Hawke’s Bay 3D Aquifer Mapping Project:

Drilling Completion Report for Borehole 17164 (3DAMP_Well3), Burnside Road, Ruataniwha Plains

August 2022
Hawkes Bay Regional Council Publication No. 5573

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EXECUTIVE SUMMARY

This report describes the drilling undertaken and datasets collected at borehole/well 17164 (3DAMP_Well3), Ruataniwha Plains, Hawke's Bay. The well is part of the Hawke's Bay 3D Aquifer Mapping Project (3DAMP) that utilises SkyTEM technology (airborne transient electromagnetics) to improve mapping and modelling of groundwater resources. The borehole was drilled at a location northeast of Takapau on Burnside Road, with a proposed maximum depth of 150–180 m BGL (metres below ground level). The drilling objectives were:

- Proposed maximum depth: top of low-resistivity layer at 150–180 m depth.
- Confirm variable aquifer structure in the top 100 m to the east of the well, including near-surface low-resistivity layer, high-resistivity layer at 60–130 m BGL and medium-resistivity layer at 130–150 m BGL.
- Provide detailed lithological information, such as clay content, to assist with the interpretation of the SkyTEM data.

One combined ground Transient ElectroMagnetic (TEM) and NanoTEM measurement was made close to the drilling location and a second GroundTEM measurement was made at the actual location. The well was spudded on the 28th of July 2021 and terminated on the 5th of October 2021 at a depth of 79 m BGL, with the base of the casing set at 76.35 m BGL. The hole was terminated at a shallower depth than the planned 180 m BGL due to an increasingly slow rate of penetration, issues with 'heaving' of running sands and associated budgetary considerations. A continuous sedimentary log was produced to a depth of 57 m BGL, with spot samples taken by the drillers below this depth. Twenty-two samples were acquired for laboratory grain-size analysis. Electrical resistivity measurements were made on all of these samples and also on material between sample depths. Four series of slug tests were undertaken at 5.46 m BGL, 18.0 m BGL, 55.22 m BGL and 76.35 m BGL. No pumping tests or water sampling were undertaken. Wireline logs (natural gamma and density) were acquired through casing from a depth of 76 m BGL to near the surface.

Summaries of acquired data are provided in the Appendices of this report. Very limited interpretation of the data has been undertaken at this stage but will be the focus of future reports within 3DAMP.

1.0 INTRODUCTION

This report describes the drilling undertaken, and datasets collected, at borehole/well 17164 (HBRC Well Database ID) – alias 3DAMP_Well3 (project well ID) – in the Ruataniwha Plains, Hawke's Bay. Well 17164 is the third in a series of boreholes drilled as part of the Hawke's Bay 3D Aquifer Mapping Project (3DAMP).

1.1 Background

The Hawke's Bay 3DAMP is a three-year initiative (2019–2022) jointly funded by the Provincial Growth Fund (PGF), Hawke's Bay Regional Council (HBRC) and GNS Science (GNS). The project applies SkyTEM technology, an airborne transient electromagnetic method, to improve mapping and modelling of groundwater resources within the Heretaunga Plains, Ruataniwha Plains and Poukawa and Otane basins (Figure 1.1). 3DAMP involves collaboration between HBRC, GNS and the Aarhus University HydroGeophysics Group.

SkyTEM data were collected in the Hawke's Bay region during January/February 2020 by SkyTEM Australia (SkyTEM Australia Pty Ltd 2020). 3DAMP also planned for a drilling programme, with the objective to reduce uncertainty of the SkyTEM resistivity modelling and hydrogeological interpretations. As such, 3DAMP undertook a desktop review to assess areas of potential new data collection (unreported).

Existing publicly available geological and hydrological data were compiled by GNS within a GIS project for the Heretaunga and Ruataniwha plains. This compilation included data provided by HBRC (e.g. bore locations, aquifer test data, bore lithology, groundwater consents, water levels), published data (e.g. surface geology, geophysics reports) and the HBRC SkyTEM data (raw data at selected time gates; preliminary SkyTEM 1D resistivity models). Lithology data were quality-coded to enable a simple method of determining locations where there is good lithological control.

Key data gaps identified from the desktop review that would assist with the interpretation of the SkyTEM data included:

- A lack of geological data at depth (100–300 m deep).
- Good quality lithological information (all depths).
- Clay content of the geological units.

The locations of new groundwater wells and data collection types were planned by GNS in consultation with HBRC staff to address these information gaps. The locations were chosen based on a series of criteria, including quantity and quality of existing data that can be used to constrain the SkyTEM inversions and interpretations, proximity to low-noise SkyTEM survey data, continuity of structures and vertical discretisation within preliminary resistivity models, and land access.

Most groundwater wells in the Ruataniwha Plains are less than 50 m deep and contain information about geology and aquifer properties that varies in quality. In 2001, a series of wells were drilled that captured some more detailed information, but the reports on these wells are incomplete (Brown 2002). Wells 4697, 4700, 4701 and 4702 were drilled to greater than 100 m depth, and information from the drilling reports is available to support the interpretation of the SkyTEM data (Brown 2002). The new wells were designed to provide more complete datasets in locations where critical data were missing.

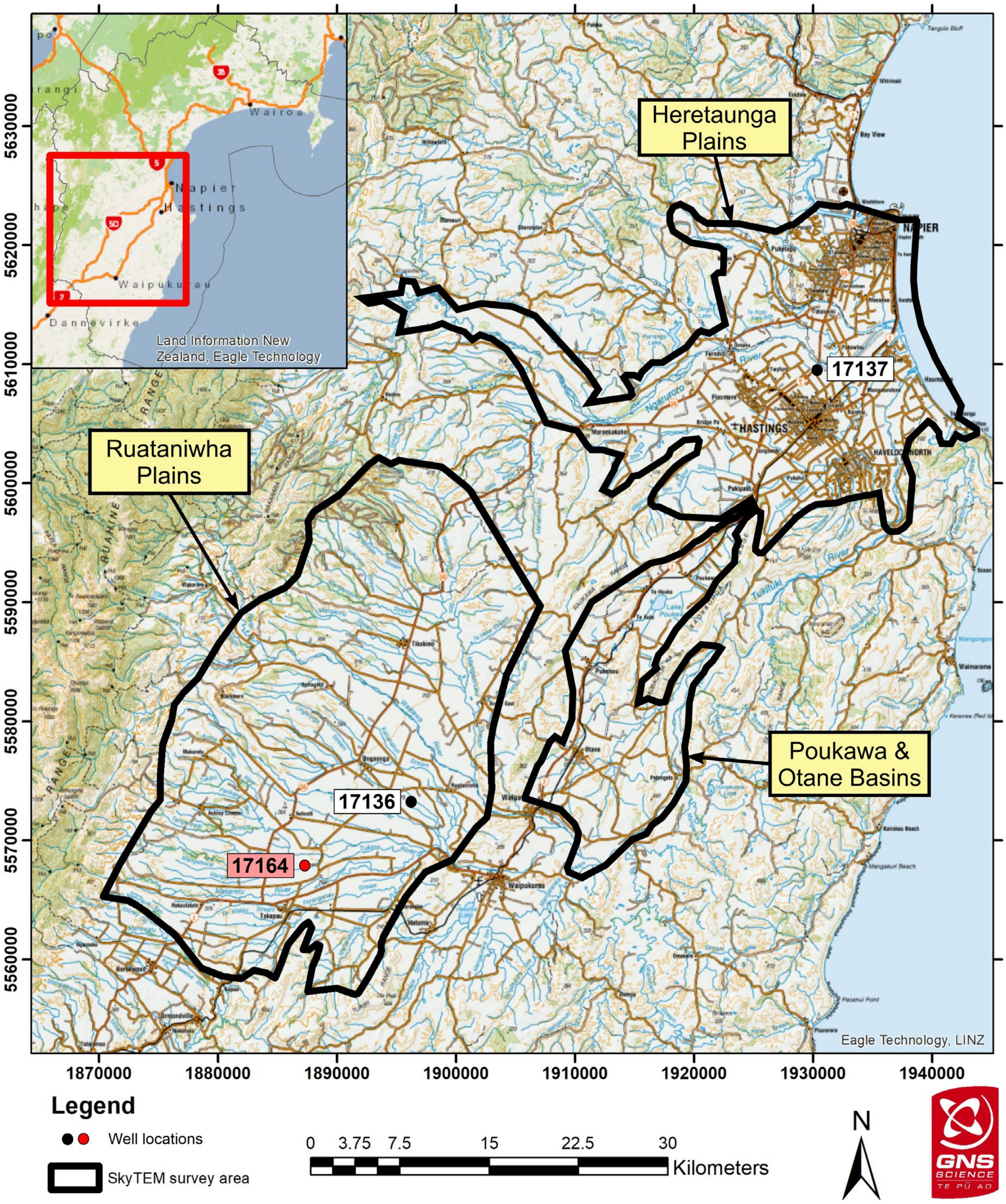

Figure 1.1 Coverage of the 3D Aquifer Mapping Project SkyTEM datasets within the Hawke's Bay region. The location of the three wells drilled as part of 3DAMP are labelled with their HBRC codes. Well 3 is 17164 (highlighted in red).

1.2 Location

Figure 1.2 shows the distribution of existing boreholes[1] in the area, colour-coded by depth. Most are less than 50 m deep. Drilling objectives specific to this site included:

- Define aquifer properties for shallow and deep aquifer units, including a limestone aquifer.

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[1] Well data obtained from the Hawke's Bay Regional Council wells database – WellStor.

- Assist with identifying hydraulic connections between aquifers in the unconfined zone.
- Confirm the extents of the high-resistivity layer at 60–130 m BGL and medium-resistivity layer at 130–150 m BGL.

The stratigraphy for this part of the Hawke's Bay area is shown in Figure 1.3. Based on the interpretation of the initial SkyTEM inversion models (SkyTEM Australia Pty Ltd 2020) and seismic lines IGNS 93 L17 (Melhuish 1993) and IP332-99-401 (Schlumberger Geco Prakla 1999), the following general prognosis was made for the borehole:

- 0–100 m BGL: Holocene gravel deposits with high resistivity and low seismic reflectivity, corresponding to a lack of bedding.
- 100–190 m BGL: Holocene/Pleistocene silt and sand with low resistivity and strong seismic reflectivity, resulting from well-defined layers.
- 190–300 m BGL: Pleistocene/Pliocene limestone with high resistivity and moderate seismic reflectivity.
- 300 m BGL: top of the mudstone mapped as a bright seismic reflector, and a subtle decrease in resistivity.

The well is located on the upthrown side of a fault and lies close to the crest of an anti-form. The axis of the anti-form trends to the north. The geological strata dip gently to the west on the footwall of the fault. On the hanging-wall side of the fault, the dips are steeper and trend to the east. The petroleum well Takapau-1, located 5 km to the west of well 17164 (Figure 1.2), lies on the crest of a similar structure (Melhuish 1990).

More detailed information was available for the top 40 m of the borehole based on the closest well (HBRC well 1398), which lies 300 m to the southeast of the drilling location (Table 1.2).

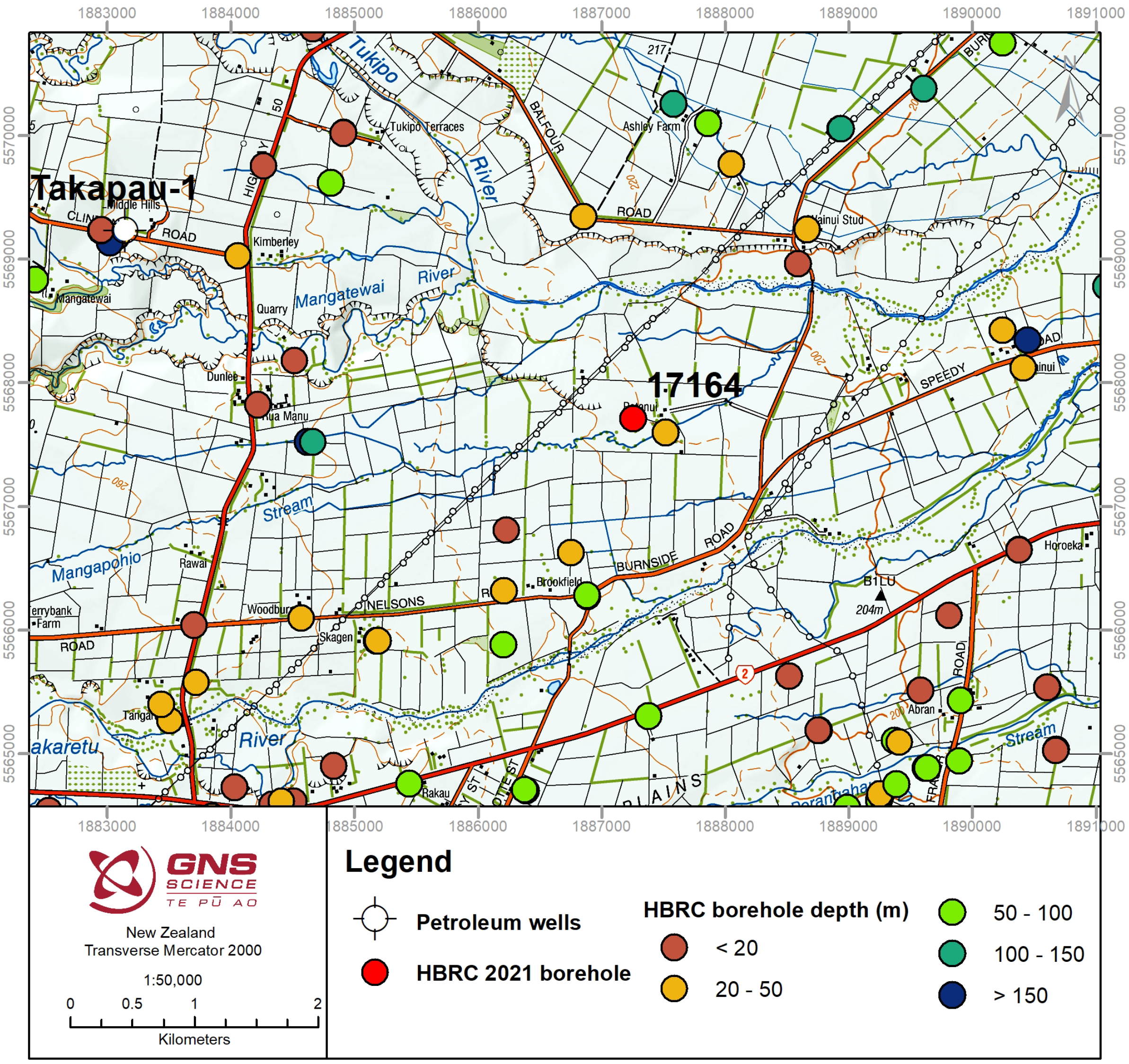

Figure 1.2 Location of the test borehole 17164 (3DAMP_Well3) near Burnside Road off Highway 2, northeast of Takapau.

Table 1.1 Borehole 17164 (3DAMP_Well3) details. Depths have been measured from the drilling reference at local ground level (GL). Relative level (RL) refers to elevation above mean sea level. Negative numbers are below sea level.

	17164 (3DAMP_Well 3)
Location (NZTM GD2000)	1887255.5 E, 5567708.0 N
Elevation (Reference)	GL 209.56 m [1]
Total Depth (TD)	79.00 m (BGL), RL 130.56 m above sea level
Location	363 Burnside Road, Takapau
Driller	Baylis Bros Ltd
Start of Drilling	28 July 2021
End of Drilling	5 October 2021

[1] GL is the drilling reference (ground level has been interpolated from LiDAR).

Table 1.2 Geology from well 1398, which is the closest well to 17164. The well was drilled in 1983 to a depth of 30 m and is located 300 m southeast of borehole 17164 (3DAMP_Well3).

From (m)	To (m)	Lithology
0	1.21	TOPSOIL
1.21	4.26	Brown CLAY with gravel
4.26	4.57	Brown GRAVEL
4.57	16.15	Brown CLAY with gravel
16.15	18.9	Brown GRAVEL
18.9	21.34	Brown/grey CLAY with gravel
21.34	23.17	Brown CLAY with sand
23.17	28.04	Brown CLAY with gravel
28.04	29.57	Brown GRAVEL with clay
29.57	29.87	Brown GRAVEL

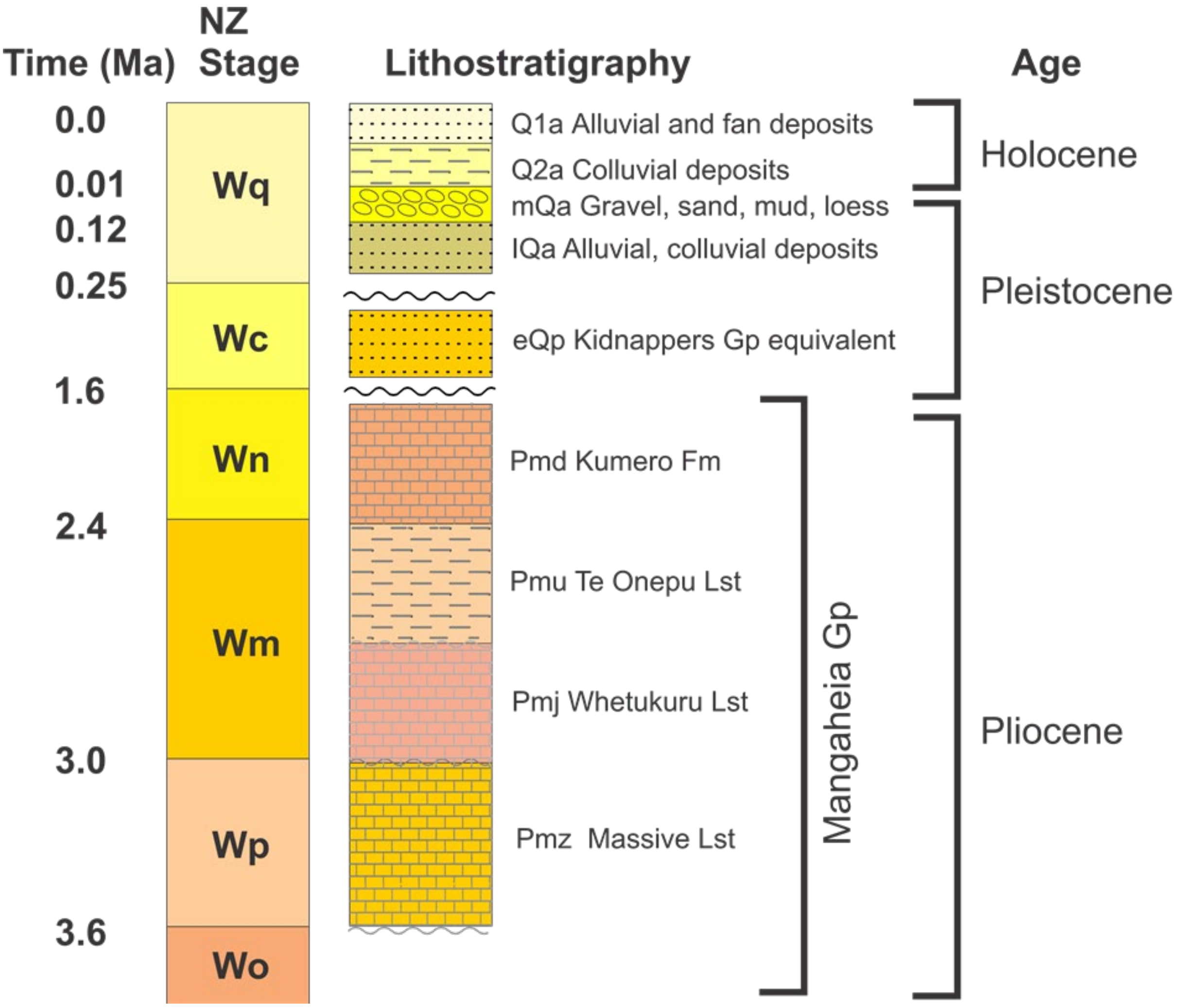

Figure 1.3 Stratigraphic column derived from the QMAP geology of the Ruataniwha Plains north of Dannevirke (Lee et al. 2020). The following abbreviations are used: Formation (Fm), Group (Gp) and Lst (Limestone) for local divisions. The New Zealand stages are Haweran (Wq), Castlecliffian (Wc), Nukumaruan (Wn), Mangapanian (Wm), Waipipian (Wp) and Opoitian (Wo).

2.0 METHODOLOGY AND FIELD DATA

2.1 TEM Survey

Two groundTEM and NanoTEM measurements were made close to the drill site prior to spudding the well. Figure 2.1 shows the location of the airborne TEM survey lines either side of the well bore and the location of the groundTEM sites. The purpose of the TEM and NanoTEM soundings are to provide a resistivity model that can be compared to the lithology of the new well and support the interpretation of the SkyTEM data (SkyTEM Australia Pty Ltd 2020).

The method and results are described in detail in Appendix 1. The data are generally of good quality for both locations. The transient decay curves are shown in Figure 2.2 for both the NanoTEM and TEM data at each site. Noisy data points were removed in both the TEM and NanoTEM soundings prior to inverting the data to derive the resistivity model. No interpretation of the results is made as part of this report, as this will be included in a later 3DAMP report.

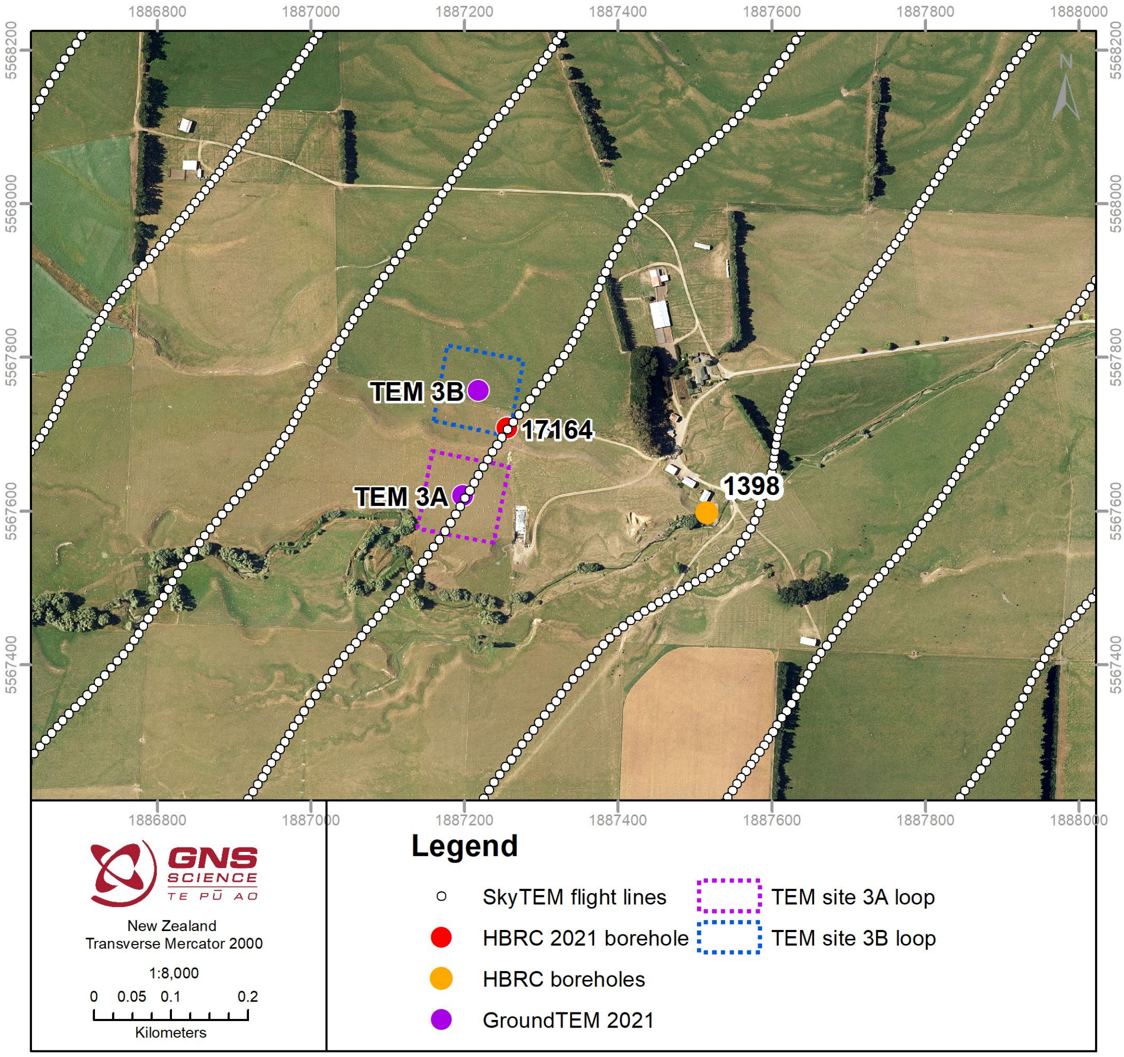

Figure 2.1 Detailed map of the well site showing the locations of the nearest SkyTEM survey points and the two GroundTEM soundings. The closest HBRC borehole is well 1398.

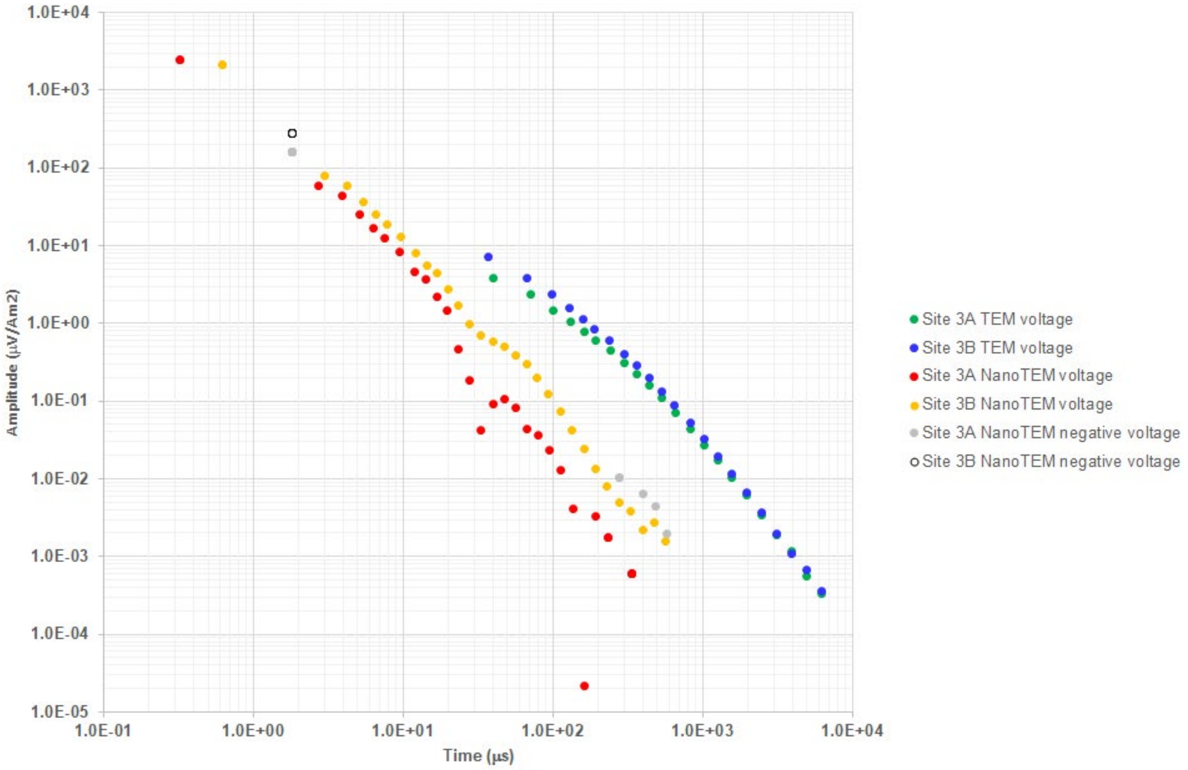

Figure 2.2 NanoTEM and TEM sounding curves for Site 3A and Site 3B.

2.2 Rig Site Operations

The scope of the project was to drill to approximately 150–180 m BGL (Section 2.2.1) and provide samples at approximately 1 m intervals for geological analysis (Section 2.2.2). Material samples were to be collected and analysed for grain size (Section 2.2.3) and resistivity (Section 2.2.5). Geophysical logging was undertaken once drilling was completed (Section 2.2.6). Five drill depths were identified for undertaking aquifer hydraulic testing (Section 2.2.7).

2.2.1 Drilling

The drilling was conducted by Baylis Bros Ltd under contract to HBRC. Three drilling methods can be employed in the construction of groundwater wells:

- rotary auger,
- cable tool, and
- rotary wash.

2.2.1.1 Rotary Auger

Augers comprise a steel drill bit that looks like a screw with curved flights that are rotated while the rig drill head applies pressure to move the bit further into the ground (Figure 2.3a). The rotation of the flights mechanically moves material to the surface. In this case, the auger was pulled out of the hole regularly so that material could be sampled directly off the bit. These bits are mainly used for initiating boreholes in soft sediments; however, initiating the well by auger drilling was deemed not necessary by the drillers.

Figure 2.3 Examples of drilling equipment: (a) auger drilling; (b) hardened drive shoe; (c) upper section of a cable tool bailer, showing piston; (d) bottom of cable tool bailer; (e) emptying cable tool bailer; (f) chisel being withdrawn from the top of the casing; (g) tricone rotary bit; (h) rotary drag bit.

2.2.1.2 Cable Tool

While this drilling method was not used for the drilling of well 17164, it is described here for comparison with the other drilling methods. Cable tool drilling involves driving lengths of casing into the ground. Casing lengths are typically in the range 2.0–4.0 m long. The casing sits in a hardened drive shoe that has a bevelled leading edge (Figure 2.3b) that aids penetration through the sediment. The cable tool or bailer (Figure 2.3c, d, e) is lowered (or run into) into the casing to remove sediment, essentially as grab samples. The bailer comprises a hollow steel cylinder with a piston at the top (Figure 2.3c) and an open flap at the base to capture the sediment (Figure 2.3d). The bailer is then withdrawn to the surface and emptied (Figure 2.3e), where a sample is collected. The tool is then run back in-hole to collect the next sample.

