Hawke's Bay 3D Aquifer Mapping Project:
Drilling Completion Report for Borehole 17136 (3DAMP_Well1), Ongaonga–Waipukurau Road, Ruataniwha Plains

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EXECUTIVE SUMMARY

This report describes the drilling undertaken and datasets collected at borehole/well 17136 (3DAMP_Well1), 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 northwest of Waipukurau on the Ongaonga–Waipukurau Road, with a planned depth of 150–180 m BGL (metres below ground level). The well objectives were to:

- Characterise the high resistivity zone in the SkyTEM data from 0 to 50 m depth.
- Identify potential aquifers in a zone of moderate resistivity at 100 to 150 m depth.
- Determine the depth to the limestone and identify the hydrogeological properties of the limestone, as well as any other units encountered.
- Provide detailed lithological information, such as clay content, to assist with the interpretation of the SkyTEM data.

Prior to drilling, a single ground Transient ElectroMagnetic (TEM) measurement and NanoTEM measurement were made at the drill site. The well was then spudded on 17 February 2021 and terminated at a depth of 168 m BGL. A continuous sedimentary log was produced to a depth of 112.0 m BGL, with spot samples taken by the drillers below this depth. Sixty-nine lithological samples were acquired, of which 46 were set aside for laboratory grain-size analysis. Electrical resistivity measurements were made on all of these samples and also on material between sample depths. One 8-hour constant-rate pumping test was undertaken at 92.0 m BGL. Ten slug tests were undertaken at 10.78 m BGL, 26 m BGL, 47.20 m BGL, 53.0 m BGL, 55.0 m BGL, 79.0 m BGL, 84.20 m BGL, 92.0 m BGL, 97.0 m BGL and 110.5 m BGL. Groundwater chemistry, environmental tracer and water-age samples were collected at the end of the pumping test drawdown period and at well total depth (168.0 m BGL). Wireline logs (natural gamma, density) were acquired through casing to a depth of 160.89 m BGL.

Summaries of acquired data are in the Appendices of this report. Limited interpretation of acquired data has been undertaken at this stage but will be the focus of future reports.

1.0 INTRODUCTION

This report describes the drilling undertaken and datasets collected at borehole/well 17136 (HBRC Well Database ID) – alias 3DAMP_Well1 (project well ID) – in the Ruataniwha Plains, Hawke’s Bay. Well 17136 is the second of three boreholes being 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 (Figure 1.1) and Poukawa and Otane basins. 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 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.

As such, the locations of new groundwater wells and data collection types were planned by GNS in consultation with HBRC staff. 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. 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.

