fine, sub-rounded.					
	Core loss 3.0-3.25m			SPT	44	1/1 1/1 2/1 **N=5**
	Gravelly SAND, as above - 3.6m: changes to grey			HQ3	100	1 @ 3.8m
	Core loss 4.5-4.7m			SPT	55	2/2 4/4 5/4 **N=17**
	Gravelly SAND, as above, changes to medium dense					

RL (m)	Depth (m)
33	1
32	2
31	3
30	4

Graphic Log	ROCK DEFECTS: Defect Log	Fracture Spacing (mm) 2000 600 200 60 20	RQD (%)	Description & Additional Observations	Fluid Loss (%) 25 50 75	Water Level	Casing	Installation	Core Box No
TS						21/06/2017			Box 1, 0.0-3.8m

COMMENTS: Static water level recorded 21/06/2017 at 2.9mbgl

Hole Depth
19.95m

Scale 1:25

Rev.: A

General Log - 27/07/2017 12:37:30 PM - Produced with Core-GS by GeRoc

Tonkin+Taylor

BOREHOLE LOG

BOREHOLE No.:

BH104

SHEET: 2 OF 4

DRILLED BY: TG/SM
LOGGED BY: HU
CHECKED: RWOT
START DATE: 21/06/2017
FINISH DATE: 21/06/2017
CONTRACTOR: Perry Drilling Ltd

PROJECT: Te Tumu TCC
JOB No.: 1002034.2000
LOCATION: 581D Bell Road

CO-ORDINATES: (NZTM) 5816779 mN 1898414 mE
DIRECTION: N/A
ANGLE FROM HORIZ.: -90°

R.L. GROUND: 34.00m
R.L. COLLAR: 34.00m
DATUM: Moturiki 1953
SURVEY: Handheld GPS

GEOLOGICAL UNIT | DESCRIPTION OF CORE: SOIL: Classification, colour, consistency / density, moisture, plasticity; ROCK: Weathering, colour, fabric, name, strength, cementation | Rock Weathering (UW SW MW HW CW) | Rock Strength (ES VS S MS W VW EW) | Sampling Method | Core Recovery (%) | Testing | RL (m) | Depth (m) | Graphic Log | ROCK DEFECTS: Defect Log | Fracture Spacing (mm) (2000 600 200 60 20) | RQD (%) | Description & Additional Observations | Fluid Loss (%) (25 50 75) | Water Level | Casing | Installation | Core Box No

DESCRIPTION OF CORE	Sampling Method	Core Recovery (%)	Testing
Gravelly fine to coarse SAND; dark grey. Medium dense, wet, well graded; gravel, fine, sub-rounded.	HQ3	100	
Core loss 6.0-6.2m	SPT	55	2/2 3/4 2/3 **N=12**
Gravelly SAND, as above			
Fine to medium SAND with minor gravel; dark grey. Medium dense, wet, well graded; gravel, fine, sub-rounded. - 7.4m: 100mm lens - changes to dark green grey	HQ3	100	
Core loss 7.5-7.65m	SPT	66	1/2 4/5 6/7 **N=22**
SAND, as above, changes to dark grey			
Fine to medium SAND with trace gravel; dark grey. Medium dense, wet, well graded; gravel, fine, sub-rounded.	HQ3	100	
Gravelly fine to coarse SAND; dark grey. Medium dense, wet, well graded, minor shell fragments (~10%); gravel, fine to medium, sub-rounded.			
Core loss 9.0-9.15m	SPT	66	2/3 4/7 8/9 **N=28**
Gravelly SAND, as above			
Core loss 9.45-9.7m			
Gravelly SAND, as above			

RL (m)	Depth (m)
28	6
27	7
26	8
25	9
24	

Core Box No: Box 2, 3.8-7.3m

COMMENTS: Static water level recorded 21/06/2017 at 2.9mbgl

Hole Depth
19.95m

Scale 1:25

Rev.: A

Tonkin+Taylor

BOREHOLE LOG

BOREHOLE No.:

BH104

SHEET: 3 OF 4

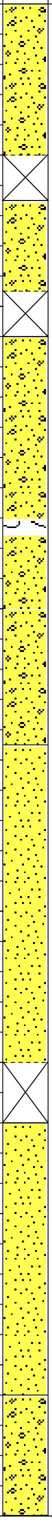
DRILLED BY: TG/SM
LOGGED BY: HU
CHECKED: RWOT
START DATE: 21/06/2017
FINISH DATE: 21/06/2017
CONTRACTOR: Perry Drilling Ltd

PROJECT: Te Tumu TCC
JOB No.: 1002034.2000
LOCATION: 581D Bell Road

CO-ORDINATES: (NZTM) 5816779 mN 1898414 mE
DIRECTION: N/A
ANGLE FROM HORIZ.: -90°

R.L. GROUND: 34.00m
R.L. COLLAR: 34.00m
DATUM: Moturiki 1953
SURVEY: Handheld GPS

GEOLOGICAL UNIT	DESCRIPTION OF CORE SOIL: Classification, colour, consistency / density, moisture, plasticity ROCK: Weathering, colour, fabric, name, strength, cementation	Rock Weathering UW SW MW HW CW	Rock Strength ES VS S MS W VW EW	Sampling Method	Core Recovery (%)	Testing	RL (m)	Depth (m)	Graphic Log	ROCK DEFECTS: Defect Log	Fracture Spacing (mm) 2000 600 200 60 20	RQD (%)	Description & Additional Observations	Fluid Loss (%) 25 50 75	Water Level	Casing	Installation	Core Box No
	Gravelly fine to coarse SAND; dark grey. Medium dense, saturated, well graded, minor shell fragments (~10%); gravel, fine to medium, sub-rounded.			HQ3	76													
	Core loss 10.5-10.65m			SPT	66	1/1 3/4 7/9 **N=23**												
	Gravelly SAND, as above																	Box 3, 7.3-11.0m
	Core loss 10.95-11.1m						23	11										
	Gravelly fine to coarse SAND; dark grey. Medium dense, saturated, well graded, minor shell fragments (~10%); gravel, fine to medium, sub-rounded.			HQ3	85	2 @ 11.5m												
	- 11.7m: 50mm lens - shell fragments (~5-10%)																	
	- 12.0m: changes to trace shell fragments (~5%)			SPT	100	1/2 2/4 5/6 **N=17**	22	12										
	Fine to coarse SAND with trace gravel; dark grey. Medium dense, saturated, well graded, trace shell fragments (~5%); gravel, fine, sub-rounded.			HQ3	100		21	13										
	Core loss 13.5-13.7m			SPT	55	1/1 2/2 3/4 **N=11**												Box 4, 11.0-14.0m
	SAND, as above			HQ3	100		20	14										
	Gravelly fine to coarse SAND; dark grey. Medium dense, wet, well graded, minor shell fragments (~10%); gravel, fine to medium, sub-rounded.						19											



COMMENTS: Static water level recorded 21/06/2017 at 2.9mbgl

Hole Depth
19.95m

Scale 1:25

Rev.: A

Tonkin+Taylor

BOREHOLE LOG

BOREHOLE No.: BH104

SHEET: 4 OF 4

DRILLED BY: TG/SM
LOGGED BY: HU
CHECKED: RWOT
START DATE: 21/06/2017
FINISH DATE: 21/06/2017
CONTRACTOR: Perry Drilling Ltd

PROJECT: Te Tumu TCC
JOB No.: 1002034.2000
LOCATION: 581D Bell Road

CO-ORDINATES: (NZTM) 5816779 mN 1898414 mE
DIRECTION: N/A
ANGLE FROM HORIZ.: -90°

R.L. GROUND: 34.00m
R.L. COLLAR: 34.00m
DATUM: Moturiki 1953
SURVEY: Handheld GPS

DESCRIPTION OF CORE (SOIL: Classification, colour, consistency / density, moisture, plasticity; ROCK: Weathering, colour, fabric, name, strength, cementation)	Sampling Method	Core Recovery (%)	Testing	RL (m)	Depth (m)	Core Box No
Core loss 15.0-15.15m	SPT	66	2/3 4/5 5/6 **N=20**			
Gravelly fine to coarse SAND; dark grey. Medium dense, saturated, well graded, minor shell fragments (~10%); gravel, fine to medium, sub-rounded.						
Core loss 15.45-15.7m	HQ3	76				
Gravelly SAND, as above			3 @ 16.2m	18	16	
SILT with minor sand; dark grey. Very stiff, wet, low plasticity; sand, fine. - 16.4m: changes to light brownish grey.	SPT	100	3/4 4/5 6/7 **N=22**			Box 5, 14.0-17.0m
	HQ3	100	4 @ 17.0m	17	17	
Silty fine SAND; light grey. Medium dense, wet, low plasticity; pumiceous.						
Gravelly fine to coarse SAND; light grey; Medium dense, saturated, well graded; gravel, fine, sub-rounded; pumiceous.	SPT	100	3/4 4/5 5/5 **N=19**	16	18	
- 18.75m: gravel changes to fine to medium.	HQ3	100		15	19	
	SPT	100	3/4 5/6 6/7 **N=24**			Box 6, 17.0-20.0m
19.95m: END OF BOREHOLE						

Other columns: GEOLOGICAL UNIT; Rock Weathering; Rock Strength; Graphic Log; ROCK DEFECTS: Defect Log, Fracture Spacing (mm), RQD (%), Description & Additional Observations; Fluid Loss (%); Water Level; Casing; Installation.

COMMENTS: Static water level recorded 21/06/2017 at 2.9mbgl

Hole Depth
19.95m

Scale 1:25

Rev.: A

Tonkin+Taylor

BOREHOLE LOG

BOREHOLE No.:
BH105
SHEET: 1 OF 4

DRILLED BY: TG/SM
LOGGED BY: HU
CHECKED: RWOT
START DATE: 22/06/2017
FINISH DATE: 22/06/2017
CONTRACTOR: Perry Drilling Ltd

PROJECT: Te Tumu TCC
JOB No.: 1002034.2000
LOCATION: CPT 132

CO-ORDINATES: (NZTM) 5817077 mN
1899460 mE
DIRECTION: N/A
ANGLE FROM HORIZ.: -90°

R.L. GROUND: 42.55m
R.L. COLLAR: 42.55m
DATUM: Moturiki 1953
SURVEY: Handheld GPS

DESCRIPTION OF CORE
SOIL: Classification, colour, consistency / density, moisture, plasticity
ROCK: Weathering, colour, fabric, name, strength, cementation

DESCRIPTION OF CORE	Sampling Method	Core Recovery (%)	Testing	Graphic Log
Organic fine to medium SAND with minor rootlets and trace silt; brown. Medium dense, wet, low plasticity (Topsoil). Fine to coarse SAND; dark brown. Medium dense, wet, well graded.	HQ3	100		TS
Core loss 1.5-1.65m	SPT	66	1/1 2/3 2/3 **N=10**	
SAND, as above	HQ3	100		
Core loss 3.0-3.15m	SPT	66	2/3 4/5 5/6 **N=20**	
Fine to coarse SAND; dark brown. Medium dense, wet, well graded. - 3.7m: changes to light brown	HQ3	100		
Core loss 4.5-4.95m	SPT	0	2/3 4/4 4/4 **N=16**	

RL (m): 42, 41, 40, 39, 38
Depth (m): 1, 2, 3, 4

Core Box No: Box 1, 0.0-3.7m

Column headings: GEOLOGICAL UNIT; Rock Weathering (UW SW MW HW CW); Rock Strength (ES VS S MS W VW EW); Sampling Method; Core Recovery (%); Testing; RL (m); Depth (m); Graphic Log; ROCK DEFECTS: Defect Log, Fracture Spacing (mm) (2000 600 200 60 20), RQD (%), Description & Additional Observations; Fluid Loss (%) (25 50 75); Water Level; Casing; Installation; Core Box No

COMMENTS: Static water level recorded 22/06/2017 at 6.6mbgl

Hole Depth
19.95m

Tonkin+Taylor

BOREHOLE LOG

BOREHOLE No.:
BH105
SHEET: 2 OF 4

DRILLED BY: TG/SM
LOGGED BY: HU
CHECKED: RWOT
START DATE: 22/06/2017
FINISH DATE: 22/06/2017
CONTRACTOR: Perry Drilling Ltd

PROJECT: Te Tumu TCC
JOB No.: 1002034.2000
LOCATION: CPT 132

CO-ORDINATES: (NZTM) 5817077 mN
1899460 mE
DIRECTION: N/A
ANGLE FROM HORIZ.: -90°

R.L. GROUND: 42.55m
R.L. COLLAR: 42.55m
DATUM: Moturiki 1953
SURVEY: Handheld GPS

GEOLOGICAL UNIT	DESCRIPTION OF CORE SOIL: Classification, colour, consistency / density, moisture, plasticity ROCK: Weathering, colour, fabric, name, strength, cementation	Rock Weathering UW SW MW HW CW	Rock Strength ES VS S MS W VW EW	Sampling Method	Core Recovery (%)	Testing	RL (m)	Depth (m)	Graphic Log	Defect Log	Fracture Spacing (mm) 2000 600 200 60 20	RQD (%)	Description & Additional Observations	Fluid Loss (%) 25 50 75	Water Level	Casing	Installation	Core Box No
	Fine to coarse SAND; light brown. Medium dense, wet, well graded.			HQ3	100		37											
	Core loss 6.0-6.15m			SPT	66	2/3 4/5 4/5 **N=18**		6										
	SAND, as above			HQ3	100		36	7							▼ 22/06/2017			Box 2, 3.7-7.5m
	Core loss 7.5-7.7m			SPT	55	3/4 5/5 5/5 **N=20**	35											
	Fine to coarse SAND; light brown. Medium dense, wet, well graded.			HQ3	100		34	8										
	Core loss 9.0-9.2m			SPT	55	4/5 6/7 7/9 **N=29**		9										
	SAND, as above - 9.9m: changes to dark brown with blackish mottling						33											

COMMENTS: Static water level recorded 22/06/2017 at 6.6mbgl

Hole Depth
19.95m

Scale 1:25

Rev.: A

Tonkin+Taylor

BOREHOLE LOG

BOREHOLE No.:
BH105
SHEET: 3 OF 4

PROJECT: Te Tumu TCC
JOB No.: 1002034.2000
LOCATION: CPT 132

CO-ORDINATES: (NZTM) 5817077 mN 1899460 mE
DIRECTION: N/A
ANGLE FROM HORIZ.: -90°

R.L. GROUND: 42.55m
R.L. COLLAR: 42.55m
DATUM: Moturiki 1953
SURVEY: Handheld GPS

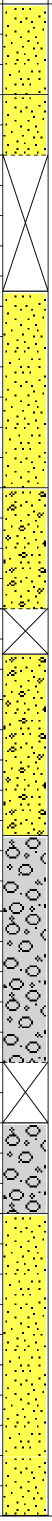
DRILLED BY: TG/SM
LOGGED BY: HU
CHECKED: RWOT
START DATE: 22/06/2017
FINISH DATE: 22/06/2017
CONTRACTOR: Perry Drilling Ltd

GEOLOGICAL UNIT | DESCRIPTION OF CORE (SOIL: Classification, colour, consistency / density, moisture, plasticity; ROCK: Weathering, colour, fabric, name, strength, cementation) | Rock Weathering (UW SW MW HW CW) | Rock Strength (ES VS S MS W VW EW) | Sampling Method | Core Recovery (%) | Testing | RL (m) | Depth (m) | Graphic Log | ROCK DEFECTS: Defect Log | Fracture Spacing (mm) (2000 600 200 60 20) | RQD (%) | Description & Additional Observations | Fluid Loss (%) (25 50 75) | Water Level | Casing | Installation | Core Box No

DESCRIPTION OF CORE	Sampling Method	Core Recovery (%)	Testing
Fine to coarse SAND; dark brown with blackish mottling. Medium dense, wet, well graded.	HQ3	100	
Fine to coarse SAND; light brown. Medium dense, wet, well graded.			
Core loss 10.5-10.95m	SPT	0	5/6 5/4 4/5 **N=18**
Fine to coarse SAND with minor gravel; dark brown. Medium dense, saturated, well graded; gravel, fine, sub-rounded.	HQ3	100	
Gravelly fine to coarse SAND; dark brown. Very dense, saturated, well graded, trace shell fragments (~5%); gravel, fine, sub-rounded.			
Core loss 12.0-12.15m	SPT	92	5/8 15/15 18 for 2mm **N>=50**
Gravelly SAND, as above			
Sandy fine GRAVEL; dark brown. Very dense, saturated, well graded, minor shell fragments (~10%) ; sand, fine to coarse; gravel, sub-angular to sub-rounded.	HQ3	100	
Core loss 13.5-13.7m	SPT	71	12/18 26/24 for 50mm **N>=50**
Sandy GRAVEL, as above			
Fine to coarse SAND with trace gravel; dark brown. Very dense, saturated, well graded; gravel, fine, sub-rounded. - 14.7m: 100mm lens - gravelly fine to coarse SAND; gravel, fine, sub-rounded. - 14.8m: Fine to medium SAND; dark brown. Very dense, saturated, poorly graded, trace shell fragments (~5%)	HQ3	100	

RL (m): 32 31 30 29 28

Depth (m): 11 12 13 14



Box 3, 7.5-11.3m

COMMENTS: Static water level recorded 22/06/2017 at 6.6mbgl

Hole Depth
19.95m

Scale 1:25

Rev.: A

Tonkin+Taylor

BOREHOLE LOG

BOREHOLE No.:
BH105
SHEET: 4 OF 4

PROJECT: Te Tumu TCC	CO-ORDINATES: (NZTM) 5817077 mN 1899460 mE	R.L. GROUND: 42.55m
JOB No.: 1002034.2000		R.L. COLLAR: 42.55m
LOCATION: CPT 132	DIRECTION: N/A	DATUM: Moturiki 1953
	ANGLE FROM HORIZ.: -90°	SURVEY: Handheld GPS

DRILLED BY: TG/SM
LOGGED BY: HU
CHECKED: RWOT
START DATE: 22/06/2017
FINISH DATE: 22/06/2017
CONTRACTOR: Perry Drilling Ltd

GEOLOGICAL UNIT | DESCRIPTION OF CORE (SOIL: Classification, colour, consistency / density, moisture, plasticity; ROCK: Weathering, colour, fabric, name, strength, cementation) | Rock Weathering (LW SW MW HW CW) | Rock Strength (ES VS S MS W VW EW) | Sampling Method | Core Recovery (%) | Testing | RL (m) | Depth (m) | Graphic Log | ROCK DEFECTS: Defect Log, Fracture Spacing (mm) (2000 600 200 60 20), RQD (%), Description & Additional Observations | Fluid Loss (%) (25 50 75) | Water Level | Casing | Installation | Core Box No

DESCRIPTION OF CORE
Core loss 15.0-15.15m
Fine to medium SAND with trace gravel; dark brown. Very dense, saturated, trace shell fragments (~5%); gravel, fine to medium, sub-rounded.
Sandy fine to medium GRAVEL; dark brown. Very dense, saturated, some shell fragments (~15-20%); sand, fine to coarse.
Fine to coarse SAND with minor gravel; dark brown. Very dense, saturated, well graded; gravel, fine, sub-rounded.
Gravelly fine to coarse SAND; dark brown. Very dense, saturated, well graded, minor shell fragments (~10%); gravel, fine, sub-rounded.
Core loss 16.5-16.7m
Gravelly SAND, as above
Fine to medium SAND with trace gravel; dark brown. Very dense, saturated; gravel, fine, sub-rounded.
Core loss 18.0-18.3m
Fine to coarse SAND with some gravel; brownish grey. Very dense, saturated, well graded, minor shell fragments (~10%); gravel, fine, sub-rounded.
Fine to medium SAND; greyish brown. Dense, saturated, poorly graded, trace shell fragments (~5%) .
Core loss 19.5-19.7m
SAND, as above
19.95m: END OF BOREHOLE

Sampling Method	Core Recovery (%)	Testing
SPT	78	14/16 15/15 20 for 3mm **N>=50**
HQ3	100	
SPT	62	6/8 22/28 for 70mm **N>=50**
HQ3	100	
SPT	39	7/10 22/25 for 2mm **N>=50** Bouncing
HQ3	100	
SPT	55	10/11 8/7 16/14 **N=45**

RL (m): 27, 26, 25, 24, 23

Depth (m): 16, 17, 18, 19

Core Box No: Box 4, 11.3-17.6m; Box 5, 17.6-20.0m

COMMENTS: Static water level recorded 22/06/2017 at 6.6mbgl

Hole Depth
19.95m

General Log - 27/07/2017 12:37:44 PM - Produced with Core-GS by GeRoc

Scale 1:25

Rev.: A

GEOTECHNICS

Our Ref: 1003875.0.0./REP01
Customer Ref: 1002034.2000
24 July 2017

Tonkin + Taylor
Level 1
525 Cameron Road
Tauranga 3110

Attention: Mike Jacka

Dear Mike,

Te Tumu Natural Hazards

Laboratory Test Report

Samples from the above mentioned site have been tested as received according to your instructions. Test results are included in this report.

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.

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 this page.

GEOTECHNICS LTD

Report prepared by:

....
Troy Robertson
Geotechnician

Authorised for Geotechnics by:

....
Steven Anderson
Project Director

Report checked by:

....
David Boston
Project manager
Approved Signatory

IANZ ACCREDITED LABORATORY

All tests reported herein have been performed in accordance with the laboratory's scope of accreditation

This document consists of 9 pages.

24-Jul-17
t:\geotechnicsgroup\projects\1003875\workingmaterial\20170724.tasr.te tumu natural hazards.rep01.final.docx

Geotechnics Project ID	1003875
Customer Project ID	1002034.2
Customer Project Name	

DETERMINATION OF LIQUID & PLASTIC LIMIT, PLASTICITY INDEX - NZS 4402: 1986 Tests 2.2 (4 Point), 2.3 & 2.4

TEST DETAILS

LOCATION	**ID**	BH01		
	Description	N/A		
	Data	N/A		
SAMPLE	**Geotechnics ID**	GEOT201707180	**Date Received**	12/07/2017
	Reference	N/A	**Depth**	2.80m - 2.90m
	Description	Silty, fine to coarse SAND, with minor organics; dark grey with some dark brown mottling. Wet.		
SPECIMEN	**Reference**	2	**Depth**	N/A
	Description	N/A		

TEST RESULTS

Liquid Limit	**Not Suitable**
Plastic Limit	**Not Suitable**
Plasticity Index	**Not Obtainable**

TEST REMARKS

- The material was unsuitable for testing both the Liquid Limit and the Plastic Limit.
- Material too sandy and dilatant.