- Advantages:
  - Best method for obtaining sediment samples, as it minimises drilling damage to large grain sizes (i.e. gravels).
  - In unconsolidated sediment, anecdotal evidence suggests that ±0.20–0.30 m depth is gained with each individual cable tool run.
- Disadvantages:
  - Maximum grain size is limited to the interior diameter of the cable tool.
  - Sand and silt grain sizes are not always adequately sampled.
  - Poor rate of penetration through compacted lithologies.
  - Overall slow rate of penetration.

Where sediments were consolidated due to burial compaction, grain packing or cementation, the percussion technique of ‘chiselling’ is required to loosen material in order for the cable tool to penetrate. The chisel comprises a heavy steel static bit (Figure 2.3f) that is raised a short distance off the bottom of the well and then dropped repeatedly. This technique has the potential to break up large (gravel) grains, thereby skewing grain-size distributions. To some extent, damage to large grains could be recognised, and such grains were excluded to maintain representative samples.

2.2.1.3 Rotary Wash

Rotary wash drilling was used for well 17164 in preference to the cable tool. This was as a result of budgetary constraints. Rotary wash drilling employs a diamond-dipped tricone rotary bit (Figure 2.3g) or drag bit (Figure 2.3h) attached to the bottom of the drill pipe. To penetrate the sediment, the drill pipe is rotated by a diesel motor at the top of the derrick (top drive). While drilling, fluid (water or air) is cycled down and up the well. The fluid carries (or washes) the sediment out of the borehole onto a screen where it is collected.

- Advantages:
  - High rate of penetration.
  - Continuous sampling.
  - All sample sizes are brought to the surface.
- Disadvantages:
  - Potential damage to coarse grain sizes resulted in modification to the grain-size distribution.

- Sample depth control is reduced, resulting in samples representing a larger depth interval than with a cable tool.

2.2.1.4 Well 17164 Drilling Summary

- All depths are quoted as relative to ground level (m BGL) unless otherwise stated.
- Casing was driven in and rotary wash drilling commenced on 28 July 2021.
- Rotary drilling was used for the entire borehole.
- In the lower sand-dominated parts of the borehole (c. >50 m), sand commonly moved hydraulically up the well ('heaved') inside the casing overnight and had to be bailed out in the morning prior to commencing further drilling. A maximum of about 19 m of up-hole sand movement was recorded.
- The hole was terminated at a depth of 79 m BGL (total depth) on 5 October 2021 as a result of an increasingly slow rate of penetration, issues with 'heaving of running sands and associated budgetary considerations. However, due to hole conditions, such as running sands 'heaving' up the borehole, the base of the casing was set at 76.35 m BGL. To be consistent with the reports from wells 17136 and 17137 (Lawrence et al. 2021, 2022), total depth to the base of the casing (76.35 m BGL) is used unless otherwise stated.
- Some interruption of drilling and alterations to drilling plans occurred as a result of COVID-19 alert level changes.

Table 2.1 provides details of the well construction.

Table 2.1 Casing information.

Casing Type	Diameter (mm)	Top (m BGL)	Base (m BGL)
Production	200	0.0	76.35

2.2.2 Sedimentary Logging

Sediment was logged continuously as material was brought to the surface. Due to the nature of the drilling method, samples reflect an 'average' over a c. 1.0 m interval. The designated depth for each sample was taken as the middle of the sampled interval. It should be noted that samples were collected from the well with a sieve, so the finest material was not retained. The hand-drawn logs are provided in Appendix 3.

Colour was broadly based on the Munsell colour chart system; however, Munsell charts were not used *senso stricto* due to the material always being wet.

Sedimentary logging comprised visual descriptions of sedimentological texture, i.e. grain size, grain sorting and grain angularity. The nature of grain packing and orientation could not be assessed due to the drilling technique.

Standard visual comparators were used for grain size, sorting and grain roundness (Figure 2.4):

- Grain size is based on the Wentworth scale (Wentworth 1922). Grain sizes below very fine sand are difficult to visually distinguish, so the terms 'clay' and 'mud' have been used interchangeably in the field logs. Strictly, the term 'mud' refers to mixtures of silt and clay (see also Table 2.4).
- Angularity or roundness is based on silhouette charts (e.g. Krumbein 1941). A = angular, SA = sub-angular, SR = sub-rounded, R = rounded, WR = well rounded.

- Sorting is based on visual comparison (e.g. Folk 1951). P = poorly sorted, M = moderately sorted, MW = moderately well sorted, W = well sorted, VW = very well sorted.

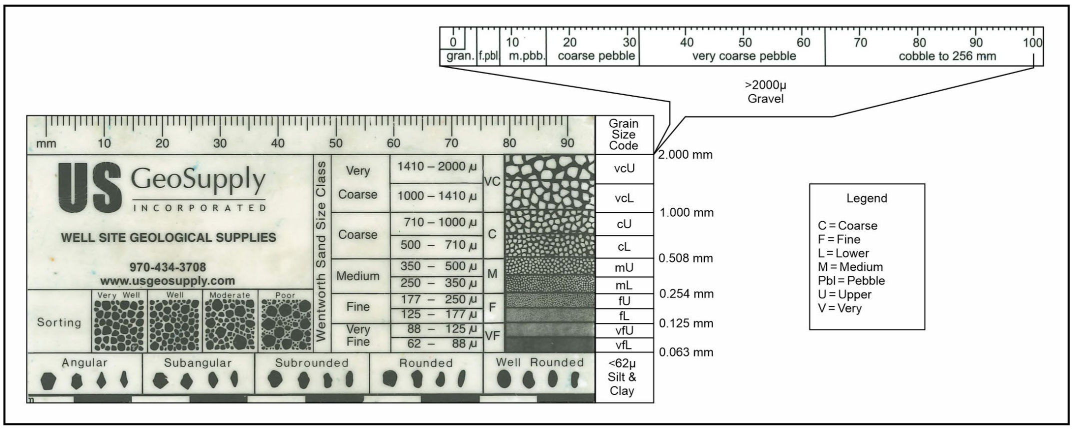

Figure 2.4 Visual comparator for grain size, sorting and grain angularity.

A summary of the lithological log and relative grain-size data is given in the composite log (Figure 2.5). Note that the grain-size curve is a visually estimated average based on the observed grain-size range.

Samples were also collected on-site by sieve for the purpose of laboratory grain-size analysis (Section 2.2.3) and resistivity measurements (Section 2.2.5). These samples were collected at a series of depths designed to be comparative to the SkyTEM data vertical resolution (Table 2.2), as well as where the on-site GNS geologist noted changes in lithology.

Table 2.2 Designated sample collection depths for well 17164.

Depth (m GL)	Depth (m GL)	Depth (m GL)	Depth (m GL)
2	10	25	40
4	15	30	50
7	20	35	70

2.2.3 Laboratory Grain-Size Analysis

Laboratory grain-size analysis was undertaken to produce more detailed and precise size distributions than could be determined in the field. Analyses were undertaken on samples obtained at the designated collection depths (Table 2.2) and on additional samples where lithological changes were noted and resistivity measurements (Section 2.2.5) were made. Sample W3BR-3 was not analysed for grain size, as clasts appeared to show drilling damage (i.e. clasts broken into fragments) and would not be representative of the sub-surface material.

2.2.3.1 Sample Pre-Treatment

Up to 2–3 kg of sediment were acquired for each sample at the rig site to ensure as representative a range of grain sizes as possible. None of the samples were lithified or cemented, so chemical sample disaggregation was not required. Organic matter and detrital carbonate material were not removed. All samples were dried at 60°C for at least 24 hours. It was noted that the drying process caused muds to form aggregates encasing coarser grains in some samples. Where this occurred, the samples were disaggregated again by soaking in water and then wet-sieved through a 1 mm mesh sieve. The coarse (>1 mm) and fine (<1 mm) fractions were then dried again at 60°C for at least 24 hours.

2.2.3.2 Mechanical Sieving

Mechanical sieving was undertaken on the ≥1.0-mm-size fraction using the sieve stack detailed in Table 2.3. Sieves were shaken using a Retsch Vibro mechanical sieve shaker (Figure 2.6) for 15 minutes (e.g. McManus 1988), and the material retained on each sieve was weighed. Results are reported as weight percent for each grain-size class. Estimated uncertainty is less than 2%. Sediment that passed through the 1.0 mm sieve was caught in a pan at the base of the sieve stack. The pan material was weighed and set aside for laser diffraction grain-size analysis.

Table 2.3 Sieve stack used for grain-size analysis of the ≥1.0 mm fraction, well 17164. The size class refers to the material retained on each sieve and is defined in Figure 2.4. Note that laboratory grain sizes can be reported as millimetres, microns or Φ units ($\Phi = -\log_2$ mm).

Sieve Mesh Aperture (mm)	Sieve Mesh Aperture (μ)	Φ Value	Size Class
32	32,000	-5.0	Very coarse pebble and larger
16	16,000	-4.0	Coarse pebble
11.2	11,200	-3.5	Upper medium pebble
8	8000	-3.0	Lower medium pebble
4	4000	-2.0	Fine pebble
2	2000	-1.0	Granule
1.4	1400	-0.5	vcU sand
1	1000	0.0	vcL sand

2.2.3.3 Laser Diffraction Analysis

Laser diffraction analysis was undertaken on the <1.0-mm-size fraction using a Beckman Coulter LS 320 Laser Diffraction Particle Size Analyser (Beckman Coulter 2003). Only a few grams were required for each analysis. Three separate sub-samples were run to ensure repeatability (i.e. precision). Raw results were output as volume percent for each grain-size range. Estimated uncertainty is less than 2%.

2.2.3.4 Results

Samples where both analytical techniques were required necessitated data being combined and normalised to weight percent to produce an overall grain-size distribution. Statistical analysis of the data was undertaken using a Microsoft-Excel-based computational programme called GRADISTAT (Blott and Pye 2001). The grain-size ranges and descriptive terminology used in the GRADISTAT package are defined in Table 2.4.

Initial results are illustrated in Figure 2.7, with key points summarised below:

1. The finest grain sizes are generally in the coarse silt range, which matches findings from the field where most of the so-called clays felt silty or sandy.
2. Sands generally tend to be variably muddy (5–48%), and there are four sandy muds. These sands and sandy muds constitute what the drillers refer to as ‘running sands’.
3. Gravels are dominantly sandy or muddy (>20%), with eight classified as ‘muddy sandy’ gravels.
4. The majority of samples analysed fall into four broad groups with no overlap, outlined in blue in Figure 2.7.

Table 2.4 GRADISTAT software package definitions summarised from Blott and Pye (2001). The Wentworth (1922) scale is included for comparison. Statistical formulae are modified from Folk and Ward (1957), where P_x = grain diameter in millimetres at the cumulative percentile value of x.

Grain Size		**Descriptive Terms**		
ϕ (-$\log_2$ size mm)	mm and µm	GRADISTAT Programme	Wentworth 1922 and others	
		Very coarse gravel or pebbles	Pebbles	Gravel
-5	32 mm	Coarse gravel or pebbles		
-4	16 mm	Medium gravel or pebbles		
-3	8 mm	Fine gravel or pebbles		
-2	4 mm	Very fine gravel or pebbles	Granules	
-1	2 mm	Very coarse sand	Very coarse sand	Sand
0	1 mm	Coarse sand	Coarse sand	
1	500 µm	Medium sand	Medium sand	
2	250 µm	Fine sand	Fine sand	
3	125 µm	Very fine sand	Very fine sand	
4	63 µm	Very coarse silt	Silt	Mud
5	31 µm	Coarse silt		
6	16 µm	Medium silt		
7	8 µm	Fine silt		
8	4 µm	Very fine silt	Clay	
9	2 µm	Clay		

Mean (M_G)	$M_G = \exp \frac{\ln P_{16} + \ln P_{50} + \ln P_{84}}{3}$	Measure of the average grain size.
Standard deviation (σ_G)	$\sigma_G = \exp\left(\frac{\ln P_{16} - \ln P_{84}}{4} + \frac{\ln P_5 - \ln P_{95}}{6{\cdot}6}\right)$ Very well sorted <1.27 Well sorted 1.27–1.41 Moderately well sorted 1.41–1.62 Moderately sorted 1.62–2.00 Poorly sorted 2.00–4.00 Very poorly sorted 4.00–16.00 Extremely poorly sorted >16.00	Spread about the average, which is a measure of grain-size sorting.
Skewness (Sk_G)	$Sk_G = \frac{\ln P_{16} + \ln P_{84} - 2(\ln P_{50})}{2(\ln P_{84} - \ln P_{16})} + \frac{\ln P_5 + \ln P_{95} - 2(\ln P_{50})}{2(\ln P_{25} - \ln P_5)}$ Very fine skewed -0.3 to -1.0 Fine skewed -0.1 to -0.3 Symmetrical -0.1 to +0.1 Coarse skewed +0.1 to +0.3 Very coarse skewed +0.3 to +1.0	Distribution asymmetry, which provides an indication of whether there is more fine (- skewness) or coarse (+ skewness) material present.
Kurtosis (K_G)	$K_G = \frac{\ln P_5 - \ln P_{95}}{2{\cdot}44(\ln P_{25} - \ln P_{75})}$ Very platykurtic <0.67 Platykurtic 0.67–0.90 Mesokurtic 0.90–1.11 Leptokurtic 1.11–1.50 Very leptokurtic 1.50–3.00 Extremely leptokurtic >3.00	Distribution 'peakedness', which is another measure of sorting. Platykurtic indicates poor sorting and leptokurtic indicates good sorting.

2.2.4 Radiocarbon Ages

Radiocarbon dating was not undertaken on samples from well 17164.

2.2.5 Resistivity Measurements

The SkyTEM airborne TEM survey and groundTEM sounding produce models of the electrical resistivity of the sub-surface. Any information on the resistivity of the sediments from samples collected while drilling will be useful in helping to refine the relationships between lithology, clay content, porosity, permeability and bulk resistivity derived from the geophysical inversions.

A measurement of electrical resistivity was made on samples of the unconsolidated sediments using a Miller cell. A Miller cell utilises four electrodes to calculate the electrical resistivity of a sample consistent with the American Standard for Testing Materials requirements (ASTM G-57-06; ASTM International 2020). The samples were placed into a plexiglass rectangular cell and a DC current (I) was passed between the end caps, while the voltage drop (V) was measured using two probes located at set distances along the sample using an Iris Syscal Pro resistivity meter. The resulting resistance (R = V/I) calculated from the input current and observed voltage was corrected for the geometry of the cell and translated into a bulk resistivity for the sample in units ohm.m. Good-quality measurements require minimal disturbance of the sample between collecting the sample and inserting it into the cell. In-situ conditions can be maintained by using fluid from the well at the same depth to saturate the sample.

The error in the observed voltage (V) and the value of the contact resistance (R) were also measured using the Iris Syscal Pro resistivity meter. Contact resistances were generally below 10 k ohm, but there is a strong positive linear correlation between contact resistances and bulk resistivity. The average error on the observed voltage is 52 mV, resulting in an average uncertainty of +/- 2 ohm.m for the calculated resistivity.

Measurements were made by filling the Miller cell with a saturated typical sample of the sediment. As there is no way of determining in-situ sediment packing or grain orientation in the sub-surface (Section 2.2.2), the cell was simply filled with as much sediment as possible, gently tapped down but not compacted. For poorly sorted coarse gravels, it was ensured that large grains were always surrounded by fine material. All visible pore space in the cell had to contain water to ensure saturation and, in some cases, additional water had to be added. For practical purposes, the small Miller cell (area = 30 x 24 mm^2, pin separation = 72 mm) was used for more clay-rich samples, while the larger Miller cell (area = 40 x 32 mm^2, pin separation = 128 mm) was used for sands and gravels. The results of the sampling are given in Appendix 4, and the resistivity data are shown in Figure 2.8. The data are also included in the composite log (Figure 2.9).

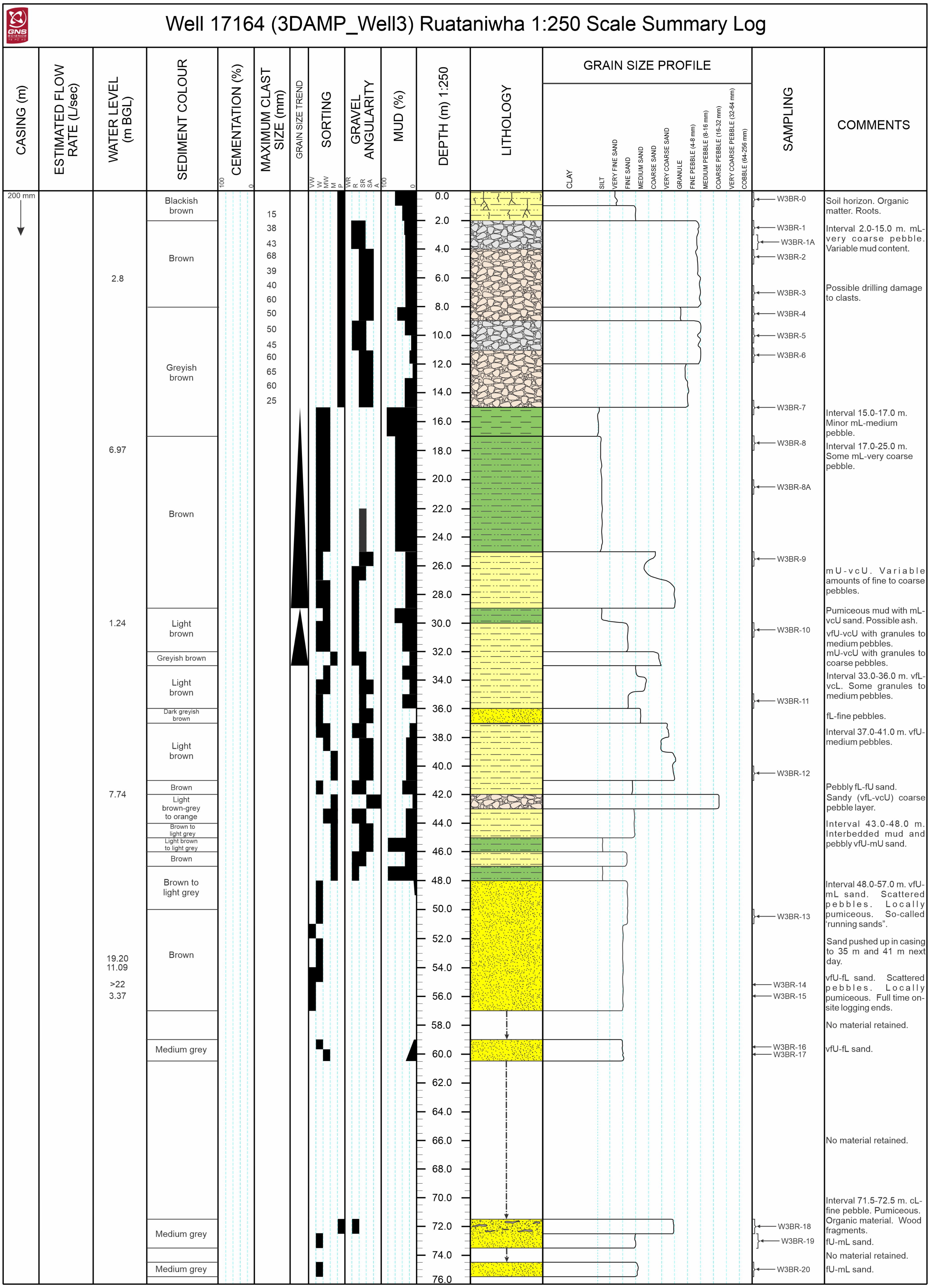

Figure 2.5 1:250-scale summary lithological log for well 17164 (3DAMP_Well3) (legend on next page). Grain-size codes used in the log are described in Figure 2.4.

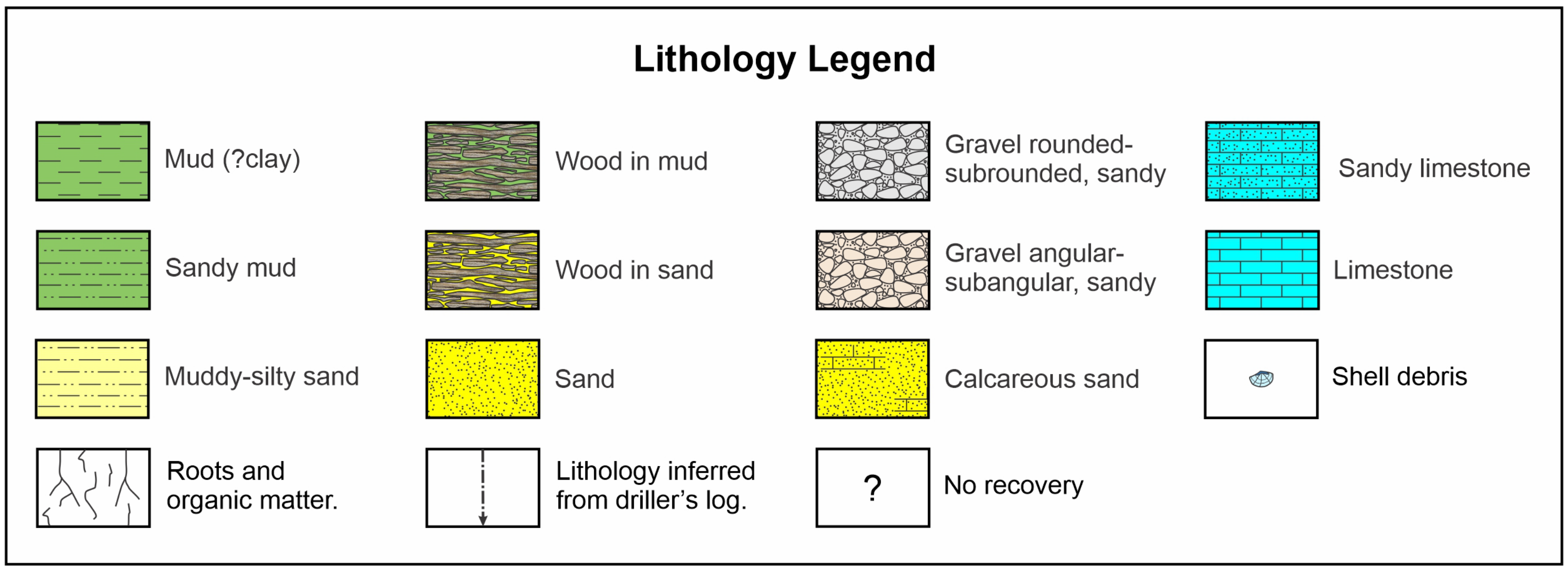

Figure 2.5 1:250-scale summary lithological log for well 17164 (3DAMP_Well3) (legend).

Figure 2.6 Laboratory grain-size analysis equipment: (a) sieve stack, (b) Coulter LS 13 320 Laser Diffraction Particle Size Analyser.

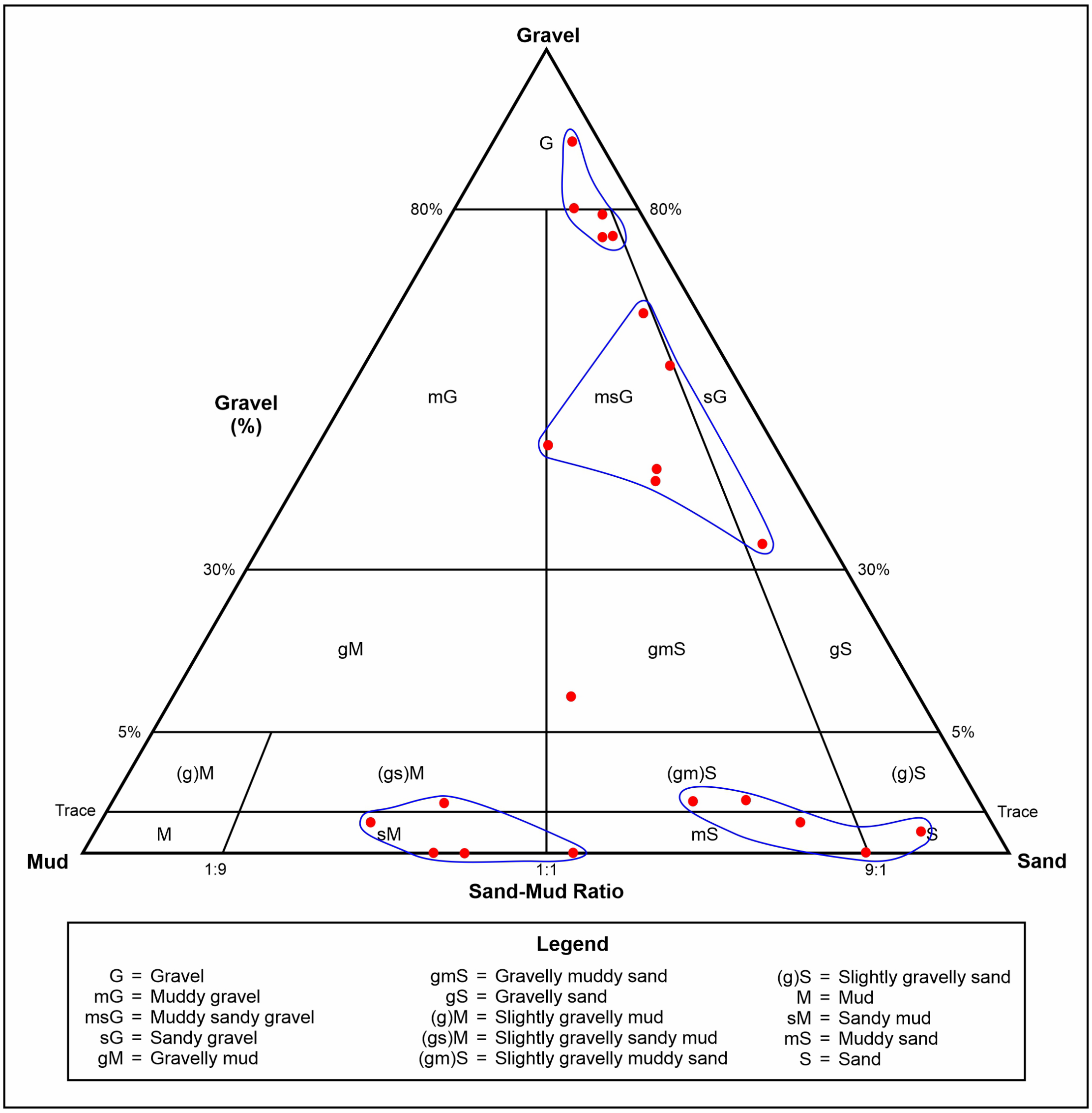

Figure 2.7 Ternary diagram summary of laboratory-derived grain-size results (after Folk et al. 1970).

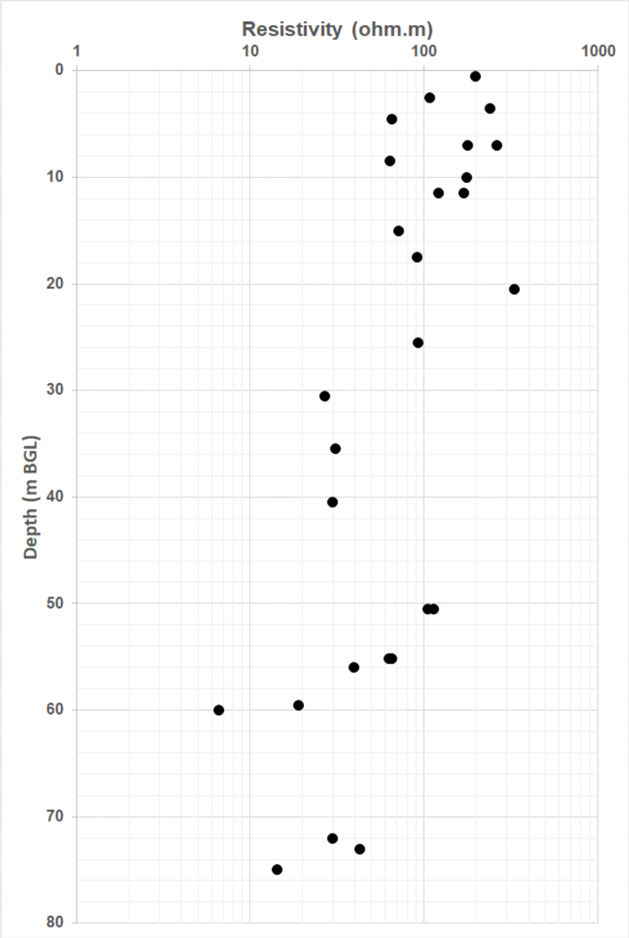

Figure 2.8 Resistivity measured on samples collected during drilling of the borehole.

2.2.6 Wireline Logs

Geophysical data can also be obtained using tools that are lowered into the borehole to measure physical properties of the formations in open boreholes or beyond the casing. In groundwater wells, the small diameter of the hole and the logistical difficulty of getting access to an open hole during drilling restricts the type of measurements that are possible. Only logging tools that can detect the formation through steel casing were able to be used at the well location. For the wells being drilled as part of 3DAMP, New Zealand company RDCL Limited was contracted to collect the geophysical logs using their slim-hole Mount Sopris logging system and the Century Coal Combination Sonde (CCS). The logging suite collected in the cased hole included:

- natural gamma (GR),
- density (long-spaced, short-spaced and compensated), and
- caliper.

GR measurements are sensitive to the concentrations of potassium, thorium and uranium in the sediments. Fine-grained and clay-rich sediments have higher concentrations than coarse-grained sand and gravels. The readings are output in standard API (American Petroleum Institute) format and are relative unless the tool is calibrated against a standard. The density tool measures the energy scattered back from geological units when they are exposed to a source of neutrons. This scattered energy is interpreted in terms of particle density. The two depths of investigation (long-spaced and short-spaced) investigate different volumes around the borehole and are combined in the compensated reading to produce a standard bulk density in kg/m^3. The caliper measurement is made at the same time as the density measurement by pushing the tool against the side of the borehole using a sprung arm. Changes in the diameter of the borehole are detected by the movements of the arm, with units in millimetres (Rider 1996).

The data were collected on 12 October 2021. The hole was logged from ground level to 69.97 m BGL depth. A repeat run was made between 16.61 and 29.80 m BGL. There is no conductor casing in the well, but the data were collected through 200 mm steel casing for the entire length of the well. The density values are relative not absolute due to the presence of metal casing.