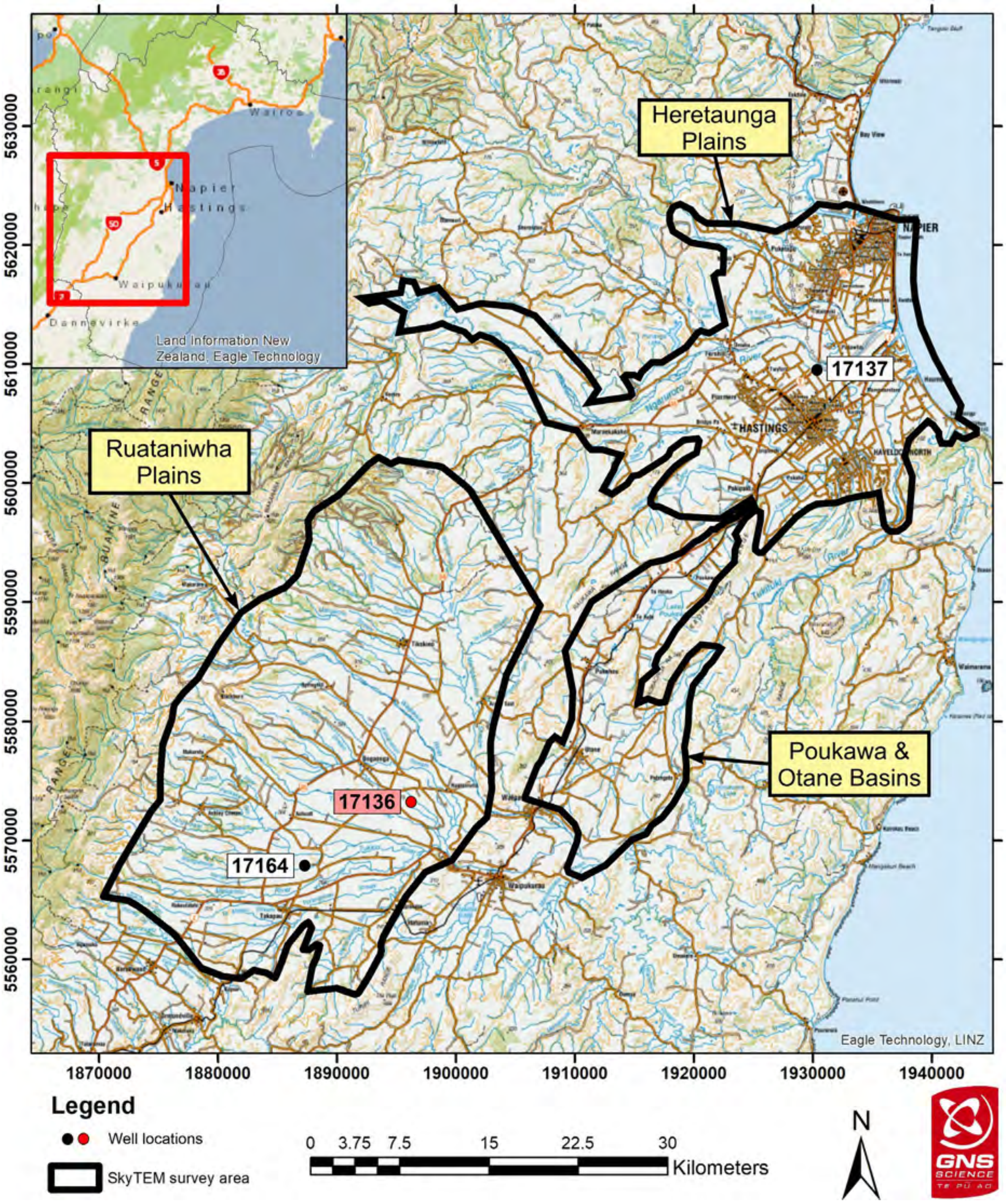


Figure 1.1 Coverage of the 3D Aquifer Mapping Project SkyTEM datasets within the Hawke's Bay region. The location of the three wells drilled as part of 3DAMP are labelled with their HBRC codes. Well 1 is 17136 (highlighted in red).

1.2 Location

The borehole 17136 (3DAMP_Well1) was drilled at a location on the Ongaonga–Waipukurau road northwest of the town of Waipukurau (Figures 1.1 and 1.2; Table 1.1). The original data collection plan (Reeves et al. 2019) was designed to address the following gaps in information:

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

Figure 1.2 shows the distribution of boreholes in the area from the HBRC database, colour-coded by depth. There are few boreholes in the area and most are less than 50 m deep. The new borehole drilling included the following objectives:

- Provide information from the ground surface down to the top of the predicted limestone (as characterised by a low-resistivity anomaly at approximately -50 m RL [relative level; refers to elevation above mean sea level]).
- Define hydraulic properties for shallow and deep aquifer units.
- Define base of aquifers.
- Constrain deeper high-resistivity anomaly (approximately 20 to -20 m RL, or 150–200 m deep).
- Help constrain discharges to the river.

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 line IP328-97-11 (Small 1997), the following general prognosis was made for the borehole:

- 0–50 m BGL recent gravel deposits with high resistivity.
- 50–150 m BGL Holocene gravel, sand and silt with moderate resistivity.
- 150–250 m BGL Pleistocene well bedded silt and clay with low resistivity.
- 250–400 m BGL Top of Pleistocene/Pliocene Limestone.

More detailed information was available for the top 100 m of the borehole based on the closest well (16668), which lies 760 m to the southwest of the proposed location (Table 1.2).