This test result is IANZ accredited.

Approved By	DFB	**Date**	24/07/2017

Geotechnics Project ID	1003875
Customer Project ID	1002034.2
Customer Project Name	

DETERMINATION OF LIQUID & PLASTIC LIMIT, PLASTICITY INDEX - NZS 4402: 1986 Tests 2.2 (4 Point), 2.3 & 2.4

TEST DETAILS

LOCATION	**ID**	BH04		
	Description	N/A		
	Data	N/A		
SAMPLE	**Geotechnics ID**	GEOT201707185	**Date Received**	12/07/2017
	Reference	N/A	**Depth**	16.95m - 17.05m
	Description	Sandy SILT; light grey. Wet; sand, fine.		
SPECIMEN	**Reference**	2	**Depth**	N/A
	Description	N/A		

TEST RESULTS

Liquid Limit	**Not Suitable**
Plastic Limit	**Not Suitable**
Plasticity Index	**Not Obtainable**

TEST REMARKS

• The material was unsuitable for testing both the Liquid Limit and the Plastic Limit. • M aterial too sandy and dilatant.

This test result is IANZ accredited.

Approved By	DFB	**Date**	24/07/2017

Geotechnics Project ID	1003875
Customer Project ID	1002034.2
Customer Project Name	

DETERMINATION OF THE WATER CONTENT & FINES CONTENT - GEO190-13

TEST DETAILS

LOCATION	**ID**	BH01		
	Description	N/A		
	Data	N/A		
SAMPLE	**Geotechnics ID**	GEOT201707180	**Date Received**	12/07/2017
	Reference	N/A	**Depth**	2.80m - 2.90m
	Description	Silty, fine to coarse SAND, with minor organics; dark grey with some dark brown mottling. Wet.		
SPECIMEN	**Reference**	3	**Depth**	N/A
	Description	N/A		

TEST RESULT

Natural Water Content	**51.2%**
Fines Content Passing 75µm Sieve	**20.1%**
Fines Content Passing 63µm Sieve	**N/A**

TEST REMARKS

- The material used for testing was natural, whole soil.

This test result is IANZ accredited.

Approved By	DFB	**Date**	24/07/2017

Geotechnics Project ID	1003875
Customer Project ID	1002034.2
Customer Project Name	

DETERMINATION OF THE WATER CONTENT & FINES CONTENT - GEO190-13

TEST DETAILS

LOCATION	**ID**	BH01		
	Description	N/A		
	Data	N/A		
SAMPLE	**Geotechnics ID**	GEOT201707181	**Date Received**	12/07/2017
	Reference	N/A	**Depth**	3.40m - 3.50m
	Description	Fine to coarse SAND, with some gravel, trace silt; dark grey. Wet; gravel, fine.		
SPECIMEN	**Reference**	2	**Depth**	N/A
	Description	N/A		

TEST RESULT

Natural Water Content	**26.2%**
Fines Content Passing 75µm Sieve	**2.7%**
Fines Content Passing 63µm Sieve	**N/A**

TEST REMARKS

- The material used for testing was natural, whole soil.

This test result is IANZ accredited.

Approved By	DFB	**Date**	24/07/2017

GEOTECHNICS

15c Amber Crescent,
Judea
Tauranga 3110
New Zealand

p. +64 7 571 0280

Geotechnics Project ID	1003875
Customer Project ID	1002034.2
Customer Project Name	

DETERMINATION OF THE WATER CONTENT & FINES CONTENT - GEO190-13

TEST DETAILS

LOCATION	**ID**	BH02		
	Description	N/A		
	Data	N/A		
SAMPLE	**Geotechnics ID**	GEOT201707183	**Date Received**	12/07/2017
	Reference	N/A	**Depth**	4.10m - 4.20m
	Description	Fine to medium SAND, with trace silt; greyish brown. Wet.		
SPECIMEN	**Reference**	2	**Depth**	N/A
	Description	N/A		

TEST RESULT

Natural Water Content	**25.2%**
Fines Content Passing 75µm Sieve	**2.3%**
Fines Content Passing 63µm Sieve	**N/A**

TEST REMARKS

- The material used for testing was natural, whole soil. Sample was not bagged on site, water content is not considered in-situ.

This test result is IANZ accredited.

Approved By	DFB	**Date**	24/07/2017

Geotechnics Project ID	1003875
Customer Project ID	1002034.2
Customer Project Name	

DETERMINATION OF THE WATER CONTENT & FINES CONTENT - GEO190-13

TEST DETAILS

LOCATION	**ID**	BH03		
	Description	N/A		
	Data	N/A		
SAMPLE	**Geotechnics ID**	GEOT201707184	**Date Received**	12/07/2017
	Reference	N/A	**Depth**	6.00m - 6.20m
	Description	Fine to medium SAND, with trace silt; greyish brown. Wet to saturated.		
SPECIMEN	**Reference**	2	**Depth**	N/A
	Description	N/A		

TEST RESULT

Natural Water Content	**28.5%**
Fines Content Passing 75µm Sieve	**1%**
Fines Content Passing 63µm Sieve	**N/A**

TEST REMARKS

- The material used for testing was natural, whole soil.

This test result is IANZ accredited.

Approved By	DFB	**Date**	24/07/2017

DETERMINATION OF THE WATER CONTENT & FINES CONTENT - GEO190-13

TEST DETAILS

LOCATION	**ID**	BH01		
	Description	N/A		
	Data	N/A		
SAMPLE	**Geotechnics ID**	GEOT201707182	**Date Received**	12/07/2017
	Reference	N/A	**Depth**	6.00m - 6.15m
	Description	Fine to coarse SAND, with trace silt; dark grey. Wet to saturated.		
SPECIMEN	**Reference**	2	**Depth**	N/A
	Description	N/A		

TEST RESULT

Natural Water Content	**22.4%**
Fines Content Passing 75µm Sieve	**3.1%**
Fines Content Passing 63µm Sieve	**N/A**

TEST REMARKS

- The material used for testing was natural, whole soil.

This test result is IANZ accredited.

Approved By	DFB	**Date**	24/07/2017

15c Amber Crescent,
Judea
Tauranga 3110
New Zealand

p. +64 7 571 0280

Geotechnics Project ID	1003875
Customer Project ID	1002034.2
Customer Project Name	

DETERMINATION OF THE WATER CONTENT & FINES CONTENT - GEO190-13

TEST DETAILS

LOCATION	**ID**	BH04		
	Description	N/A		
	Data	N/A		
SAMPLE	**Geotechnics ID**	GEOT201707185	**Date Received**	12/07/2017
	Reference	N/A	**Depth**	16.95m - 17.05m
	Description	Sandy SILT; light grey. Wet; sand, fine.		
SPECIMEN	**Reference**	3	**Depth**	N/A
	Description	N/A		

TEST RESULT

Natural Water Content	**76.3%**
Fines Content Passing 75µm Sieve	**66.4%**
Fines Content Passing 63µm Sieve	**N/A**

TEST REMARKS

- The material used for testing was natural, whole soil.

This test result is IANZ accredited.

Approved By	DFB	**Date**	24/07/2017

Appendix C: Groundwater modelling

- **Groundwater modelling text**
- **Figure C2 – Median groundwater level surface**
- **Figure C3 – Median groundwater level surface with 1.25m of sea level rise**
- **Figure C4 – Median groundwater level surface with 1.9m of sea level rise**
- **Figure C5 – Median depth to groundwater surface using existing 2015 LiDAR DEM**
- **Figure C6 – Median depth to groundwater surface with 1.25m SLR using existing 2015 LiDAR DEM**
- **Figure C7 – Median depth to groundwater surface with 1.9m SLR using existing 2015 LiDAR DEM**
- **Figure C8 – Median depth to groundwater surface using proposed DEM**
- **Figure C9 – Median depth to groundwater surface with 1.25m SLR using proposed DEM**
- **Figure C10 – Median depth to groundwater surface with 1.9m SLR using proposed LiDAR DEM**

C.1 Groundwater monitoring

As part of Tauranga City Council's wider groundwater monitoring programme, groundwater levels are currently being monitored and automatically recorded at 15 minute intervals in 55 locations across the city. This includes 17 monitoring wells installed around Tauranga City, 11 in Mount Maunganui and 27 in Papamoa. 15 of the monitoring wells located in eastern Papamoa and the Te Tumu area have been used in this study to assess groundwater levels within the Te Tumu Urban Growth Area. Of these, 11 are the monitoring wells are located within the Te Tumu Urban Growth Area.

The period of continuous data available for the Papamoa/Te Tumu monitoring locations is 8 months (October 2016 to May 2017). Discrete records of groundwater level were available at some locations for a longer period but these were not used as they were taken at weekly, or greater, intervals and so do not capture tidal or other short term responses.

The monitoring wells were drilled to a target depth and a 100m PVC screen and casing assembly inserted into the hole. Table C1 presents the median groundwater levels calculated using all measurements between October 2016 and May 2017 for a given monitoring well. This is the level which is exceeded for 50% of the monitoring period.

The source data used to create the median groundwater level surface is summarised in Table C1. This data has been referenced against the Moturiki 1953 datum. The locations of the monitoring wells are shown in all figures in Appendix C.

Table C1 - Source data used to create the median groundwater surface.

Monitoring well ID	Monitoring well locations		Median groundwater level (m RL)	Well located in Te Tumu urban growth area?
	Northing (NZTM)	Easting (NZTM)		
4A	1894192	5820626	1.32	N
4B	1894139	5820400	2.09	N
4C	1894072	5820187	2.45	N
P9	1893938	5819969	2.93	N
P10	1893873	5819763	2.96	N
A1	1895704	5819572	1.94	N
B1	1897125	5818581	1.45	Y
B2	1896904	5818284	1.70	Y
B3	1896727	5818029	1.48	Y
B4	1896597	5817873	1.32	Y
B5	1896377	5817604	0.85	Y
C1	1898344	5817817	1.17	Y
C3	1898214	5817624	1.79	Y
C4	1898075	5817474	0.74	Y
C5	1897882	5817219	0.74	Y

C.2 Sea level monitoring

Sea level around the open coast and the river level in the Kaituna River forms a boundary to which groundwater within the shoreline drains. The mean sea level used in this study is 0.1m RL (referenced against the Moturiki 1953 datum) in accordance with previous groundwater level studies undertaken by T+T for TCC[1]. Mean seal level was also used for water level within the Kaituna River.

C.3 Median groundwater modelling methodology

The process of developing the median groundwater table involved:

- Selection of all relevant data, identifying the monitoring wells with sufficiently reliable data.
- Calculation of a median water table elevation at each well.
- Pair mean sea level with median groundwater levels at each well to infer the groundwater surface by interpolating between known points to manually derive groundwater contours.

In order to form a continuous surface for groundwater level, these contours were extrapolated to areas where no monitoring data was available. To do this required making some assumptions, and in general the following process was adopted:

- Groundwater flow direction was assumed to be normal towards the sea or towards the closest surface water body directly connected with the sea.
- Groundwater gradient would be similar in similar ground types.
- Groundwater level would follow ground profile in areas close to the coast. This meant that in an area of no measured groundwater data, groundwater level could be approximated by the groundwater level measured at similar ground elevation elsewhere. This assumption was applied by making use of the nearest measured groundwater level in similar underlying soil types at similar ground elevation.
- The 2015 mean sea level formed the lower bound groundwater contour on the coastline.

An example of how the groundwater contours were developed from the monitored data is shown in Figure C1 below.

---

[1] Tonkin + Taylor (2014). Effect of Sea Level Rise on Groundwater Levels – Tauranga Study. 30 June 2016. Prepared for Tauranga City Council. T+T Ref 30485.002.

Figure C1 – Map showing the creation of median groundwater contours in the Te Tumu urban growth area.

C.4 Incorporating sea level rise

In order to assess the potential increase in liquefaction vulnerability as a result of sea level rise, two scenarios of sea level rise were applied to the median model (1.25 m and 1.9 m), as requested by TCC. These levels are in accordance with local sea level rise projection scenarios provided in a recent NIWA study.[2] The sea level rise projection of 1.25 m represents a 100 year timeframe as required by BOP RPS Policy NH11B.[3] The sea level rise projection of 1.9 m represents an upper bound scenario for the purpose of stress testing green field development.

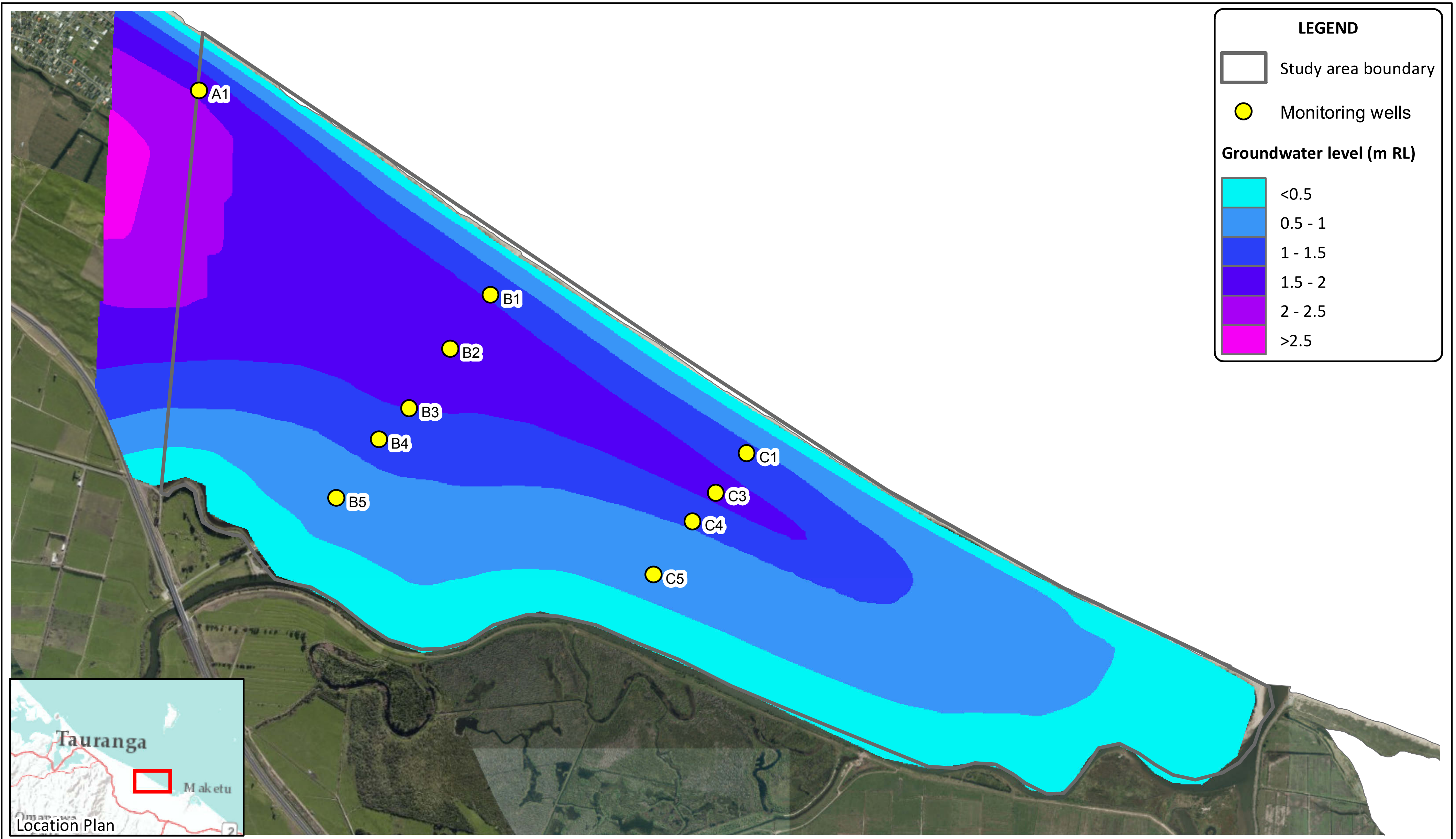
The complexities associated with how sea level rise would influence the hydrological mechanics of the region are largely unknown. Therefore, to model sea level rise, the median surface was simply raised by a constant of 1.25m and 1.9m. The main limitation with this approach is that it fails to accommodate the reality that an increase in sea level would not cause the same increase in the height of the water table further inland. However, given the site's proximity to the coast, the inland damping effects of sea level rise are expected to be minimal.

These changes in groundwater elevation are presented in Figures C3 and C4 respectively. Once again, corresponding depth to groundwater surfaces were created accounting for 1.25m and 1.9m of sea level rise for both the existing 2015 LiDAR DEM and the proposed DEM. These are presented in Figures C6, C7, C9 and C10.

---

[2] NIWA, 2017. "Tauranga Harbour extreme sea level analysis." NIWA Project: BOP17202. Hamilton, New Zealand. National Institute of Water & Atmospheric Research Ltd.

[3] Bay of Plenty Regional Council, 2016. "Operative Regional Policy Statement for the Bay of Plenty." Retrieved from https://www.boprc.govt.nz/plans-policies-and-resources/policies/operative-regional-policy-statement/



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Notes: RL referenced against Moturiki Datum 1953.

A4 SCALE 1:25,000

0 0.25 0.5 0.75 1 1.25 (km)

N

Tonkin+Taylor

105 Carlton Gore Rd, Newmarket, Auckland
www.tonkintaylor.co.nz

DRAWN	DXLR	Aug.17
CHECKED	VL	Aug.17
APPROVED	PRC	Jul.18

ARCFILE
1002034-006.mxd

SCALE (AT A4 SIZE)
1:25,000

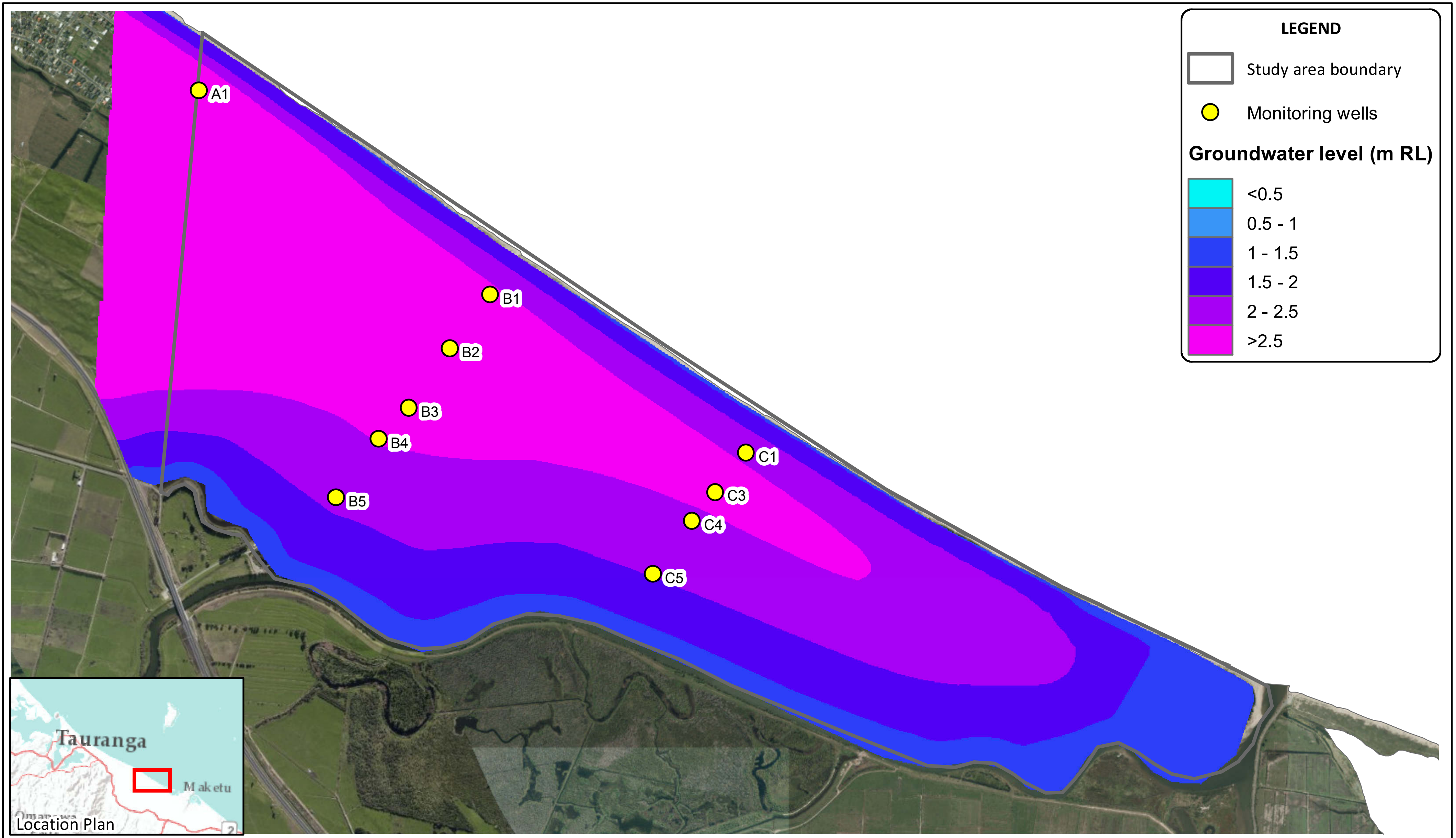
PROJECT No.
1002034.2000

TAURANGA CITY COUNCIL

TE TUMU URBAN GROWTH AREA
Median Groundwater Level Surface

FIGURE No. Figure C2

Rev. 0



Path: \\ttgroup.local\corporate\Tauranga\Projects\1002034\1002034.2000\WorkingMaterial\GIS\MapDocuments\1002034-026.mxd Date: 29/08/2017 Time: 9:47:58 a.m.

Notes: RL referenced against Moturiki Datum 1953.