The detailed wireline logs are included as Appendix 5, with the raw data in the supplemental material in Log ASCII Standard (LAS) format. A composite summary log of the wireline logs, lithology information and sample resistivity are provided in Figure 2.9.

Despite being logged though steel casing, the gamma ray log shows variations between 50 and 150 API that correlate with the changes in lithology. The interval between 25 and 60 m (BGL) has a gamma ray response that tracks the alternating sand, silt and clay units.

The density log shows anomalously low values (1.5 to 2.5 g/cc) that may be caused by the steel casing. The density logs show a change in character at 38.27 m BGL that may be related to hole conditions behind the casing; however, such changes are not mentioned in the drillers’ notes. The logging company (RDCL Limited) identified several zones of potential wash-outs or cave-ins behind the casing at 8.26–9.91 m BGL, 59.21–60.28 m BGL and 65.91–66.88 m BGL (see Appendix 5). The geophysical logs are not reliable over these zones. The interpretation stage will include more detailed analysis of the wireline geophysical logs and other geological data to verify the effects of borehole wall collapse on the records from the well.

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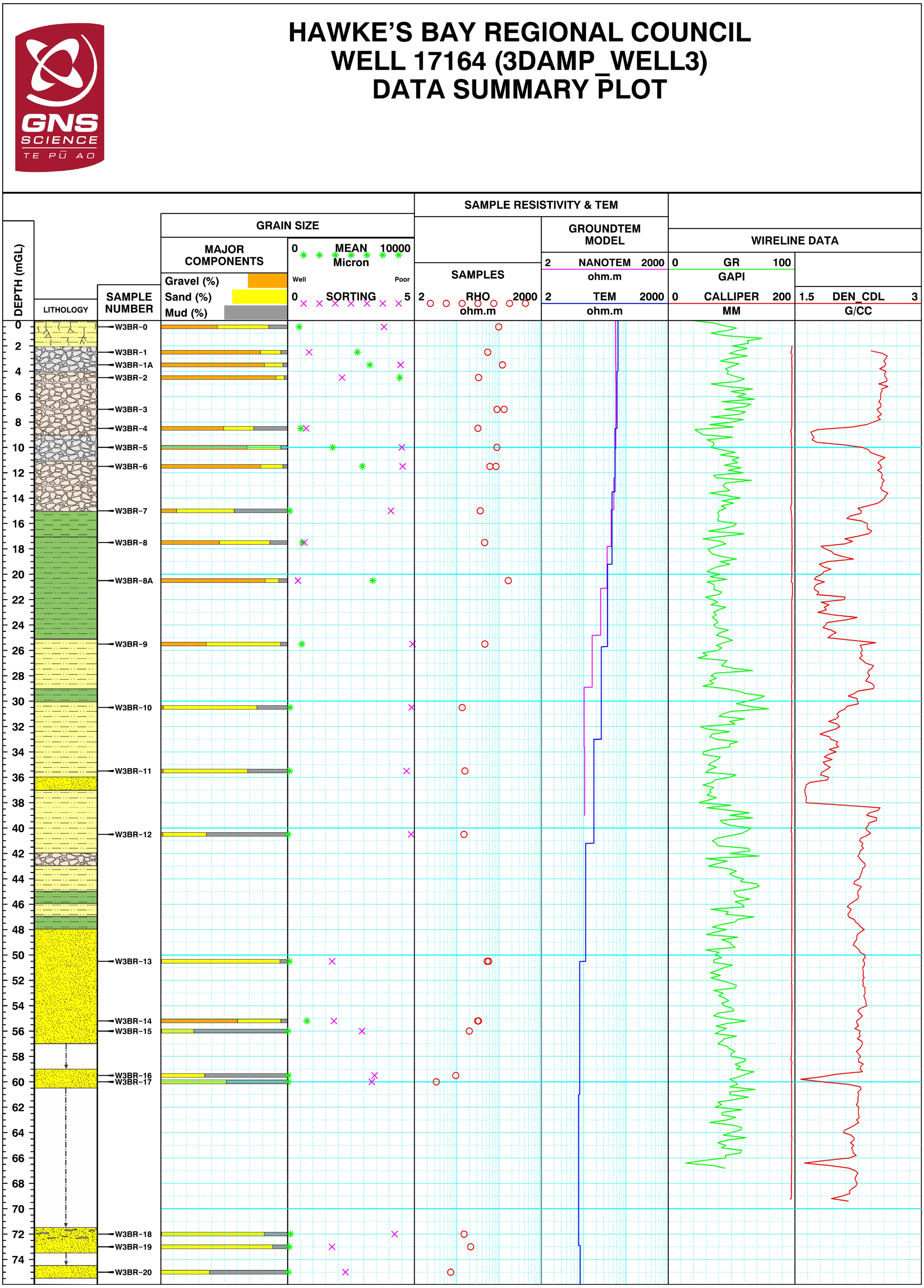

Figure 2.9 Composite summary log of lithology, sample locations, grain size, sample resistivity (RHO), groundTEM models (resistivity) and wireline logs (GR = gamma; DEN_CDL = compensated density). Note that the lithology here has been interpreted over intervals of poor recovery and where there is only information from the driller. See Figure 2.5 for lithology track legend.

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2.2.7 Aquifer Testing

No pumping test was conducted at well 17164.

A series of slug tests were conducted at multiple depth intervals at well 17164 between August and October 2021, exhibiting potentially different hydraulic properties: 5.46 m, 18.0 m, 55.22 m and 76.35 m BGL. An approximate depth of the slug tests was agreed on prior to the start of the drilling, with the aim of obtaining hydraulic properties of the layers possibly encountered at those depths. However, the exact depth was adjusted while drilling once the lithologies of interest were attained.

Slug tests are efficient at testing different hydraulic property layers quickly. They can be done in low as well as high permeability layers and can be repeated multiple times to ensure good-quality results. However, slug tests only give an indication of the hydraulic properties of the tested layer in the immediate vicinity of the bore (i.e. only a few metres radius). Once a layer or lithology of interest was attained, drilling stopped for the duration of the tests, and enough time was left prior to the start of the tests, if possible, for the water level to reach static level. Most slug tests were performed the morning after drilling was stopped. Well 17164 had a 1.2 m screen sitting at the bottom of the casing 0.150 m above the casing shoe (casing diameter of 200 mm [8"]). During most slug tests, one or two GNS employees were present on site to undertake the tests, and the driller from Baylis Bros Ltd stayed on site during the entirety of the tests to ensure that safety measures were observed around the drilling site.

Based on the lithology encountered while drilling (Figure 2.5) and the water level measured at the beginning of each slug test (Table A7.1), we assume the layer encountered during slug test 1 at 5.46 m BGL to be an unconfined aquifer, with the base defined by the clay layer encountered during slug test 2 at 18.0 m BGL. We also assume the layers encountered during slug tests 3 and 4 (at 55.22 m and 76.35 m BGL, respectively) to be a confined aquifer, with the top of this aquifer at 48.0 m BGL. We have assumed the total drilled depth of 79.0 m BGL to be the base of this aquifer.

For most tests, a Level TROLL 700 data logger and a HOBO Bluetooth data logger were utilised to record water level fluctuations at 250 ms and 1 s time intervals, respectively. The HOBO Bluetooth data loggers, being vented, self-compensate for barometric pressure changes. The Level TROLL 700 data loggers utilised are non-vented and do not self-compensate for barometric changes, meaning that the data needed to be corrected afterwards. Out of the six slugs available, two different-sized slugs were selected depending on the observed layer conditions prior to the tests. For example, in a layer where lower permeability was expected, the smallest slug was utilised to start with; however, in a gravel layer where good permeability was expected, the biggest slug was utilised first. Both slugs were not always selected at each depth; for example, in a low permeability layer, only the smallest slug could be utilised for all repeats, decreasing the amount of time needed for the water level to recover back to static. Slugs and loggers were attached to a non-moving part of the drilling rig to ensure good data-recording precision (Figure 2.10).

A HOBO Bluetooth data logger was utilised to record barometric pressure on-site during slug tests 2, 3 and 4. For slug test 1, barometric data from the Waipawa weather station, recorded every 10 minutes, was obtained from New Zealand’s Climate Database web portal CliFlo (NIWA c2022) was used. The barometric pressure data was then utilised to correct water-level data for barometric pressure variations.

All water-level data recorded with the Level TROLL 700 data logger that displayed a non-negligible impact of barometric pressure was corrected prior to being analysed. Additional barometric correction details and results are given in Appendix 7.

Figure 2.10 Picture of the slug test settings: (a) the yellow cord holding the slug and the red cord holding the two data loggers' cables were attached to a fixed part of the rig; (b) close-up picture of the red and yellow cords.

Each series of slug tests was individually analysed, when possible, using AQTESOLV software. Water-level data obtained during the slug tests at 5.46 m BGL were of good quality, and all data at this depth has been analysed. Some issues occurred in the data obtained during slug tests at 18.0 m and 55.22 m BGL; therefore, not all data from these depths has been analysed, and the confidence in the results is not particularly high (more details of the analysis are given in Appendix 7). Finally, the data obtained during slug tests at 76.35 m BGL could not be analysed, as the water level was not stable prior to the start of the tests. A summary of the results is provided in Table 2.5. An individual description of the test conditions, setting details, analysis and results is given in Appendix 7.

Slug test 1 was undertaken in an unconfined layer comprising of poorly sorted gravel. Slug test 2 was undertaken in a moderately well to well-sorted clay layer. Slug tests 3 and 4 were undertaken in running sand layers. In these layers, the sands 'heaved' up the inside of the casing to above the top of the screen; therefore, the well screen was entirely covered by the sand (Table 2.5).

Table 2.5 Summary table of the settings for each slug test series and the average hydraulic conductivity K per series. A negative static water level indicates a water level below ground level (BGL); a positive static water level indicates a water level above ground level (AGL). Slugs 2 and 6 have a volume of 5.76 L and 1.30 L, respectively.

	Slug Test 1	**Slug Test 2**	**Slug Test 3**	**Slug Test 4**
Date	02/08/2021	04–05/08/2021	09–10/09/2021	08–11/10/2021
Casing Depth (m BGL)	5.46	18.0	55.22 *	76.35 *
Screen Interval (m BGL)	4.107 5.307	16.65 17.85	53.87 55.07	75 76.2
Bottom of Bore (m BGL)	-	-	52.42 (09/09/2021) * 51.64 (10/09/2021) *	69.76 (08/10/2021) * 69.71 (11/10/2021) *
Depth of Logger / Slug (m BGL)	4.7 / 2.34	14.14 / 2.5	12.34 / 0.33 (m AGL)	13.3 / 1.0
Static Water Level (m AGL)	-1.74	SWL not reached **	SWL not reached **	SWL not reached **
Slug Number (Slug Volume)	6 (1.30 L)	2 (5.76 L) and 6 (1.30 L)	6 (1.30 L)	6 (1.30 L)
Primary Lithology	Gravel	Clay	Running sand	Running sand
Average K (m/day)	0.875	0.250***	0.011***	No analysis possible **

* During slug tests 1 and 2, the bottom of the bore corresponds to the casing depth. However, for slug tests 3 and 4, the sand moved back above the top of the screen; therefore, the bottom of the bore was higher than the base of the casing.

** Static water level prior to slug tests 2, 3 and 4 was not reached; therefore, no analysis was undertaken (more detail is provided in Sections A7.3, A7.4 and A7.5).

*** Low confidence in this value due to quality of the data.

2.2.8 Groundwater Chemistry

No samples were collected for water-quality analysis at this well.

3.0 DIGITAL DELIVERABLES

The data obtained during the drilling of this well is provided in a series of digital files. Table 3.1 describes the file names and data types.

Table 3.1 File names and data format of data obtained during drilling.

	File Names	Data Format
GroundTEM Data	S3A_NTEM.usf S3A_TEM.usf S3B_NTEM.usf S3B_TEM.usf	ASCII tables of raw data in Universal Sounding File Format
Geophysical Logs	Appendix_5_WELL3_BURNSIDE_ROAD_FINAL.las	Log ASCII Standard (LAS) format
Sample Resistivity	Appendix 4 Sample Resistivity.xlsx	Excel spreadsheet
Slug Test Data	SlugTests5m46_02-08-2021.xlsx SlugTests18m_05-08-2021.xlsx SlugTests55m22_09-09-2021.xlsx SlugTests76m35_08-10-2021.xlsx	Excel spreadsheets
Slug Test Analysis	5m5_Bluetooth_Slug6ain.aqt 5m5_Bluetooth_Slug6aout.aqt 5m5_Bluetooth_Slug6bin.aqt 5m5_Bluetooth_Slug6bout.aqt 5m5_Bluetooth_Slug6cin.aqt 5m5_Bluetooth_Slug6cout.aqt 5m5_Slug6ain_barocorr.aqt 5m5_Slug6aout_barocorr.aqt 5m5_Slug6bin_barocorr.aqt 5m5_Slug6bout_barocorr.aqt 5m5_Slug6cin_barocorr.aqt 5m5_Slug6cout_barocorr.aqt	AQTESOLV software analysis files
Lithology Log	Digital_Lithology_Log_17164.xlsx	Excel spreadsheet
Grain Size	GrainSize_17164_Well3.xlsx	Excel spreadsheet

4.0 SUMMARY

1. Well 17164 was drilled as part of the Hawke’s Bay 3D Aquifer Mapping Project (3DAMP) to assist with the interpretation of the SkyTEM data.
2. A set of groundTEM and NanoTEM measurements was made at the drill site prior to spudding the well.
3. The proposed maximum depth for well 17164 was 150–180 m BGL.
4. The well was spudded on 28 July 2021 and terminated at a depth of 79 m BGL (total depth) on 5 October 2021, with the base of the casing set at 76.35 m BGL. The proposed maximum depth was not reached because of the increasingly slow rate of penetration, issues associated with heaving of running sands and associated budgetary decisions.
5. A continuous sedimentary log was produced to a depth of 57.0 m BGL. Below this depth, spot samples were provided by the drillers where changes in lithology were observed.
6. A total of 22 lithological samples were acquired for later laboratory analysis. The electrical resistivity of all of these samples has been analysed.
7. Wireline logs (natural gamma, density) were acquired through casing to a depth of 69.97 m BGL.
8. Four slug tests were conducted at 5.46 m, 18.0 m, 55.22 m and 76.35 m BGL. No pumping tests were undertaken or water samples collected from this well.

5.0 ACKNOWLEDGEMENTS

The authors acknowledge the work of the team at Baylis Bros Limited Drilling, without whom the well would not have been completed. They provided excellent assistance during all on-site operations. All work was carried out under the watchful eyes of Simon Harper (Hawke's Bay Regional Council) and project manager Amanda Langley (Project Haus). The GNS Science NZGAL laboratory (Wairakei) aided with water sampling analysis, the GNS Science Tritium and Water Dating Laboratory (Lower Hutt) provided the age-dating analysis and the GNS Science Rafter Radiocarbon Laboratory (Lower Hutt) produced the ^{14}C dates. Akansha Sirohi assisted with the GNS Science laser grain-size analysis. Thorough internal GNS Science reviews of the document were provided by Conny Tschritter and Stewart Cameron. Simon Harper (Hawke's Bay Regional Council) was the external reviewer. The final formatting was done by Kate Robb. This work has been jointly funded by the New Zealand Government's Provincial Growth Fund, Hawke's Bay Regional Council and GNS Science's Strategic Science Investment Fund (Ministry of Business, Innovation & Employment).

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APPENDICES

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APPENDIX 1 TEM MEASUREMENTS

The method and equipment used for the TEM measurements are the same as for previous TEM soundings in the Hawke's Bay (Reeves et al. 2019) and are summarised below.

An 'in-loop' standard set of TEM and NanoTEM measurements was made (Nabighian and Macnae 1991). NanoTEM measurements record very early decay-time responses of the electromagnetic wave to obtain higher-resolution data in the near-surface compared to the standard TEM method that is used to target deeper structures. The centre point of the site was the same for both the standard TEM and NanoTEM soundings and was measured with a GPS. The centre point of the TEM sounding was made as close as possible/practicable to the location of the proposed borehole. The TEM sounding was made before the exploratory bore was drilled.

The following equipment was used for the measurements:

- Standard TEM: Zonge GDP32 receiver, a battery-powered Zonge NT-20 multi-purpose TEM transmitter, TEM3 receiver magnetic coil for vertical measurements only (effective area 10,000 m^2) and 400 m of single-core electrical wire arranged into a square loop, having nominal 100-m-long edges.
- NanoTEM: Zonge GDP32 receiver; a battery-powered Zonge NT-20 multi-purpose TEM transmitter; 20 m of single-core electrical wire arranged into a square loop, with 5 m edges as the receiver; and 80 m of single-core electrical wire arranged into a square-shaped loop, with 20 m edges as the transmitter loop.

The loop resistance was checked once all equipment was connected. Data were collected using a 32 Hz switching (square wave) with transmitter electrical currents of approximately 1.8A for the standard TEM and 2.8A for the NanoTEM. Ramp time (the time it takes for the electrical current to reduce to zero when switching) for the standard TEM was measured prior to each sounding and was set to 75 µs, and the NanoTEM ramp time was set to 1.5 µs, as per the Zonge manual. At least three sets of 8192 (and 4096 for the NanoTEM) measurements were collected and stacked to produce a high signal to noise ratio. The first five TEM data blocks were collected with an incorrect polarity (and therefore not used). This was rectified in the field, and additional data blocks were recorded with the correct polarity.

The raw TEM and NanoTEM data were converted into Universal Sounding Format (USF) and imported into the Aarhus Geosoftware SPIA TEM processing software (Auken et al. 2015). The individual data points in the transient decay curves were reviewed, and noisy data were removed to improve the signal quality. The NanoTEM and TEM data were inverted separately to find the best-fitting sparse-layered and smooth models. The smooth models comprise 20 layers.

A1.1 Results and Modelling

Two sets of GroundTEM soundings were collected at borehole 17164. Site 3A (centred on NZTM grid reference 1887198E 5567620N) was surveyed on 28 April 2021. The first location was not suitable for drilling due to surface infrastructure, so a second survey was made at site 3B (centred on NZTM grid reference 1887218E 5567757N) on 28 May 2021. The TEM and NanoTEM data from both sites are generally of good quality, and both layered and smooth resistivity models have been generated for the locations. In all models, the green dashed line shows the calculated depth of investigation (DOI) that refers to the depth to which the resistivity model is deemed valid. Site 3B is considered to be the most representative of the drilling locations, and the models are shown in Figures A1.1, A1.2, A1.3 and A1.4. The models for Site 3A are shown in Figures A1.5, A1.6, A1.7 and A1.8.

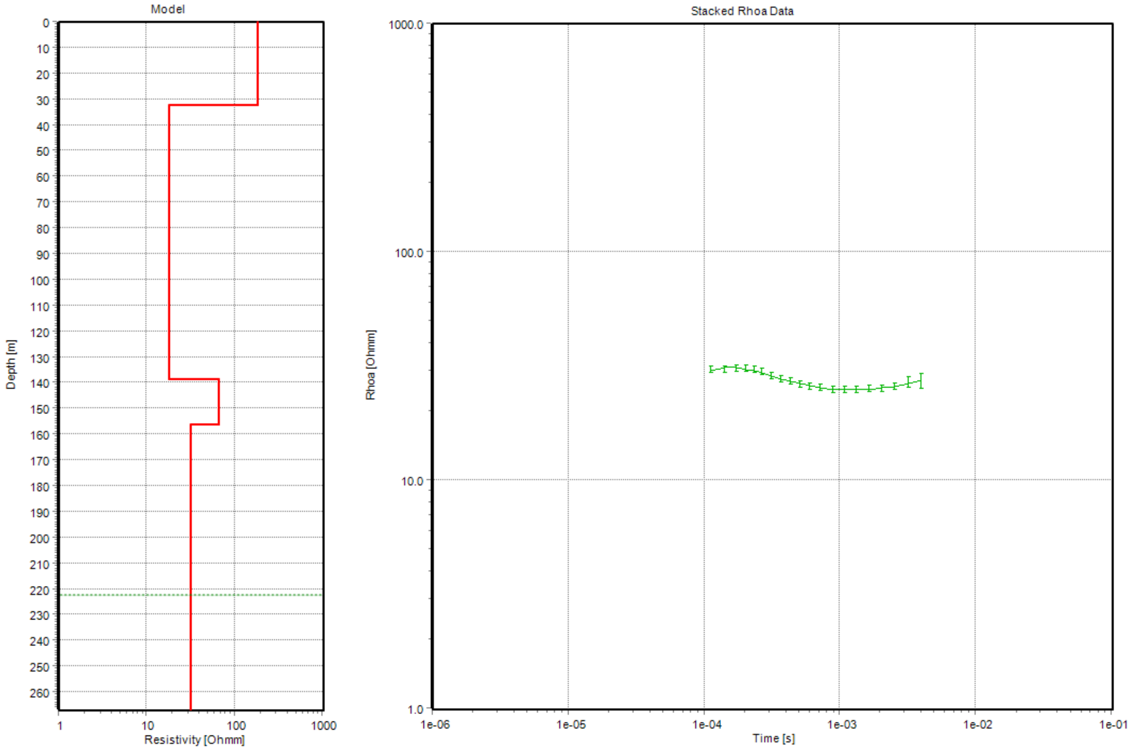

Figure A1.1 Site 3B. Layered resistivity model with depth for the TEM data (left). DOI is 220 m. TEM data and model fit (right).

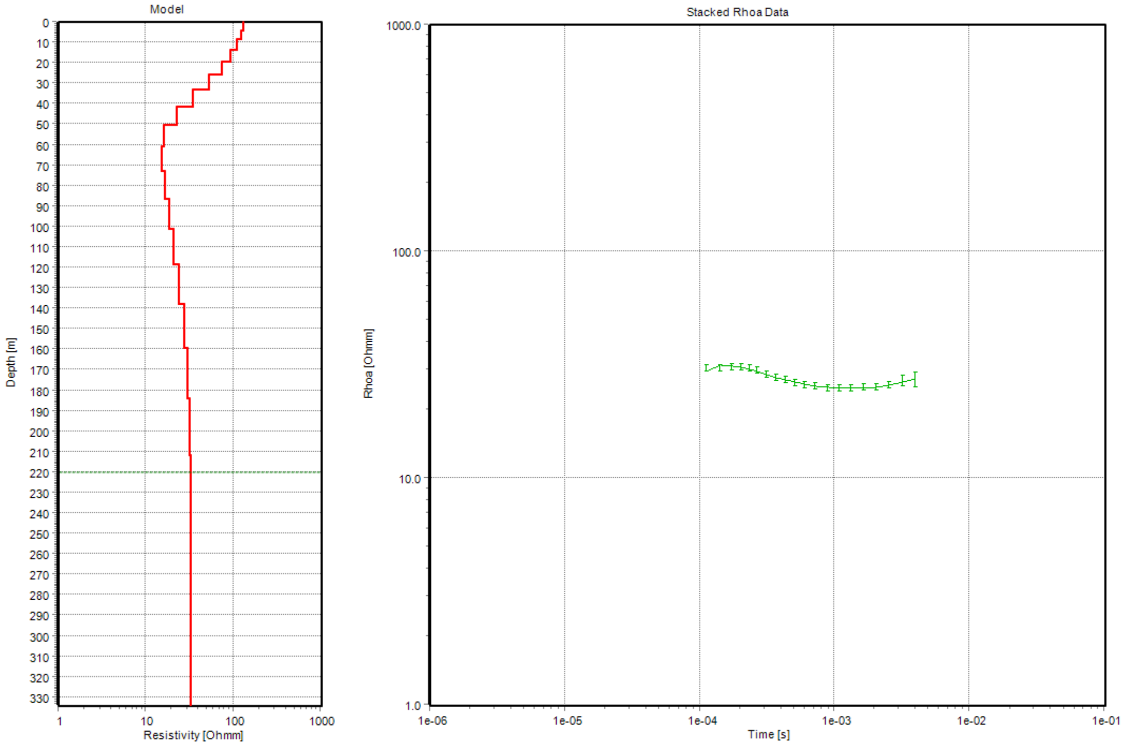

Figure A1.2 Site 3B. Smooth resistivity model with depth for the TEM data (left). The DOI is 220 m. TEM data and model fit (right).

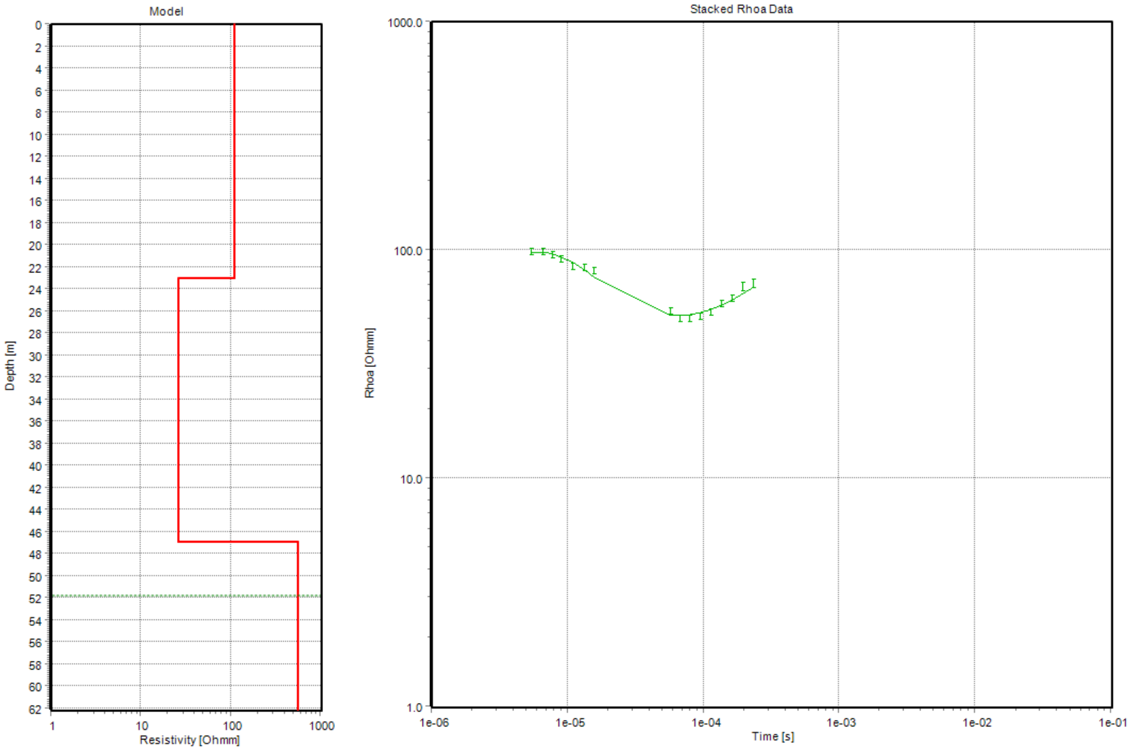

Figure A1.3 Site 3B. Layered resistivity model with depth for the NanoTEM data (left). The DOI is 52 m. NanoTEM sounding curve and model fit (right).

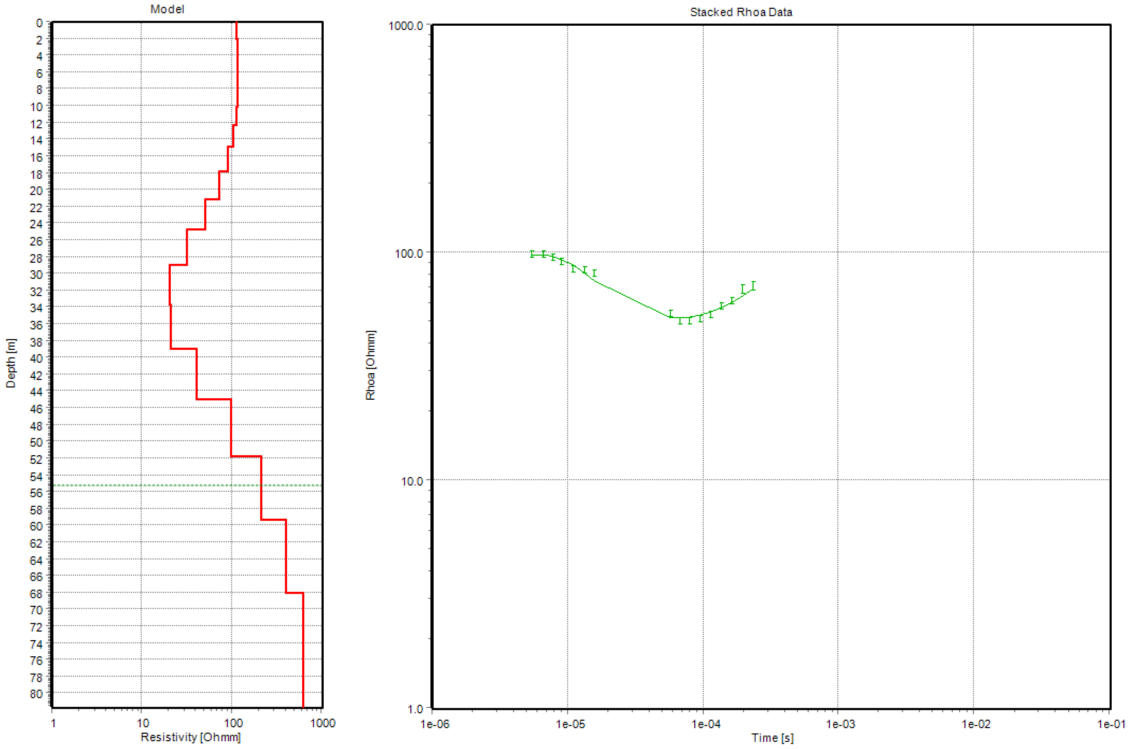

Figure A1.4 Site 3B. Smooth resistivity model with depth for the NanoTEM data (left). The DOI is 55 m. NanoTEM sounding curve and model fit (right).