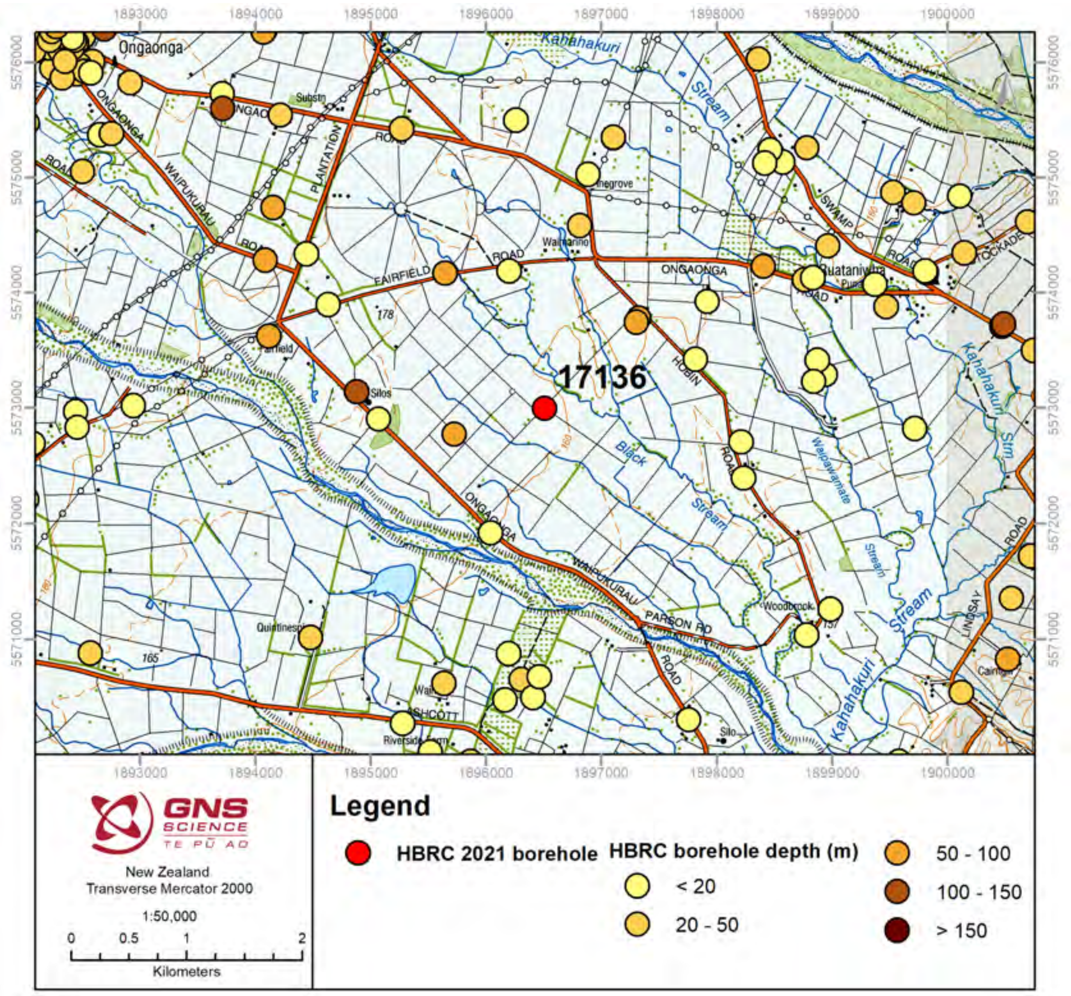


Figure 1.2 Location of the test borehole 17136 (3DAMP_Well1) on the Ongaonga–Waipukurau Road northwest of Waipukurau. HBRC boreholes are colour-coded by depth.

Table 1.1 Borehole 17136 (3DAMP_Well1) details. Negative numbers are below sea level (m ASL). BGL = below ground level.[1] Picked from LiDAR.

	17136 (3DAMP_Well 1)
Location (NZTM GD2000)	1896508 E, 5572997 N
Elevation at the ground surface (DEM)	161 (m asl)[1]
Total depth	168 (m BGL), RL -7 (m ASL)
Location	337 Ongaonga–Waipukurau Road, Ongaonga
Driller	Baylis Bros Ltd
Start of drilling	16 March 2021
End of drilling	12 July 2021

Table 1.2 Lithological units and depth (m BGL) logged at well HBRC 16668. The well is located 760 m southwest of borehole 17136 (3DAMP_Well1) and was drilled to a depth of 102 m BGL.

From	To	Lithology
0	3	Silt with gravel
3	8	Grey clay
8	39	Red and brown gravel
39	40	Blue clay
40	53	Brown gravel
53	69	Interbedded brown gravel and blue clay
69	84	Blue and red gravel with sand
84	87	Siltstone
87	100	Red gravel
100	102	Blue siltstone