A4 SCALE 1:25,000

0 0.25 0.5 0.75 1 1.25 (km)

N

Tonkin+Taylor

105 Carlton Gore Rd, Newmarket, Auckland
www.tonkintaylor.co.nz

DRAWN	DXLR	Aug.17
CHECKED	VL	Aug.17
APPROVED	PRC	Jul.18

ARCFILE
1002034-026.mxd

SCALE (AT A4 SIZE)
1:25,000

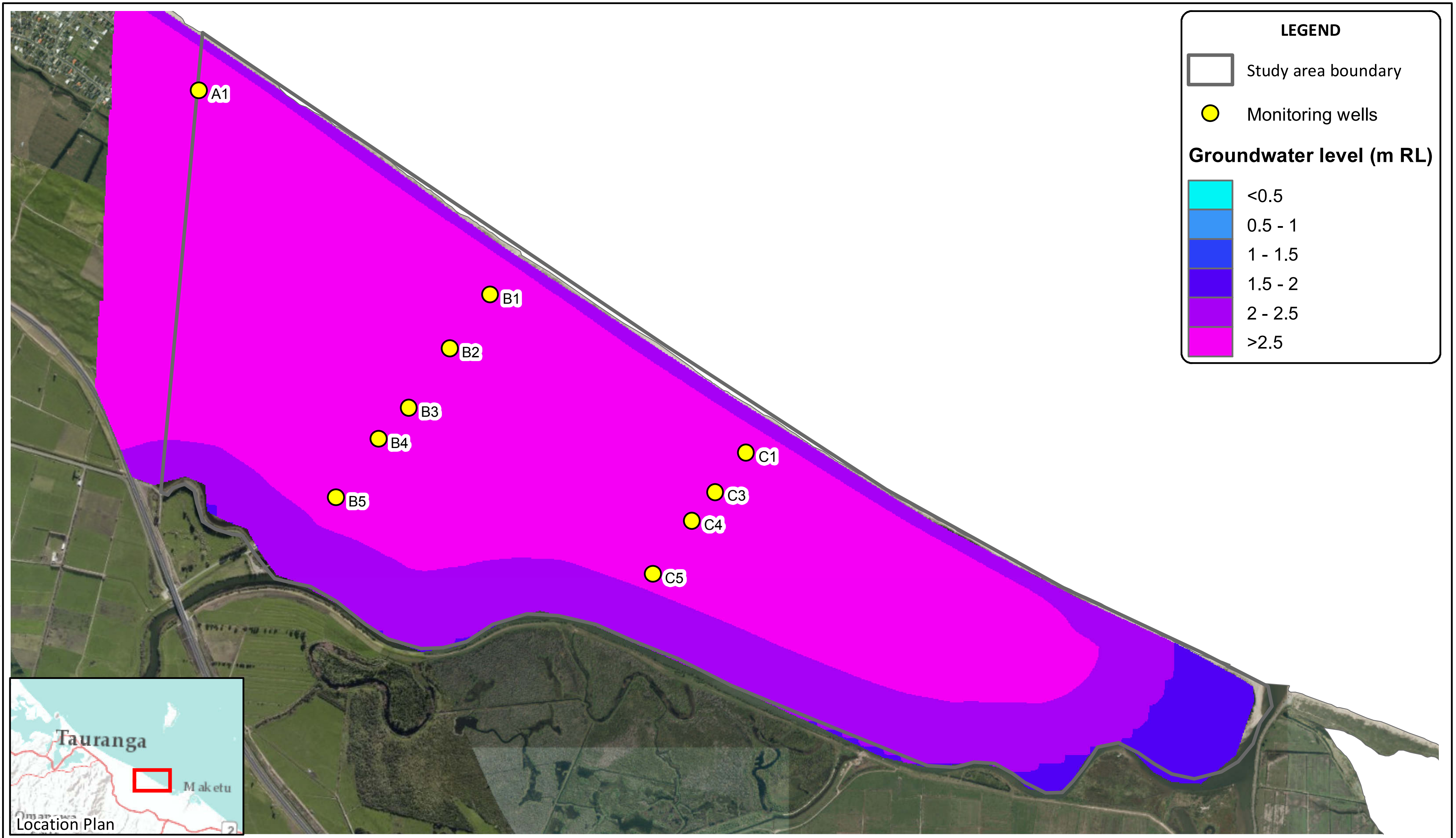
PROJECT No.
1002034.2000

TAURANGA CITY COUNCIL

TE TUMU URBAN GROWTH AREA
Median Groundwater Level Surface with
1.25m of Sea Level Rise

FIGURE No.
Figure C3

Rev.
0



Notes: RL referenced against Moturiki Datum 1953.

A4 SCALE 1:25,000

0 0.25 0.5 0.75 1 1.25 (km)

Tonkin+Taylor

105 Carlton Gore Rd, Newmarket, Auckland
www.tonkintaylor.co.nz

DRAWN	DXLR	Aug.17
CHECKED	VL	Aug.17
APPROVED	PRC	Jul.18

ARCFILE
1002034-004.mxd

SCALE (AT A4 SIZE)
1:25,000

PROJECT No.
1002034.2000

TAURANGA CITY COUNCIL

TE TUMU URBAN GROWTH AREA
Median Groundwater Level Surface with 1.9m of Sea Level Rise

FIGURE No. Figure C4

Rev. 0

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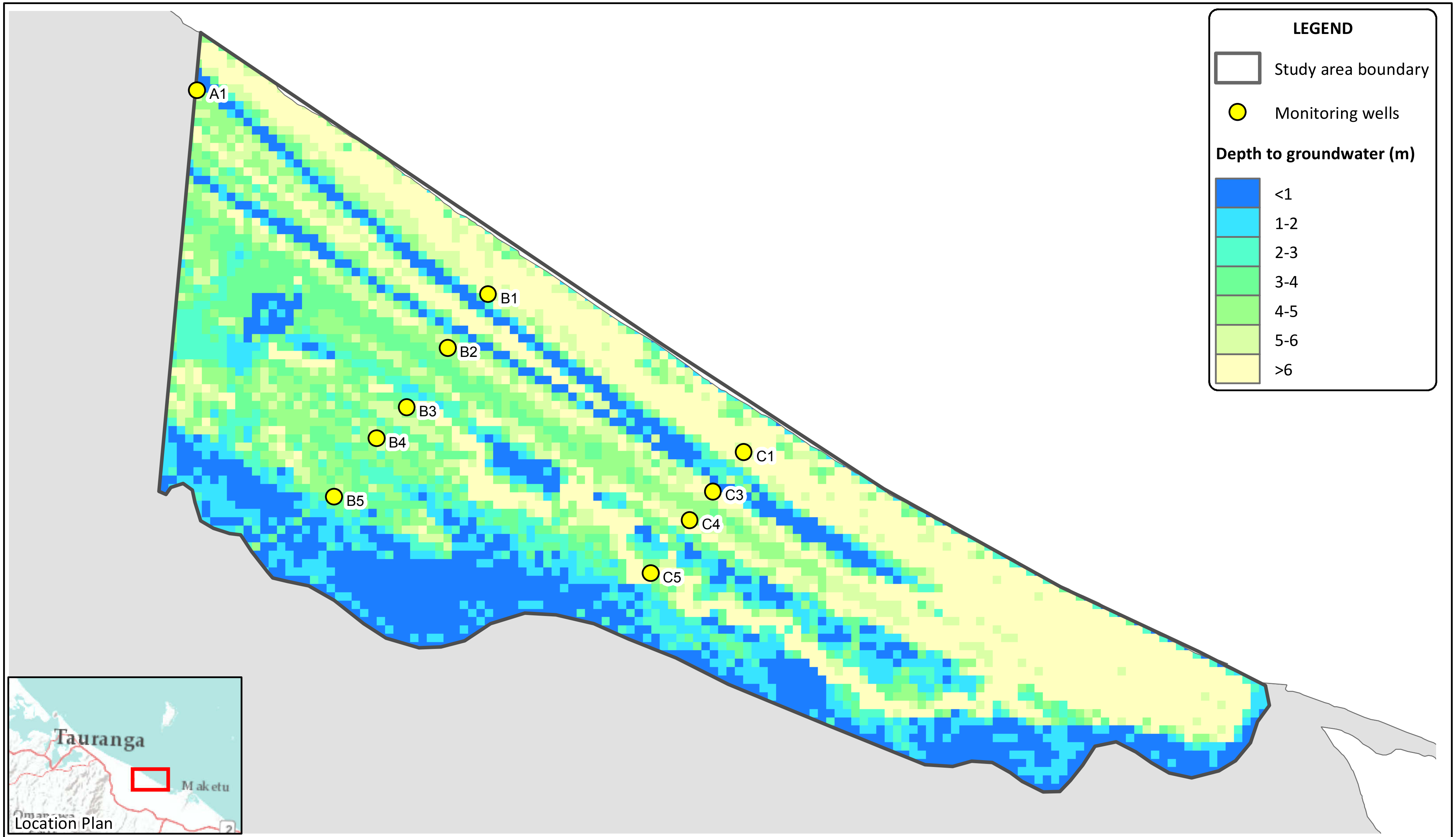

Notes:

A4 SCALE 1:25,000

0 0.25 0.5 0.75 1 1.25 (km)

Tonkin+Taylor

105 Carlton Gore Rd, Newmarket, Auckland
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DRAWN	DXLR	Aug.17
CHECKED	VL	Aug.17
APPROVED	PRC	Jul.18

ARCFILE
1002034-003.mxd

SCALE (AT A4 SIZE)
1:25,000

PROJECT No.
1002034.2000

TAURANGA CITY COUNCIL

TE TUMU URBAN GROWTH AREA

Median Depth to Groundwater Surface using Existing 2015 LiDAR DEM

FIGURE No. Figure C5

Rev. 0

Path: \\ttgroup.local\corporate\Tauranga\Projects\1002034\1002034.2000\WorkingMaterial\GIS\MapDocuments\1002034-003.mxd Date: 29/08/2017 Time: 9:03:24 a.m.

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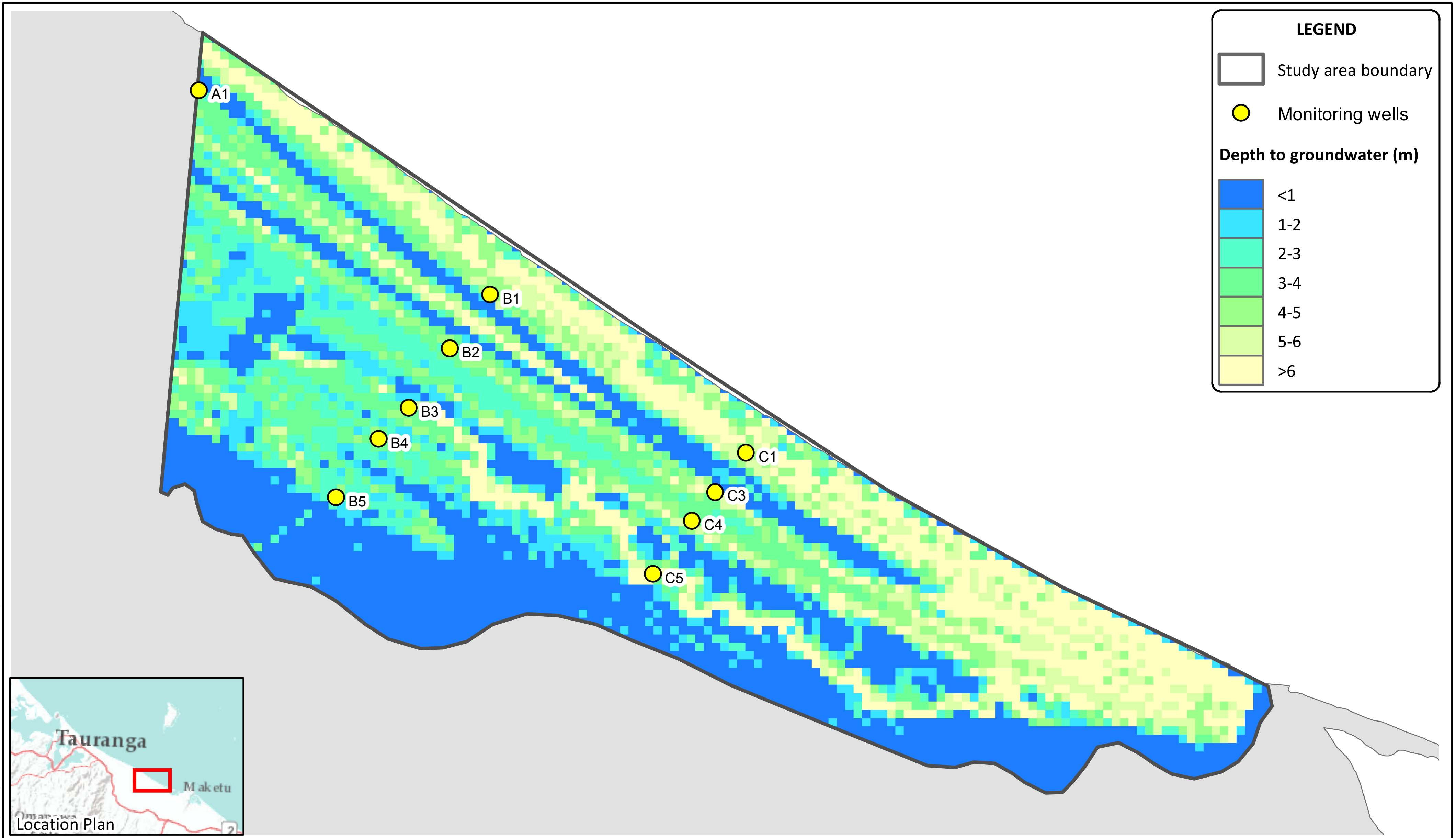

Notes:

A4 SCALE 1:25,000

0 0.25 0.5 0.75 1 1.25 (km)

Tonkin+Taylor

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DRAWN	DXLR	Aug.17
CHECKED	VL	Aug.17
APPROVED	PRC	Jul.18

ARCFILE
1002034-027.mxd

SCALE (AT A4 SIZE)
1:25,000

PROJECT No.
100203.2000

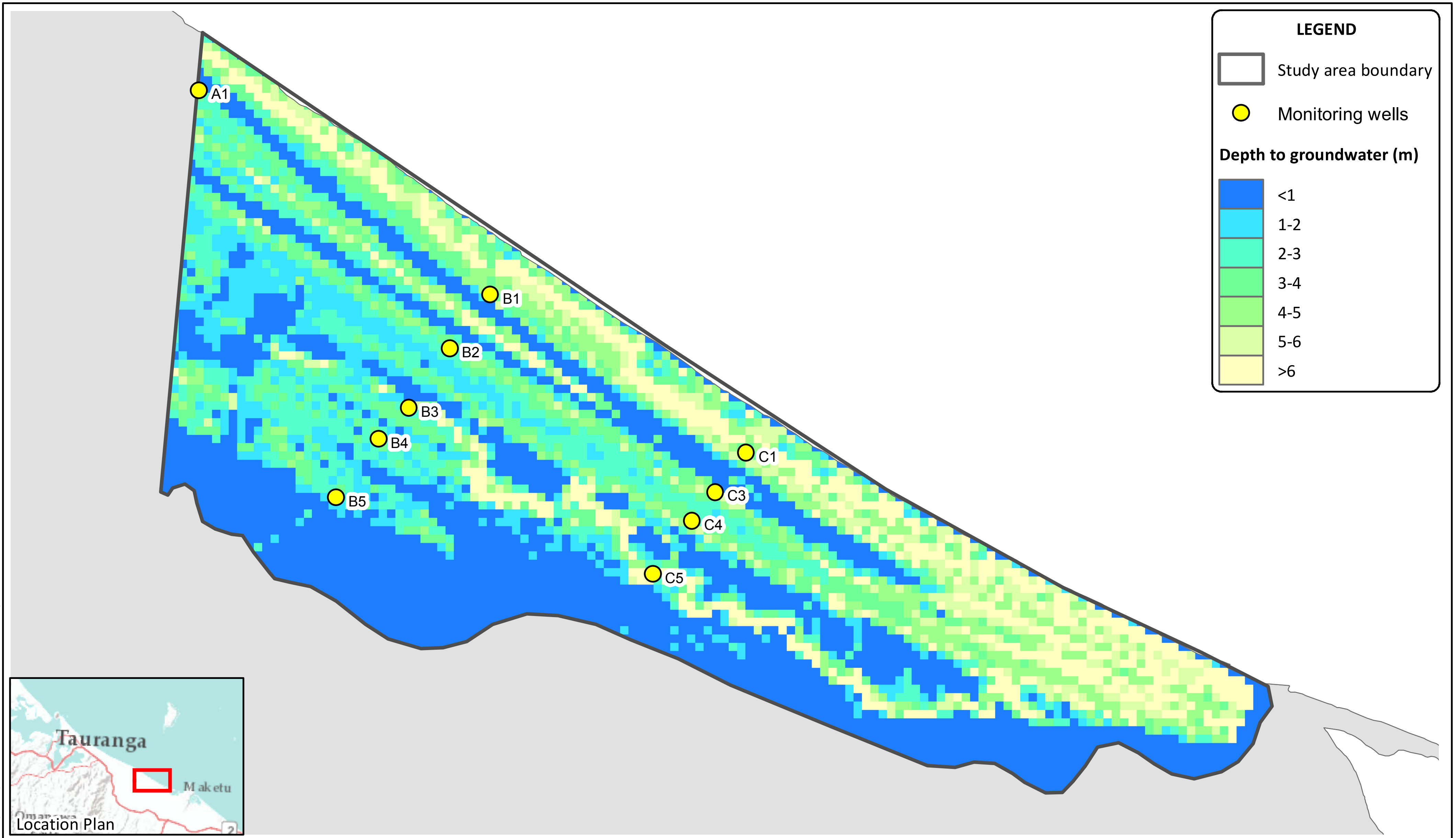
TAURANGA CITY COUNCIL

TE TUMU URBAN GROWTH AREA

Median Depth to Groundwater Surface with 1.25m of SLR using Existing 2015 LiDAR DEM

FIGURE No.
Figure C6

Rev.
0



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Notes:

A4 SCALE 1:25,000

0 0.25 0.5 0.75 1 1.25 (km)

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DRAWN	DXLR	Aug.17
CHECKED	VL	Aug.17
APPROVED	PRC	Jul.18

ARCFILE
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SCALE (AT A4 SIZE)
1:25,000

PROJECT No.
100203.2000

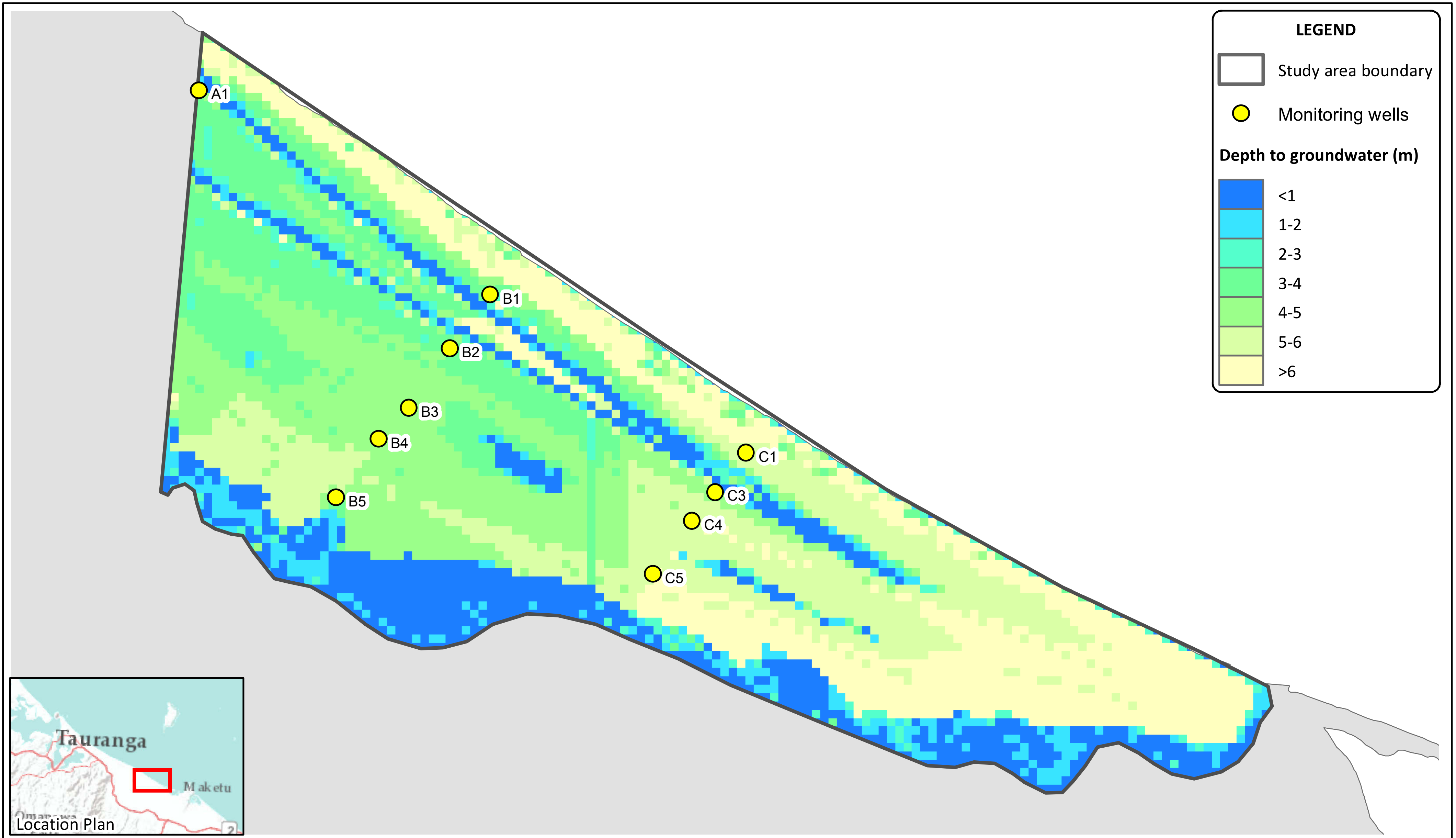
TAURANGA CITY COUNCIL

TE TUMU URBAN GROWTH AREA

Median Depth to Groundwater Surface with 1.9m of SLR using Existing 2015 LiDAR DEM

FIGURE No.
Figure C7

Rev.
0



Notes:

A4 SCALE 1:25,000

0 0.25 0.5 0.75 1 1.25 (km)

Tonkin+Taylor

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DRAWN	DXLR	Aug.17
CHECKED	VL	Aug.17
APPROVED	PRC	Jul.18

ARCFILE
1002034-008.mxd

SCALE (AT A4 SIZE)
1:25,000

PROJECT No.
1002034.2000

TAURANGA CITY COUNCIL
TE TUMU URBAN GROWTH AREA
Median Depth to Groundwater Surface using Proposed DEM