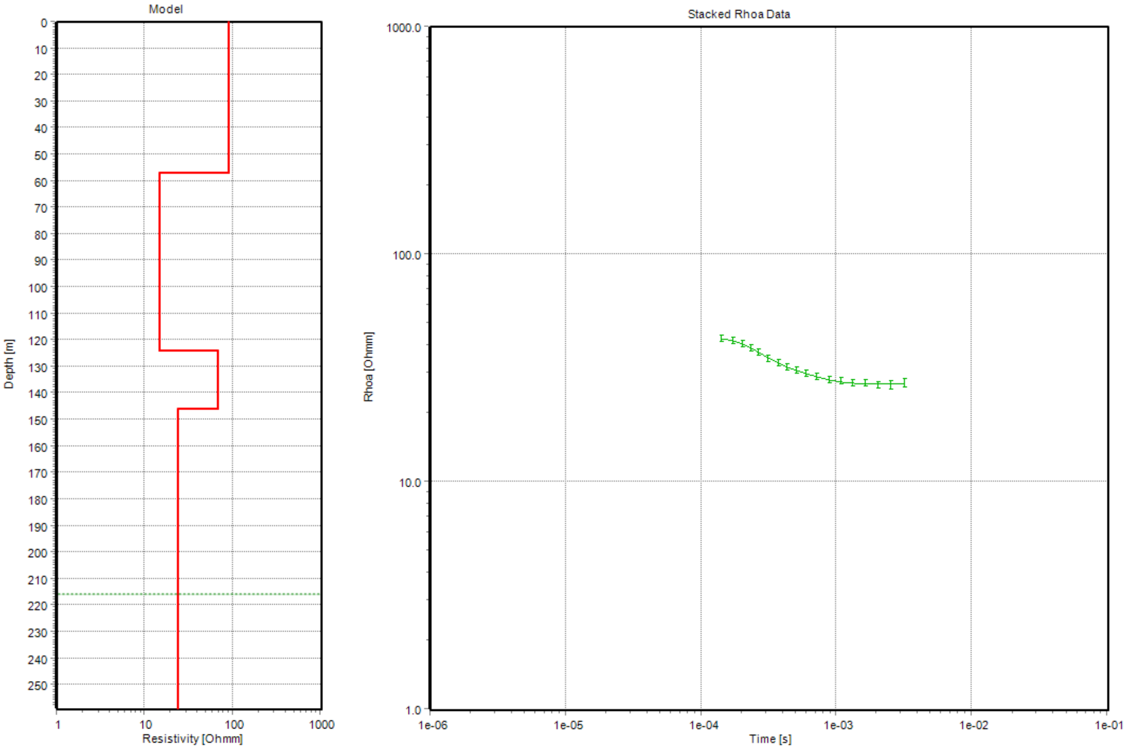

Figure A1.5 Site 3A. Layered resistivity model with depth for the TEM data (left). DOI is 215 m. TEM data and model fit (right).

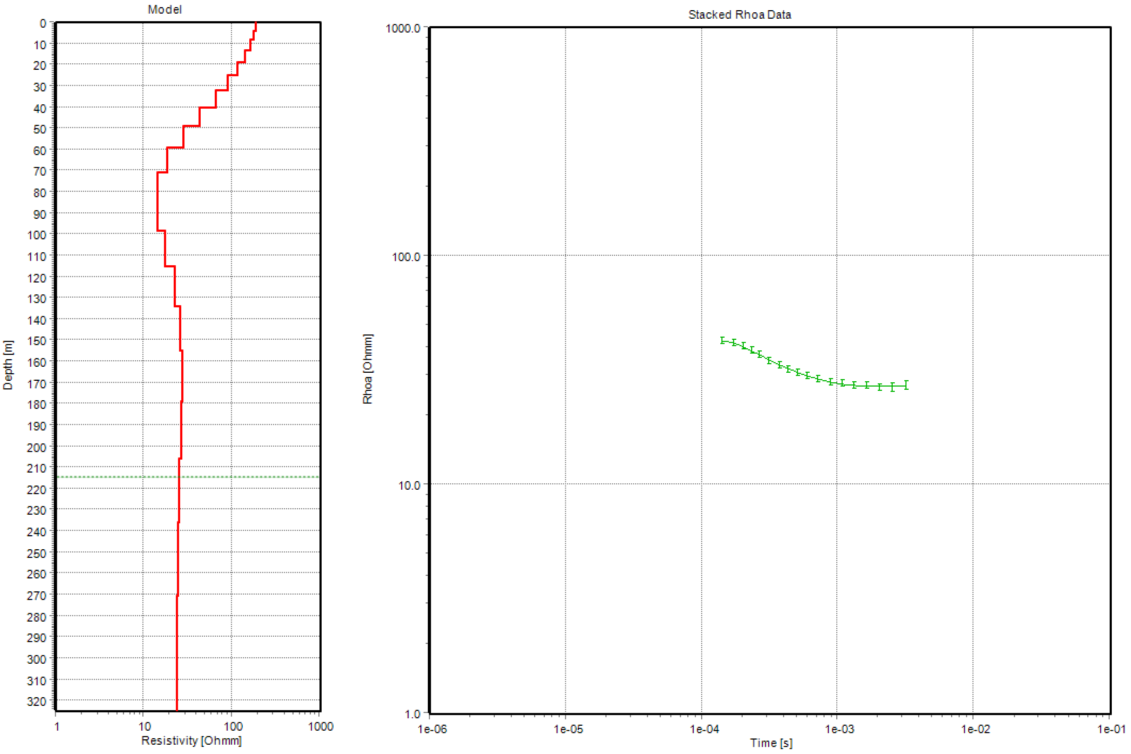

Figure A1.6 Site 3A. Smooth resistivity model with depth for the TEM data (left). The DOI is 215 m. TEM data and model fit (right).

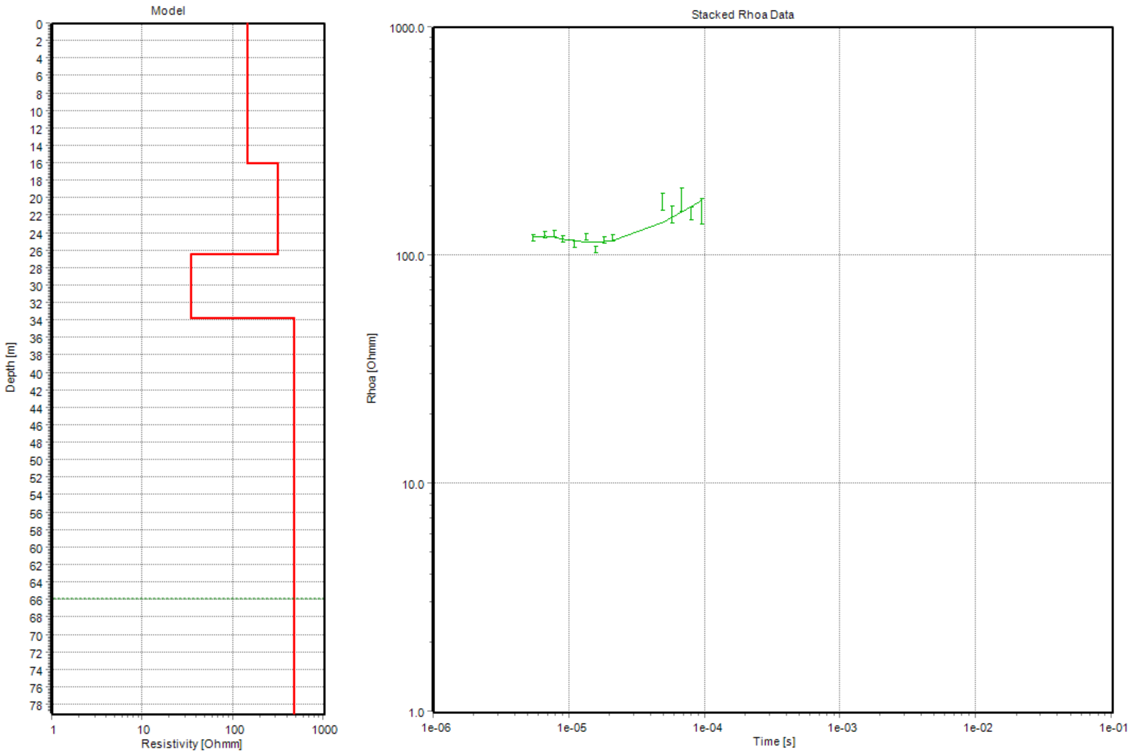

Figure A1.7 Site 3A. Layered resistivity model with depth for the NanoTEM data (left). The DOI is 66 m. NanoTEM sounding curve and model fit (right).

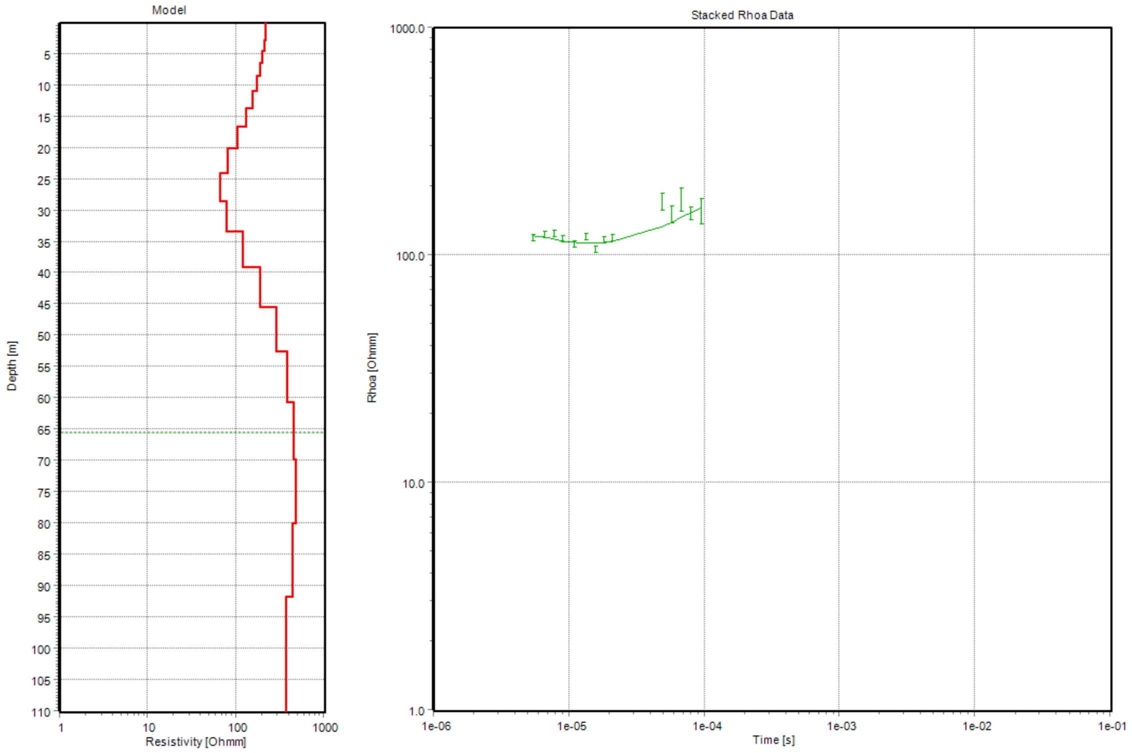

Figure A1.8 Site 3B. Smooth resistivity model with depth for the NanoTEM data (left). The DOI is 65 m. NanoTEM sounding curve and model fit (right).

APPENDIX 2 DAILY DRILLING REPORTS

The daily drilling reports comprise the daily emails sent by the on-site GNS geologist to summarise progress. They are distinct from any drilling reports supplied by Baylis Bros Ltd. Note: Drilling began before GNS personnel could get on site.

A2.1 30 July 2021

Summary

Total depth so far is at 6.0 m. Water level at 2.8 m (on the 29th).

Details

Drilling started on the 28th of July. Already down to the level of the first slug test, which will be undertaken on Monday so drilling halted until then. Collected sediments logged on the 30th of July comprise a top 2 m of soil to pebbly soil, overlying 4 m of brown, variably muddy, poorly sorted gravels. Possible drilling damage to some larger grains.

Additional Comments

All GNS gear back in the re-located shed including the resistivity meter, but hopefully not the mouse.

A2.2 2 August 2021

Summary

Total depth still at 6.0 m. Water level measured at 2.40 m this morning.

Details

Slug test performed today at 6 m. Three tests undertaken in this section, with slow recovery noted in all three tests. Unfortunately, due to the longer than expected tests, we were not able to make any ground with the drilling. Drillers have welded up the next 6 m section of casing to begin tomorrow morning.

Additional Comments

Next slug test is scheduled around 18 m depth, we are likely to hit this depth by tomorrow with the expected drilling rate. Will update you all tomorrow with this progress.

A2.3 3 August 2021

Summary

Total depth at 18.0 m. Water level measured at ~11:30 am 3.82 m (top of casing) this morning (note that this was measured directly after drilling).

Details

- 6.0–8.0 m – brown mL – very coarse pebbles, clay 20–30%.
- 8.0–9.0 m – grey/blue clayey mL – very coarse pebble, clay ~50%

- 9.0–11.0 m – grey/blue mL – very coarse pebbles; clay 20–30%, with clay content decreasing from 10.0–11.0 m.
- 11.0–13.0 m – as above; however, an increase in fines content.
- 13.0–15.0 m – as above, with increasing clay content from this interval.
- 15.0–17.0 m – grey/blue clay with minor mL – very coarse pebbles.
- 17.0–18.0 m – brown sandy clay with some fL– very coarse pebbles inter-mixed.

Water measurements taken at the end of the day, as water was recovering.

- 3:50 pm – 17.2 m
- 4:00 pm – 17.15 m
- 4:10 pm – 17.05 m
- 4:20 pm – 16.85 m
- 4:30 pm – 16.705 m.

Additional Comments

Next slug test at 18.0 m is arranged for tomorrow morning. Will monitor water levels tomorrow morning to see how it has recovered overnight.

A2.4 4 August 2021

Summary

Total depth still at 18.0 m, water depth was measured at 6.97 m (9:00 am) this morning, but water was still recovering from yesterday's drilling at a rate of 5–10 cm every 10 minutes. As a result, we were unable to undertake the slug test today as the water is still rising. Piezometer was installed in the hole this afternoon to monitor the water recovery and we will return tomorrow to complete the slug test.

I will be off-site from late tomorrow morning. Drillers will collect samples over this period while we are off-site and bag them for us. We will collect and log these samples on Friday or Monday.

A2.5 9 August 2021

Summary

After a chilly day on the rig (including some snow), the well has been drilled and cased to 42 m. The morning water level was 1.24 m.

Details

- Clay and pebbles with increasing sand from 19 to 25 m.
- Predominantly sands from 25 to 29 m.
- Ash and pumice layer at 29–30 m.
- Sand and pebbles at 32 m with some rounded sandstone pebbles.
- Another ash and pumice layer at 33 m.

A2.6 10 August 2021

Summary

Water level this morning was 7.74 m. Drilling and casing reached 54 m today. Running sands were encountered from 50 m.

Details

- 36–37 m sand with fine pebbles.
- 37–41 m sand clay and pebbles with some sandstone and mudstone pebbles.
- 41–42 m sand with mudstone and sandstone pebbles.
- 42–45 m mudstone and sandstone gravels (possibly drilling-induced).
- 45–48 m clay with pebbles; organic staining in some of the clay at 47–48 m.
- 48–50 m sand with mudstone pebbles.
- 50–54 m running sands.

Additional Comments

Tomorrow morning the drillers will assess the uplifted sand depth and make the call on continuing or changing drill rigs.

Water level at the end of the day was 19.2 m.

A2.7 11 August 2021

Summary

Casing is at 55.8 m and we are still in running sands. The sand had risen 19 m to 35 m BGL. Morning groundwater was 11.09 m. Afternoon measurement water level is deeper than the tricone, which is at 22 m BGL.

Details

We are still in fine running sands with trace to minor coarse pumice sand.

Additional Comments

View of and from the GNS all-weather mobile sediment logging facility.

A2.8 13 August 2021

Summary

Yesterday morning water level was 3.37 m. Sand level was 41 m. The well is at 55.8 m.

Details

The drillers successfully bailed the sands, clearing to a depth of 54 m. Following this, the water level was 9.31 m at 2:45 pm and 7.68 m at 3:18 pm.

Additional Comments

Depending on the water level readings this morning, we may proceed with slug testing.

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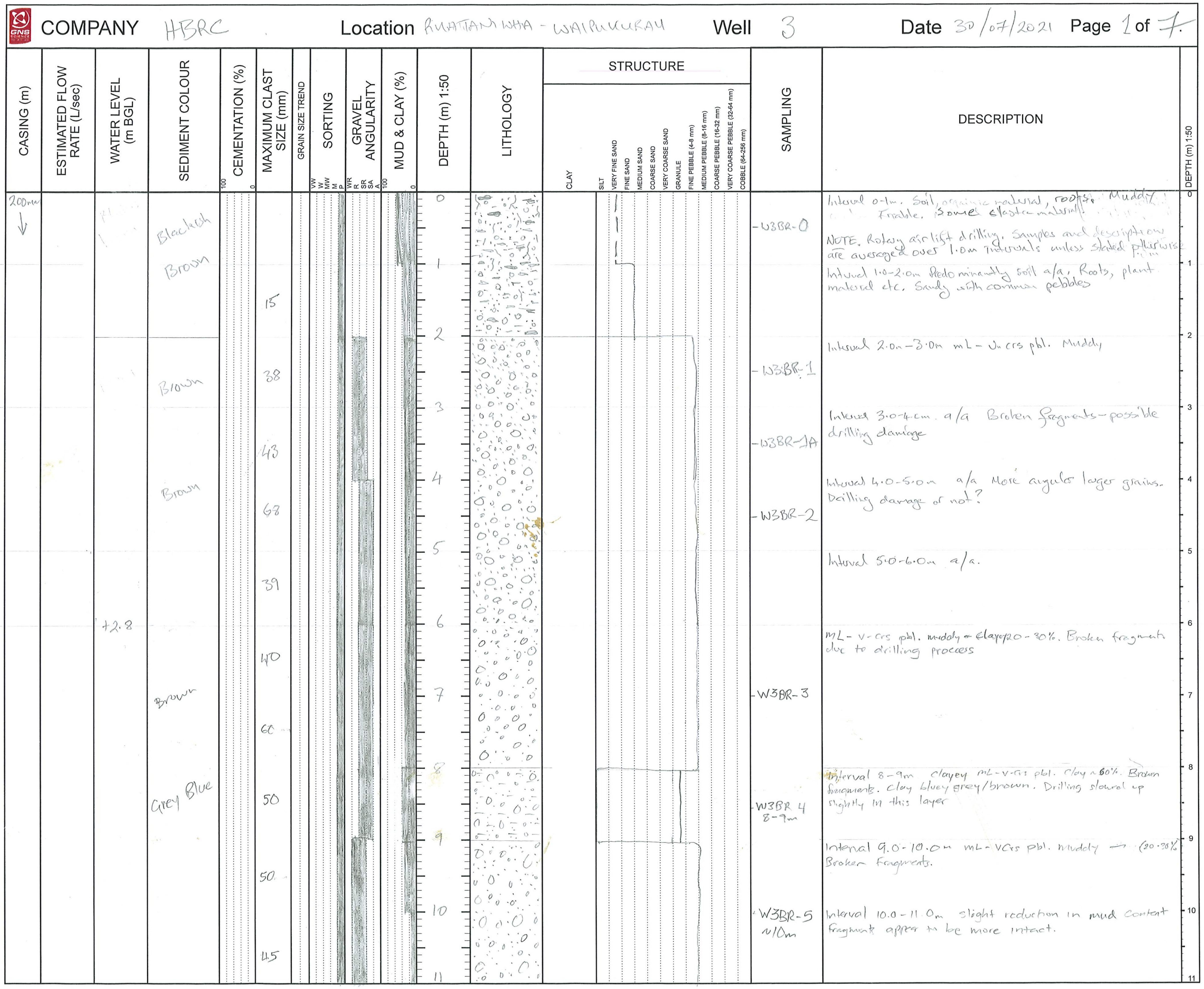
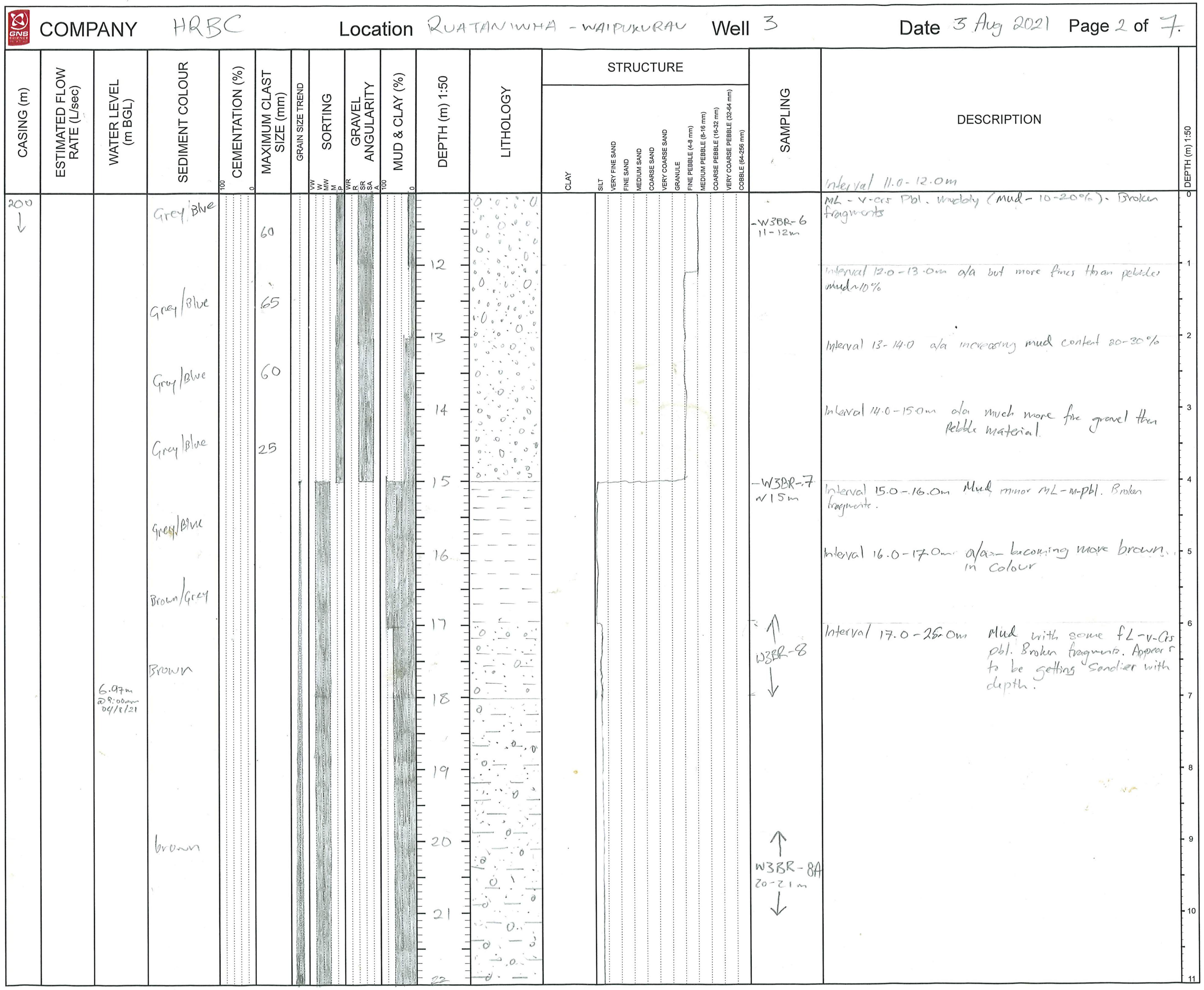
APPENDIX 3 LITHOLOGICAL LOGS



COMPANY HBRC Location RUATANIWHA - WAIPUKURAU Well 3 Date 30/07/2021 Page 1 of 7.

DEPTH (m) 1:50	CASING (m)	WATER LEVEL (m BGL)	SEDIMENT COLOUR	MAXIMUM CLAST SIZE (mm)	SAMPLING	DESCRIPTION
0–1	200mm ↓		Blackish Brown		W3BR-0	Interval 0-1m. Soil, organic material, roots. Muddy. Friable. Some clastic material. NOTE. Rotary air lift drilling. Samples and description are averaged over 1.0m intervals unless stated otherwise
1–2				15		Interval 1.0-2.0m Predominantly soil a/a, Roots, plant material etc. Sandy with common pebbles
2–3			Brown	38	W3BR-1	Interval 2.0m–3.0m mL – v. crs pbl. Muddy
3–4				43	W3BR-1A	Interval 3.0-4.0m. a/a Broken fragments – possible drilling damage
4–5			Brown	68	W3BR-2	Interval 4.0-5.0m a/a More angular larger grains. Drilling damage or not?
5–6				39		Interval 5.0-6.0m a/a.
6–7		+2.8		40		ML – v-crs pbl. muddy ~ clayey 20-30%. Broken fragments due to drilling process
7–8			Brown	60	W3BR-3	
8–9			Grey Blue	50	W3BR 4 8-9m	Interval 8–9m clayey ML–v-crs pbl. Clay ~60%. Broken fragments. Clay bluey grey/brown. Drilling slowed up slightly in this layer
9–10				50		Interval 9.0-10.0m mL-vcrs pbl. muddy → (20-30% Broken fragments.
10–11				45	W3BR-5 ~10m	Interval 10.0-11.0m slight reduction in mud content fragments appear to be more intact.

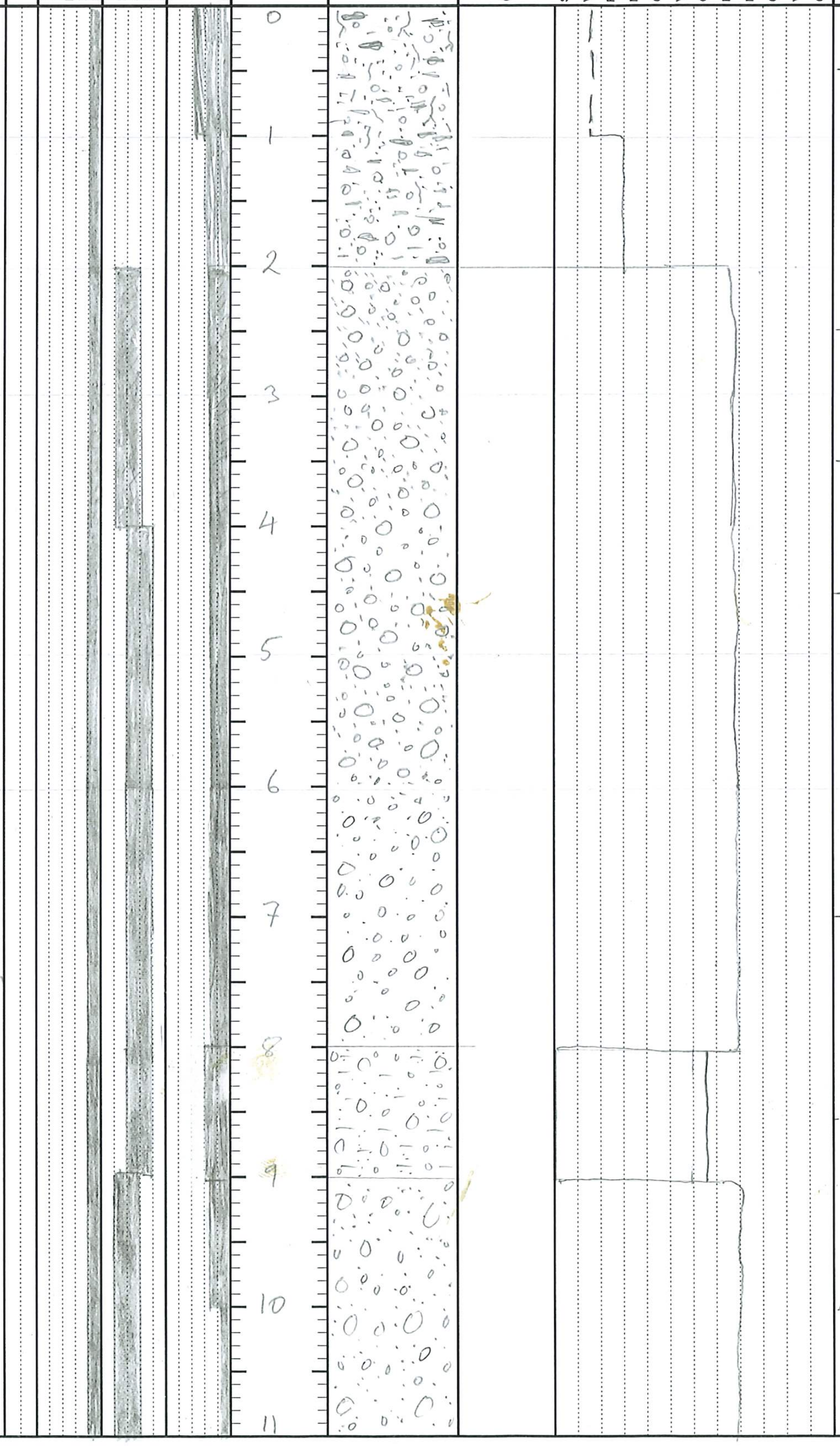
3.82
TOC



COMPANY HRBC Location RUATANIWHA - WAIPUKURAU Well 3 Date 3 Aug 2021 Page 2 of 7.