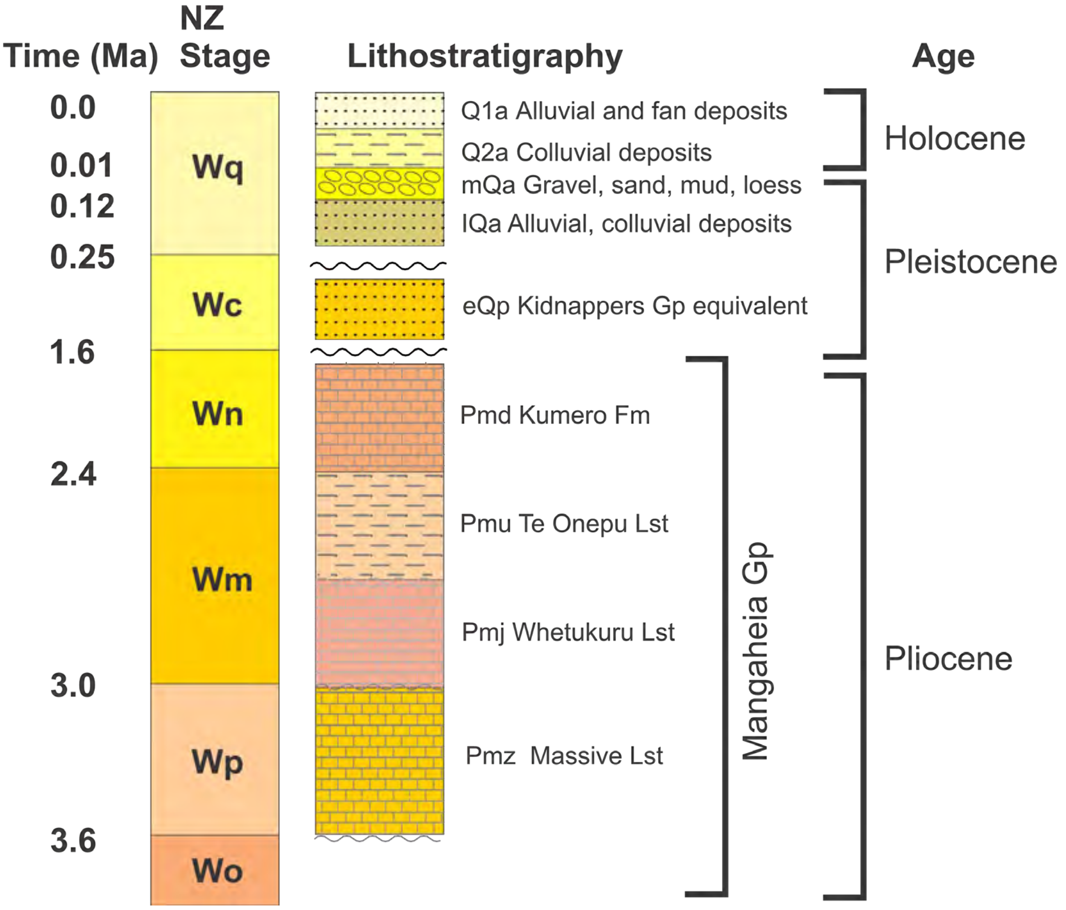


Figure 1.3 Stratigraphic column derived from the QMAP geology of the Ruataniwha Plains north of Dannevirke. The following abbreviations are used: Formation (Fm), Group (Gp) and Lst (Limestone) for local divisions. The New Zealand stages are Haweran (Wq), Castlecliffian (Wc), Nukumaruan (Wn), Mangapanian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

2.0 METHODOLOGY AND FIELD DATA

2.1 TEM Survey

A single ground Transient ElectroMagnetic (TEM) measurement and NanoTEM measurement were made at 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 site and the location of the groundTEM site. 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 results of the NanoTEM and TEM sounding are shown in Figure 2.2 as a transient decay curve. The data are presented as the average of the individual sweeps. The NanoTEM data are of poor quality ('noisy') with negative voltages and scattered data, indicating possible electromagnetic interference. Therefore, they were not used for the modelling. The TEM data show a strong signal to noise ratio over the entire range and have been used in the 1D inversion modelling.

The upper portions of the resistivity model are displayed in the composite log (Figure 2.9). No interpretation is made as part of this report, as this will be included in a later 3DAMP report.