FIGURE No. Figure C8

Rev. 0

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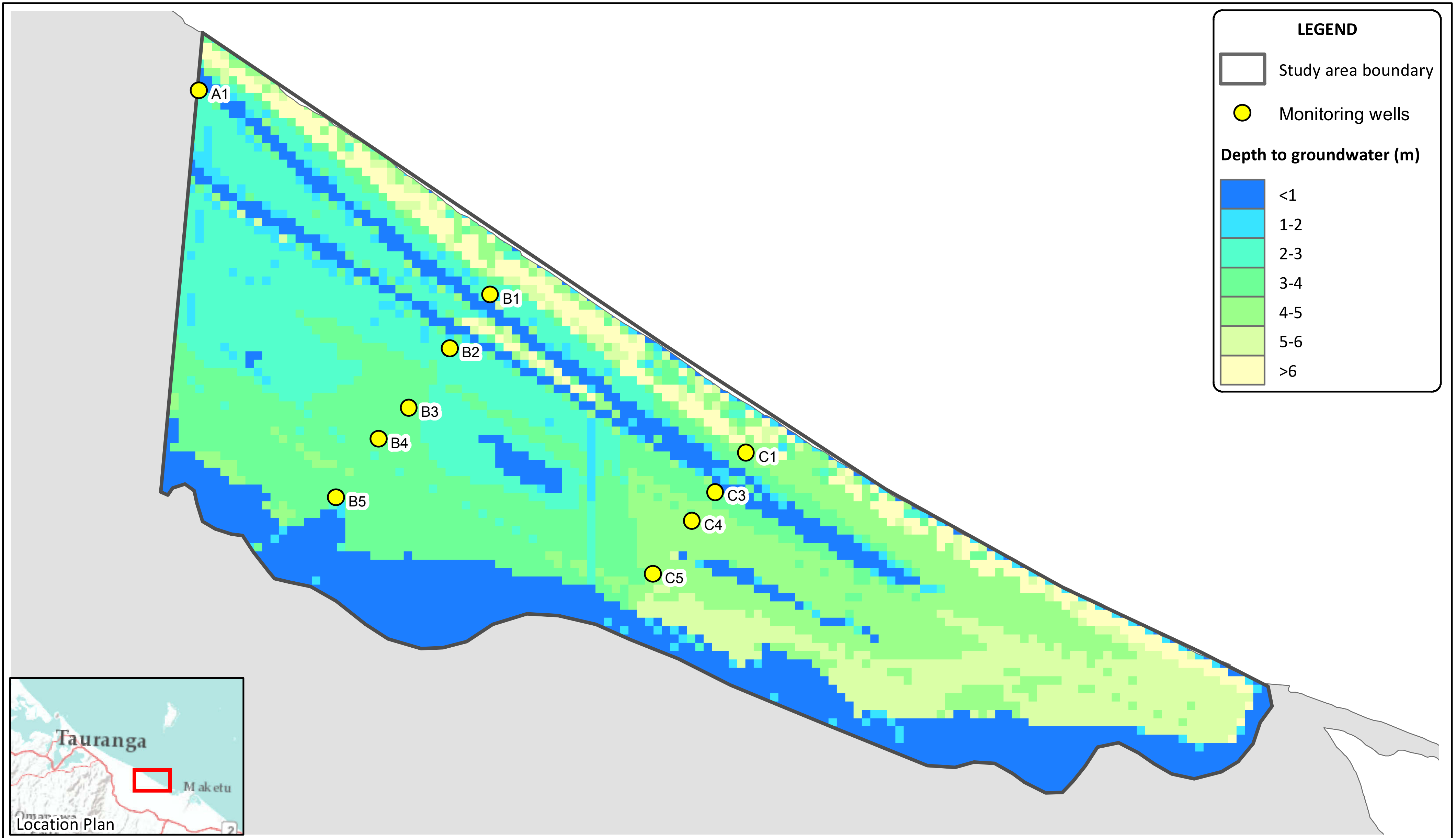

Notes:

A4 SCALE 1:25,000

0 0.25 0.5 0.75 1 1.25 (km)

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DRAWN	DXLR	Aug.17
CHECKED	VL	Aug.17
APPROVED	PRC	Jul.18

ARCFILE
1002034-028.mxd

SCALE (AT A4 SIZE)
1:25,000

PROJECT No.
1002034.2000

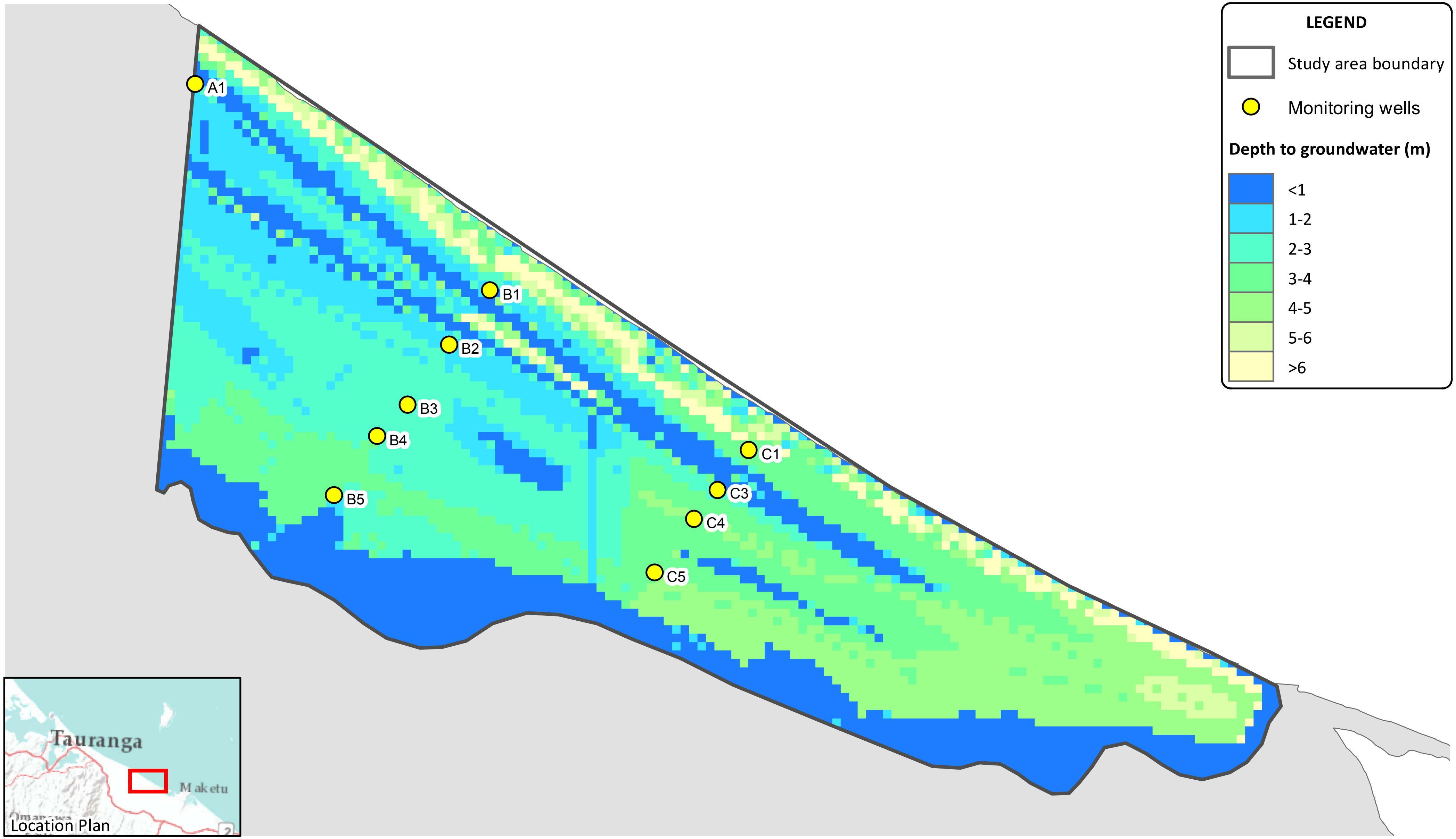
TAURANGA CITY COUNCIL

TE TUMU URBAN GROWTH AREA

Median Depth to Groundwater Surface with 1.25m SLR using Proposed DEM

FIGURE No. Figure C9

Rev. 0



Notes:

A4 SCALE 1:25,000

0 0.25 0.5 0.75 1 1.25 (km)

Tonkin+Taylor
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DRAWN	DXLR	Aug.17
CHECKED	VL	Aug.17
APPROVED	PRC	Jul.18

ARCFILE
1002034-009.mxd

SCALE (AT A4 SIZE)
1:25,000

PROJECT No.
1002034.2000

TAURANGA CITY COUNCIL

TE TUMU URBAN GROWTH AREA

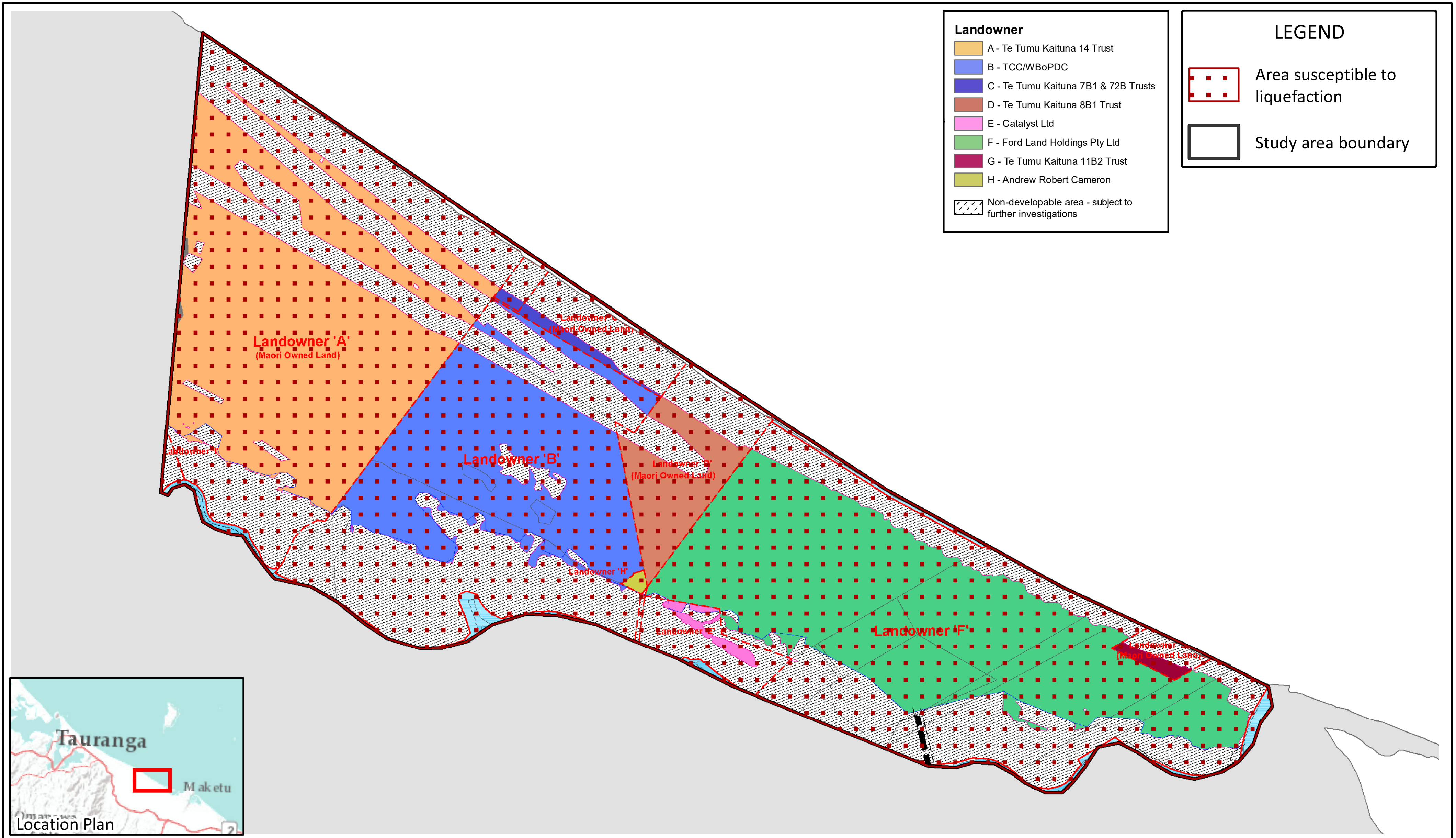
Median Depth to Groundwater Surface with 1.9m SLR using Proposed DEM

FIGURE No.
Figure C10

Rev.
0

Path: \\ttgroup.local\corporate\Tauranga\Projects\1002034\1002034.2000\WorkingMaterial\GIS\MapDocuments\1002034-009.mxd Date: 29/08/2017 Time: 10:31:20 a.m.

Appendix D: Liquefaction assessment results



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Notes: The background map showing the proposed future growth of Te Tumu was obtained from Tauranga City Council and is indicative only.

A4 SCALE 1:25,000

0 0.25 0.5 0.75 1 1.25 (km)

N

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DRAWN	DXLR	Nov.17
CHECKED	VL	Nov.17
APPROVED	PRC	Jul.18

ARCFILE
1002034-031.mxd

SCALE (AT A4 SIZE)
1:25,000

PROJECT No.
102034.2000

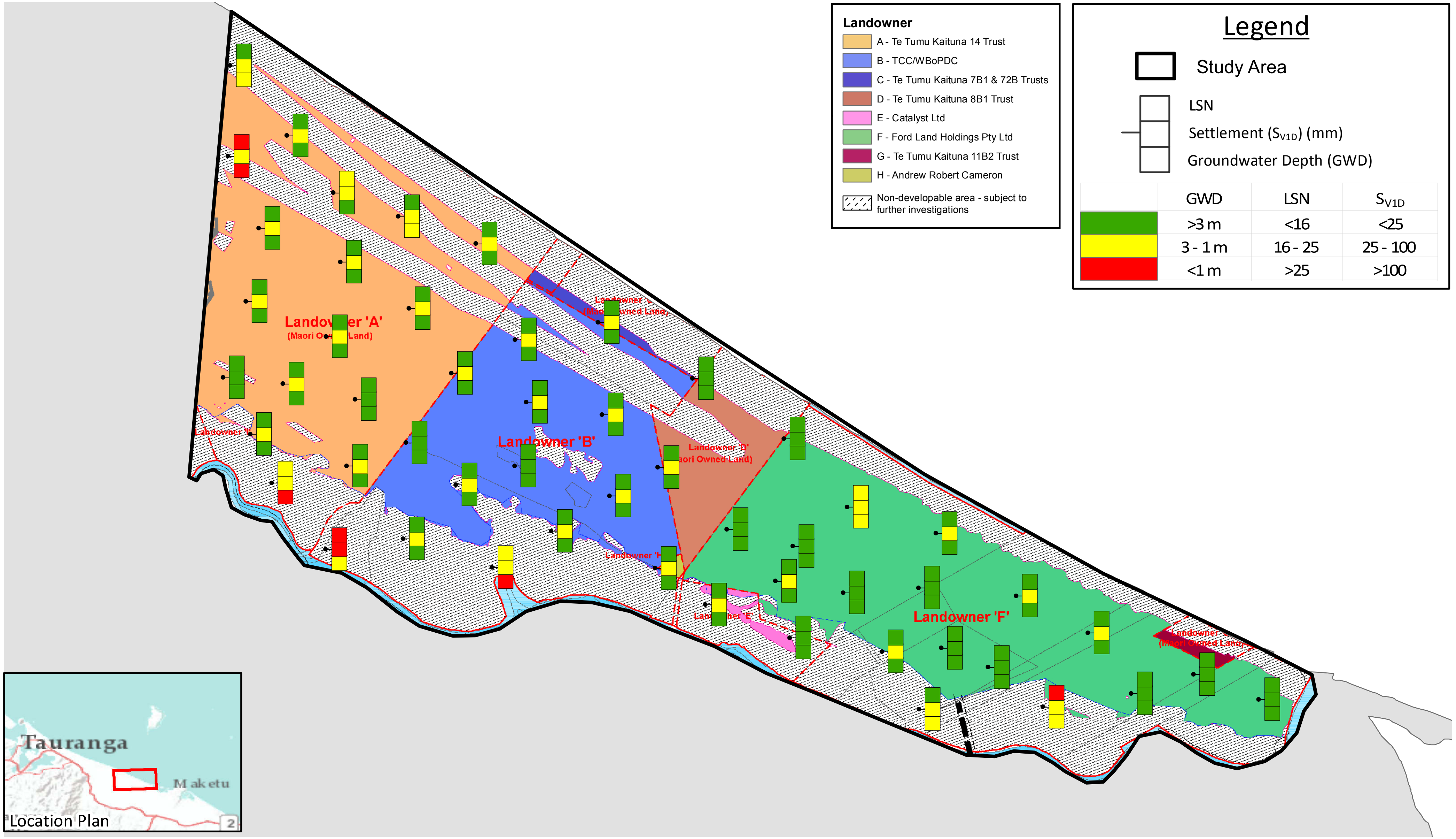
TAURANGA CITY COUNCIL

TE TUMU URBAN GROWTH AREA

Area Susceptible to Liquefaction Damage Overlaid on Landowner Blocks

FIGURE No. Figure D1

Rev. 0



Landowner

🟧	A - Te Tumu Kaituna 14 Trust
🟦	B - TCC/WBoPDC
🟪	C - Te Tumu Kaituna 7B1 & 72B Trusts
🟫	D - Te Tumu Kaituna 8B1 Trust
🟪	E - Catalyst Ltd
🟩	F - Ford Land Holdings Pty Ltd
🟥	G - Te Tumu Kaituna 11B2 Trust
🟨	H - Andrew Robert Cameron
▨	Non-developable area - subject to further investigations

Legend

▭ Study Area

LSN
Settlement (S_{V1D}) (mm)
Groundwater Depth (GWD)

	GWD	LSN	S_{V1D}
🟩	>3 m	<16	<25
🟨	3 - 1 m	16 - 25	25 - 100
🟥	<1 m	>25	>100

Notes: The background map showing the proposed future growth of Te Tumu was obtained from Tauranga City Council and is indicative only.

A4 SCALE 1:25,000

0 0.2 0.4 0.6 0.8 1 (km)

N

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DRAWN	DXLR	Aug.17
CHECKED	VL	Aug.17
APPROVED	PRC	Jul.18

ARCFILE
1002034-013.mxd

SCALE (AT A4 SIZE)
1:25,000

PROJECT No.
1002034.200

TAURANGA CITY COUNCIL

WAIRAKEI/TE TUMU
Liquefaction Vulnerability Assessment
500yr Event using Median GW

FIGURE No. Figure D2

Rev. 1

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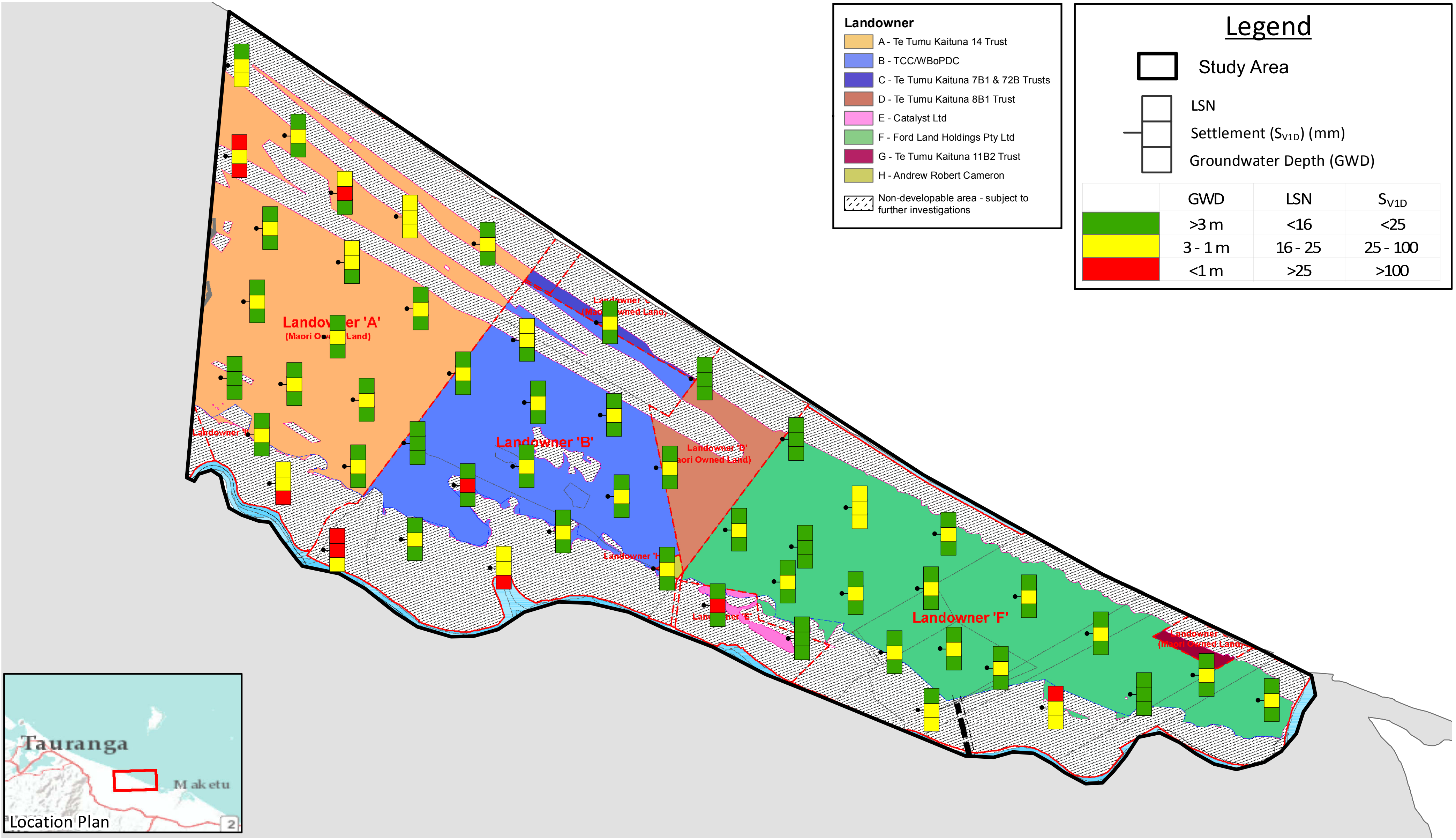

Landowner

- 🟧 A - Te Tumu Kaituna 14 Trust
- 🟦 B - TCC/WBoPDC
- 🟪 C - Te Tumu Kaituna 7B1 & 72B Trusts
- 🟫 D - Te Tumu Kaituna 8B1 Trust
- 🟪 E - Catalyst Ltd
- 🟩 F - Ford Land Holdings Pty Ltd
- 🟥 G - Te Tumu Kaituna 11B2 Trust
- 🟨 H - Andrew Robert Cameron
- ▨ Non-developable area - subject to further investigations

Legend

▭ Study Area

LSN

Settlement (S_{V1D}) (mm)

Groundwater Depth (GWD)

	GWD	LSN	S_{V1D}
🟩	>3 m	<16	<25
🟨	3 - 1 m	16 - 25	25 - 100
🟥	<1 m	>25	>100

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Notes: The background map showing the proposed future growth of Te Tumu was obtained from Tauranga City Council and is indicative only.