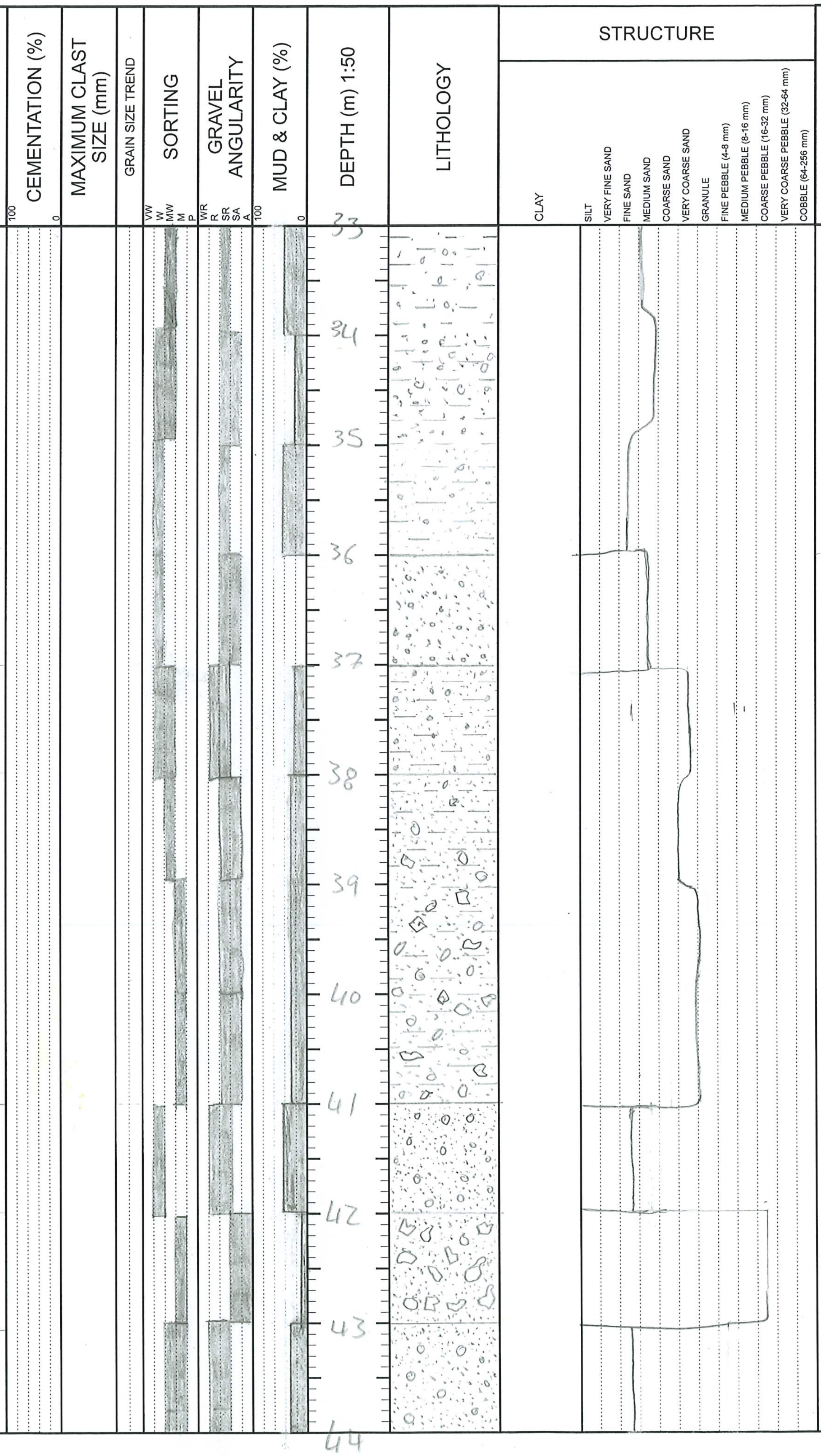
DEPTH (m) 1:50	CASING (m)	WATER LEVEL (m BGL)	SEDIMENT COLOUR	MAXIMUM CLAST SIZE (mm)	SAMPLING	DESCRIPTION
11	200 ↓		Grey/Blue	60	-W3BR-6 11-12m	Interval 11.0-12.0m ML - v-crs Pbl. muddy (Mud - 10-20%). Broken fragments
12			Grey/Blue	65		Interval 12.0-13.0m a/a but more fines than pebbles mud~10%
13			Grey/Blue	60		Interval 13-14.0 a/a increasing mud content 20-30%
14			Grey/Blue	25		Interval 14.0-15.0m a/a much more fine gravel then pebble material.
15			Grey/Blue		-W3BR-7 ~15m	Interval 15.0-16.0m Mud minor ML-m-pbl. Broken fragments.
16			Brown/Grey			Interval 16.0-17.0m a/a becoming more brown in colour
17		6.97m @9:00am 04/8/21	Brown		↑ W3BR-8 ↓	Interval 17.0-25.0m Mud with some fL-v-Crs pbl. Broken fragments. Appears to be getting sandier with depth.
20			brown		↑ W3BR-8A 20-21m ↓	

COMPANY HBRC Location RUATANIWHA - WAIPUKURAU Well 3 Date 30/07/2021 Page 1 of 7.



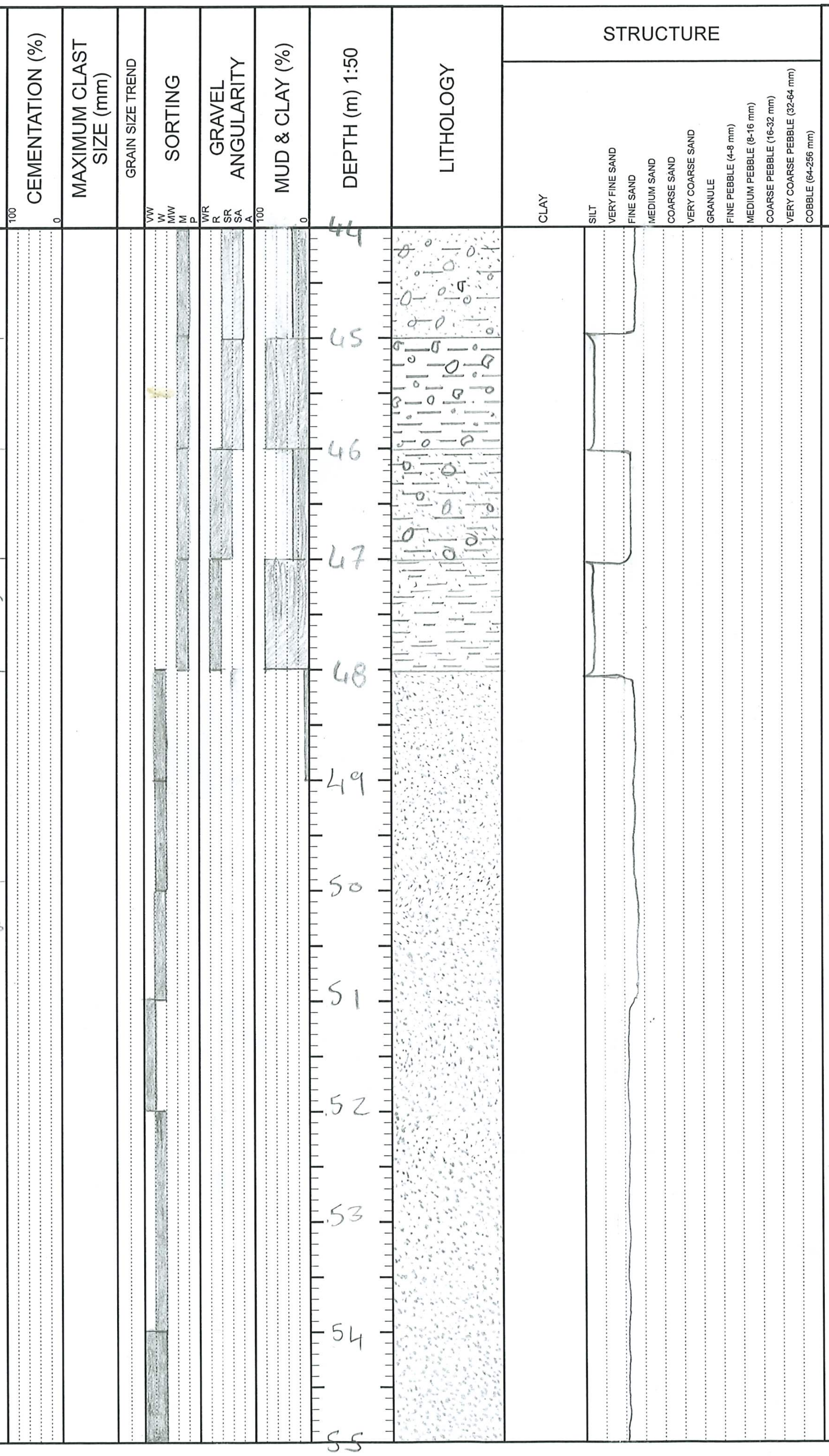
DEPTH (m) 1:50	CASING (m)	ESTIMATED FLOW RATE (L/sec)	WATER LEVEL (m BGL)	SEDIMENT COLOUR	CEMENTATION (%)	MAXIMUM CLAST SIZE (mm)	SAMPLING	DESCRIPTION
0	200mm ↓			Blackish Brown			W3BR-0	Interval 0-1m. Soil, organic material, roots. Muddy. Friable. Some clastic material.
								NOTE. Rotary air lift drilling. Samples and description are averaged over 1.0m intervals unless stated otherwise
1						15		Interval 1.0-2.0m Predominantly soil a/a, Roots, plant material etc. Sandy with common pebbles
2				Brown		38	W3BR-1	Interval 2.0m-3.0m mL - v. crs pbl. Muddy
3						43	W3BR-1A	Interval 3.0-4.0m. a/a Broken fragments - possible drilling damage
4				Brown		68	W3BR-2	Interval 4.0-5.0m a/a More angular larger grains. Drilling damage or not?
5						39		Interval 5.0-6.0m a/a.
6			+2.8			40		mL - v-crs pbl. muddy + clayey 20-30%. Broken fragments due to drilling process
7				Brown		60	W3BR-3	
8				Grey Blue		50	W3BR 4 8-9m	Interval 8-9m clayey mL-v-crs pbl. Clay ~60%. Broken fragments. Clay bluey grey/brown. Drilling slowed up slightly in this layer
9						50		Interval 9.0-10.0m mL-vcrs pbl. muddy → (20-30% Broken fragments.
10						45	W3BR-5 ~10m	Interval 10.0-11.0m slight reduction in mud content fragments appear to be more intact.
11								

COMPANY HBRC **Location** RUATANIWHA-WAIPUKURAU **Well** 3 **Date** 9 August 2021 **Page** 4 **of** 7.



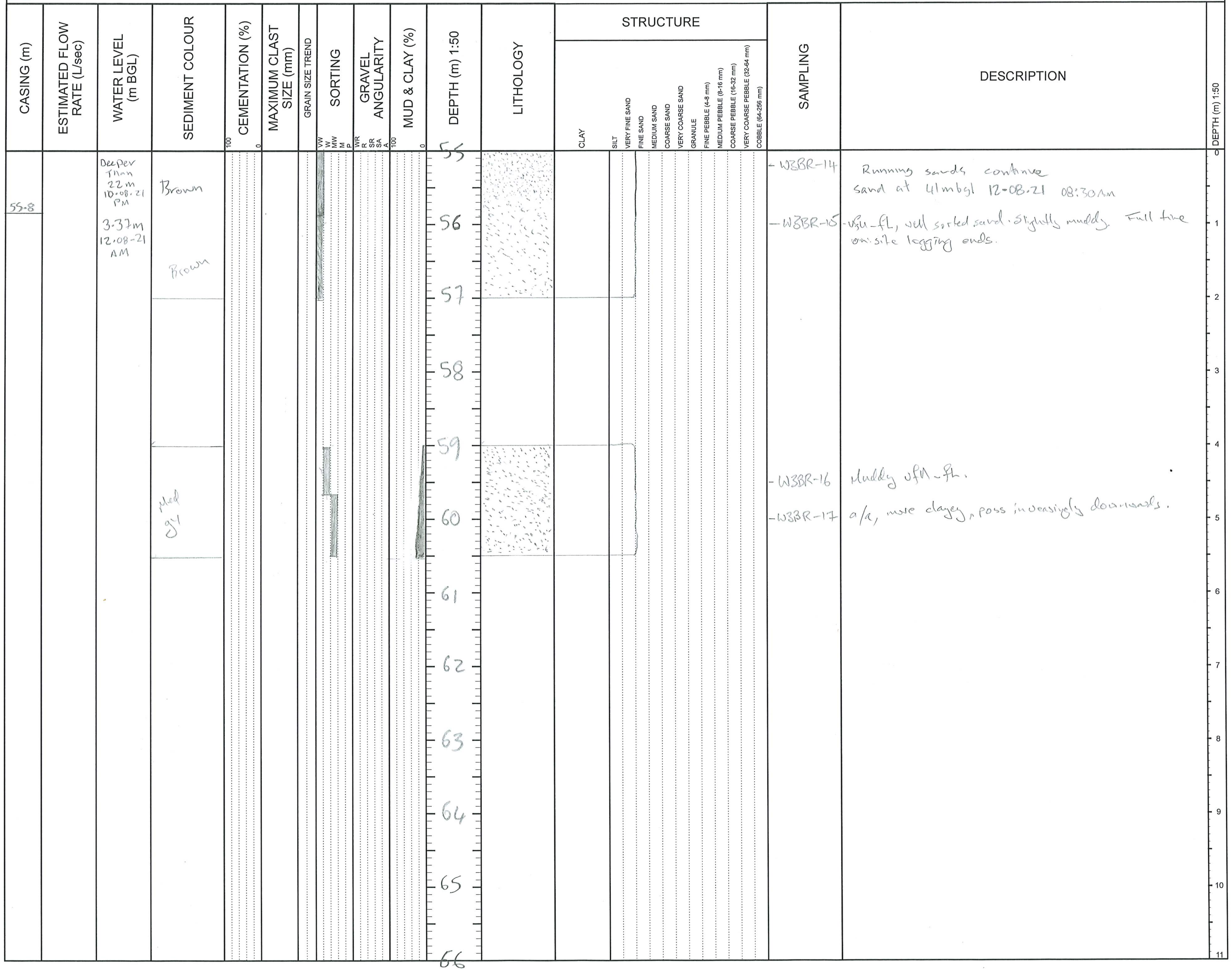
DEPTH (m) 1:50	CASING (m)	ESTIMATED FLOW RATE (L/sec)	WATER LEVEL (m BGL)	SEDIMENT COLOUR	SAMPLING	DESCRIPTION
33				Light brown		Ash/Mud+pummice vfL – vcL sands Some granules - med pebbles, clay + silt
34						becomming coarser (sands)
35	36m				W3BR-11 35-36m	Becomming finer
36				Dark grey brown		Sands fL – f pebble
37				Light brown with Dk brown speckles		fU sands to M pebble with mud
38				Light brown		vfU sands to f pebble subangular
39						More mudstone + sandstone gravels
40					W3BR-12 40-41m	
41				Brown		fL - fU sands with M-C mudstone pebbles
42	42m		7.74m 10.08.21 AM	Lt brown Lt grey orange Dk orange		mudstone + sandstone gravels angular - likely drilling induced some vfL - vcU sands
43				Brown Lt grey orange		vfU - mL sands with m pebbles of mudstone + sandstone
44						

COMPANY HBRC **Location** RUATANIWHA - WAIPUKURAU **Well** 3 **Date** 10 AUGUST 2021 **Page** 5 **of** 7.

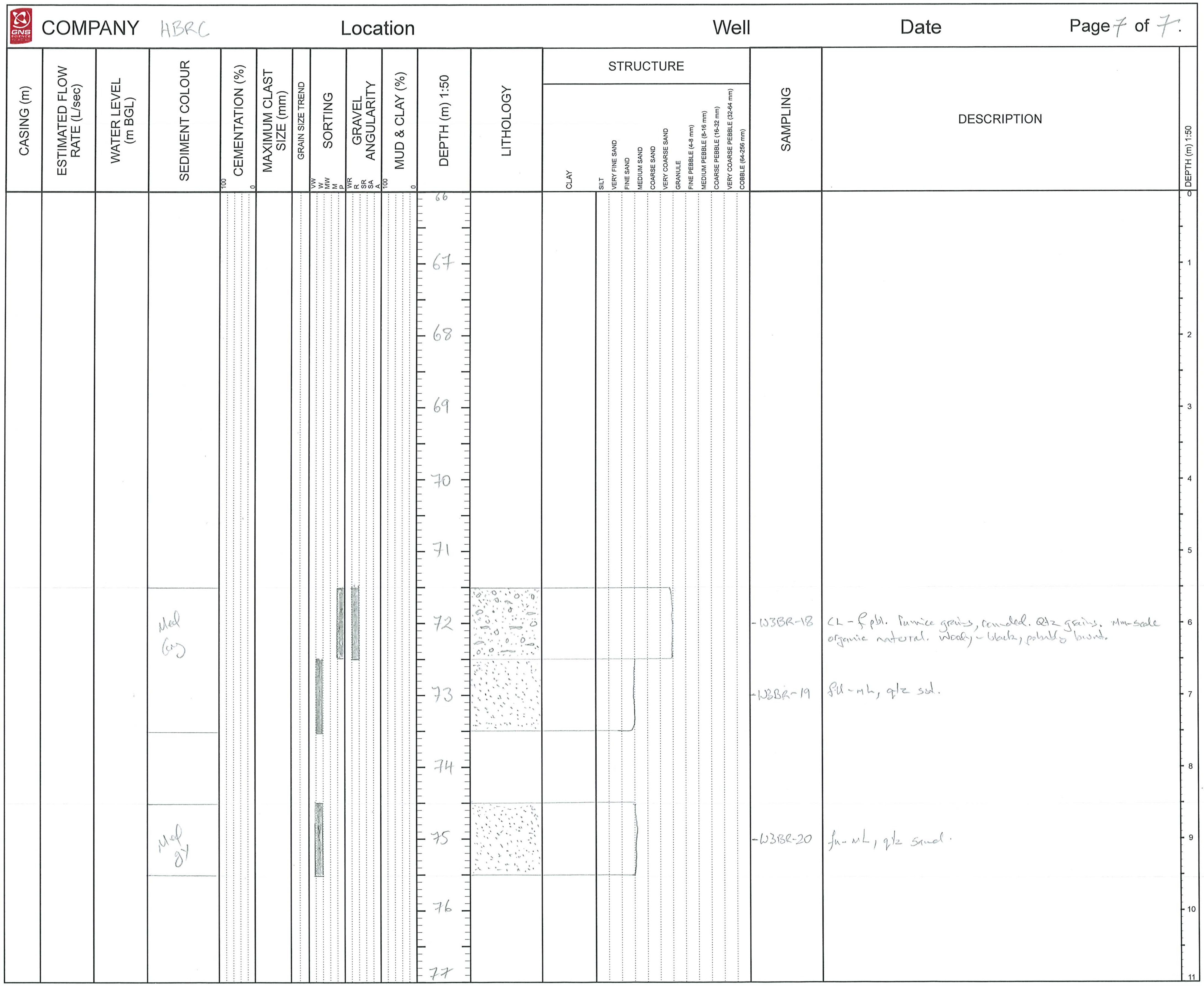


CASING (m)	ESTIMATED FLOW RATE (L/sec)	WATER LEVEL (m BGL)	SEDIMENT COLOUR	SAMPLING	DESCRIPTION	DEPTH (m) 1:50
			brown + Lt grey		Mud increased	0
			Lt brown + Lt grey		Mud with f-m pebbles of mudstone + sandstone	1
			Brown		Mud and fL-mL sands with f-m pebbles of sandstone + mudstone	2
48m			Brown Dark brown Light grey		Mud, Light grey, brown, organic stained Dark brown cobble sized pieces, minor fU-ML sands	3
			Brown w Lt grey		fL-mL sands with some f-C pebbles(mudstone)	4
						5
			Brown Lt grey speckles	W3BR-13 50-51m	fL-mL sands with minor cU-vcL pummice sand Running sands	6
					vfu-mL sands trace cU-vcL Pummice sand	7
					Minor cU-vcU pummice sand Driller Notes sands pushed up to 35m depth	8
		19.2m 10/08/21 15:50 pm				9
	54m	11.09m 11/08/21 11:15AM				10
						11

COMPANY HBRC Location RUATANIWHA - WAIPUKURAU Well 3 Date 11 AUGUST 2021 Page 6 of 7.



CASING (m)	ESTIMATED FLOW RATE (L/sec)	WATER LEVEL (m BGL)	SEDIMENT COLOUR	CEMENTATION (%)	MAXIMUM CLAST SIZE (mm)	GRAIN SIZE TREND	SORTING	GRAVEL ANGULARITY	MUD & CLAY (%)	DEPTH (m) 1:50	LITHOLOGY	STRUCTURE	SAMPLING	DESCRIPTION	DEPTH (m) 1:50
		Deeper Than 22m 10.08.21 PM	Brown							55			W3BR-14	Running sands continue sand at 41mbgl 12-08.21 08:30Am	0
55.8		3.37m 12.08-21 AM								56			W3BR-15	vfU-fL, well sorted sand. Slightly muddy. Full time on-site logging ends.	1
			Brown							57					2
										58					3
			Med gy							59			W3BR-16 W3BR-17	Muddy vfU-fL. a/a, more clayey, poss increasingly downwards.	4
										60					5
										61					6
										62					7
										63					8
										64					9
										65					10
										66					11



COMPANY HBRC Location Well Date Page 7 of 7.

Med Grey

Med gy

-W3BR-18 CL - f pbl. Pumice grains, rounded. Qtz grains. Mm-scale organic material. Woody - black, probably burnt.

-W3BR-19 fU - mL, qtz sd.

-W3BR-20 fu - mL, qtz sand.

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APPENDIX 4 CORE RESISTIVITY MEASUREMENTS

A4.1 Resistivity Measurements

Figure A4.1 shows the equipment used on well 17164. The raw data are attached to this report in an Excel file as an electronic supplement. Figure A4.2 shows the trends of the main parameters, resistivity and contact resistance as a function of depth in the borehole.

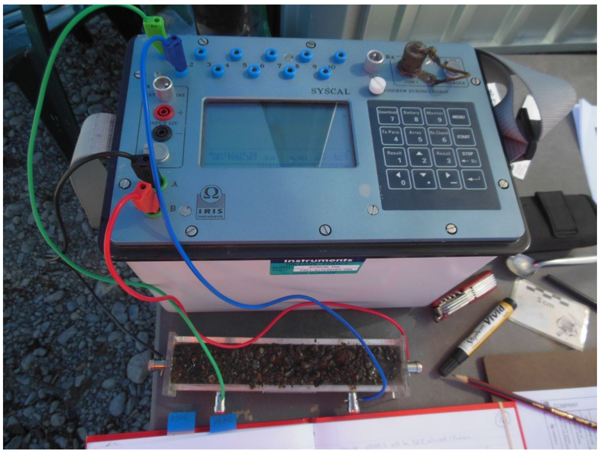

Figure A4.1 Resistivity measurements on a sample from borehole 17164 (Photo: Mark Lawrence).

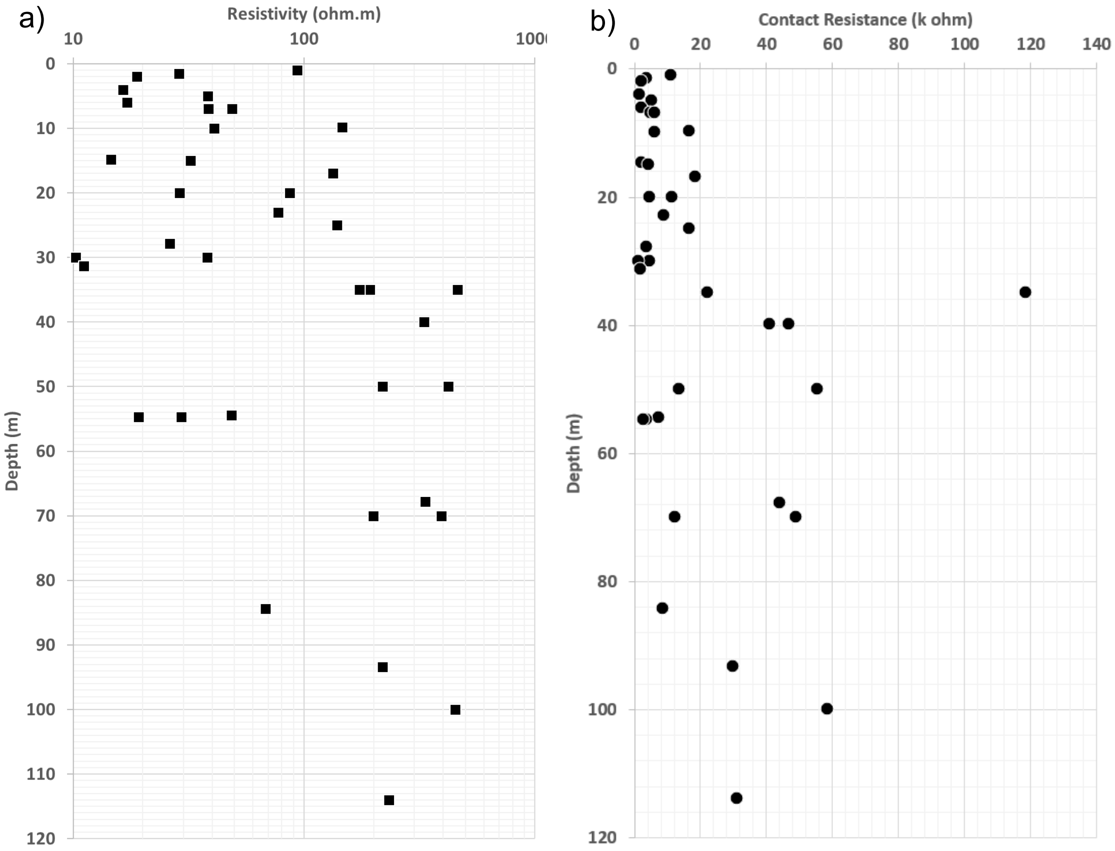

Figure A4.2 Plot of sample resistivity (a) and contact resistance (b) versus depth.

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APPENDIX 5 GEOPHYSICAL LOGS

RDCL

Level 1, Unit 2/182 Main Road
Tawa
Wellington, 5028
New Zealand

Ph: +64 6 8771652
Fax: +64 6 8775015
Email: info@rdcl.co.nz
www.rdcl.co.nz

Basic Information:

Drill hole ID: Well 3
Client: Hawke's Bay Regional Council
Run Number(s): 02 & 03
Tool Type(s): Century Coal Combination Sonde CCS
Service Company: RDCL
Operator: O Gibson
Date Logged: 12/10/2021
Field: Heretaunga
State / Province: Hawke's Bay
Country: New Zealand

Location Description:

Site 3 - Heretaunga - Burnside Road

Drillhole Information:

Log interval from (m): -0.17
Log interval to (m): 69.97
Depth Driller (m): 76.85
Depth Logger (m): 69.97 (CCS)
Fluid Type: Water
Fluid Level (m): ~0.60
Easting: 1887255.504
Northing: 5567712.696
Elevation: N/A
Coord Ref System: NZTM
Hole Azimuth: N/A
Hole Inclination: -90°
Magnetic Declination: +22° 11'
Magnetic Inclination: 65° 7'
Drill Company: Baylis Bros.

Printing Information:

Depth Unit: Metres
Log Scale: 1:100
Log Version: Final
Processed: O Gibson
Log Reviewer: K Koria

Bit Size Record:

Size (mm):	From (m):	To (m):
N/A	N/A	N/A
##.#	##.#	##.#
##.#	##.#	##.#
##.#	##.#	##.#

Casing Record:

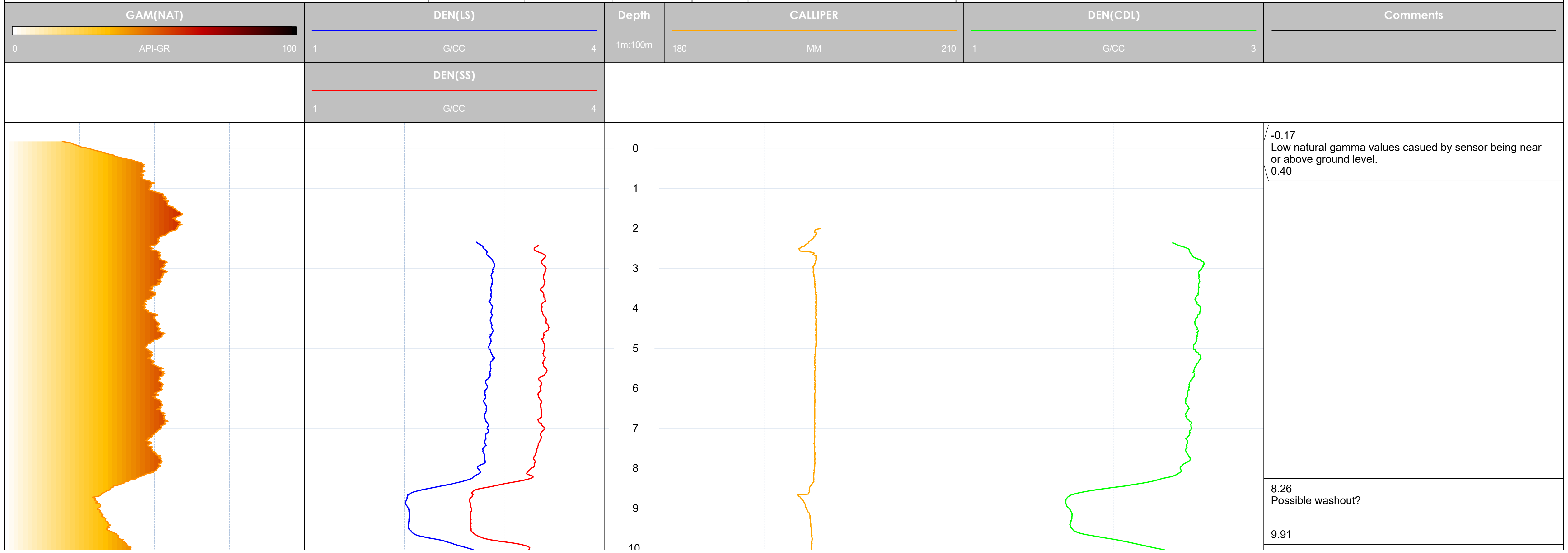
Type:	Size:	From (m):	To (m):
Well	200 mm	-0.17	76.85
XX	##.#	##.#	##.#
XX	##.#	##.#	##.#
XX	##.#	##.#	##.#

Log Nomenclature:

DEN(SS) = Short-Spaced Density
DEN(LS) = Long-Spaced Density
DEN(CDL) = Compensated Density
GAM(NAT) = Natural Gamma
CALLIPER = Single Arm Mechanical Calliper

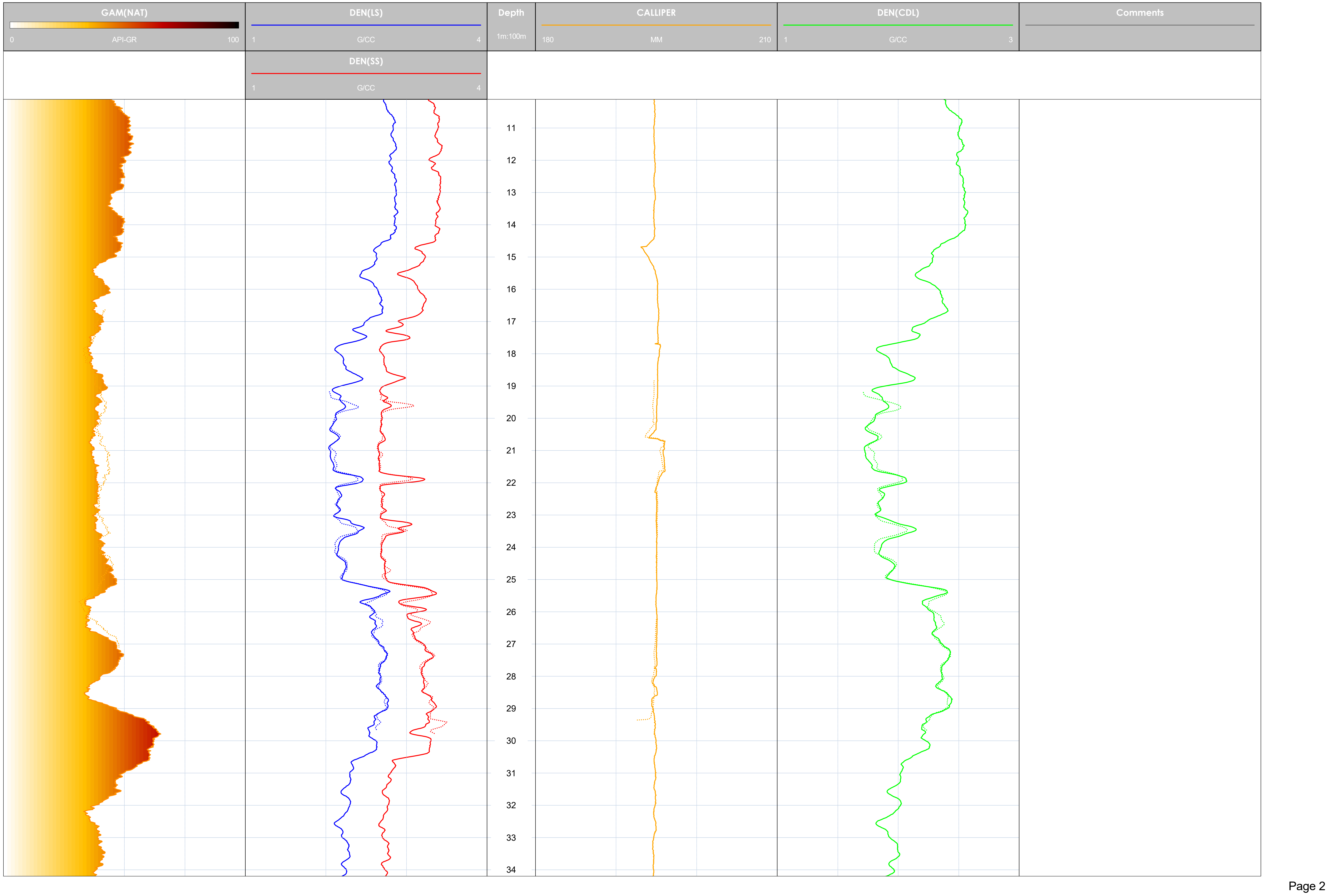
Comments:

1. Repeat run plotted as dotted lines between 16.61 - 29.80 m.
2. Density values are relative not absolute due the presence of metal casing.
3. No conductor casing in this well.