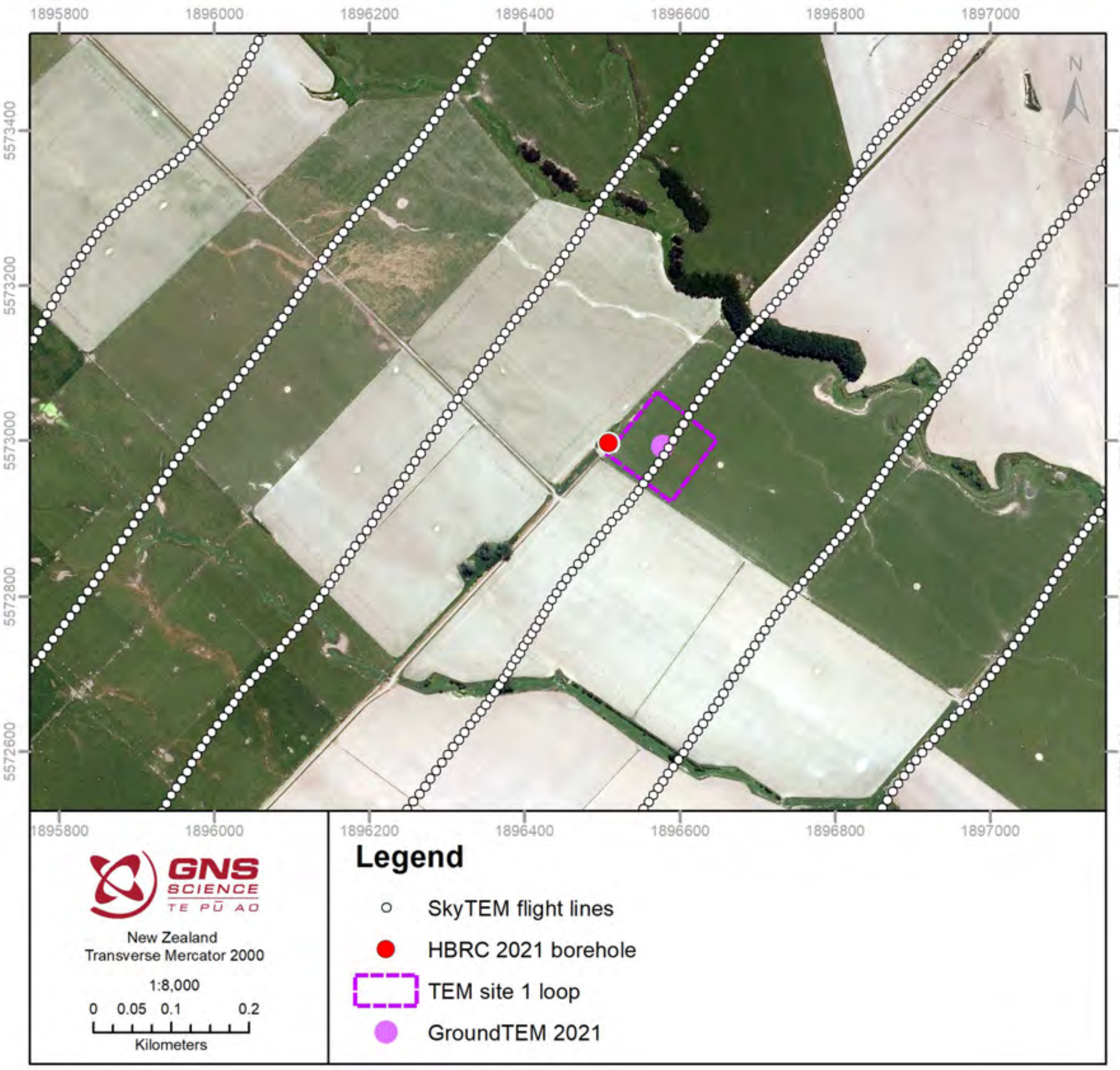


Figure 2.1 Detailed map of the well site showing the locations of the nearest SkyTEM survey points and the groundTEM sounding.