A4 SCALE 1:25,000

0 0.2 0.4 0.6 0.8 1 (km)

N

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DRAWN	DXLR	Aug.17
CHECKED	VL	Aug.17
APPROVED	PRC	Jul.18

ARCFILE
1002034-014.mxd

SCALE (AT A4 SIZE)
1:25,000

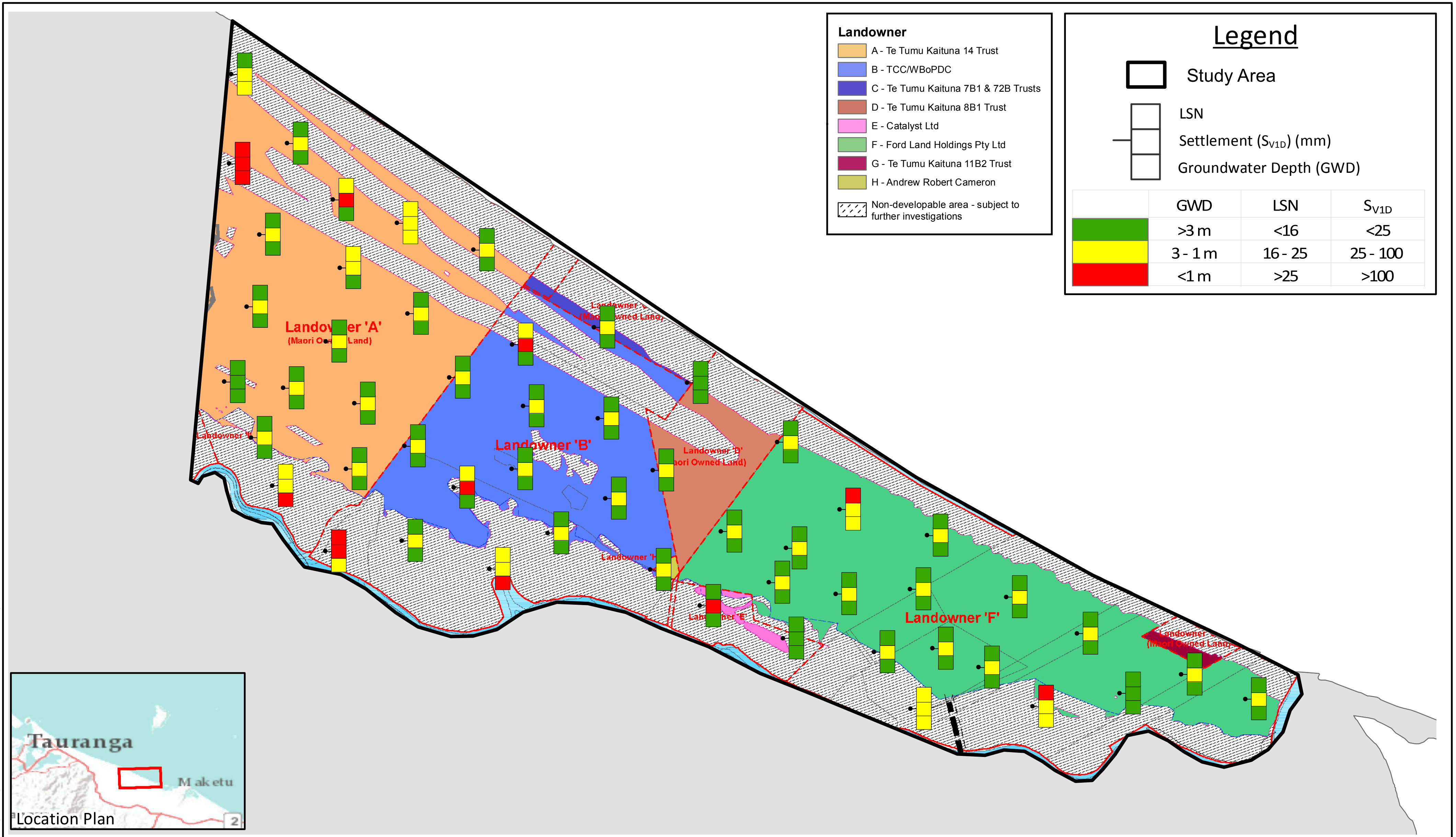
PROJECT No.
1002034.200

TAURANGA CITY COUNCIL

WAIRAKEI/TE TUMU
Liquefaction Vulnerability Assessment
1000yr Event using Median GW

FIGURE No. Figure D3

Rev. 1



Landowner

🟧	A - Te Tumu Kaituna 14 Trust
🟦	B - TCC/WBoPDC
🟪	C - Te Tumu Kaituna 7B1 & 72B Trusts
🟫	D - Te Tumu Kaituna 8B1 Trust
🟪	E - Catalyst Ltd
🟩	F - Ford Land Holdings Pty Ltd
🟥	G - Te Tumu Kaituna 11B2 Trust
🟨	H - Andrew Robert Cameron
▨	Non-developable area - subject to further investigations

Legend

Study Area

LSN
Settlement (S_{V1D}) (mm)
Groundwater Depth (GWD)

	GWD	LSN	S_{V1D}
🟩	>3 m	<16	<25
🟨	3 - 1 m	16 - 25	25 - 100
🟥	<1 m	>25	>100

Notes: The background map showing the proposed future growth of Te Tumu was obtained from Tauranga City Council and is indicative only.

A4 SCALE 1:25,000
0 0.2 0.4 0.6 0.8 1 (km)

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CHECKED	VL	Aug.17
APPROVED	PRC	Jul.18

ARCFILE
1002034-015.mxd
SCALE (AT A4 SIZE)
1:25,000
PROJECT No.
1002034.200

TAURANGA CITY COUNCIL
WAIRAKEI/TE TUMU
Liquefaction Vulnerability Assessment
3030yr Event using Median GW

FIGURE No. Figure D4
Rev. 1

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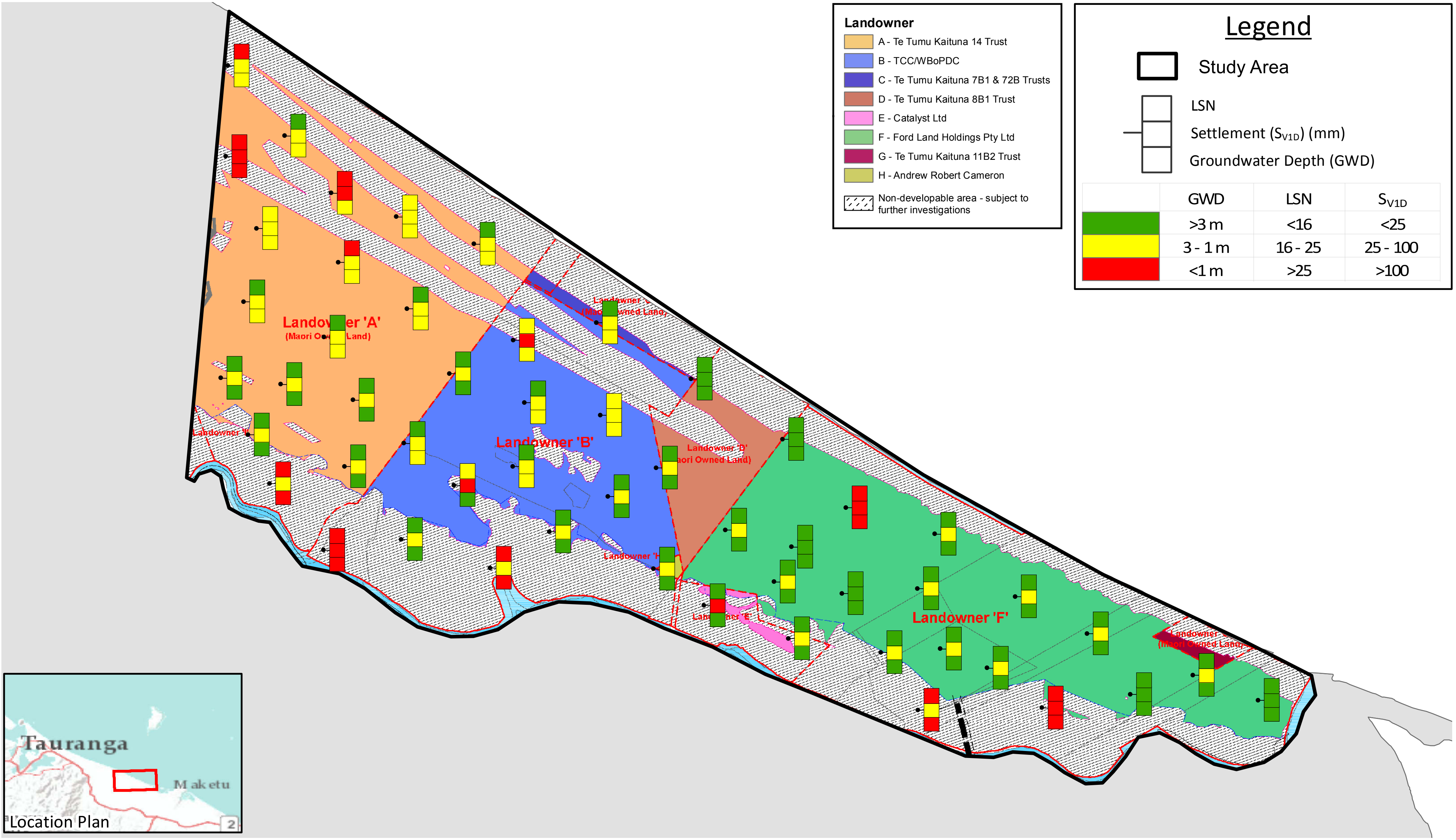

	GWD	LSN	S_{V1D}
🟩	>3 m	<16	<25
🟨	3 - 1 m	16 - 25	25 - 100
🟥	<1 m	>25	>100

Notes: The background map showing the proposed future growth of Te Tumu was obtained from Tauranga City Council and is indicative only.

A4 SCALE 1:25,000

0 0.2 0.4 0.6 0.8 1 (km)

N

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DRAWN	DXLR	Aug.17
CHECKED	VL	Aug.17
APPROVED	PRC	Jul.18

ARCFILE
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SCALE (AT A4 SIZE)
1:25,000

PROJECT No.
1002034.200

TAURANGA CITY COUNCIL

WAIRAKEI/TE TUMU

Liquefaction Vulnerability Assessment

500yr Event using Median GW with 1.25 SLR

FIGURE No. Figure D5

Rev. 1

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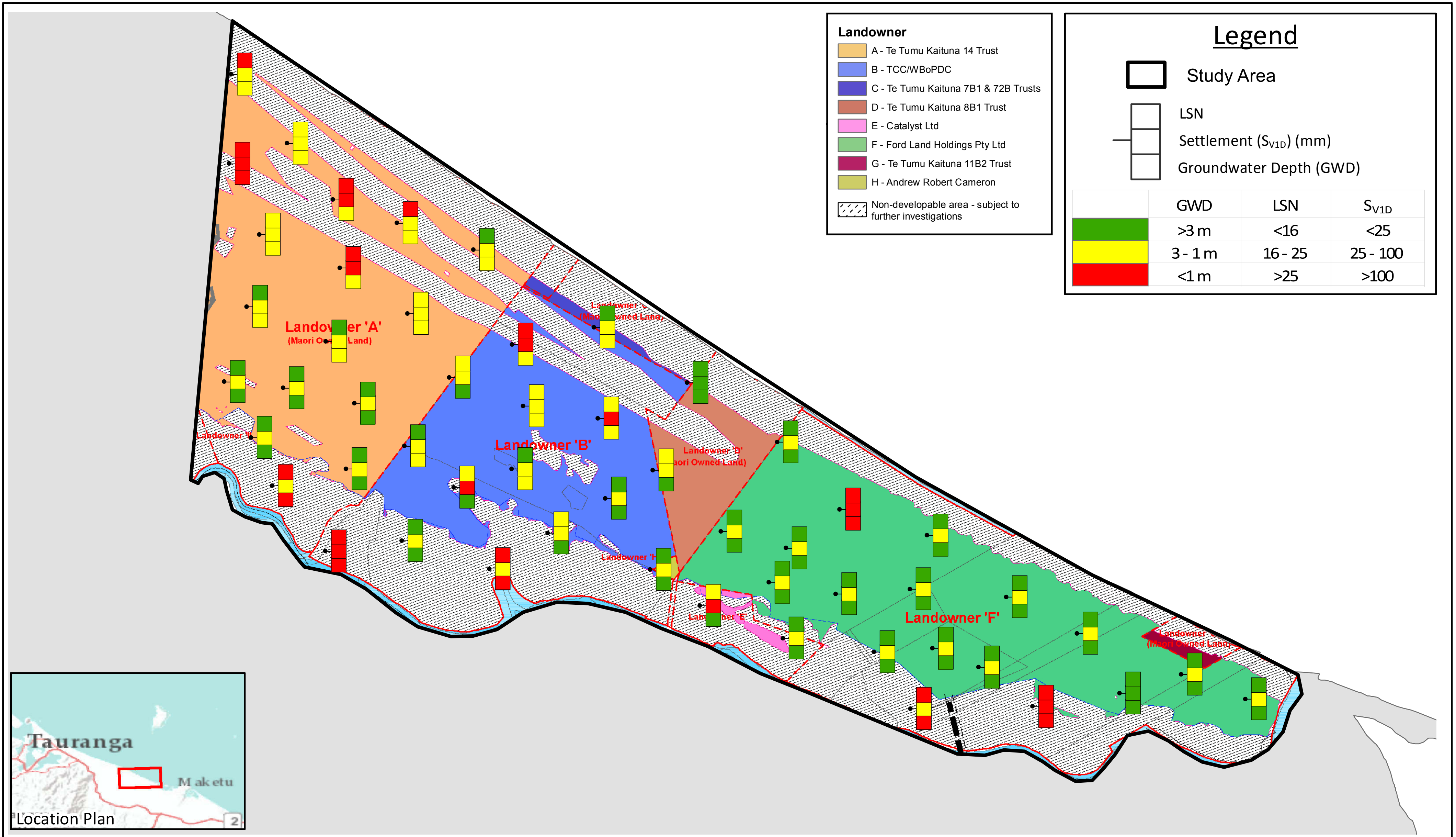

Landowner

🟧	A - Te Tumu Kaituna 14 Trust
🟦	B - TCC/WBoPDC
🟪	C - Te Tumu Kaituna 7B1 & 72B Trusts
🟫	D - Te Tumu Kaituna 8B1 Trust
🟪	E - Catalyst Ltd
🟩	F - Ford Land Holdings Pty Ltd
🟥	G - Te Tumu Kaituna 11B2 Trust
🟨	H - Andrew Robert Cameron
▨	Non-developable area - subject to further investigations

Legend

☐ Study Area

LSN
Settlement (S_{V1D}) (mm)
Groundwater Depth (GWD)

	GWD	LSN	S_{V1D}
🟩	>3 m	<16	<25
🟨	3 - 1 m	16 - 25	25 - 100
🟥	<1 m	>25	>100

Notes: The background map showing the proposed future growth of Te Tumu was obtained from Tauranga City Council and is indicative only.

A4 SCALE 1:25,000
0 0.2 0.4 0.6 0.8 1 (km)

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CHECKED	VL	Aug.17
APPROVED	PRC	Jul.18

ARCFILE
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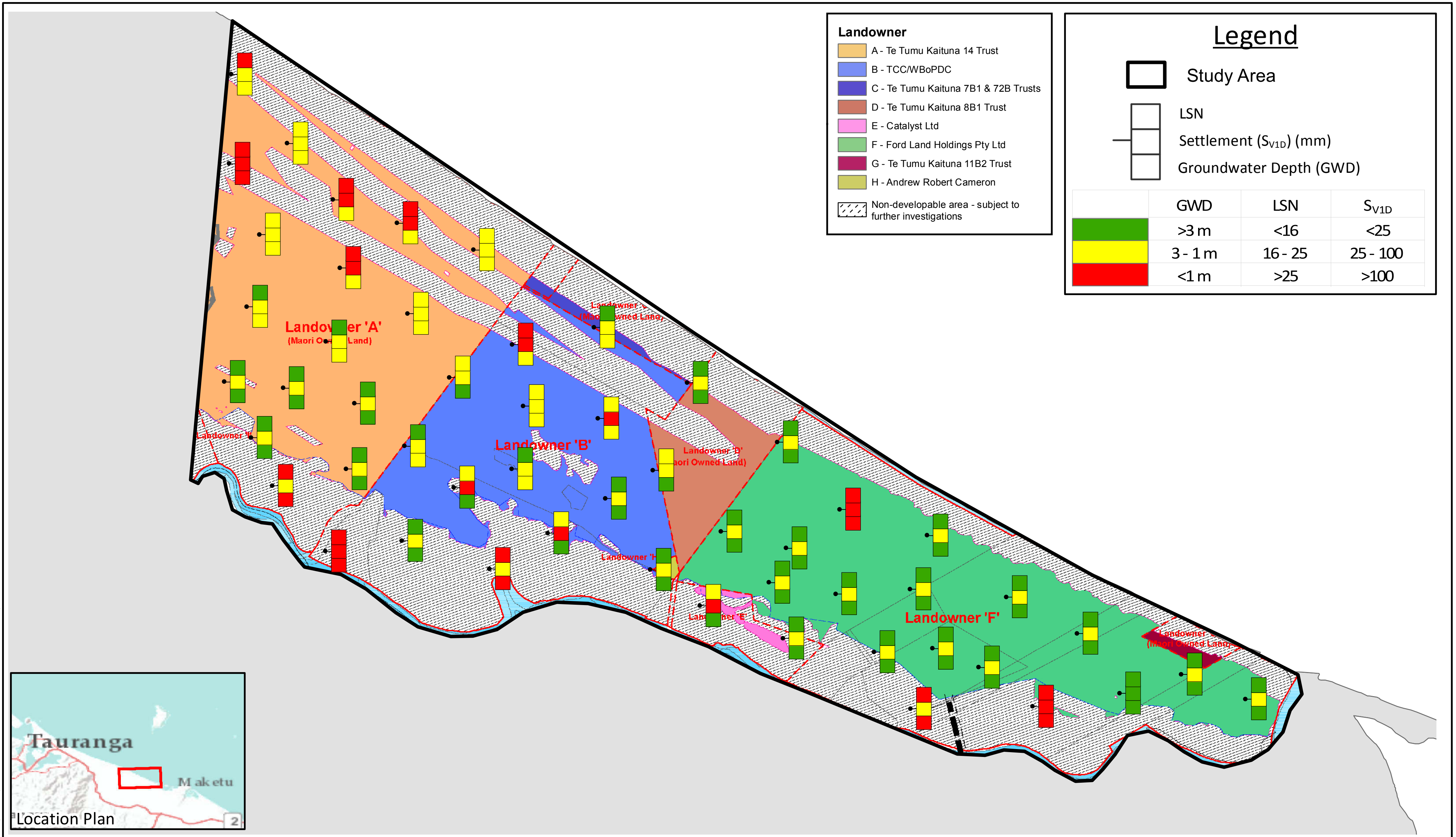
SCALE (AT A4 SIZE)
1:25,000

PROJECT No.
1002034.200

TAURANGA CITY COUNCIL
WAIRAKEI/TE TUMU
Liquefaction Vulnerability Assessment
1000yr Event using Median GW with 1.25 SLR

FIGURE No. Figure D6

Rev. 1



Landowner

- 🟧 A - Te Tumu Kaituna 14 Trust
- 🟦 B - TCC/WBoPDC
- 🟪 C - Te Tumu Kaituna 7B1 & 72B Trusts
- 🟫 D - Te Tumu Kaituna 8B1 Trust
- 🟪 E - Catalyst Ltd
- 🟩 F - Ford Land Holdings Pty Ltd
- 🟥 G - Te Tumu Kaituna 11B2 Trust
- 🟨 H - Andrew Robert Cameron
- ▨ Non-developable area - subject to further investigations

Legend

Study Area

LSN

Settlement (S_{V1D}) (mm)

Groundwater Depth (GWD)

	GWD	LSN	S_{V1D}
🟩	>3 m	<16	<25
🟨	3 - 1 m	16 - 25	25 - 100
🟥	<1 m	>25	>100

Notes: The background map showing the proposed future growth of Te Tumu was obtained from Tauranga City Council and is indicative only.