-0.17
Low natural gamma values casued by sensor being near or above ground level.
0.40

8.26
Possible washout?
9.91


GAM(NAT)
0
API-GR
100
DEN(LS)
1
G/CC
4
DEN(SS)
1
G/CC
4
Depth
1m:100m
CALLIPER
180
MM
210
DEN(CDL)
1
G/CC
3
Comments
11
12
13
14
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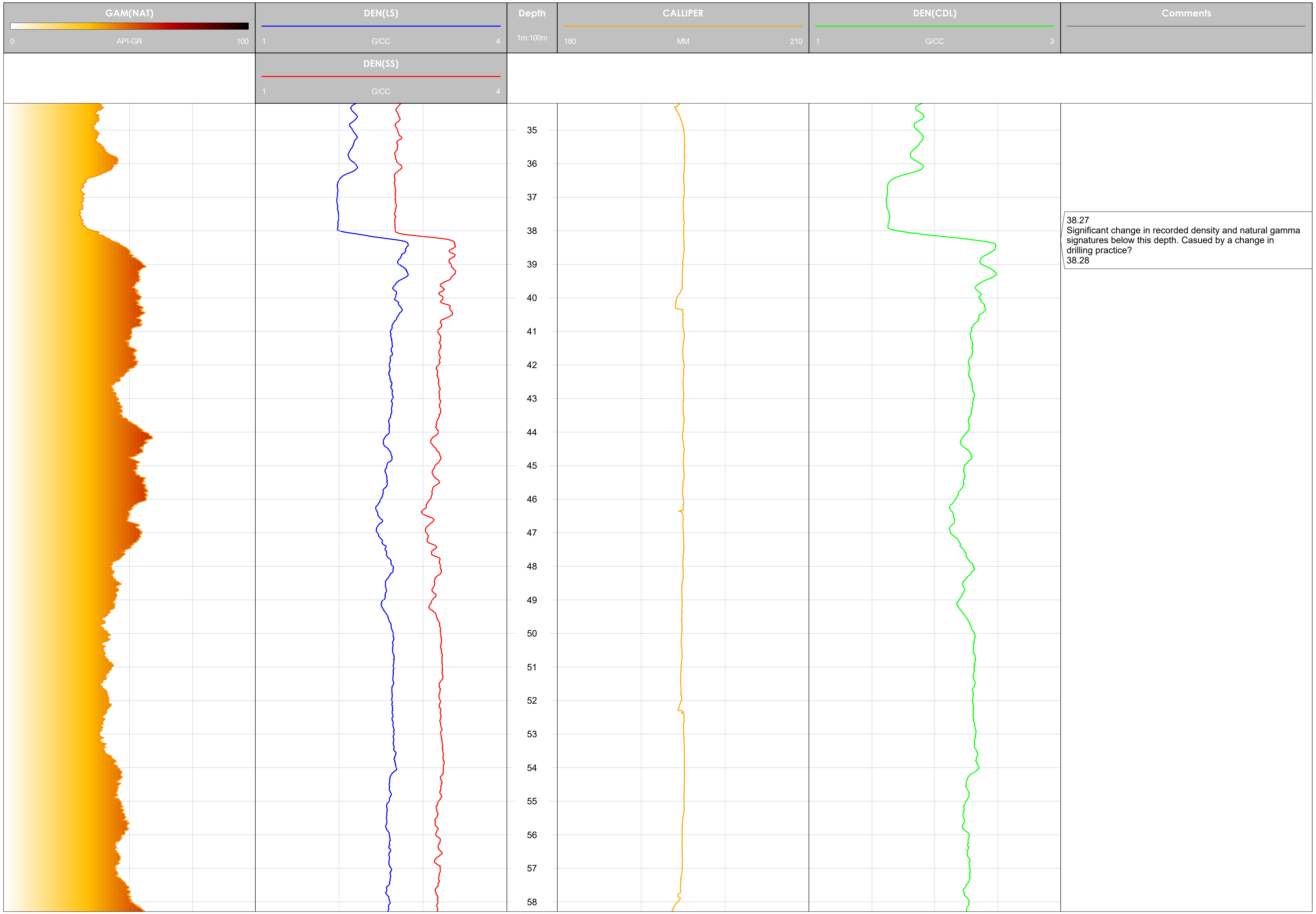
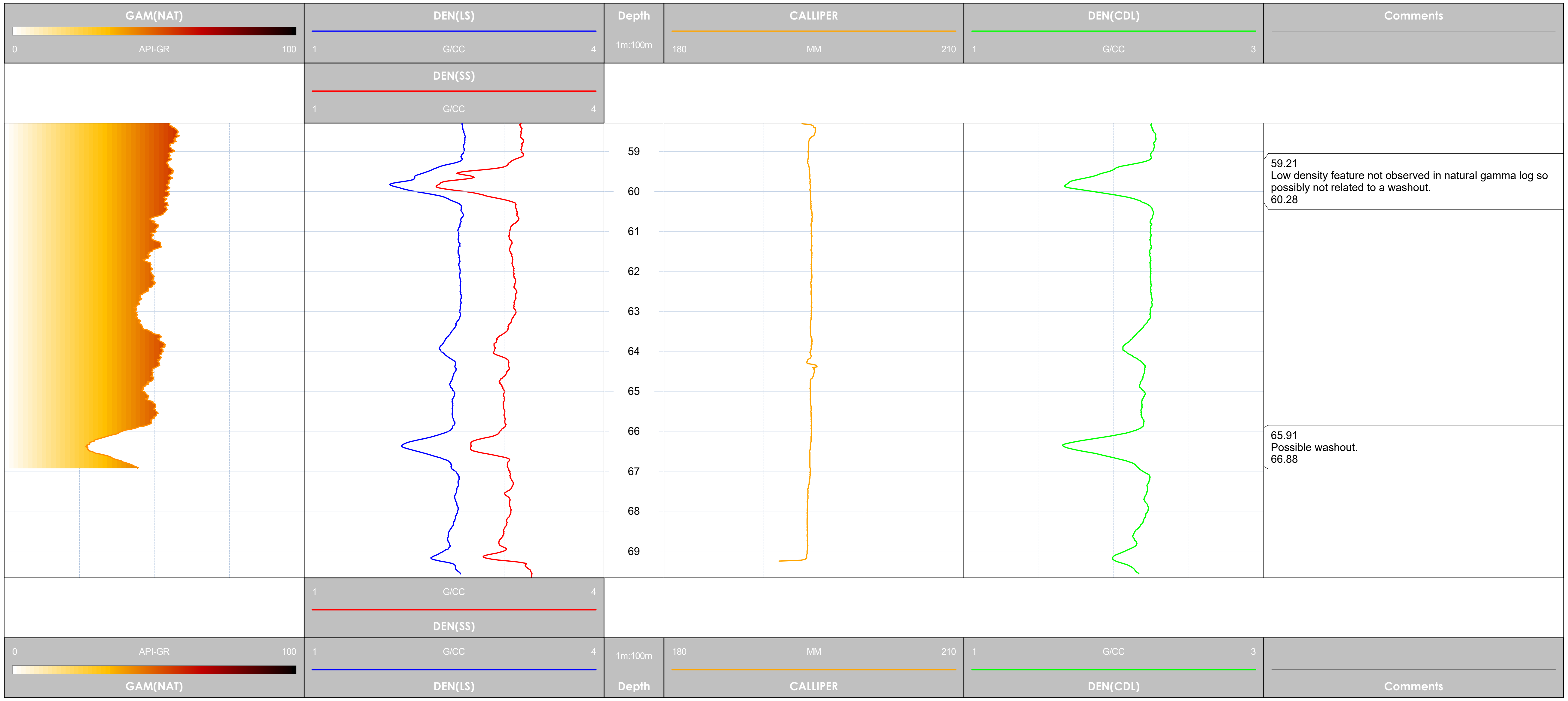
Page 2



38.27
Significant change in recorded density and natural gamma signatures below this depth. Casued by a change in drilling practice?
38.28



59.21
Low density feature not observed in natural gamma log so possibly not related to a washout.
60.28

65.91
Possible washout.
66.88

APPENDIX 6 PUMPING TEST

No pumping tests were undertaken at well 17164, as no layer with sufficient water flow was encountered.

APPENDIX 7 SLUG TESTS

Four series of slug tests were performed at different depths at well 17164. Based on the lithology encountered while drilling (Figure 2.5) and the water level measured at the beginning of each slug test (Table A7.1), we assume the layer encountered during slug test 1 to be an unconfined aquifer, with the base defined by the clay layer tested in slug test 2. We assume the layers tested during slug tests 3 and 4 to be a confined aquifer, with the top of this aquifer at 48.0 m BGL. We have assumed the total drilled depth of the bore, 79.0 m BGL, to be the base of this aquifer. More detail of each of the slug tests and their analysis and results are presented in Sections A7.2–A7.5.

We have assumed the static water level used in the analysis of slug tests 1, 2 and 3 to be the water level immediately prior to the start of the tests.

Table A7.1 Summary of the depth of each slug test and static water level of each layer encountered. SWL: Static Water Level.

	Date	Casing Depth (m BGL)	SWL (m BGL/AGL)	Recovery	Primary Lithology
Slug Test 1	02/08/2021	5.46	-1.737	Yes	Gravel
Slug Test 2	05/08/2021	18.0	No SWL*	No clear recovery	Clay
Slug Test 3	09–15/09/2021	55.22	No SWL*	No clear recovery	Running sands
Slug Test 4	08–11/10/2021	76.35	No SWL*	No clear recovery	Running sands

* The water level prior to slug tests 2, 3 and 4 was not static; more detail is provided in Sections A7.3, A7.4 and A7.5.

Two different slugs were utilised for the slug tests at this well; a summary of their volume and expected water displacement is presented in Table A7.2.

Table A7.2 Summary of the slug volumes used for the slug tests and calculated water displacement in the well.

	Slug Volume		Calculated Water Displacement in the Well	
Slug Number	**Volume (m^3)**	**Volume (L)**	**Well Diameter (m)**	**Water Displacement (m)**
2	0.0058	5.76	0.203	0.178
6	0.0013	1.30	0.203	0.040

A7.1 Barometric Correction

Barometric pressure was not recorded on-site during slug test 1; therefore, barometric pressure data from the Waipawa weather station was obtained from the web portal CliFlo (NIWA [2022]) and used to correct the water-level data recorded with the Level TROLL 700 data logger. However, the barometric pressure data from the Waipawa weather station is only recorded every 10 minutes; therefore, a linear interpolation was applied between measurements.

Barometric pressure was recorded with a HOBO Bluetooth data logger at the well site during slug tests 2, 3 and 4. The HOBO Bluetooth data loggers recording water levels are vented and self-compensate for barometric changes. The Level TROLL 700 data loggers utilised are non-vented and do not self-compensate for barometric changes, so their data needed to be corrected. Therefore, a barometric correction has only been applied to data recorded by Level TROLL 700 data loggers prior to analysis.

The barometric efficiency of the aquifer was estimated from the slug test data, as the impact of the barometric pressure was evident from the water level and barometric pressure curves (e.g. Figures A7.7 and A7.10). Details about the barometric correction applied to each slug test dataset is provided in Sections A7.2, A7.3, A7.4 and A7.5.

After the barometric efficiency coefficient was estimated, the water levels recorded during each test were corrected following Equation A7.1 (Gonthier 2007):

$$WL_{(t)corr} = WL_{(t)uncorr} - BE(B_0 - B_{(t)}) \quad \text{Equation A7.1}$$

where:

- $WL_{(t)corr}$ is the water level at time *t*, corrected for barometric pressure;
- $WL_{(t)uncorr}$ is the uncorrected water level at time *t*;
- BE is barometric efficiency of the aquifer; and
- $(B_0 - B_{(t)})$ is the barometric pressure $B_{(t)}$ at time *t*, referenced to a barometric-pressure datum B_0.

The following conventions have been applied to both the estimation of the barometric efficiency and the slug test analyses:

- Water level above ground level (artesian conditions) is noted by positive values; water level below ground level is noted by negative values.
- An increase in the water level is considered a positive change and gives the following relation:

  $$\Delta WL = WL_{t+1} - WL_t \quad \text{(Gonthier 2007)}$$

  The drawdown calculation is based on this relation.
- An increase in the barometric pressure is considered a negative change and gives the following relation:

  $$\Delta B = B_t - B_{t+1} \quad \text{(Gonthier 2007)}$$

All slug test data utilised in the analysis was corrected for barometric pressure effects. Manual water level measurements were neither corrected nor analysed, as too few data points were obtained for meaningful analysis to be undertaken.

A7.2 Slug Test 1 at 5.46 m BGL

A7.2.1 Test Details

Drilling was stopped on 29 July 2021, and a series of slug tests were performed on 2 August 2021 at a depth of 5.46 m BGL in a poorly sorted sub-angular to rounded pebble layer. The smallest-sized slug (slug 6) was used to undertake slug-in and slug-out tests. Slug tests were repeated three times for quality assurance (Figure A7.1).

Water levels were recorded with two automatic data loggers:

- Every quarter of a second using an In-Situ Level TROLL 700 (non-vented).
- Every second using a HOBO Bluetooth water-level data logger (vented).

The weather was sunny, with no rainfall recorded during the test.

Based on the lithology log acquired while drilling (Figure 2.5), it is assumed that the base of the aquifer layer at which slug test 1 was undertaken is at 15.0 m BGL, where a sharp change from gravel to clay is observed. This assumption was utilised for the calculation of the saturated thickness of the aquifer in the analysis.

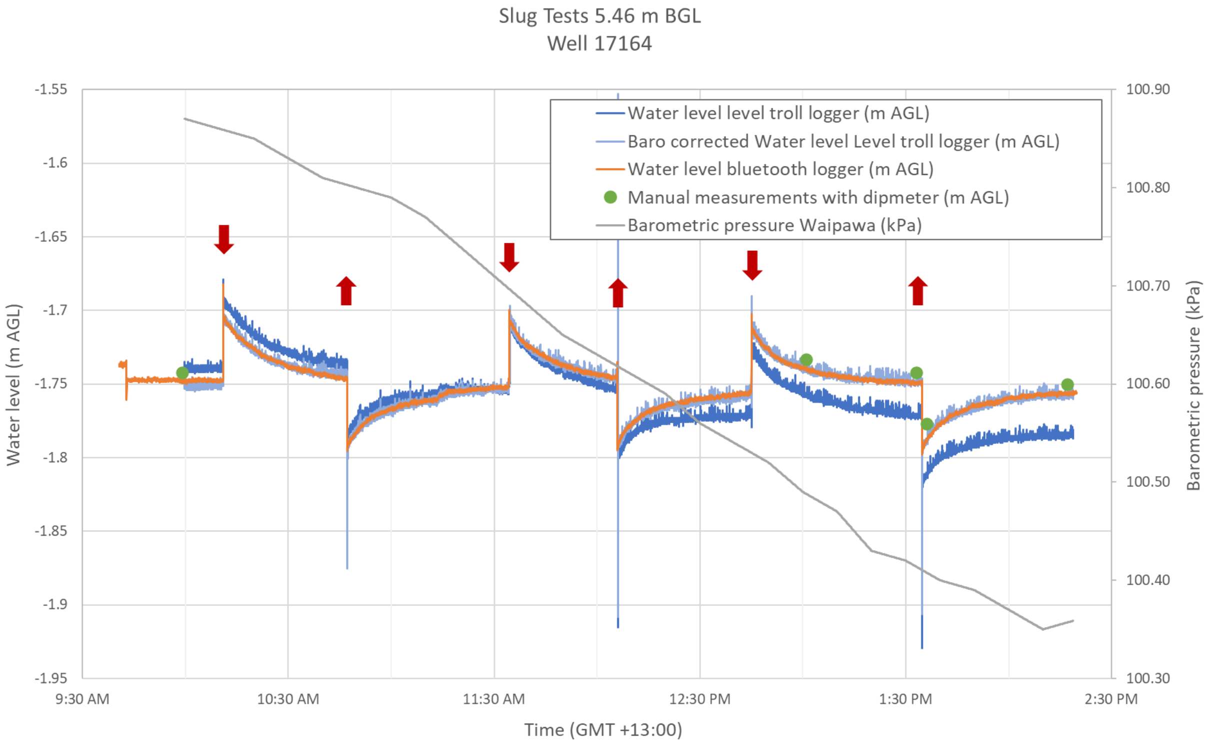


Figure A7.1 Fluctuation of the water level during the slug tests at 5.46 m BGL. Three slug tests were undertaken with the smallest slug (slug 6). The barometric pressure data from the Waipawa weather station (grey line) was used to correct the water level recorded by the Level TROLL 700 data logger (dark blue: uncorrected; light blue: corrected); the HOBO Bluetooth data logger is vented (orange line) and self-corrects for barometric pressure. Downward red arrows indicate when the slugs were lowered into the bore (beginning of slug-in tests); upward red arrows indicate when the slugs were pulled out (beginning of slug-out tests).

A7.2.2 Barometric Correction

There was no indication of influence on the water level besides the barometric pressure and the slug tests – the water levels pre- and post-slug-tests are in a similar range (-1.742 m and -1.75 m AGL, respectively). As only the Level Troll 700 logger data showed a significant difference in the water level measured pre- and post-slug-test, a barometric correction was applied to that dataset only.

A barometric efficiency coefficient of 0.75 was applied to the water-level data recorded by the Level TROLL 700 logger following Equation A7.1 (Figure A7.1).

A7.2.3 Results and Analysis

The slug test data were analysed using AQTESOLV Pro software. Each slug in and slug out were analysed independently, and a Bouwer and Rice (1976) solution was fitted to the curves (Figures A7.2, A7.3 and A7.4). From this solution, a hydraulic conductivity K was calculated and is summarised in Table A7.3. The average hydraulic conductivity for this layer is 0.875 m/day. Input parameter assumptions for this analysis (e.g. saturated thickness of the aquifer) impact the results and may be under- or over-estimated.

Table A7.3 Summary of the hydraulic conductivity calculated for each slug-in and slug-out test. The saturated thickness of the aquifer is assumed to be 13.26 m, following the assumption that the base of the aquifer layer is at 15 m BGL.

		Slug Test 6a		**Slug Test 6b**		**Slug Test 6c**	
		In	**Out**	**In**	**Out**	**In**	**Out**
K (m/day)	**Calculated from the Level TROLL 700 logger data (barometric-corrected)**	0.805	0.823	0.952	0.897	0.888	0.865
	Calculated from the Bluetooth logger data	0.820	0.815	0.994	0.893	0.861	0.885
	Average	**0.816**		**0.934**		**0.875**	
	Combined Average	**0.875**					

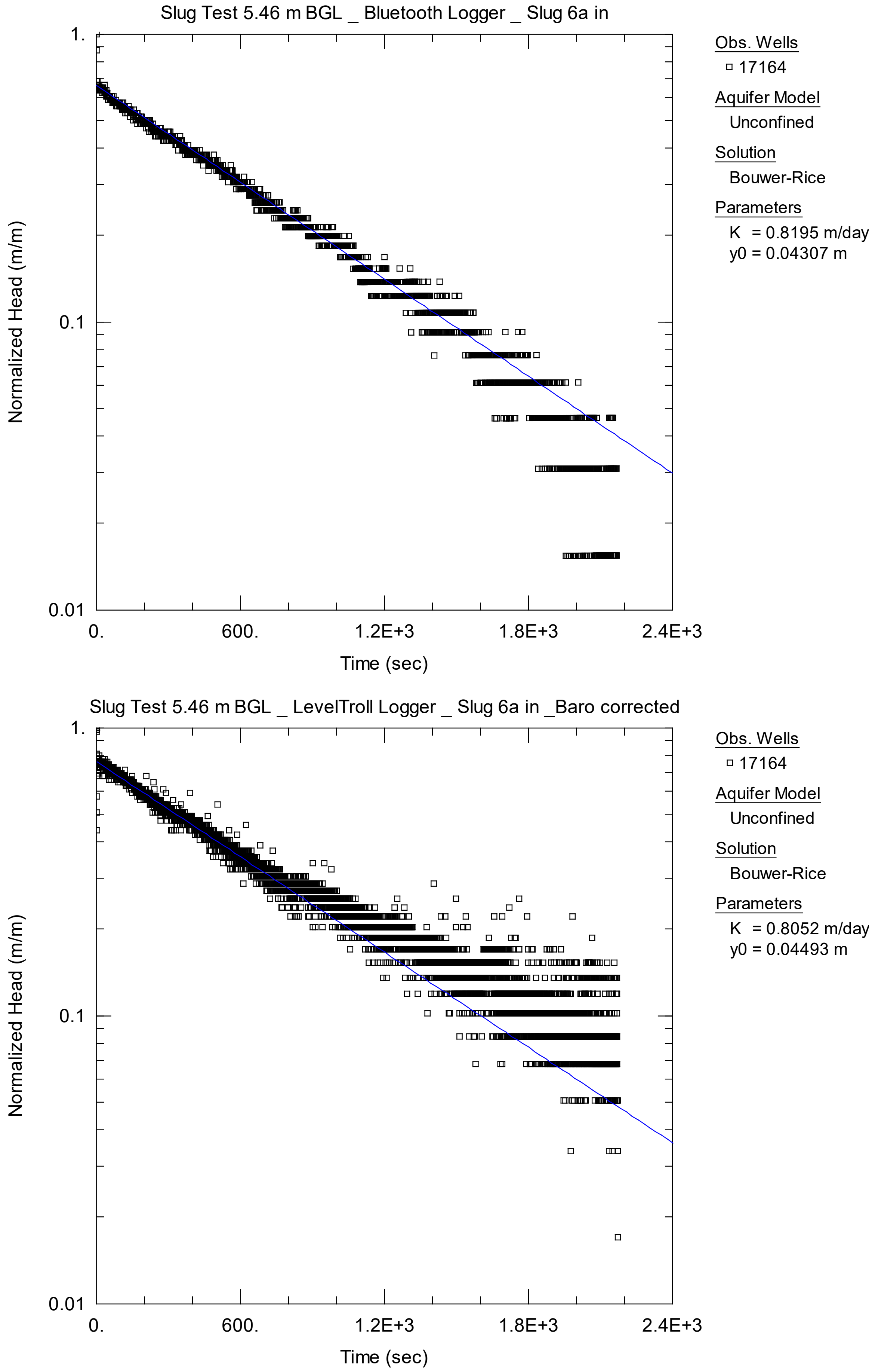
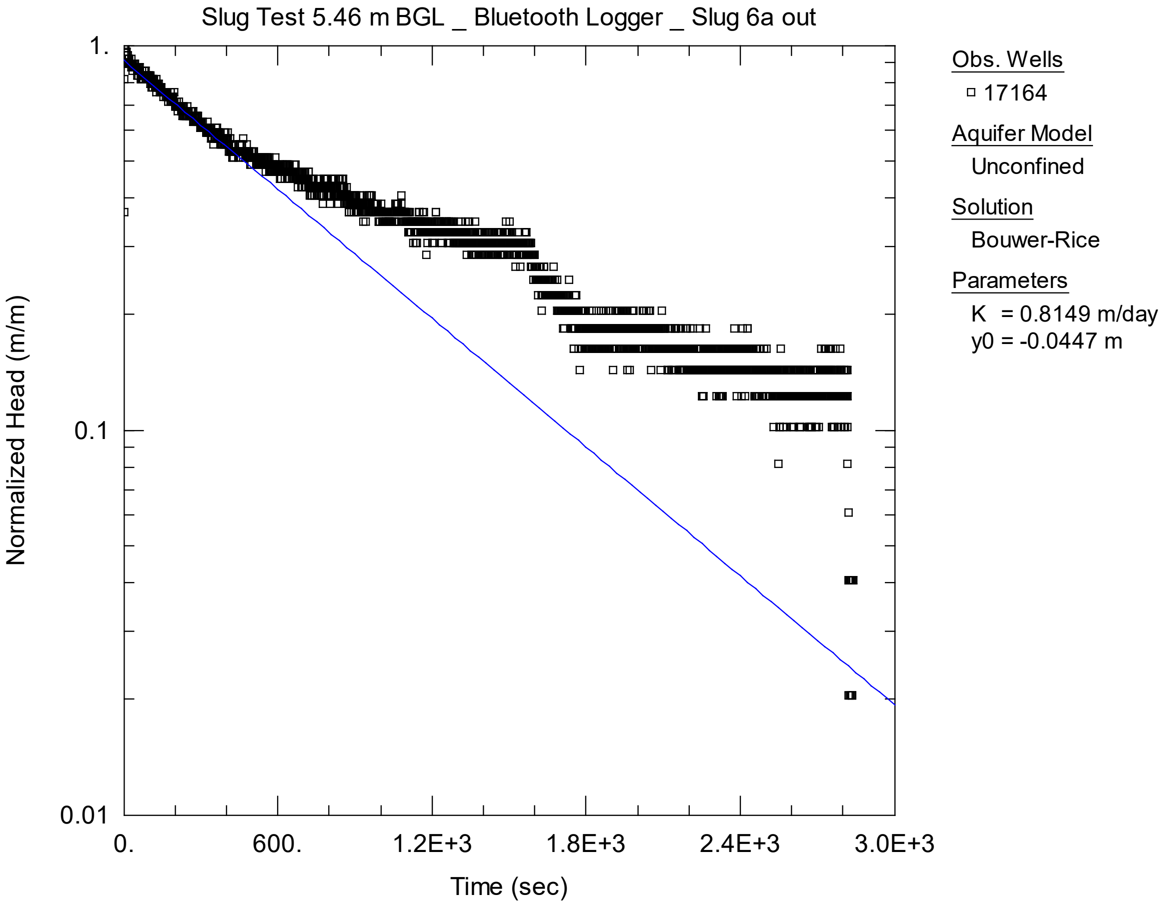


Figure A7.2 Results of slug test 1 analysis of the first slug-in (this page) and slug-out (next page) tests with slug 6 for both loggers.