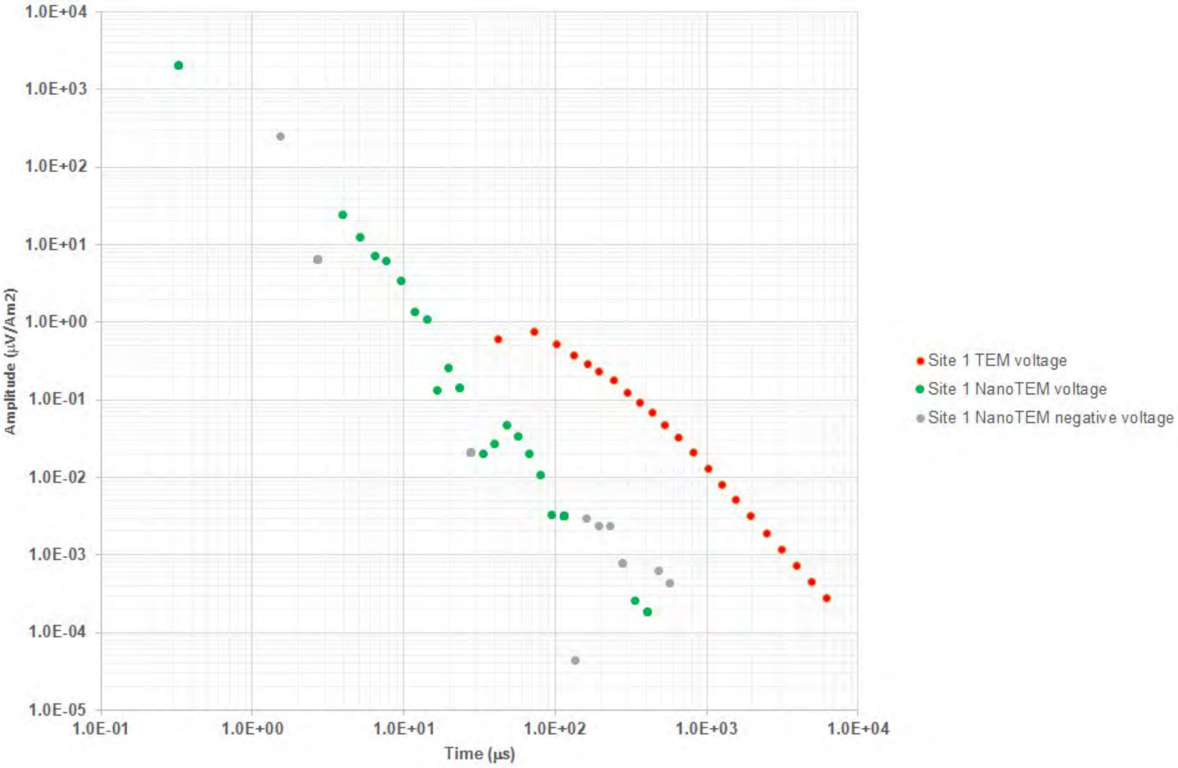


Figure 2.2 NanoTEM and TEM sounding curves. The NanoTEM data are noisy and have not been modelled.

2.2 Rig Site Operations

The scope of the project was to drill to approximately 160–200 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). Two drill depths were identified for undertaking aquifer hydraulic testing (Section 2.2.7) and water sampling (Section 2.2.8).

2.2.1 Drilling

The drilling was undertaken by Baylis Bros Ltd (Baylis) under contract to Hawke's Bay Regional Council (HBRC). Three drilling methods were employed in the construction of the groundwater wells:

- rotary auger;
- cable tool; and
- rotary air or wash, depending on whether the screen or open-hole section of the bore is in water bearing material or not.

2.2.1.1 Rotary Auger

Auger drilling was used to start the hole. 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

Cable-tool drilling involves driving lengths of casing into the ground. Casing lengths were 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 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 into the 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’ was 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. The cable-tool method was employed in the upper half of the borehole.

2.2.1.3 Rotary Wash

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. This method was used for the lower half of the borehole.

- Advantages:
  - High rate of penetration.
  - Continuous sampling.
  - All sample sizes are brought to the surface.
- Disadvantages:
  - Potential damage to coarse grain sizes, resulting 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 HBRC 17136 Drilling Summary

- All depths are quoted as relative to ground level (m BGL) unless otherwise stated.
- Drilling with the cable tool commenced from the top of the borehole and continued down to 84.2 m depth. From about 40–50 m depth, the rate of penetration decreased with increasing time required to chisel material in order to progress.
- Rotary drilling was undertaken from 84.2 m to well total depth. This resulted in an increased rate of penetration, improving the chances of reaching the project scope target depth of 160–200 m.
- The hole was terminated at a depth of 168 m BGL (total depth) on 12 July 2021 as a result of increasingly slow rate of penetration and associated budgetary considerations.

Table 2.1 provides details of the well construction.

Table 2.1 Casing information.

Casing Type	Diameter (mm)	Top (m BGL)	Base (m BGL)
Steel	200	-0.5	100.0
Steel	150	100.0	168.0

2.2.2 Sedimentary Logging

Sediment was logged continuously as material was brought to the surface. 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 comparator (e.g. Folk 1951). P = poorly sorted, M = moderately sorted, MW = moderately well sorted, W = well sorted, VW = very well sorted.

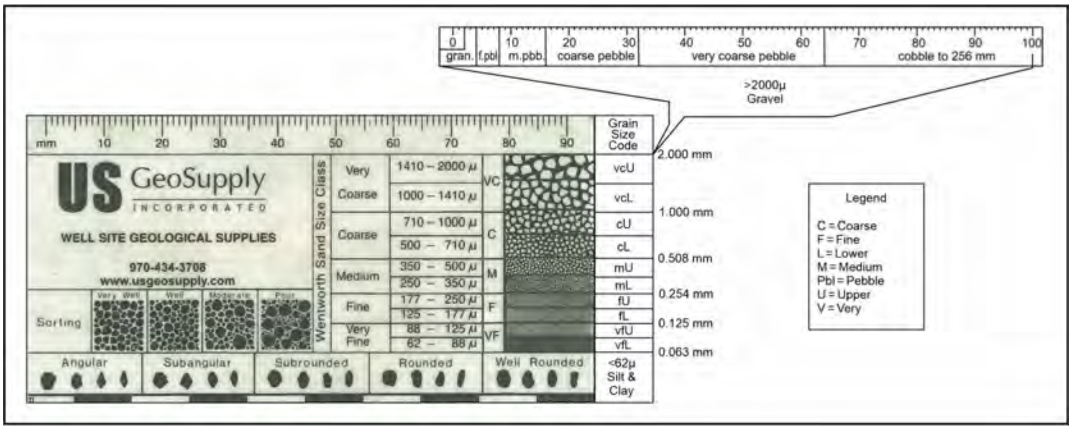


Figure 2.4 Visual comparator for grain size, sorting and grain angularity.