A4 SCALE 1:25,000

0 0.2 0.4 0.6 0.8 1 (km)

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CHECKED	VL	Aug.17
APPROVED	PRC	Jul.18

ARCFILE
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SCALE (AT A4 SIZE)
1:25,000

PROJECT No.
1002034.200

TAURANGA CITY COUNCIL

WAIRAKEI/TE TUMU

Liquefaction Vulnerability Assessment
3030yr Event using Median GW with 1.25 SLR

FIGURE No. Figure D7

Rev. 1

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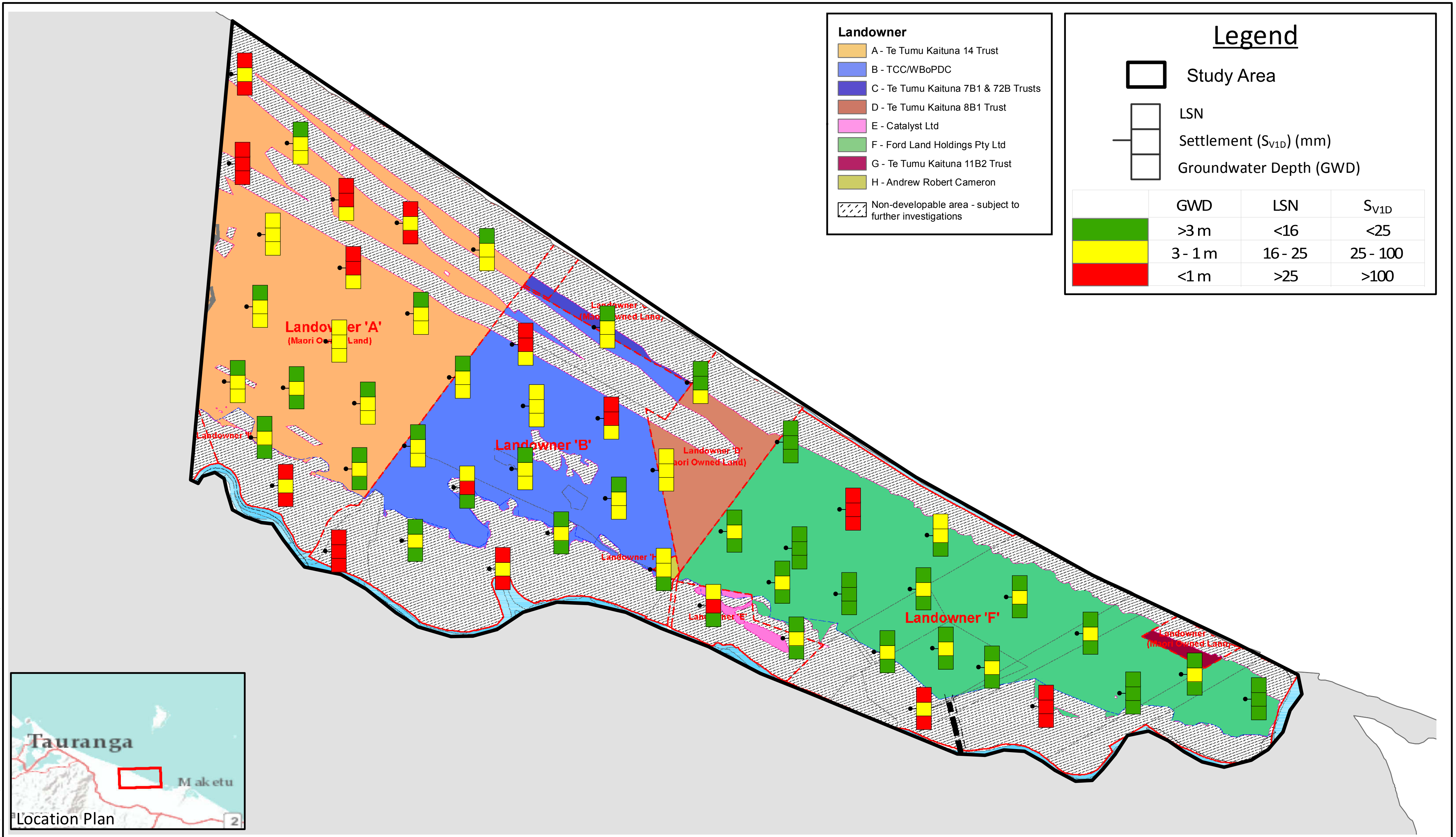

Landowner

- 🟧 A - Te Tumu Kaituna 14 Trust
- 🟦 B - TCC/WBoPDC
- 🟪 C - Te Tumu Kaituna 7B1 & 72B Trusts
- 🟫 D - Te Tumu Kaituna 8B1 Trust
- 🟪 E - Catalyst Ltd
- 🟩 F - Ford Land Holdings Pty Ltd
- 🟥 G - Te Tumu Kaituna 11B2 Trust
- 🟨 H - Andrew Robert Cameron
- ▨ Non-developable area - subject to further investigations

Legend

- ☐ Study Area
- LSN
- Settlement (S_{V1D}) (mm)
- Groundwater Depth (GWD)

	GWD	LSN	S_{V1D}
🟩	>3 m	<16	<25
🟨	3 - 1 m	16 - 25	25 - 100
🟥	<1 m	>25	>100

Notes: The background map showing the proposed future growth of Te Tumu was obtained from Tauranga City Council and is indicative only.

A4 SCALE 1:25,000

0 0.2 0.4 0.6 0.8 1 (km)

N

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DRAWN	DXLR	Aug.17
CHECKED	VL	Aug.17
APPROVED	PRC	Jul.18

ARCFILE 1002034-019.mxd

SCALE (AT A4 SIZE) 1:25,000

PROJECT No. 1002034.200

TAURANGA CITY COUNCIL
WAIRAKEI/TE TUMU
Liquefaction Vulnerability Assessment
500yr Event using Median GW with 1.9 SLR

FIGURE No. Figure D8

Rev. 1

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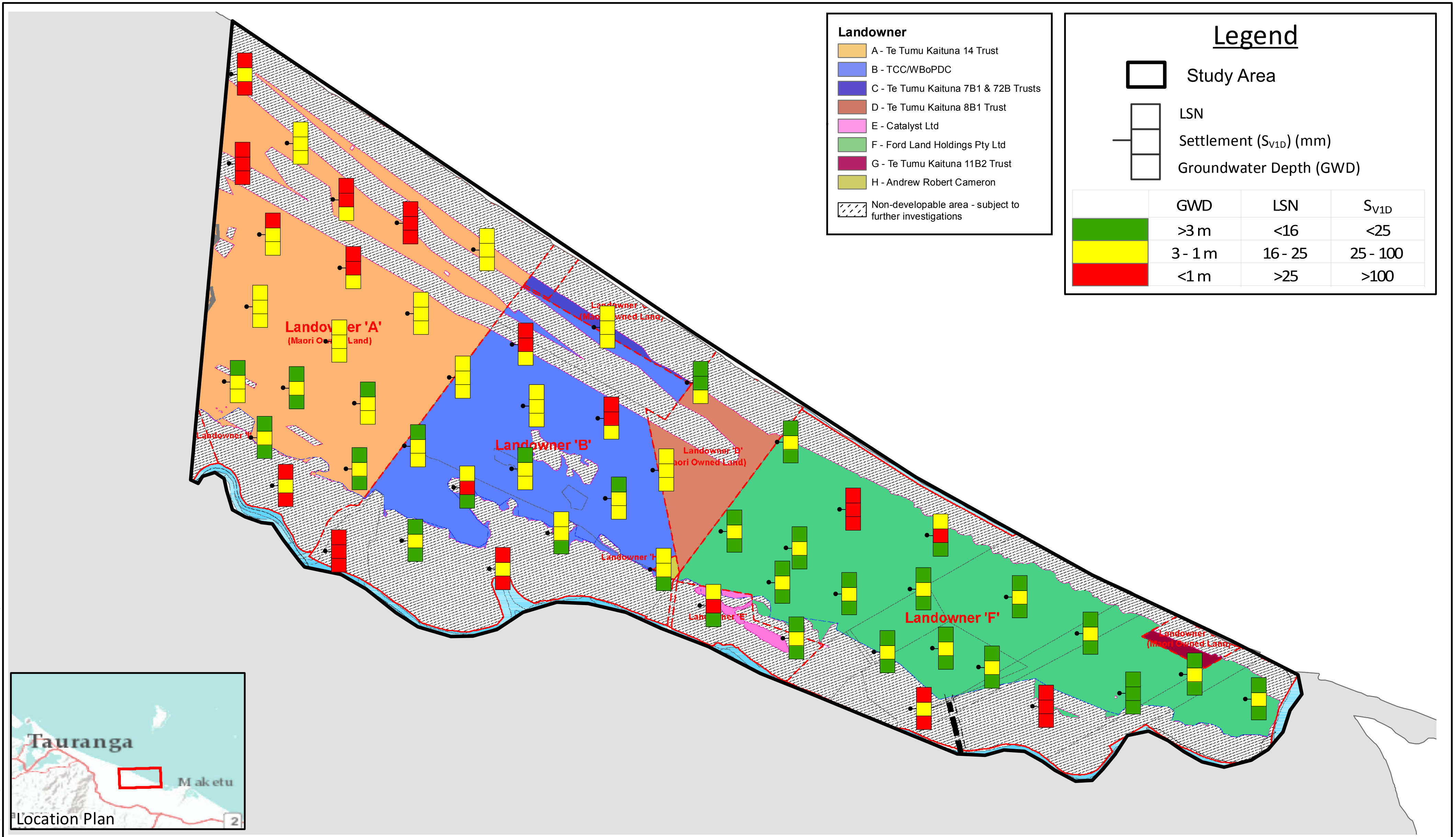

Landowner

- 🟧 A - Te Tumu Kaituna 14 Trust
- 🟦 B - TCC/WBoPDC
- 🟪 C - Te Tumu Kaituna 7B1 & 72B Trusts
- 🟫 D - Te Tumu Kaituna 8B1 Trust
- 🟪 E - Catalyst Ltd
- 🟩 F - Ford Land Holdings Pty Ltd
- 🟥 G - Te Tumu Kaituna 11B2 Trust
- 🟨 H - Andrew Robert Cameron
- ▨ Non-developable area - subject to further investigations

Legend

▭ Study Area

LSN
Settlement (S_{V1D}) (mm)
Groundwater Depth (GWD)

	GWD	LSN	S_{V1D}
🟩	>3 m	<16	<25
🟨	3 - 1 m	16 - 25	25 - 100
🟥	<1 m	>25	>100

Notes: The background map showing the proposed future growth of Te Tumu was obtained from Tauranga City Council and is indicative only.

A4 SCALE 1:25,000
0 0.2 0.4 0.6 0.8 1 (km)

N

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DRAWN	DXLR	Aug.17
CHECKED	VL	Aug.17
APPROVED	PRC	Jul.18

ARCFILE
1002034-020.mxd
SCALE (AT A4 SIZE)
1:25,000
PROJECT No.
1002034.200

TAURANGA CITY COUNCIL
WAIRAKEI/TE TUMU
Liquefaction Vulnerability Assessment
1000yr Event using Median GW with 1.9 SLR

FIGURE No. Figure D9
Rev. 1

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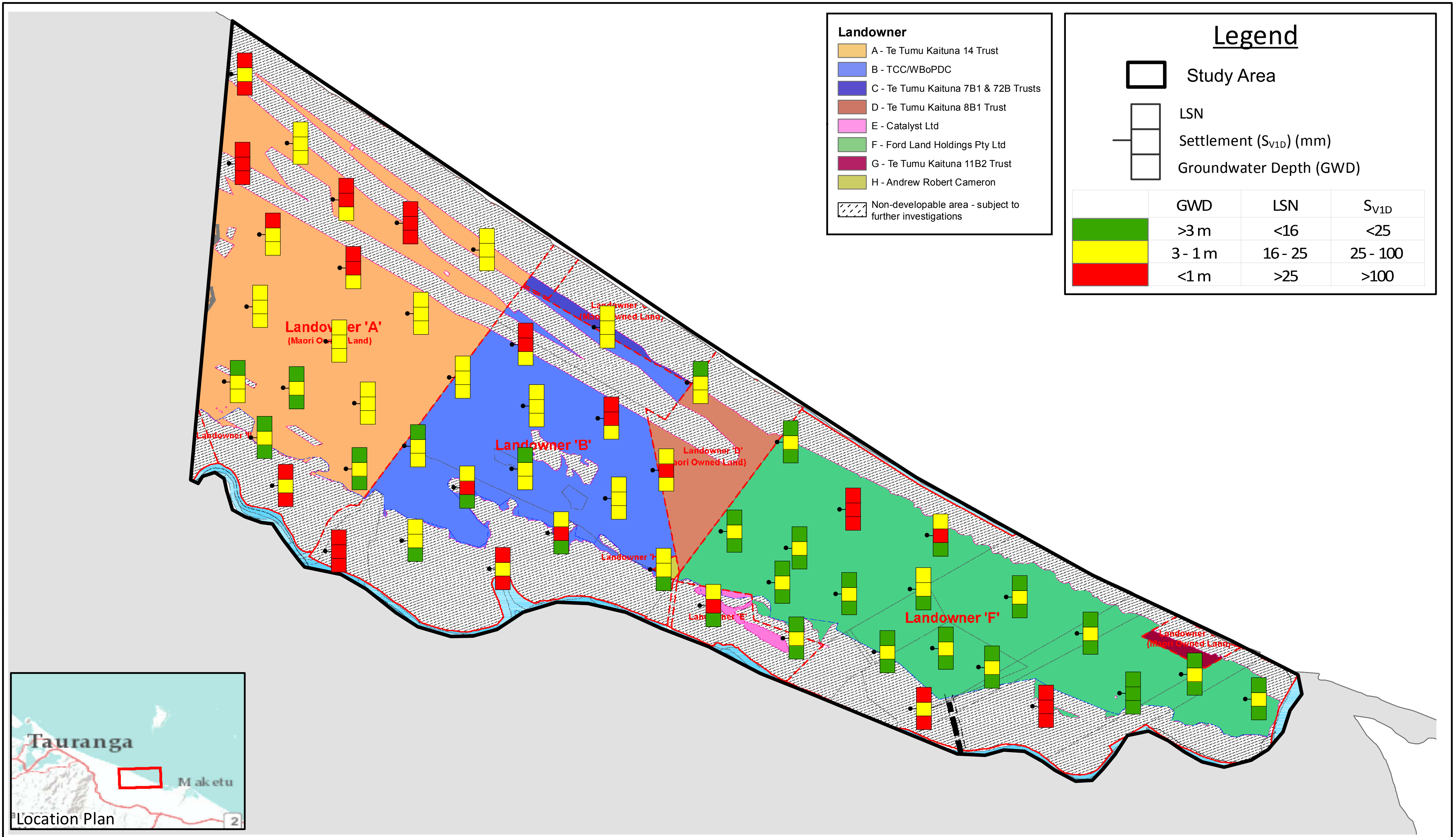

Landowner

🟧	A - Te Tumu Kaituna 14 Trust
🟦	B - TCC/WBoPDC
🟪	C - Te Tumu Kaituna 7B1 & 72B Trusts
🟫	D - Te Tumu Kaituna 8B1 Trust
🟪	E - Catalyst Ltd
🟩	F - Ford Land Holdings Pty Ltd
🟥	G - Te Tumu Kaituna 11B2 Trust
🟨	H - Andrew Robert Cameron
▨	Non-developable area - subject to further investigations

Legend

Study Area

LSN

Settlement (S_{V1D}) (mm)

Groundwater Depth (GWD)

	GWD	LSN	S_{V1D}
🟩	>3 m	<16	<25
🟨	3 - 1 m	16 - 25	25 - 100
🟥	<1 m	>25	>100

Path: \\ttgroup.local\corporate\Tauranga\Projects\1002034\1002034.2000\WorkingMaterial\GIS\MapDocuments\1002034-021.mxd Date: 29/08/2017 Time: 12:50:28 p.m.

Notes: The background map showing the proposed future growth of Te Tumu was obtained from Tauranga City Council and is indicative only.

A4 SCALE 1:25,000

0 0.2 0.4 0.6 0.8 1 (km)

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DRAWN	DXLR	Aug.17
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ARCFILE
1002034-021.mxd

SCALE (AT A4 SIZE)
1:25,000

PROJECT No.
1002034.200

TAURANGA CITY COUNCIL

WAIRAKEI/TE TUMU
Liquefaction Vulnerability Assessment
3030yr Event using Median GW with 1.9 SLR

FIGURE No. Figure D10

Rev. 1

LSN vs PGA Figures using Median Groundwater

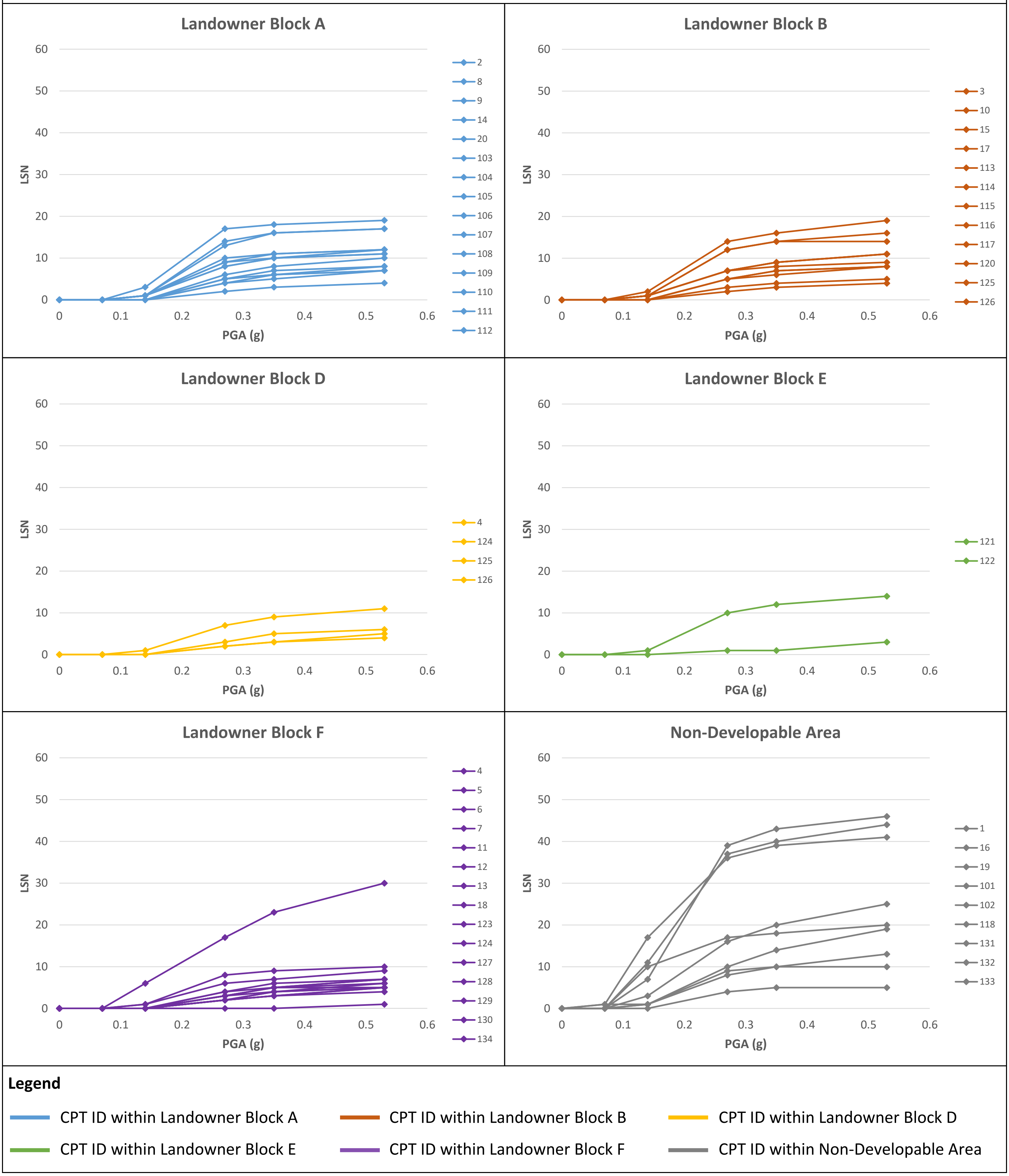
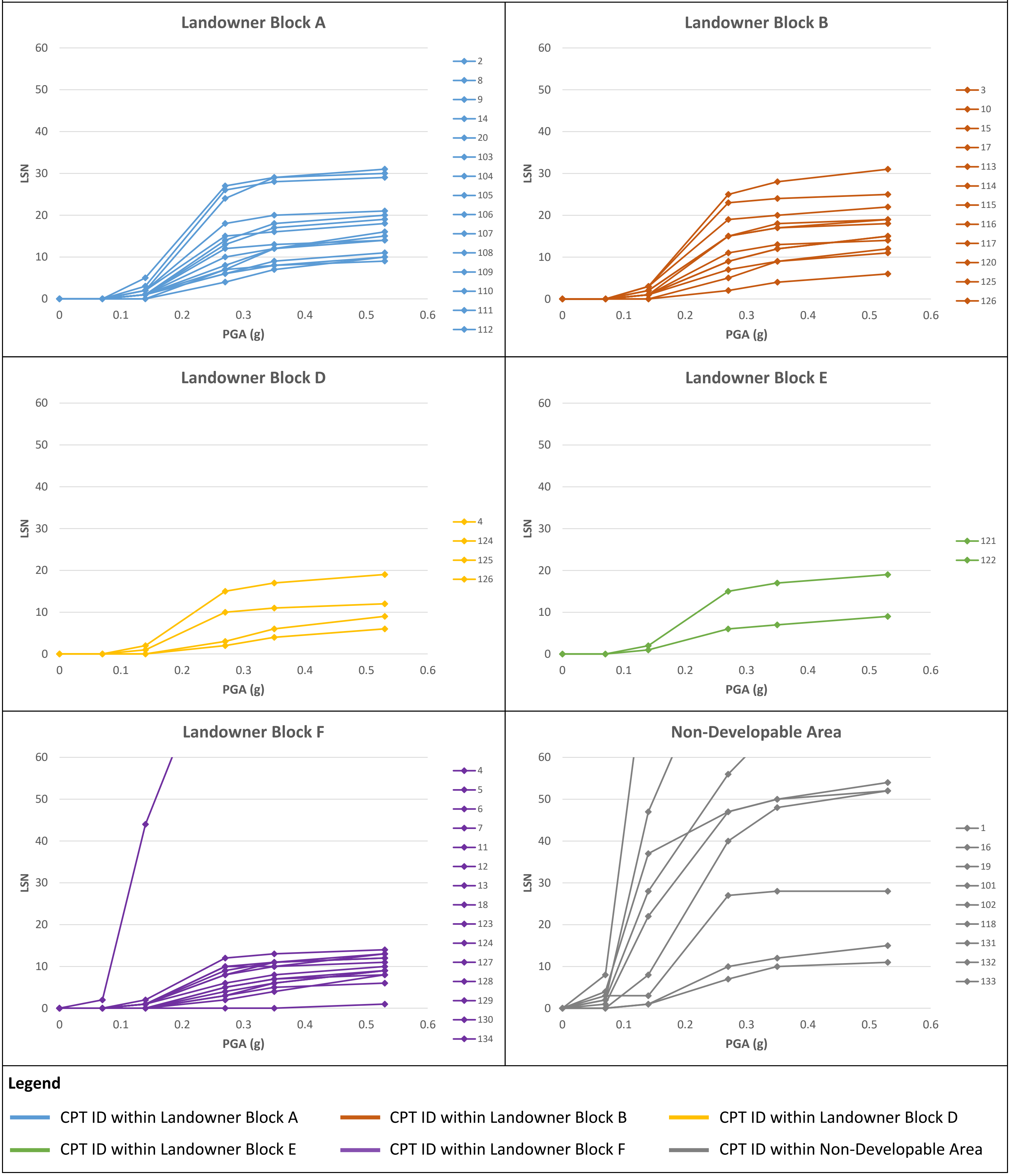