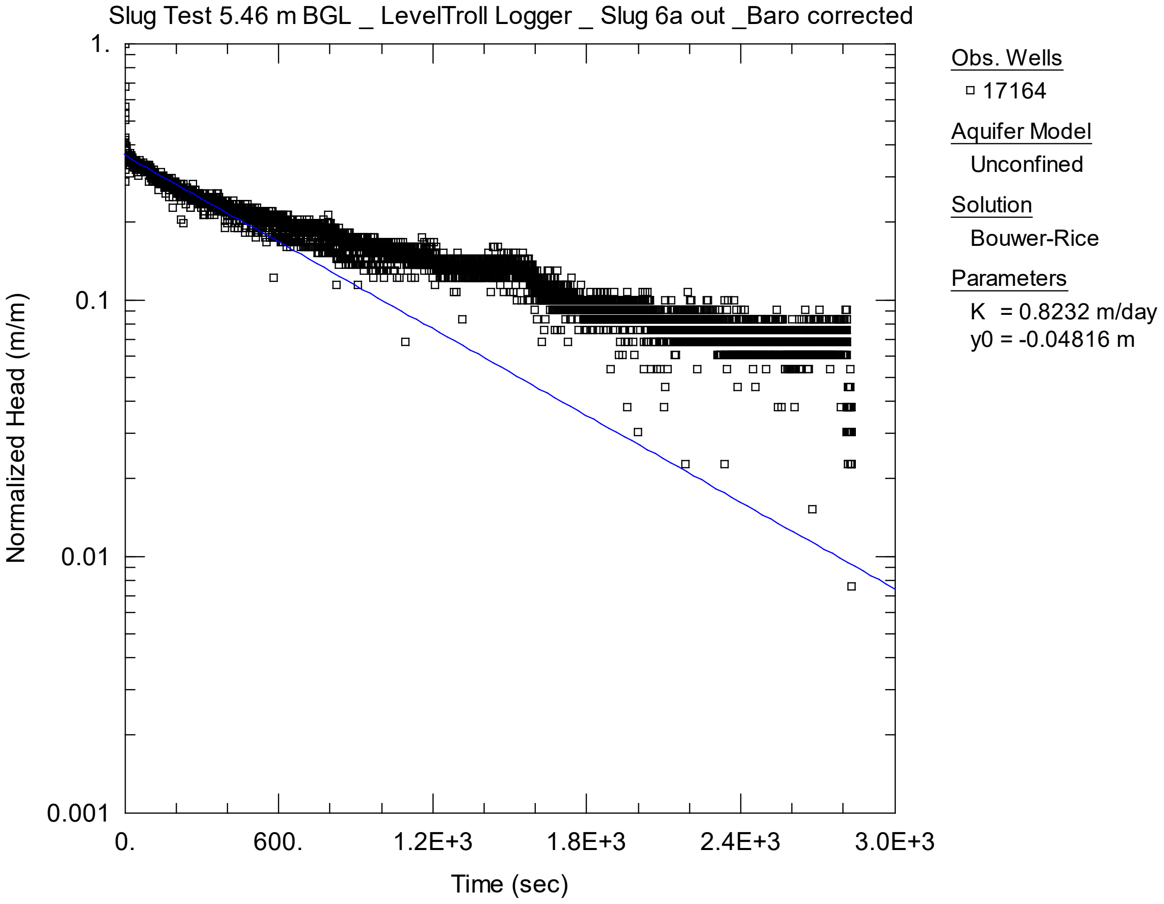
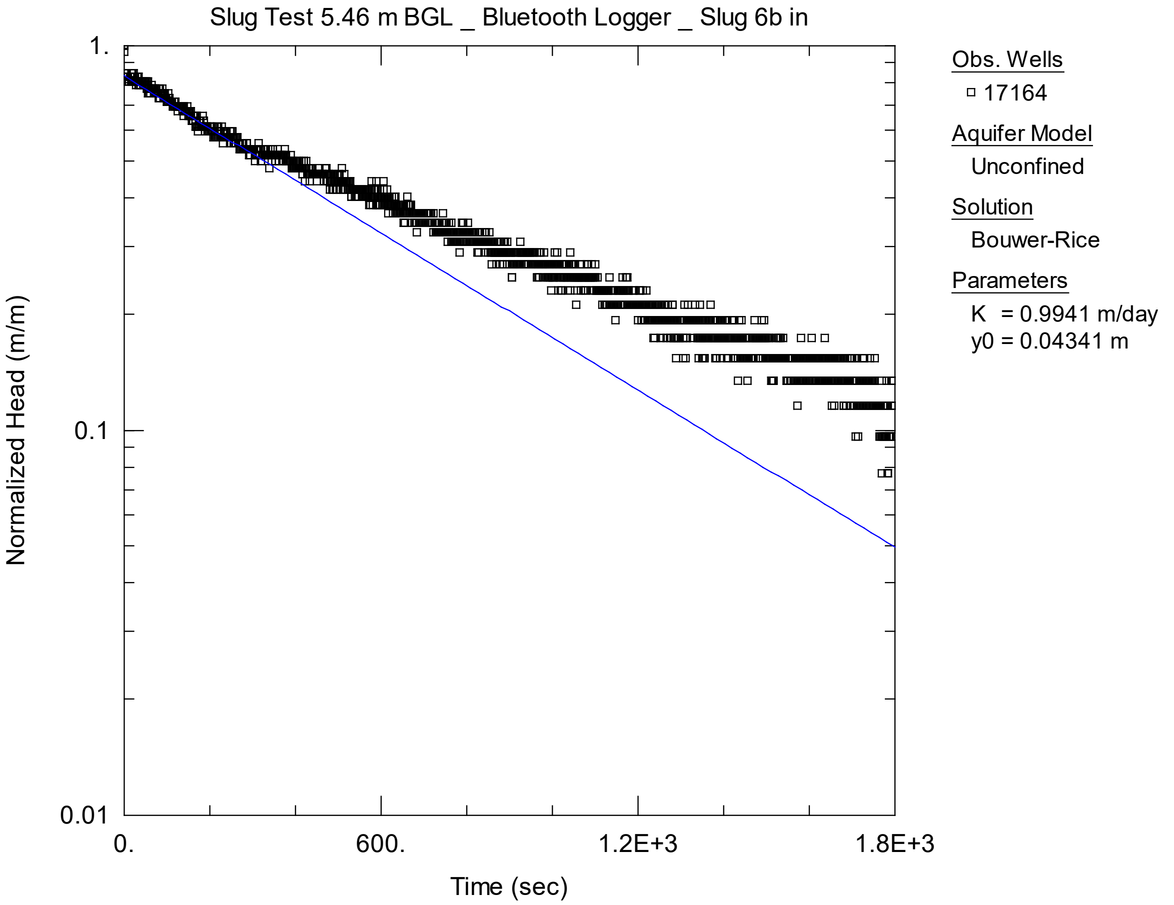


Figure A7.2 Continued.



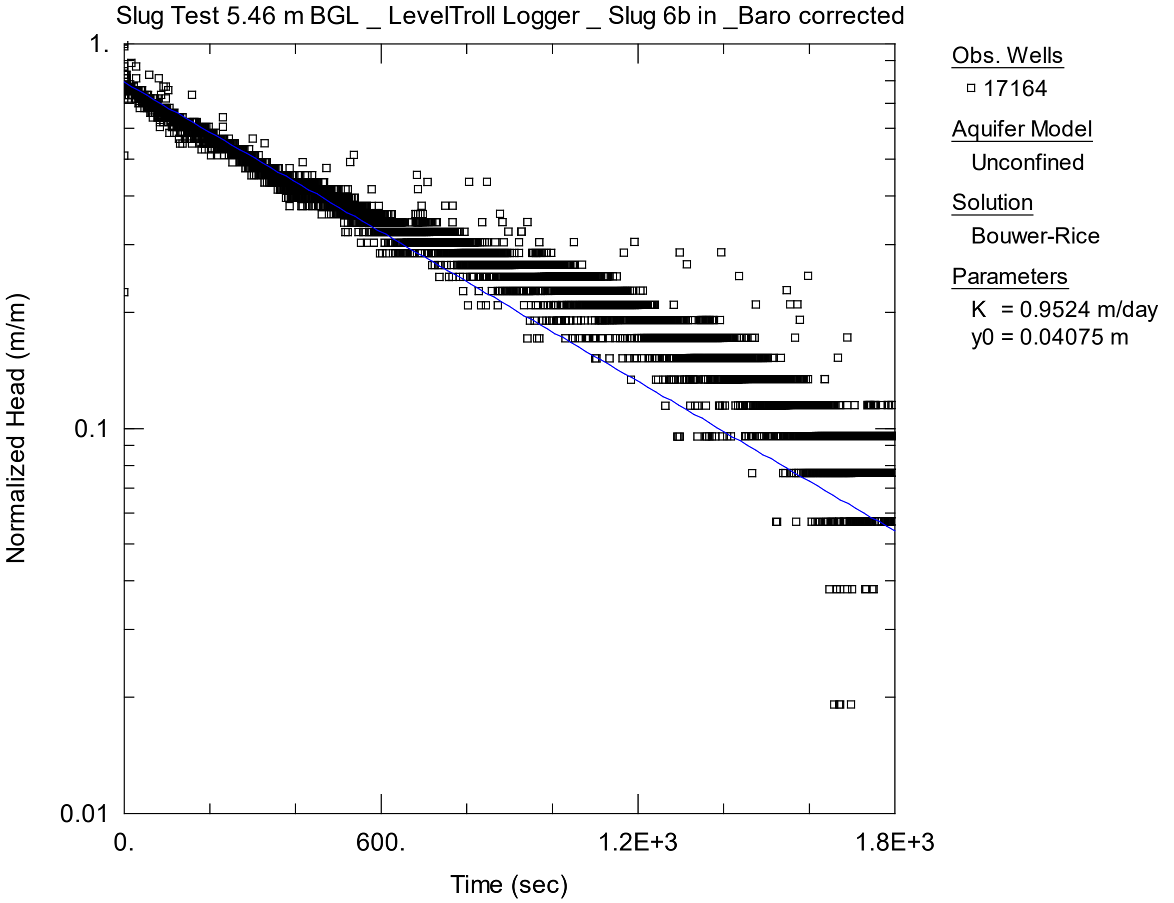
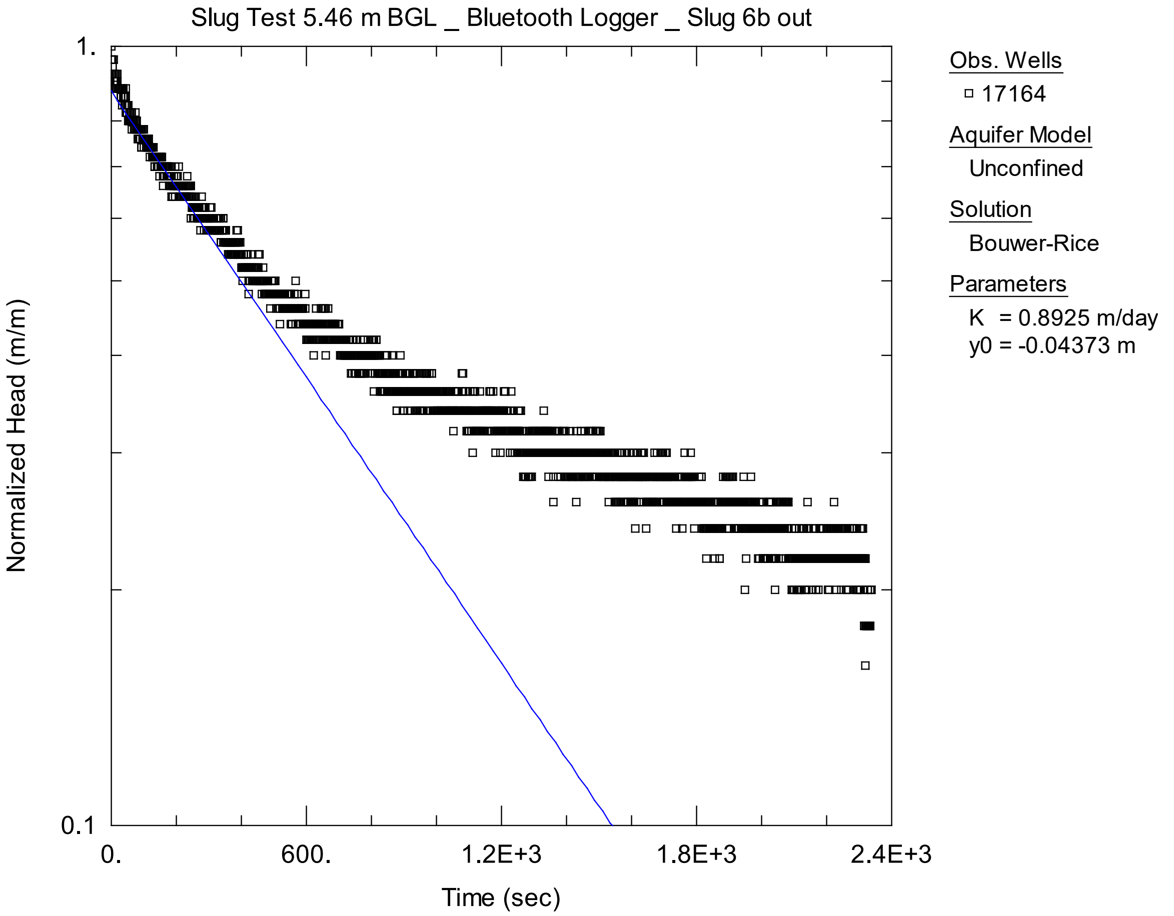


Figure A7.3 Results of slug test 1 analysis of the second slug-in (this page) and slug-out (next page) tests with slug 6 for both loggers.



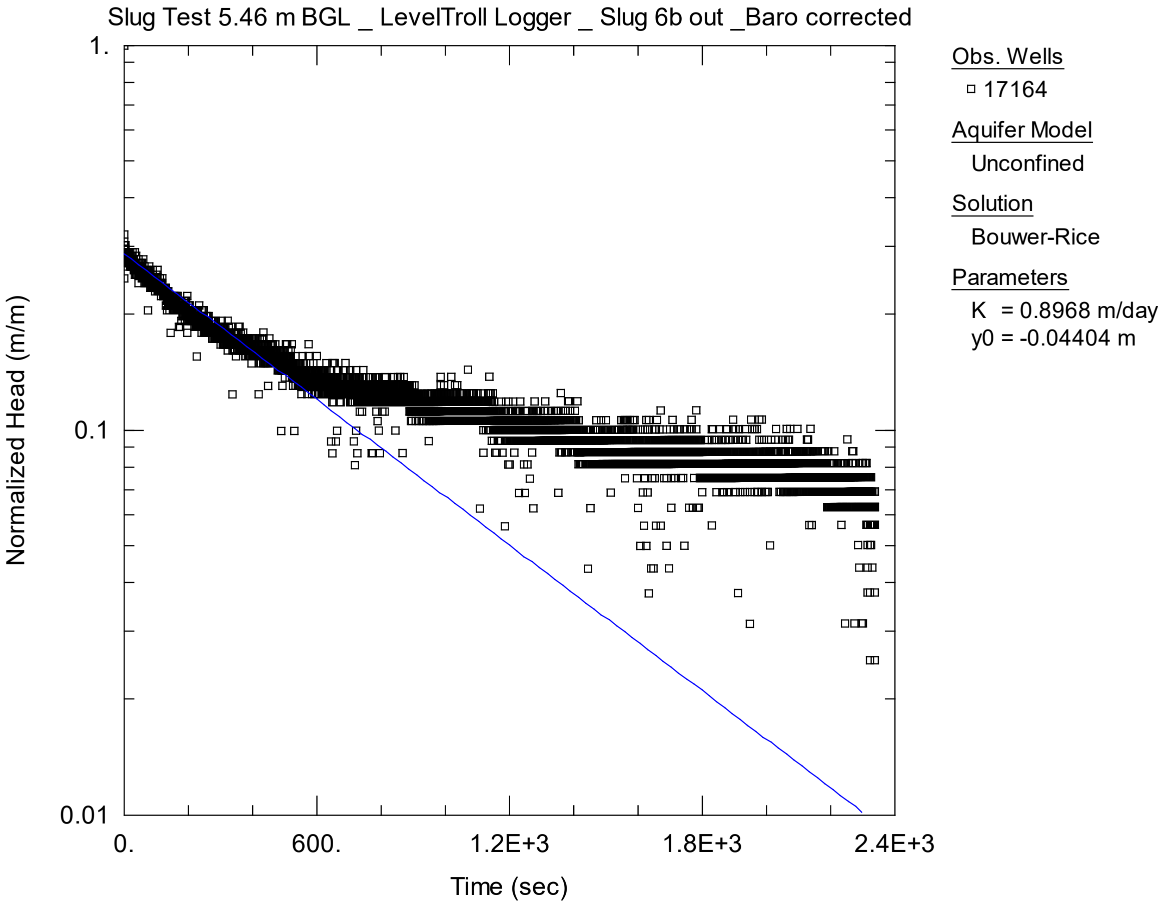
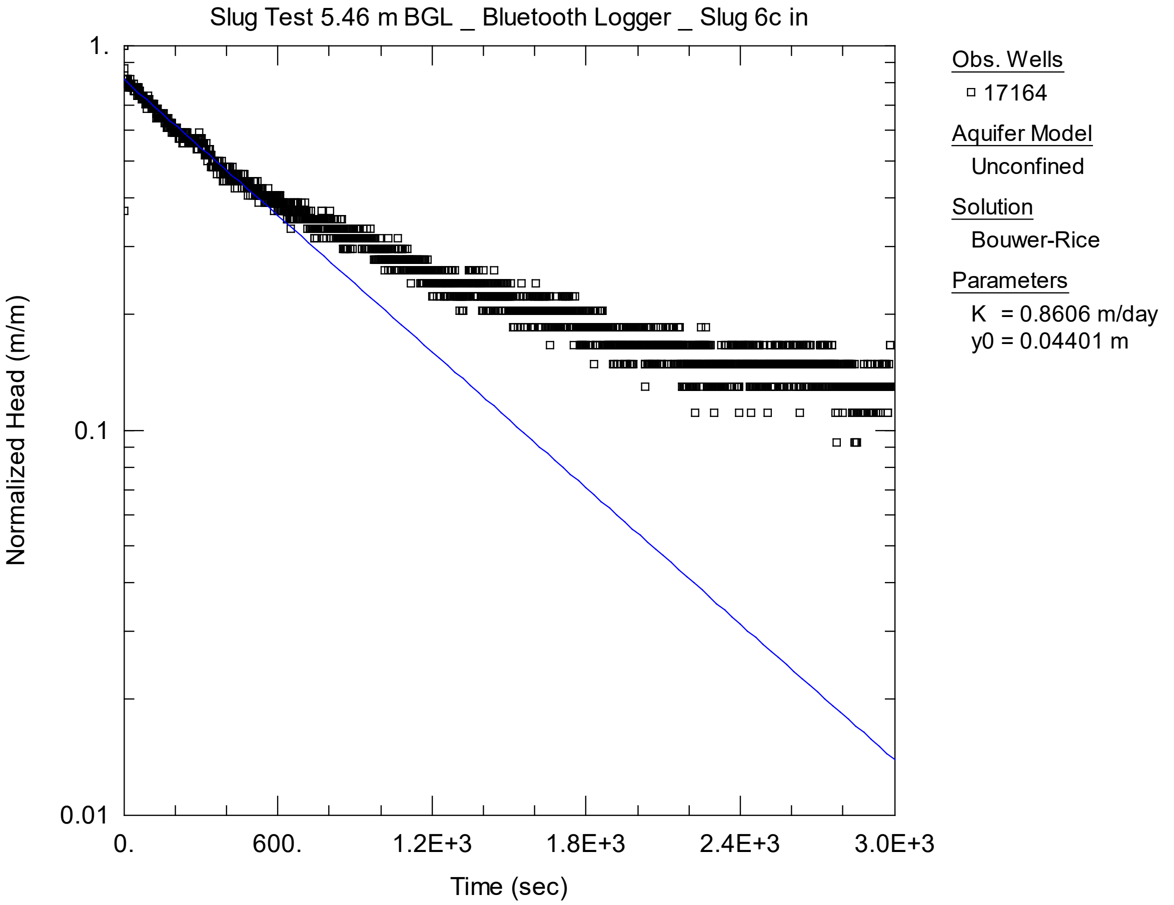


Figure A7.3 Continued.



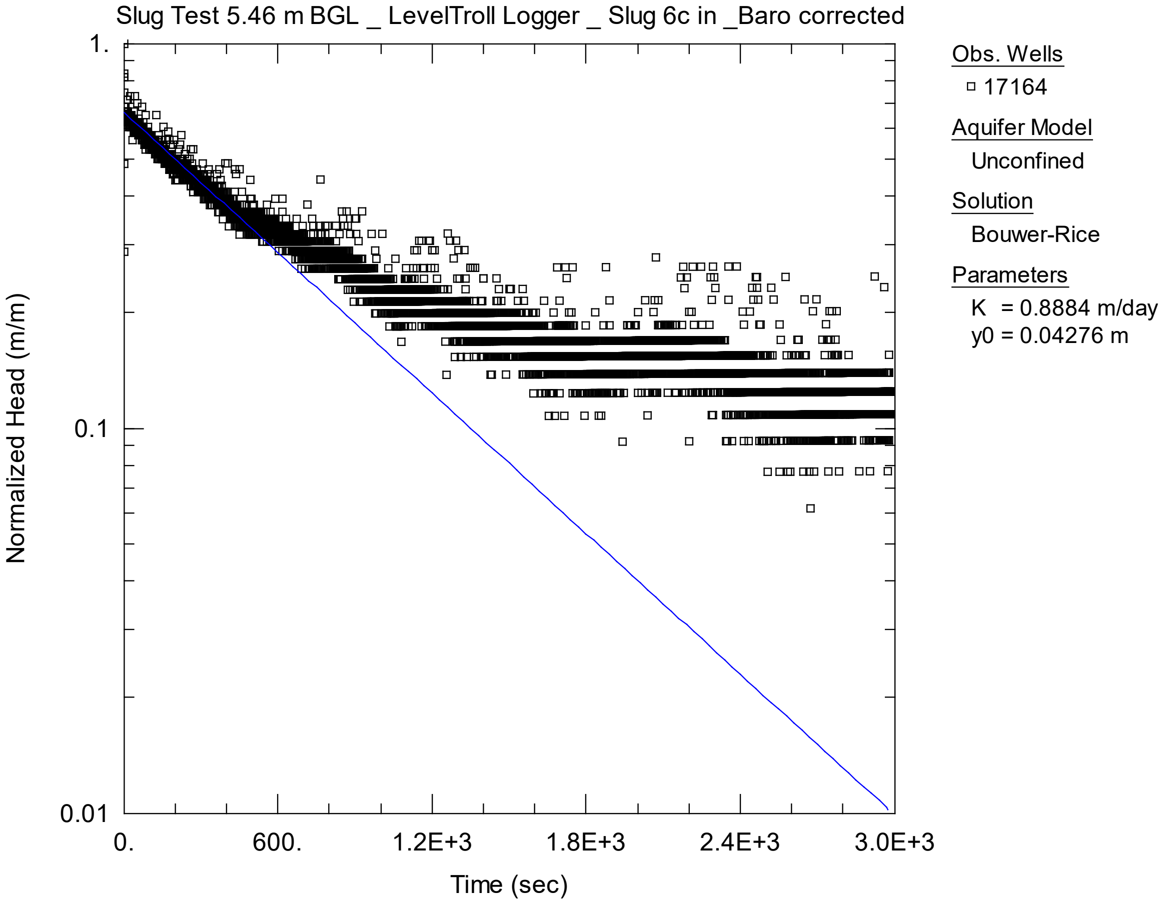
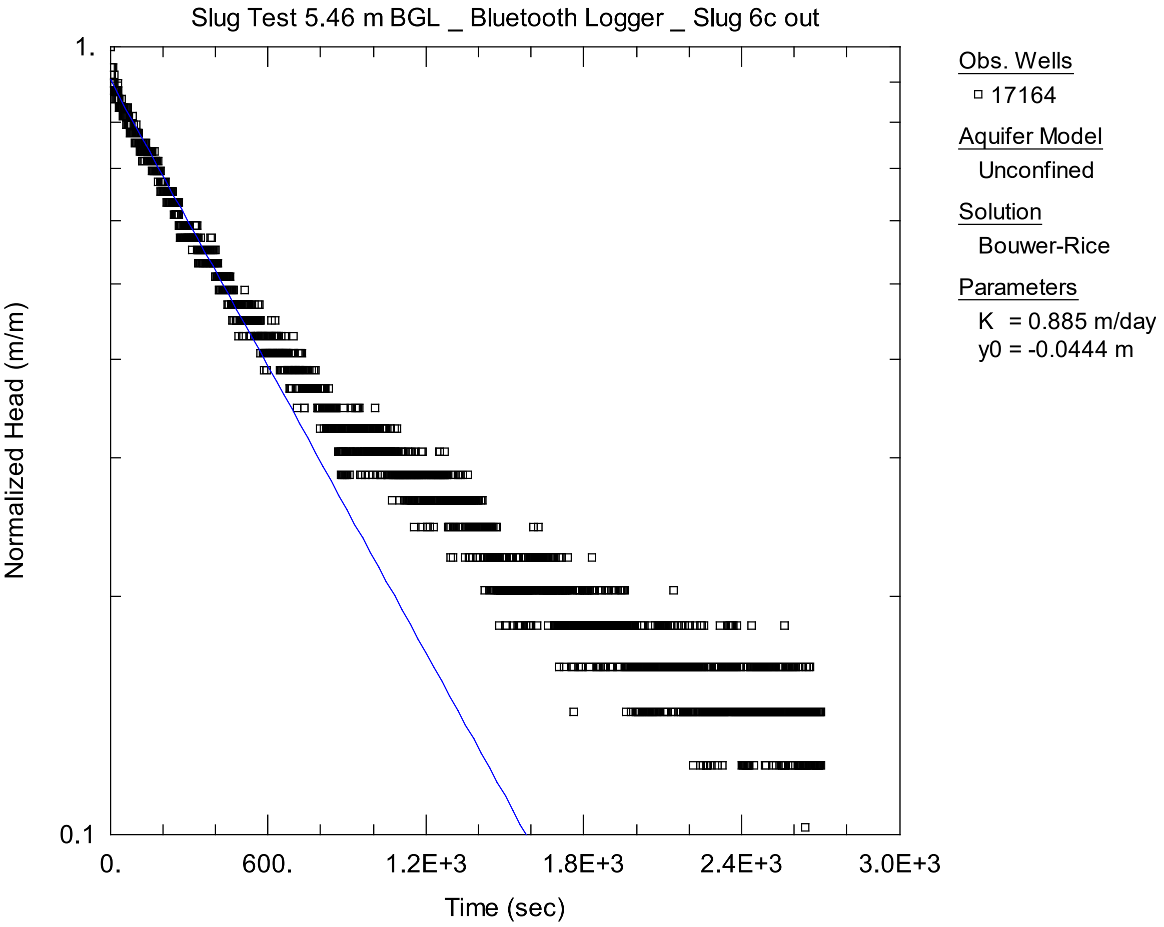


Figure A7.4 Results of slug test 1 analysis of the third slug-in (this page) and slug-out (next page) tests with slug 6 for both loggers.



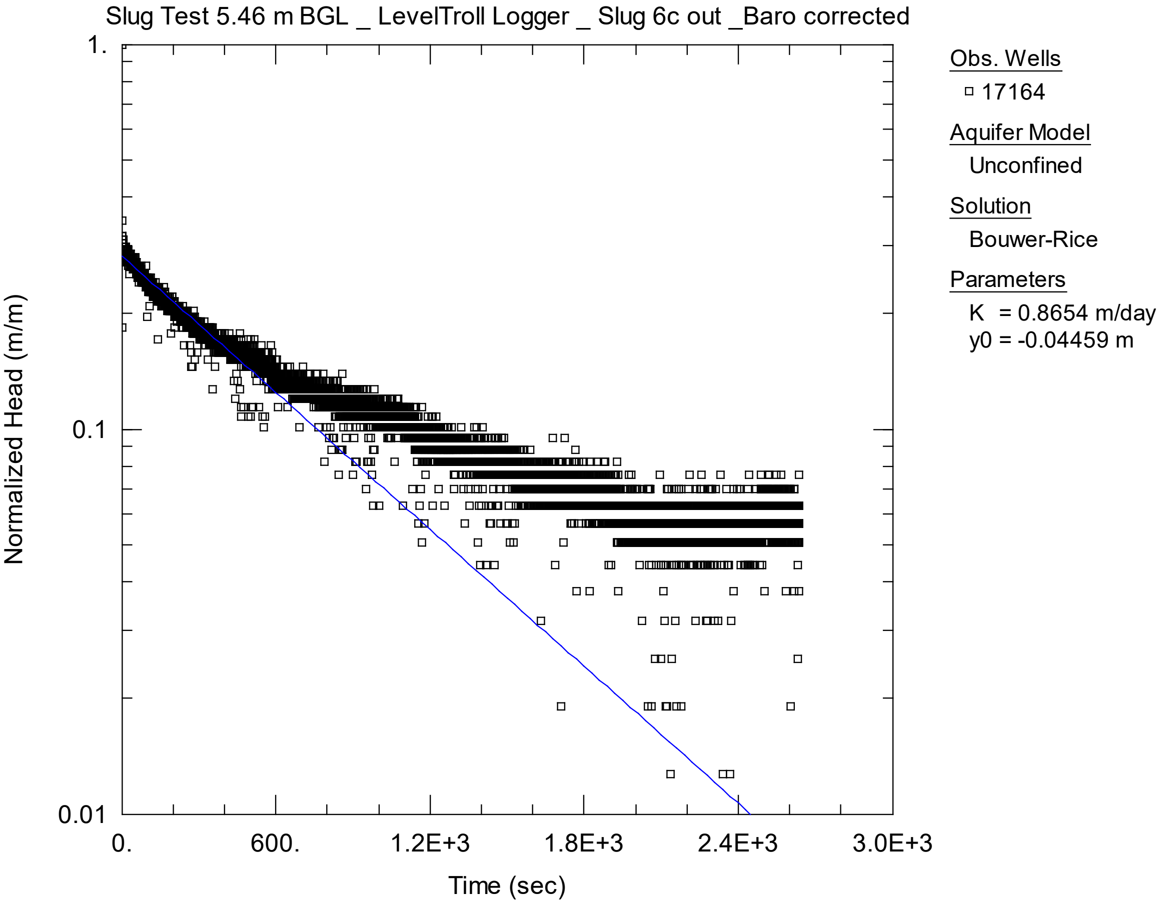


Figure A7.4 Continued.

A7.3 Slug Test 2 at 18.0 m BGL

A7.3.1 Test Details

A series of slug tests were performed on 5 August 2021 at a depth of 18.0 m BGL in a layer of moderately well to well-sorted clay with sub-rounded fine to very coarse pebble and sub-rounded sand increasing with depth.

Drilling stopped on 3 August 2021, with the slug tests planned for the next day to allow enough time for the water level to recover to static level. However, on 5 August, the water level had not reached a static level and was still rising significantly.

Based on the lithology log acquired while drilling, a sharp change from gravel to clay is observed at 15.0 m BGL (Figure 2.5); therefore, it is assumed that this layer acts as an aquitard and that its saturated thickness is 10 m.