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 for the purpose of lab 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 17136.

Depth (m BGL)	Depth (m BGL)	Depth (m BGL)	Depth (m BGL)	Depth (m BGL)
2	10	25	40	100
4	15	30	50	130
7	20	35	70	160

It is important to note that, on the hand-drawn logs (Appendix 3), there is a track labelled ‘Saturation’ that was to provide an assessment of sediment saturation. However, as this well is artesian at depth and, on occasion, the drillers flushed water down the hole to aid drilling, it was decided that saturation observations had no value and so are not discussed further.

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) made.

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 was 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. Size class refers to the material retained on each sieve; these are defined in Figure 2.4 and Table 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 (µm)	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 was less than 2%.

2.2.3.4 Results

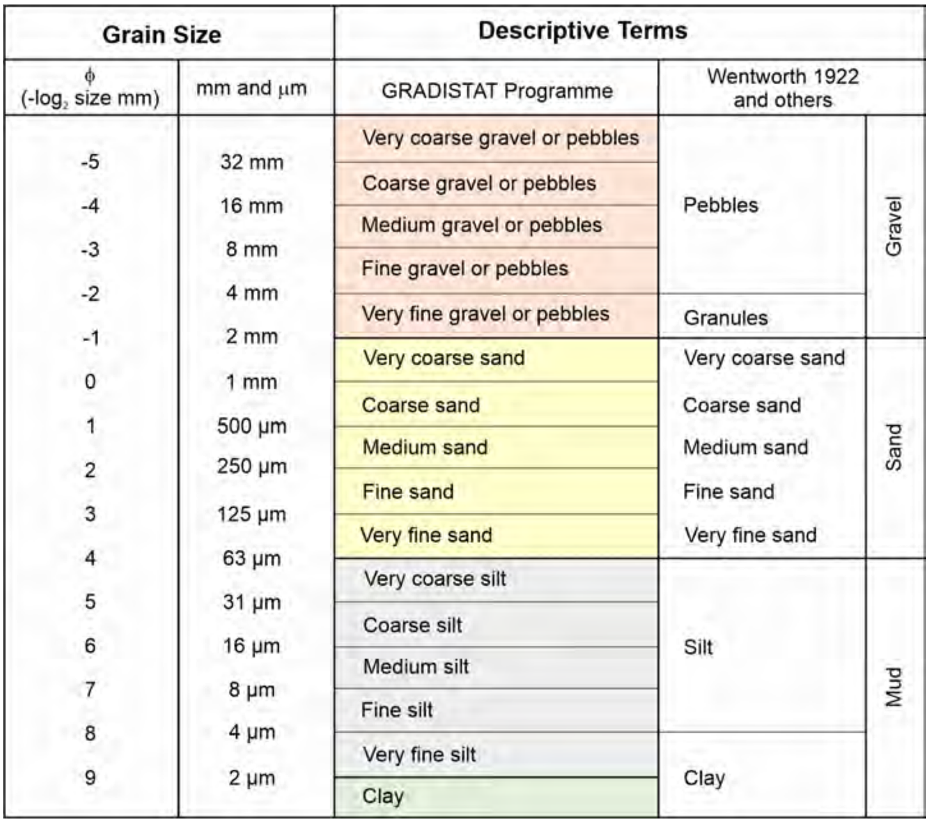
Samples where both analytical techniques were required necessitated data being combined and normalised to weight percent to produce an overall grain-size distribution. Statistical analysis of the data was undertaken using a Microsoft-Excel-based computational programme called GRADISTAT (Blott and Pye 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 (Table 2.4), which matches findings from the field where most of the so-called clays felt silty or sandy.
2. About half of the sands have very little mud (i.e. <10%), and the rest have about 10–20% mud (see Table 2.4 for the definition of mud).
3. Six sand samples contain about 5–20% gravel.

4. The majority of gravels contain ≤20% sand; however, results may be biased by a few large, heavy grains that are >32 mm in diameter.
5. Seven gravel samples contain significant amounts of sand and mud and fall in the sandy gravel and muddy sandy gravel ranges.
6. The majority of samples analysed fall into three distinct groups with no overlap, outlined in blue in Figure 2.7. The groups comprise:
    a. Gravels to sandy gravels
    b. Sandy muds
    c. Sands and gravelly to muddy sands.