Figure D11

LSN vs PGA Figures using Median Groundwater with 1.25m of Sea Level Rise



Landowner Block A

Landowner Block B

Landowner Block D

Landowner Block E

Landowner Block F

Non-Developable Area

Figure D12

LSN vs PGA Figures using Median Groundwater with 1.9m of Sea Level Rise

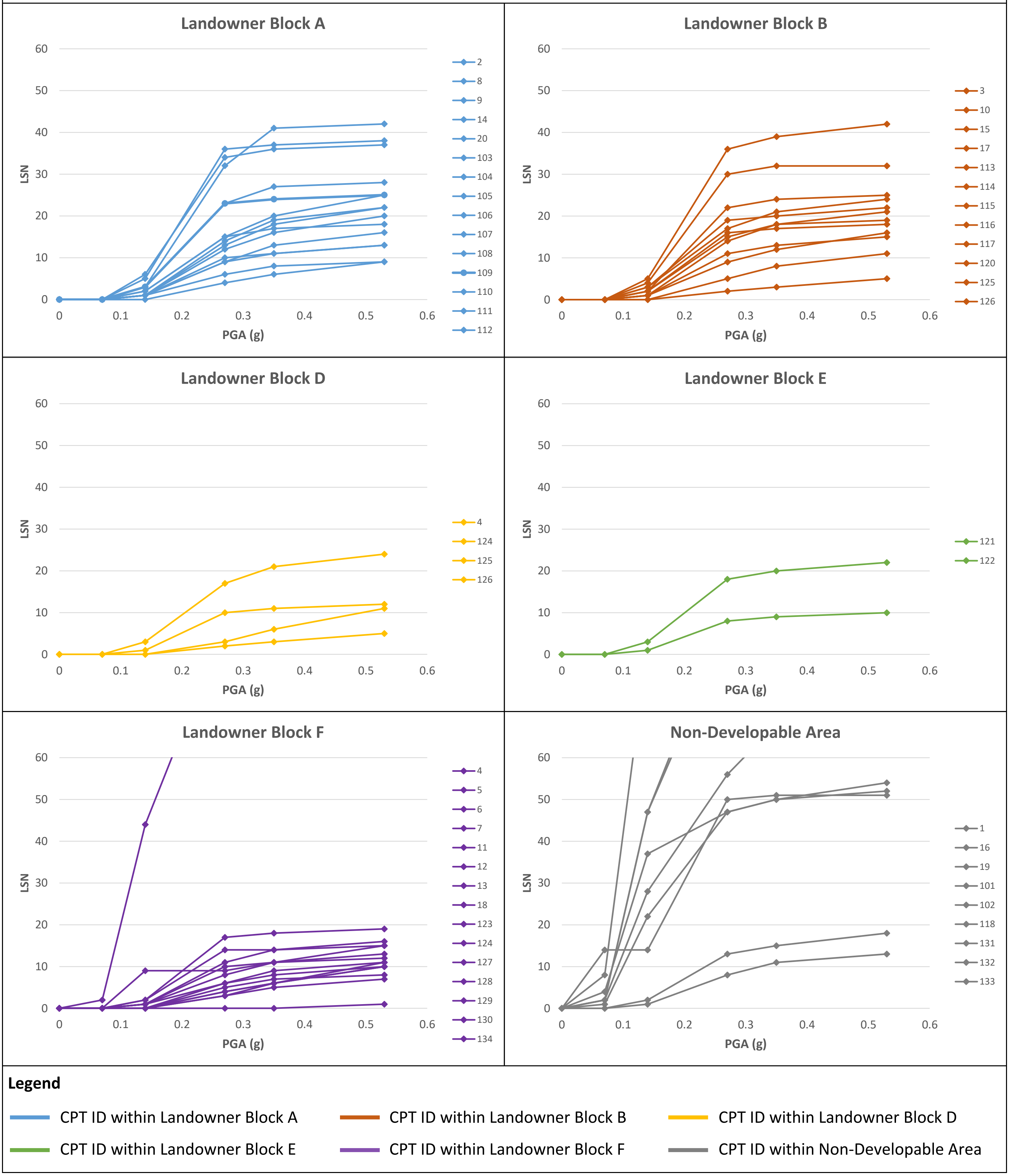
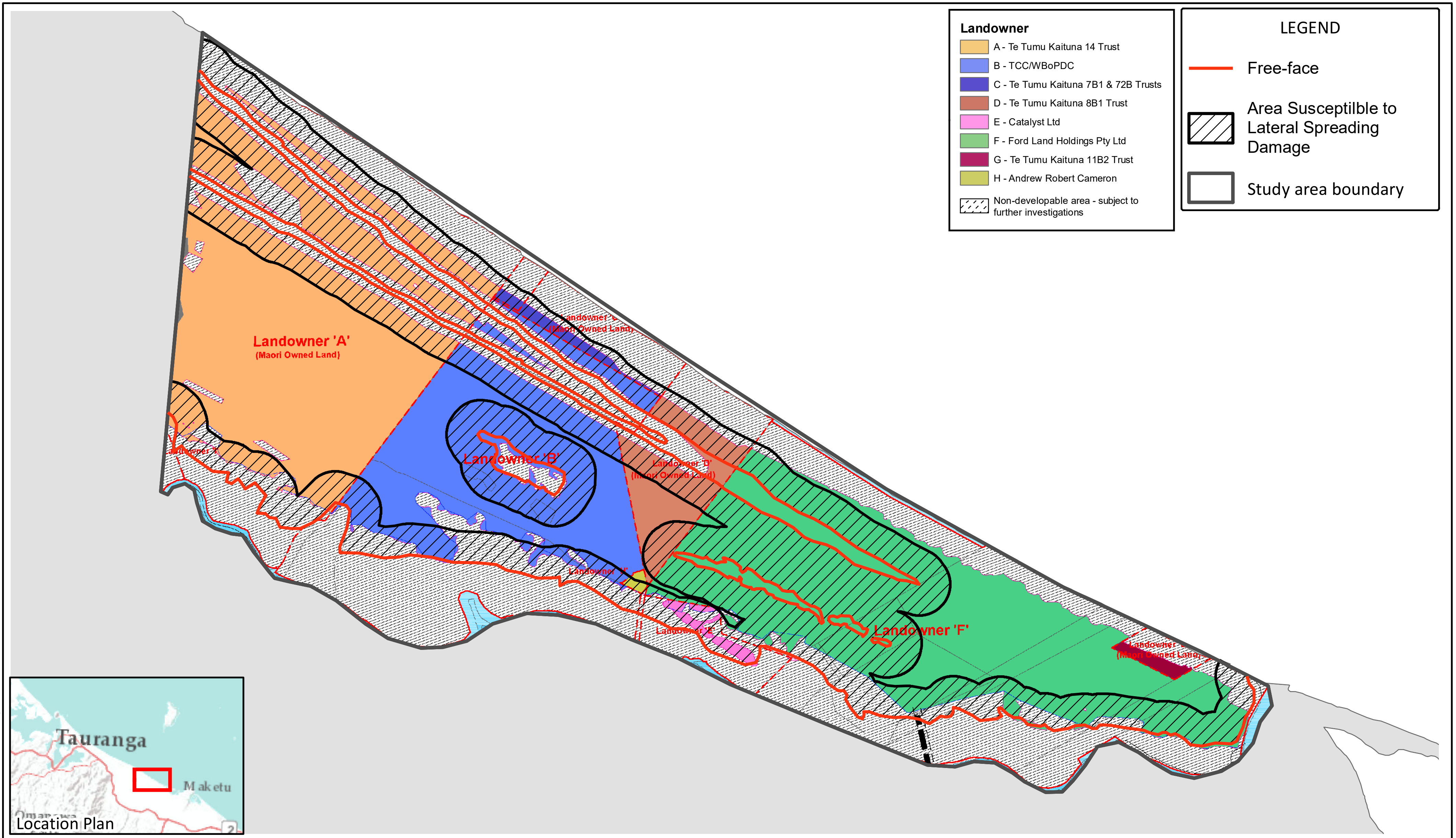


Figure D13

Appendix E: Lateral spreading assessment results

- **Figure E1 – Area susceptible to lateral spreading damage overlaid on landowner blocks**
- **Figure E2 – Area susceptible to lateral spreading damage overlaid on proposed DEM**
- **Figure E3 – Lateral spread vulnerability assessment for 500yr event using median GW**
- **Figure E4 – Lateral spread vulnerability assessment for 500yr event using median GW with 1.25m SLR**
- **Figure E5 – Lateral spread vulnerability assessment for 500yr event using median GW with 1.9m SLR**
- **Figure E6 – Lateral spread vulnerability assessment for 1000yr event using median GW with 1.25m SLR**
- **Figure E7 – Lateral spread vulnerability assessment for 3030yr event using median GW with 1.9m SLR**
- **Figure E8 – Lateral spreading – mitigation option 4 overlaid on landowner blocks**



Landowner

- 🟧 A - Te Tumu Kaituna 14 Trust
- 🟦 B - TCC/WBoPDC
- 🟪 C - Te Tumu Kaituna 7B1 & 72B Trusts
- 🟫 D - Te Tumu Kaituna 8B1 Trust
- 🟪 E - Catalyst Ltd
- 🟩 F - Ford Land Holdings Pty Ltd
- 🟥 G - Te Tumu Kaituna 11B2 Trust
- 🟨 H - Andrew Robert Cameron
- ▨ Non-developable area - subject to further investigations

LEGEND

- — Free-face
- ▨ Area Susceptible to Lateral Spreading Damage
- ☐ Study area boundary

Notes: The background map showing the proposed future growth of Te Tumu was obtained from Tauranga City Council and is indicative only.

A4 SCALE 1:25,000

0 0.25 0.5 0.75 1 1.25 (km)

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1:25,000

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102034.2000

TAURANGA CITY COUNCIL

TE TUMU URBAN GROWTH AREA

Area Susceptible to Lateral Spreading Damage Overlaid on Landowner Blocks

FIGURE No. Figure E1

Rev. 0

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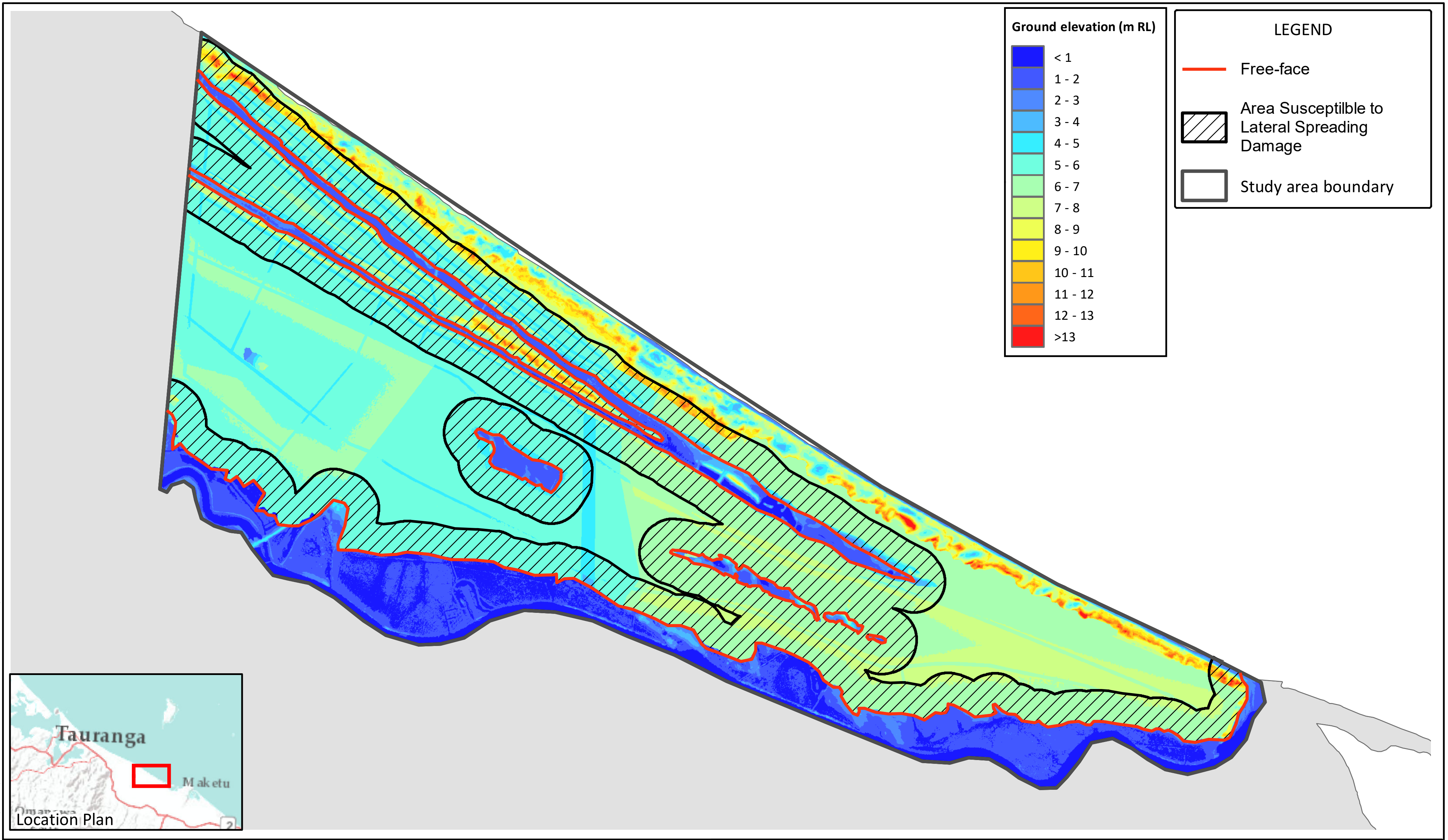

Notes: The background map showing the proposed future growth of Te Tumu was obtained from Tauranga City Council and is indicative only.

A4 SCALE 1:25,000

0 0.25 0.5 0.75 1 1.25 (km)

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SCALE (AT A4 SIZE)
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TAURANGA CITY COUNCIL

TE TUMU URBAN GROWTH AREA

Area Susceptible to Lateral Spreading Damage Overlaid on Proposed DEM

FIGURE No. Figure E2

Rev. 0

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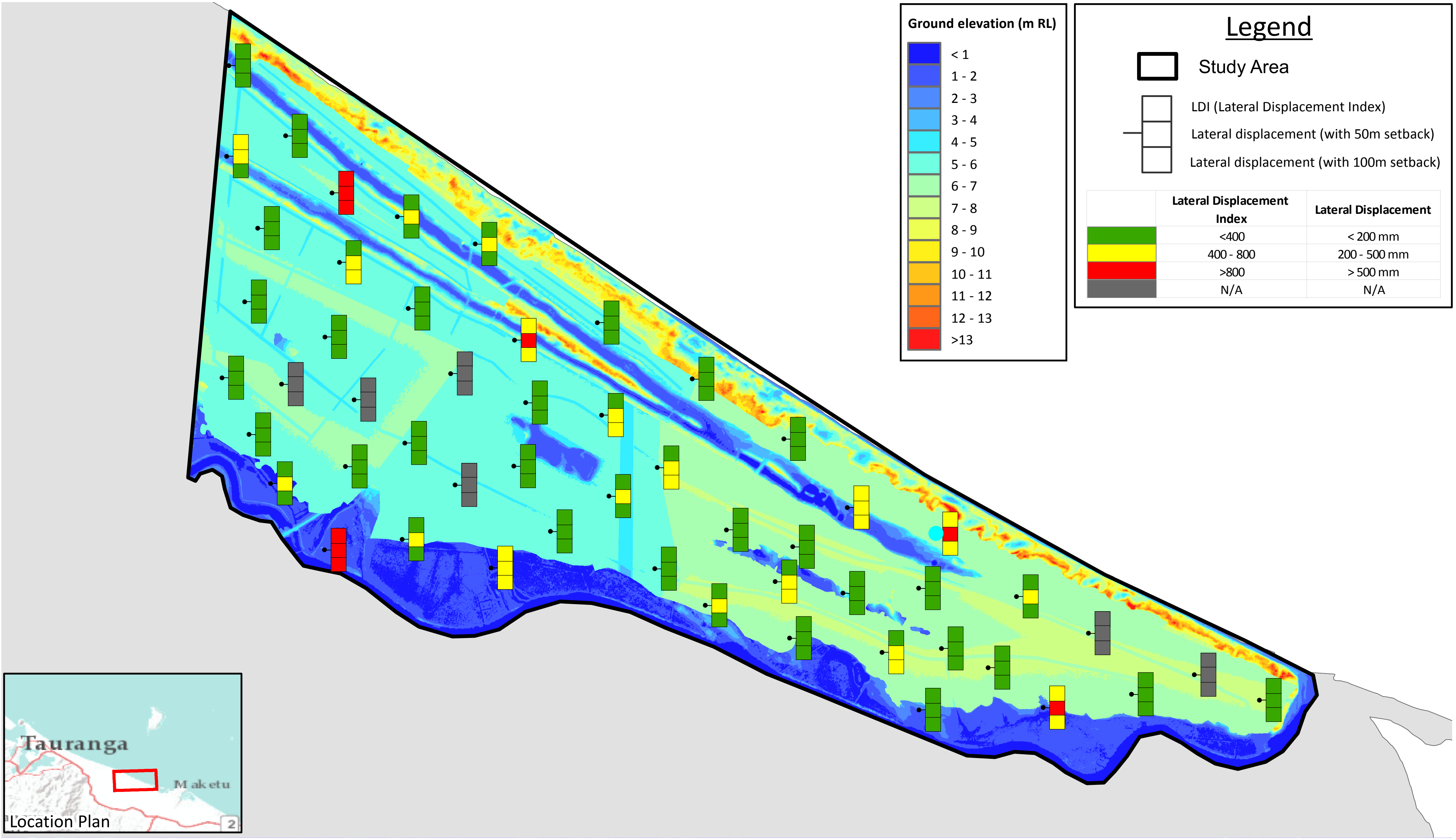

Ground elevation (m RL)

- < 1
- 1 - 2
- 2 - 3
- 3 - 4
- 4 - 5
- 5 - 6
- 6 - 7
- 7 - 8
- 8 - 9
- 9 - 10
- 10 - 11
- 11 - 12
- 12 - 13
- >13

Legend

Study Area

LDI (Lateral Displacement Index)

Lateral displacement (with 50m setback)

Lateral displacement (with 100m setback)

	Lateral Displacement Index	Lateral Displacement
🟩	<400	< 200 mm
🟨	400 - 800	200 - 500 mm
🟥	>800	> 500 mm
⬛	N/A	N/A

Notes: The background map showing the proposed future growth of Te Tumu was obtained from Tauranga City Council and is indicative only.

A4 SCALE 1:25,000

0 0.2 0.4 0.6 0.8 1 (km)

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SCALE (AT A4 SIZE)
1:25,000

PROJECT No.
1002034.200

TAURANGA CITY COUNCIL
WAIRAKEI/TE TUMU
Lateral Spread Vulnerability Assessment
500yr Event using Median GW

FIGURE No.
Figure E3

Rev.
1

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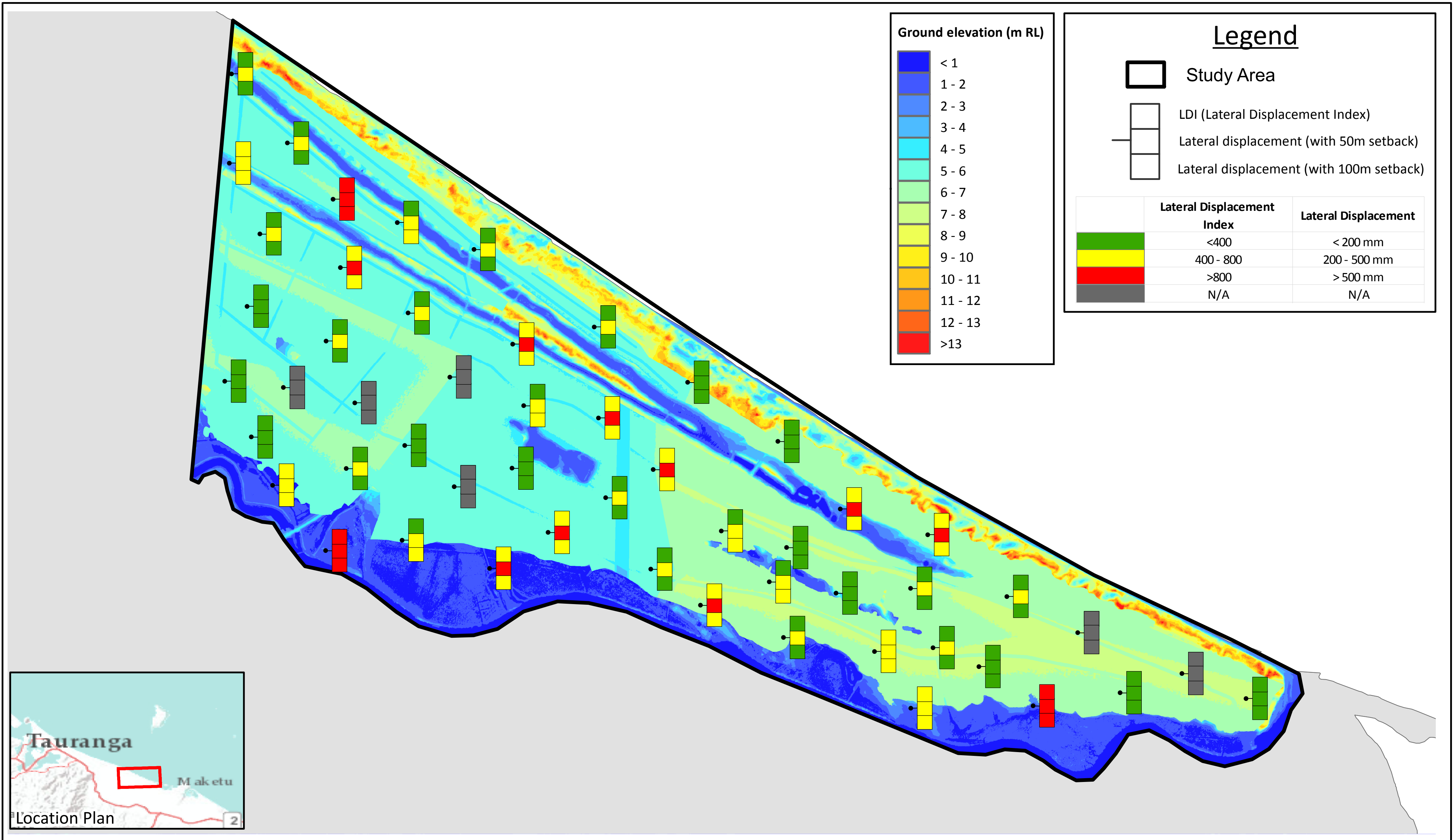

	Lateral Displacement Index	Lateral Displacement
🟩	<400	< 200 mm
🟨	400 - 800	200 - 500 mm
🟥	>800	> 500 mm
⬛	N/A	N/A

Notes: The background map showing the proposed future growth of Te Tumu was obtained from Tauranga City Council and is indicative only.