Water levels were recorded every quarter of a second using an In-Situ Level TROLL 700 (non-vented). The weather was overcast, with light rainfalls and changing conditions.

A7.3.2 Barometric Correction

Barometric pressure was recorded on-site with a HOBO Bluetooth data logger every 30 seconds during the tests and utilised for the correction of the water level recorded with the Level TROLL 700 data logger.

A barometric efficiency coefficient was visually estimated at 1 using the manual water-level measurements and a correction following Equation A7.1 was applied to the water-level data recorded by the Level TROLL 700 logger.

A7.3.3 Results and Analysis

A coarse estimation of a hydraulic conductivity for this layer was made by analysing the very early time slug-out data using AQTESOLV Pro software. A Bouwer-rice solution was fitted to the curves (Figures A7.5 and A7.6; Table A7.4), proving an average hydraulic conductivity of 0.250 m/day. Input parameter assumptions for this analysis (e.g. saturated thickness of the aquifer) impact the results and may be under- or over-estimated.

Table A7.4 Summary of the hydraulic conductivity estimated for both slug-out tests. The saturated thickness of the aquifer is assumed to be 10.0 m.

		Slug Test 6	**Slug Test 2**
		Out	**Out**
K (m/day)	**Calculated from the Level TROLL 700 logger data (barometric-corrected)**	0.245 *	0.255 *
	Average	**0.250 ***	

* As the water level in the well was rising prior to and during the tests, there is considerable uncertainty in these values.

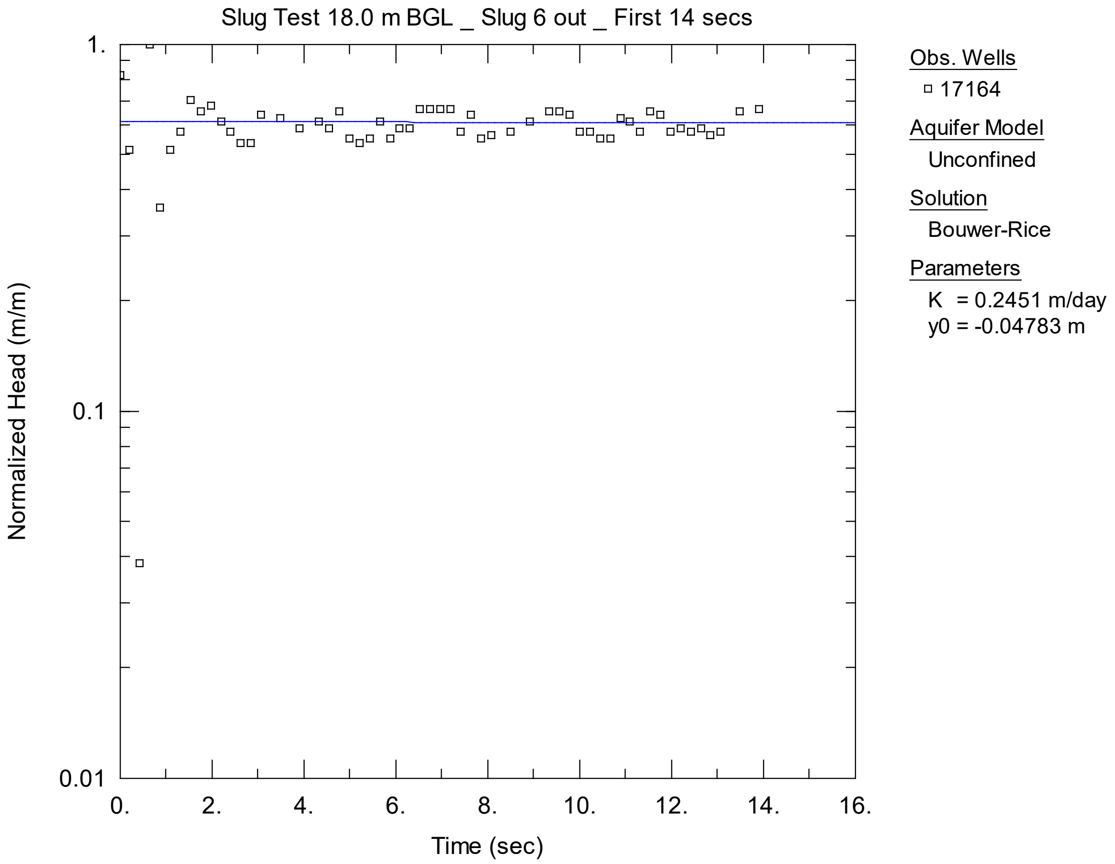


Figure A7.5 Results of the analysis for the slug-out test with slug 6, undertaken at 18.0 m BGL. Only the first 14 seconds were analysed.

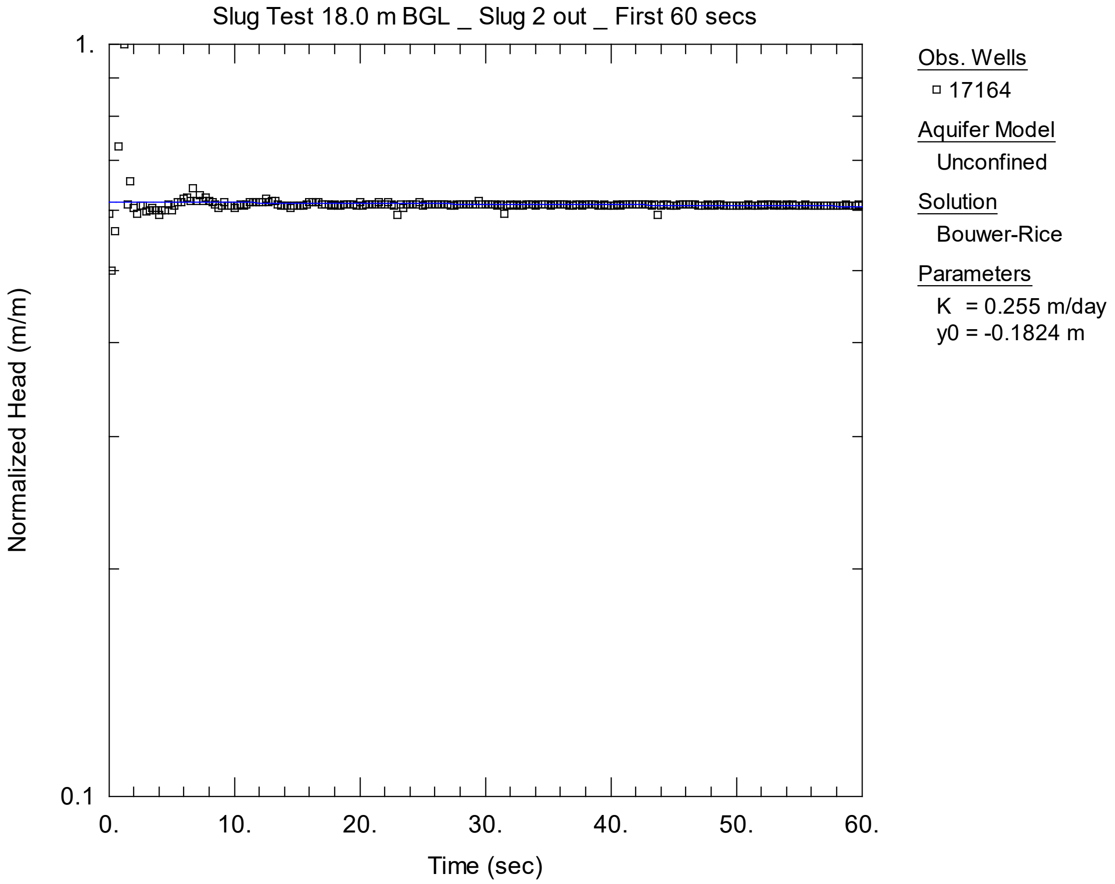


Figure A7.6 Results of the analysis for the slug-out test with slug 2, undertaken at 18.0 m BGL. Only the first 60 seconds were analysed.

A7.4 Slug Test 3 at 55.22 m BGL

A7.4.1 Test Details

Drilling was stopped on 11 August 2021, with the casing at 55.22 m BGL. The water level was lower than 22.0 m BGL when drilling ceased and had risen to 3.37 m BGL on the morning of 12 August. The sands were bailed down to 54.0 m BGL, and slug tests were planned to take place (Appendix A2.7). Drilling and testing went on hold while a decision was made about whether to continue drilling or abandon the hole. However, New Zealand went into COVID-19 Alert Level 4 lockdown on 18 August, meaning that slug tests were postponed until both Hawke's Bay and Taupō reached COVID-19 Alert Level 2. The drillers arrived back on-site on 8 September 2021; the static water level was measured at 0.9 m AGL and the sands had heaved back up to 49–50 m BGL. The sands were bailed out that day, and the water level was manually filled to 0.9 m AGL to re-establish the static level and stop the sands from hydraulicing ('heaving') into the well until slug tests were undertaken the next day.

A series of slug tests were performed on 9 and 15 September 2021 at a depth of 55.22 m BGL in a layer of well to very well-sorted fine to medium sand (running sands), with minor coarse to very coarse pumiceous sand. A slug-in test was undertaken on 9 September, and the loggers and slug were left in the well until the next day. On 10 September, the slug-out test was undertaken, and the loggers were left recording in the well until 15 September (Figure A7.7).

Water levels and barometric pressure were recorded with automatic data loggers:

- Water level every 30 seconds using an In-Situ Level TROLL 700 (non-vented).
- Water level every 30 seconds using a HOBO Bluetooth water-level data logger (vented).
- Barometric pressure every 60 seconds with a HOBO Bluetooth logger.

The weather was sunny, with no rainfall recorded on all testing days but with strong winds.

The sands inside the casing were measured at 52.42 m BGL on 9 September, prior to the start of the slug-in test. The sands were then measured at 51.64 m BGL on 10 September prior to the start of the slug-out test, meaning that the screen at 53.87–55.07 m BGL was covered by the sands during both tests (Figure A7.8).

Based on the lithological log acquired while drilling (Figure 2.5), a sharp change from clay to sand is observed at 48.0 m BGL, and it is assumed that the clay layer acts as an aquitard and corresponds to the top of the aquifer layer in which slug tests 3 and 4 were undertaken.

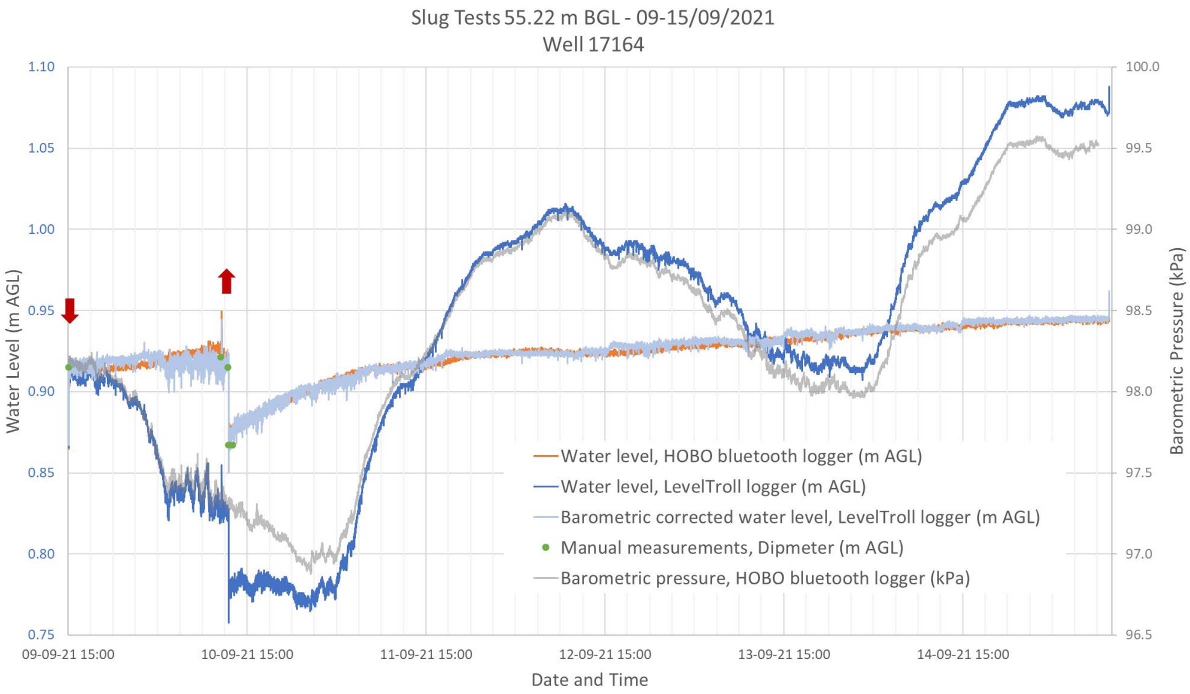


Figure A7.7 Water level and barometric pressure recorded during the second slug-in and slug-out tests at 55.22 m BGL, undertaken with slug 6. The downward red arrow indicates when the slug was lowered into the bore (beginning of slug-in test); the upward red arrow indicates when the slug was pulled out (beginning of slug-out test).

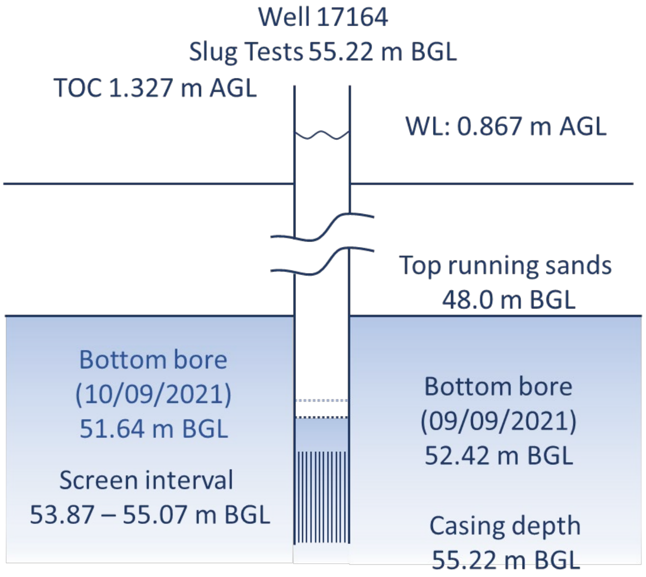


Figure A7.8 Schematic showing the well conditions during the slug tests at 55.22 m BGL. Bottom bore corresponds to the elevation of the top of sand in the bore.

A7.4.2 Barometric Correction

Barometric pressure recorded on-site was used for the correction of the water level recorded with the Level TROLL 700 data logger. The effect of the barometric pressure changes on the water level recorded with the Level TROLL 700 data logger provided a visual estimate of the barometric efficiency coefficient of 1.

A correction following Equation A7.1 was applied to the water level data recorded by the Level TROLL 700 logger, which, after correction, closely matched the water-level response recorded by the HOBO Bluetooth logger data and manual measurements (Figure A7.7).

A7.4.3 Results and Analysis

No recovery was observed during the slug-in test. Due to this, it was expected that a similar nil response would occur during the slug-out test (i.e. no recovery). However, a clear recovery curve was observed over the five days of the slug-out test. One possible explanation could be that the water level only reached a static level during the slug-in test, explaining the increase in water level following removal of the slug (Figure A7.7). The reason for the discrepancy in results is not known but could be due to:

- Groundwater level at the drill site being in recovery during the slug-in test.
- Flowing sand movement caused by insertion and/or removal of the slug.
- A combination of the above.

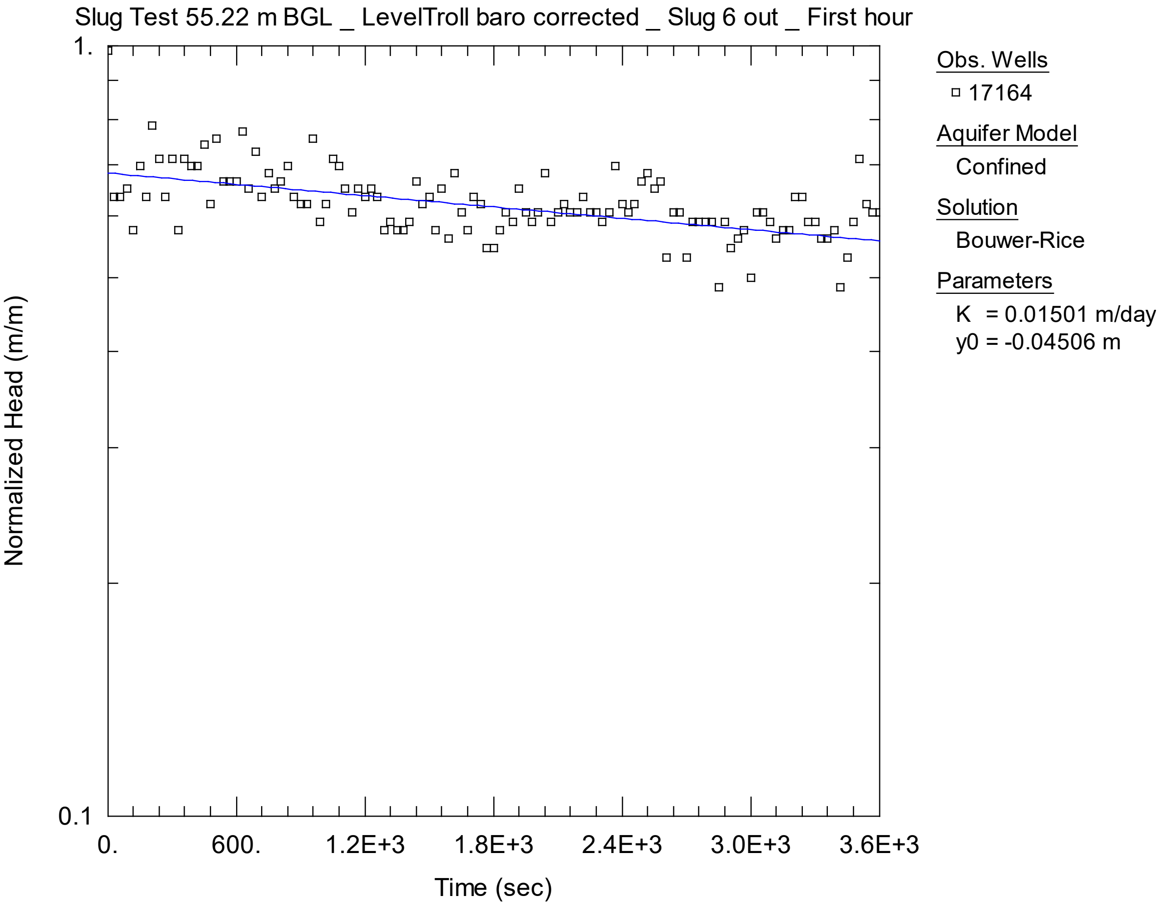
Analysis of the first hour of slug-out test data was undertaken to provide an estimate of hydraulic conductivity of this sand layer.

It is assumed for this analysis that the clay layer above 48.0 m BGL acts as an aquitard and corresponds to the top of the aquifer for the two sand layers tested during slug tests 3 and 4. It is also assumed that the two sand layers encountered between 48.0 and 79.0 m BGL are the same confined aquifer. Therefore, the saturated thickness of the aquifer is assumed to be 31.0 m for this analysis.

The slug-out test data was analysed using AQTESOLV Pro software. Both slug-out test data recorded with the HOBO Bluetooth data logger and with the Level TROLL 700 data logger were analysed by fitting a Bouwer and Rice (1976) solution (Figure A7.9; Table A7.5). A hydraulic conductivity average of 0.011 m/day is estimated for this layer. Assumptions made on the input parameters applied in this analysis (e.g. saturated thickness of the aquifer and static water level) impact the results and may be under- or over-estimated.

Table A7.5 Summary of the hydraulic conductivity estimated for the slug-out test at 55.22 m BGL. The saturated thickness of the aquifer is assumed to be 31.0 m. Because the sands heaved back higher than the top of the screen, there is considerable uncertainty in these values.

		Slug-Out Test
K (m/day)	Calculated from the Level TROLL 700 logger data (barometric-corrected)	0.015
	Calculated from the HOBO Bluetooth logger data	0.008
	Average	**0.011**



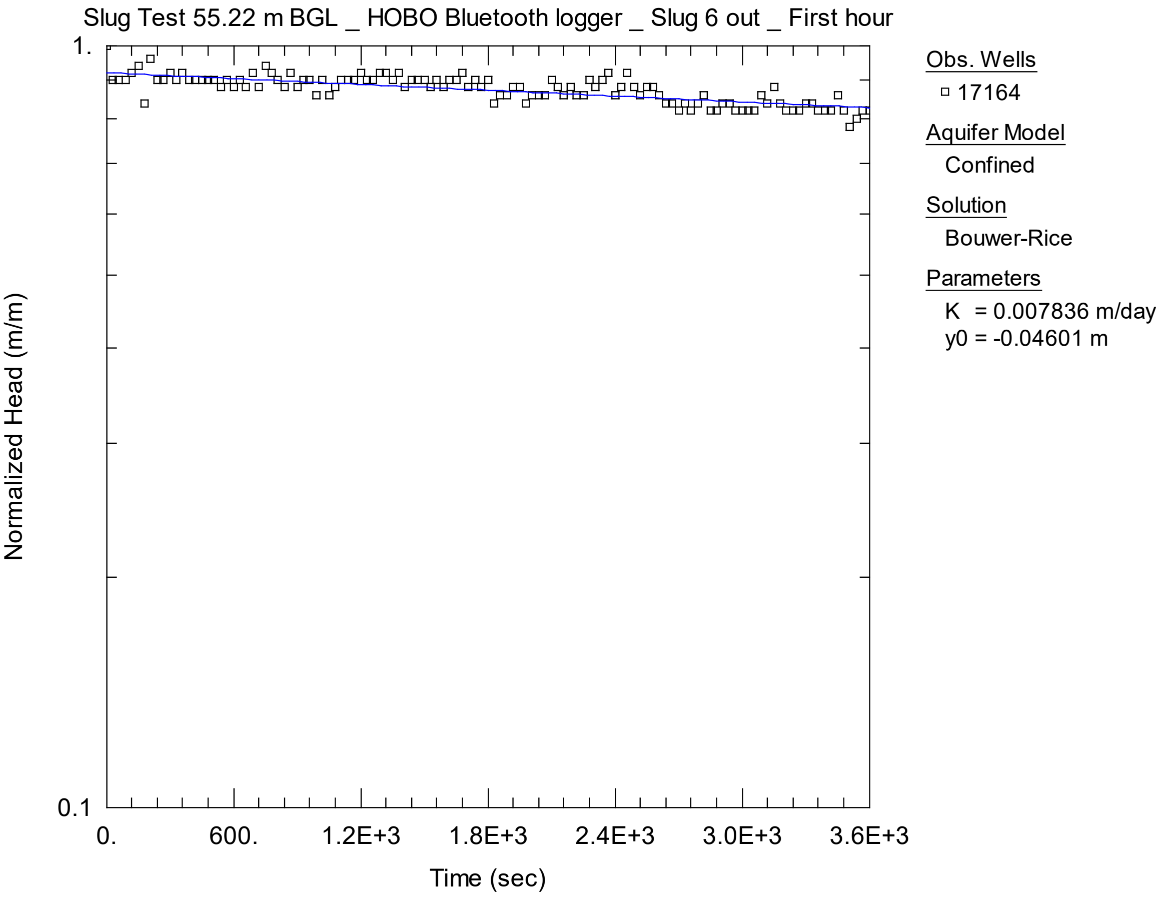


Figure A7.9 Results of the analysis for the first hour of the slug-out test with slug 6, undertaken at 55.22 m BGL for both loggers.

A7.5 Slug Test 4 at 76.35 m BGL

A7.5.1 Test Details

Drilling was stopped on 5 October 2021, with the casing at 76.35 m BGL and the sands heaving up inside the casing to 24.5 m BGL. In the following days, the sands were bailed out from the casing down to 69.76 m BGL to prepare for the tests, maintaining water level in the well to restrict the movement of sands into the casing. For logistical reasons, the slug tests had to be started on 8 October, despite the water level in the well not being static level.

A slug test was performed between 8 and 11 October 2021 at a depth of 76.35 m BGL in a layer of well-sorted fine to medium quartz sand (running sands). The smallest-sized slug (slug 6) was used to undertake slug-in and slug-out tests. As no apparent recovery was observed during the slug-in test, slug tests were not repeated, and the water level was monitored for three days (Figure A7.10). By the end of the test, the sands heaved back up to 69.71 m BGL within the casing. As the top of the screen was located at 75.0 m BGL, the screen was entirely covered by the sands (Figure A7.11).

Water levels and barometric pressure were recorded with automatic data loggers:

- Water level every 250 milliseconds for the first five hours of recording and every 15 seconds thereafter using an In-Situ Level TROLL 700 (non-vented).
- Water level every second for the first five hours of recording and every 15 seconds thereafter using a HOBO Bluetooth water-level data logger (vented).
- Barometric pressure every 60 seconds with a HOBO Bluetooth data logger.

For the slug-in test, the slug and loggers were left in the well overnight, 8 October, with the landowner removing the slug (morning of 9 October); with the loggers recording the recovery of the slug-out test. The weather was sunny, with no rainfall recorded during the tests.

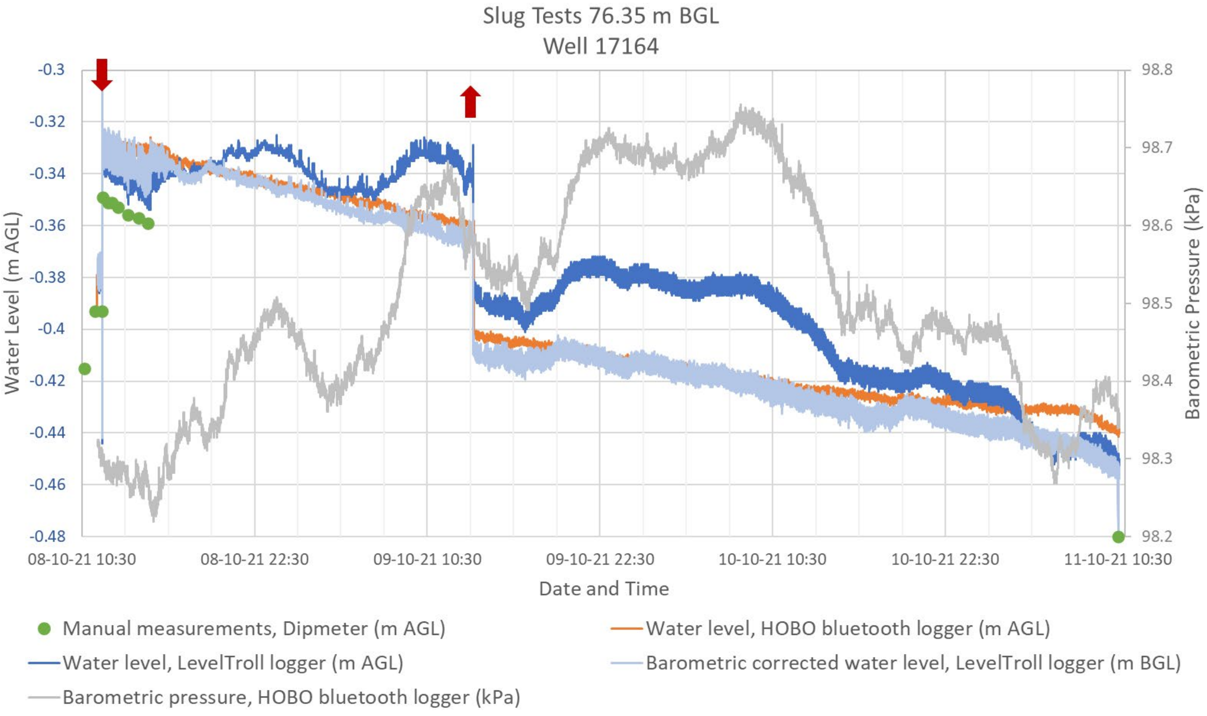


Figure A7.10 Water level measured during the slug tests at 76.35 m BGL. The downward red arrow indicates when the slug was lowered into the bore (beginning of the slug-in test); the upward red arrow indicates when the slug was pulled out (beginning of the slug-out test).

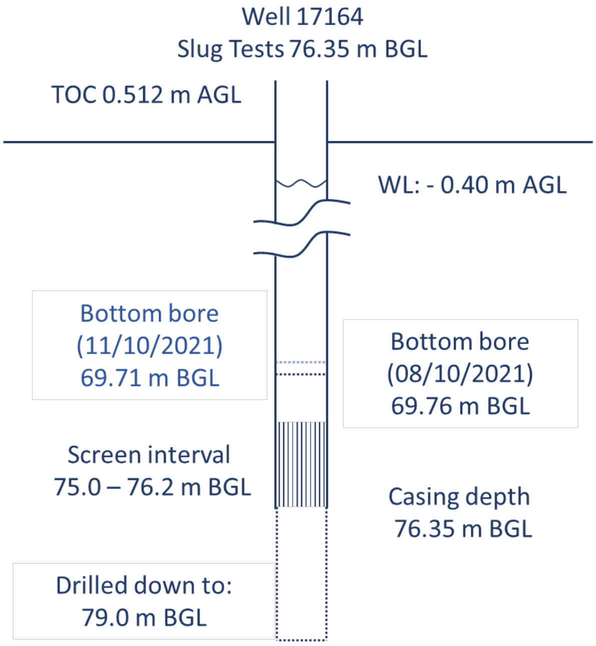


Figure A7.11 Schematic showing the well condition during the slug tests at 76.35 m BGL. Bottom bore corresponds to the elevation of the top of the sands in the well casing.

A7.5.2 Barometric Correction

Barometric pressure recorded on-site was used for correction of the water level recorded with the Level TROLL 700 data logger. The effect of the barometric pressure changes,

on the water level recorded with the Level TROLL 700 data logger provided a visual estimate of the barometric efficiency coefficient of 0.9. A correction following Equation A7.1 was applied to the water level data (Figure A7.10).

A7.5.3 Results and Analysis

No analysis was undertaken for the slug tests at 76.35 m BGL, as the water level did not reach a static level prior to the start of the test, and the recovery of the water level shadowed any potential response resulting from the tests.

APPENDIX 8 WATER CHEMISTRY

No water samples were collected at well 17164.

www.gns.cri.nz

Principal Location

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