A4 SCALE 1:25,000

0 0.2 0.4 0.6 0.8 1 (km)

N

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SCALE (AT A4 SIZE)
1:25,000

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TAURANGA CITY COUNCIL

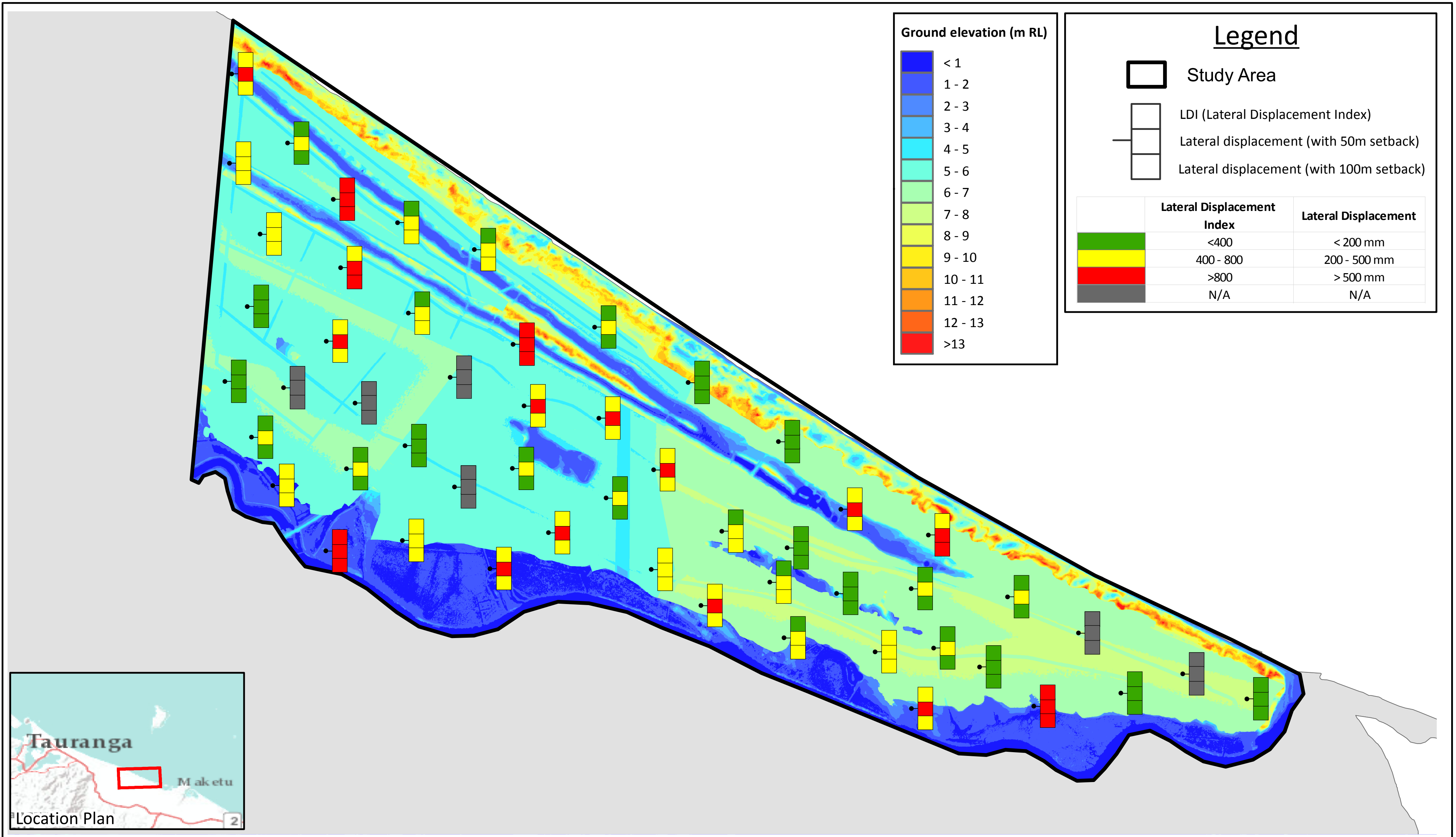
WAIRAKEI/TE TUMU

Lateral Spread Vulnerability Assessment

500yr Event using Median GW +1.25m SLR

FIGURE No.
Figure E4

Rev.
1



Ground elevation (m RL)

- < 1
- 1 - 2
- 2 - 3
- 3 - 4
- 4 - 5
- 5 - 6
- 6 - 7
- 7 - 8
- 8 - 9
- 9 - 10
- 10 - 11
- 11 - 12
- 12 - 13
- >13

Legend

Study Area

LDI (Lateral Displacement Index)
Lateral displacement (with 50m setback)
Lateral displacement (with 100m setback)

	Lateral Displacement Index	Lateral Displacement
🟩	<400	< 200 mm
🟨	400 - 800	200 - 500 mm
🟥	>800	> 500 mm
⬛	N/A	N/A

Notes: The background map showing the proposed future growth of Te Tumu was obtained from Tauranga City Council and is indicative only.

A4 SCALE 1:25,000

0 0.2 0.4 0.6 0.8 1 (km)

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SCALE (AT A4 SIZE)
1:25,000

PROJECT No.
1002034.200

TAURANGA CITY COUNCIL

WAIRAKEI/TE TUMU

Lateral Spread Vulnerability Assessment

500yr Event using Median GW +1.9m SLR

FIGURE No. Figure E5

Rev. 1

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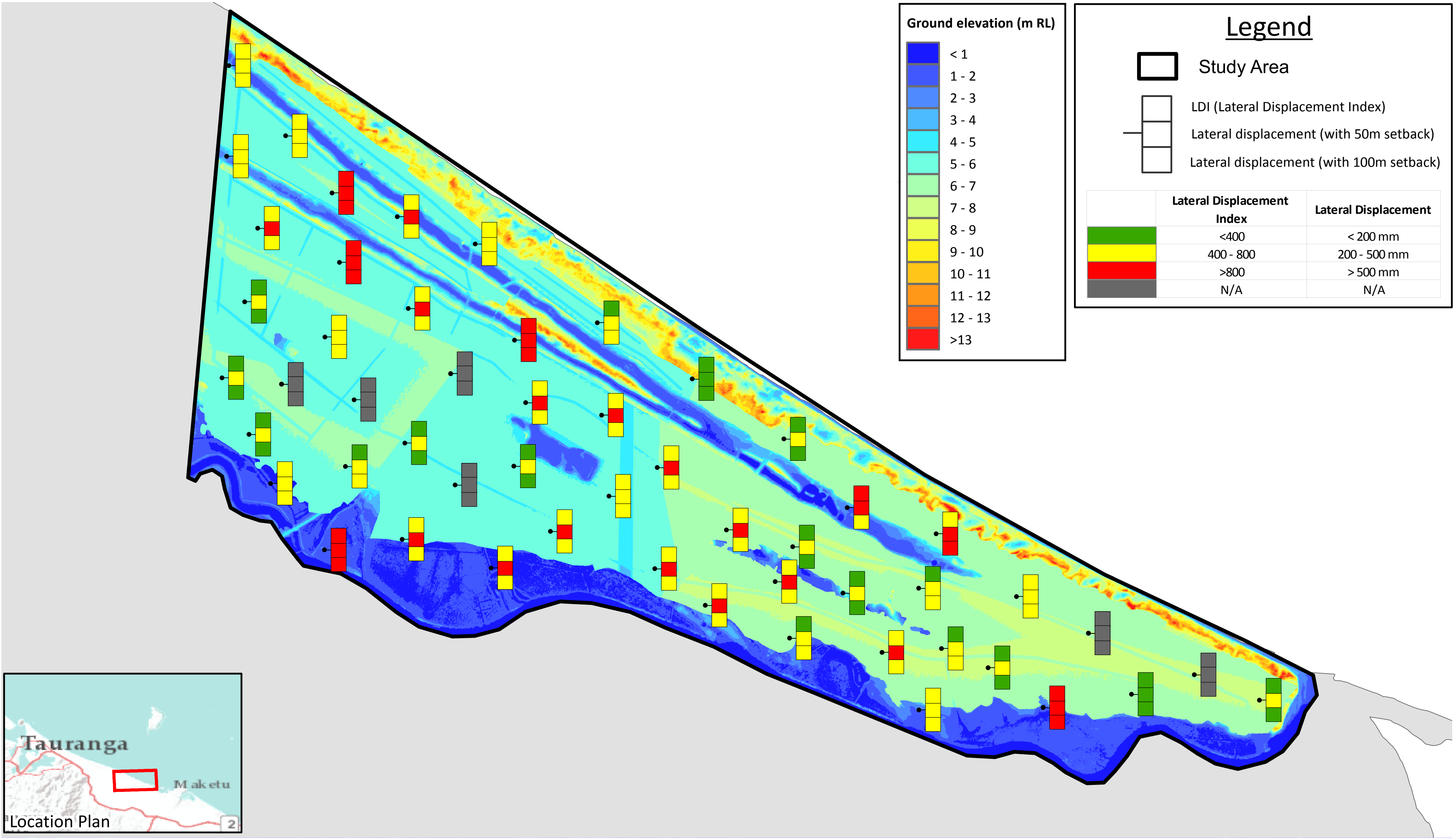

Ground elevation (m RL)	
🟦	< 1
🟦	1 - 2
🟦	2 - 3
🟦	3 - 4
🟦	4 - 5
🟦	5 - 6
🟩	6 - 7
🟩	7 - 8
🟨	8 - 9
🟨	9 - 10
🟧	10 - 11
🟧	11 - 12
🟧	12 - 13
🟥	>13

Legend

Study Area

LDI (Lateral Displacement Index)
Lateral displacement (with 50m setback)
Lateral displacement (with 100m setback)

	Lateral Displacement Index	Lateral Displacement
🟩	<400	< 200 mm
🟨	400 - 800	200 - 500 mm
🟥	>800	> 500 mm
⬛	N/A	N/A

Notes: The background map showing the proposed future growth of Te Tumu was obtained from Tauranga City Council and is indicative only.

A4 SCALE 1:25,000
0 0.2 0.4 0.6 0.8 1 (km)

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1:25,000
PROJECT No.
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TAURANGA CITY COUNCIL
WAIRAKEI/TE TUMU
Lateral Spread Vulnerability Assessment
1000yr Event using Median GW +1.25m SLR

FIGURE No.
Figure E6

Rev.
1

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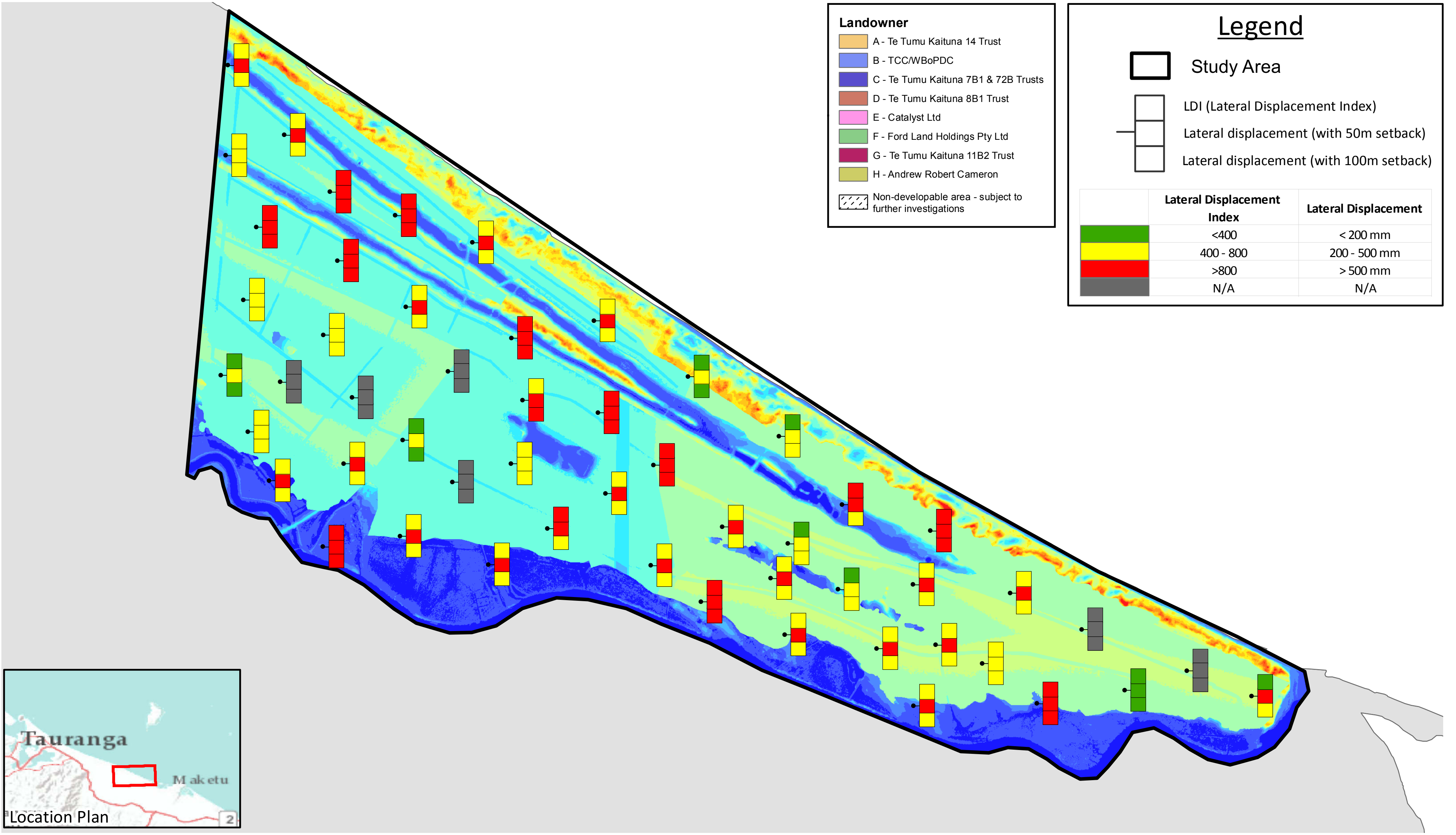

Notes: The background map showing the proposed future growth of Te Tumu was obtained from Tauranga City Council and is indicative only.

A4 SCALE 1:25,000

0 0.2 0.4 0.6 0.8 1 (km)

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ARCFILE 1002034-024.mxd

SCALE (AT A4 SIZE) 1:25,000

PROJECT No. 1002034.200

TAURANGA CITY COUNCIL
WAIRAKEI/TE TUMU
Lateral Spread Vulnerability Assessment
3030yr Event using Median GW + 1.9 SLR

FIGURE No. Figure E7

Rev. 1

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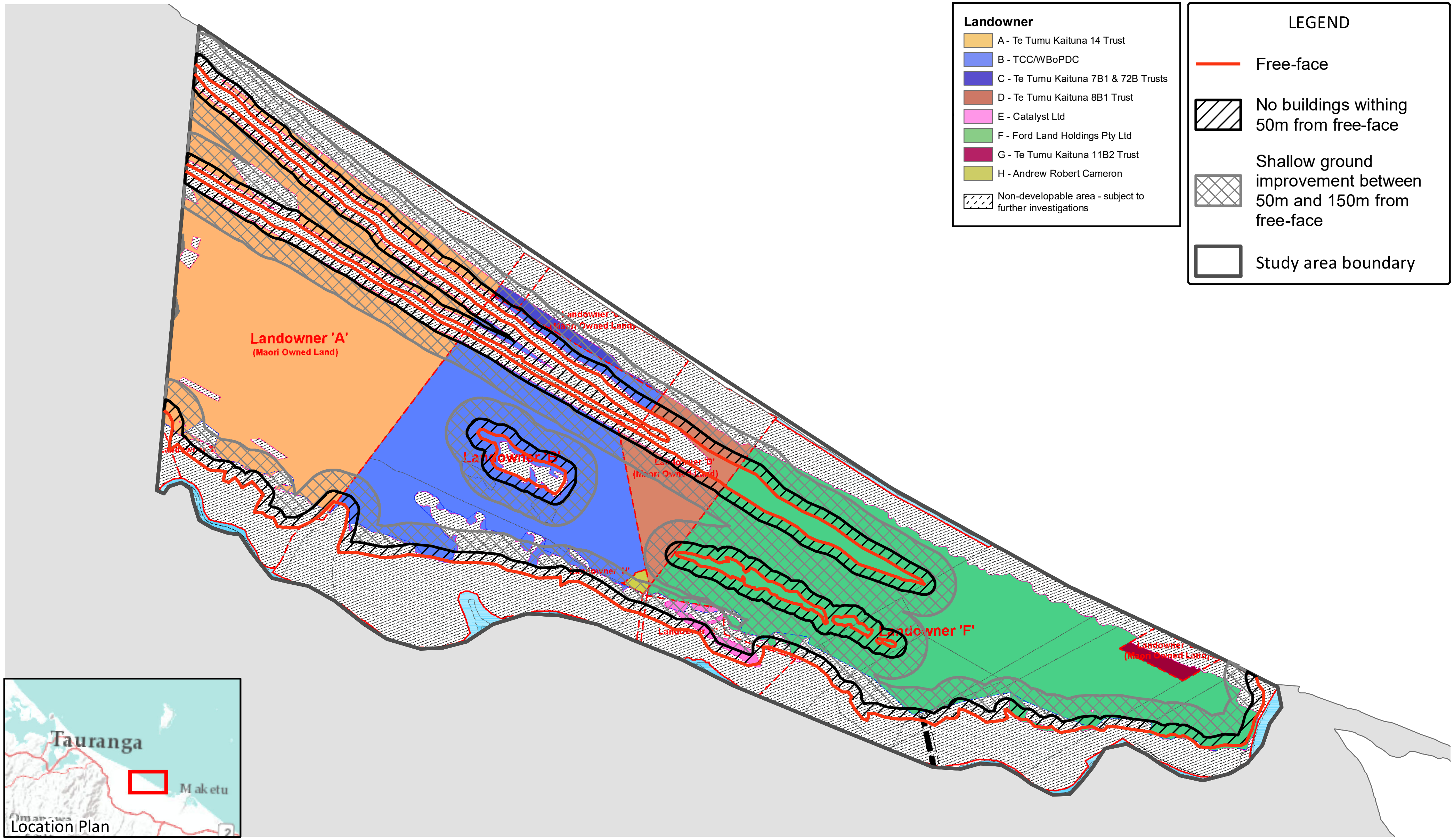

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Notes: The background map showing the proposed future growth of Te Tumu was obtained from Tauranga City Council and is indicative only.

A4 SCALE 1:25,000

0 0.25 0.5 0.75 1 1.25 (km)

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1:25,000

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102034.2000

TAURANGA CITY COUNCIL

TE TUMU URBAN GROWTH AREA

Lateral Spreading – Mitigation Option 4
Overlaid on Landowner Blocks

FIGURE No.
Figure E8

Rev.
0

Table E.1: Lateral spreading assessment for Scenario 1 (for a 500 year return period earthquake event with median groundwater and no sea level rise)

Potential Lateral Spread Area	LDI		LD (mm) at 50m		LD (mm) at 100m		LD (mm) at 150m	
	Range	Median	Range	Median	Range	Median	Range	Median
River Plain	430-1030	600	180-1010	470	110-580	270	80-420	200
River Fill	40-360	180	50-350	170	30-200	100	20-150	70
Stream	90-820	220	100-900	240	60-520	140	40-380	100
Pond (west)	130-350	200	140-380	210	80-220	120	60-160	90
Pond (east)	80-270	110	110-350	130	60-200	80	50-150	60

Table E.2: Lateral spreading assessment for Scenario 2 (for a 500 year return period earthquake event with median groundwater and 1.25m of sea level rise)

Potential Lateral Spread Area	LDI		LD (mm) at 50m		LD (mm) at 100m		LD (mm) at 150m	
	Range	Median	Range	Median	Range	Median	Range	Median
River Plain	430-1030	600	400-1010	520	230-580	300	170-420	220
River Fill	40-590	240	50-560	270	30-320	150	20-230	110
Stream	110-1060	350	120-1160	340	70-670	200	50-480	140
Pond (west)	190-630	300	200-690	330	110-400	190	80-290	140
Pond (east)	90-370	210	120-460	260	70-270	150	50-190	110

Table E.3: **Lateral spreading assessment for Scenario 3 (for a 500 year return period earthquake event with median groundwater and 1.9m of sea level rise)**

Potential Lateral Spread Area	LDI		LD (mm) at 50m		LD (mm) at 100m		LD (mm) at 150m	
	Range	Median	Range	Median	Range	Median	Range	Median
River Plain	470-1030	600	420-1010	540	240-580	310	180-420	230
River Fill	40-690	290	50-660	310	30-380	180	20-270	130
Stream	110-1130	460	120-1240	420	70-710	240	50-510	170
Pond (west)	260-760	370	270-840	420	160-480	240	110-350	170
Pond (east)	110-370	230	150-460	280	90-270	160	60-190	120

Table E.4: **Lateral spreading assessment for Scenario 4 (for a 1000 year return period earthquake event with median groundwater and 1.25m of sea level rise)**

Potential Lateral Spread Area	LDI		LD (mm) at 50m		LD (mm) at 100m		LD (mm) at 150m	
	Range	Median	Range	Median	Range	Median	Range	Median
River Plain	530-1140	650	490-1120	570	280-640	330	200-470	240
River Fill	40-760	360	50-720	390	30-410	230	20-300	160
Stream	150-1180	550	170-1300	520	100-750	300	70-540	220
Pond (west)	280-780	470	290-860	520	170-490	300	120-360	220
Pond (east)	160-490	380	210-610	450	120-350	260	90-250	190

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