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.

		
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; leptokurtic indicates good sorting.

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		

2.2.4 Radiocarbon Ages

Radiocarbon dating was not undertaken on samples from well 17136.

2.2.5 Resistivity Measurements

The SkyTEM airborne TEM survey and groundTEM sounding produce models of the electrical resistivity of the subsurface. Any information on the resistivity of the sediments from samples collected while drilling will be useful in helping to refine the relationships between lithology, silt and 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 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 contact resistance (R) was 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 subsurface (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).

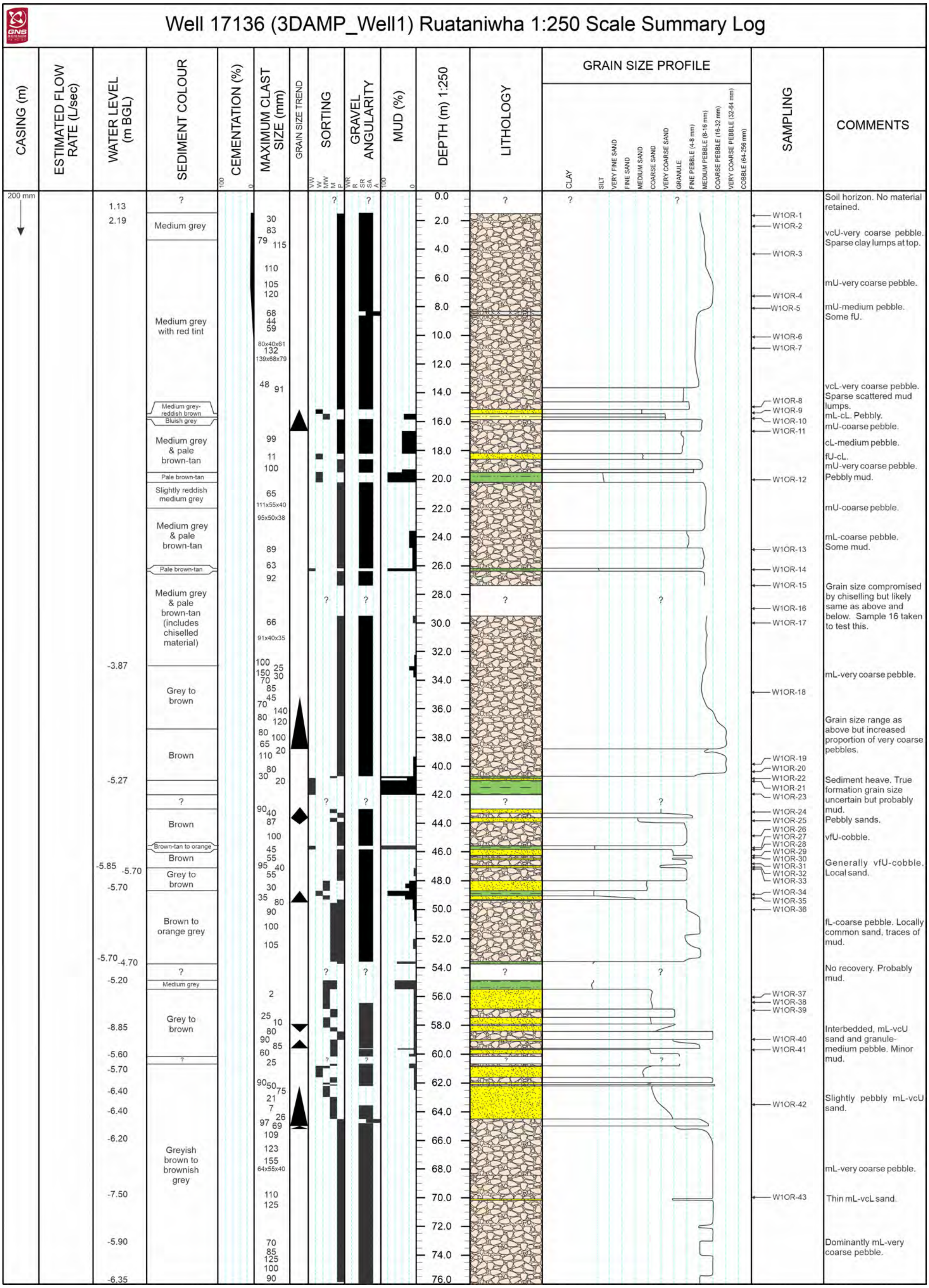


Figure 2.5 1:250-scale summary lithological log for well 17136 (3DAMP_Well1) (continued on next page). Note: Sample 22 is stratigraphically above sample 21 due to depth issues resulting from sediment migrating up the casing overnight.

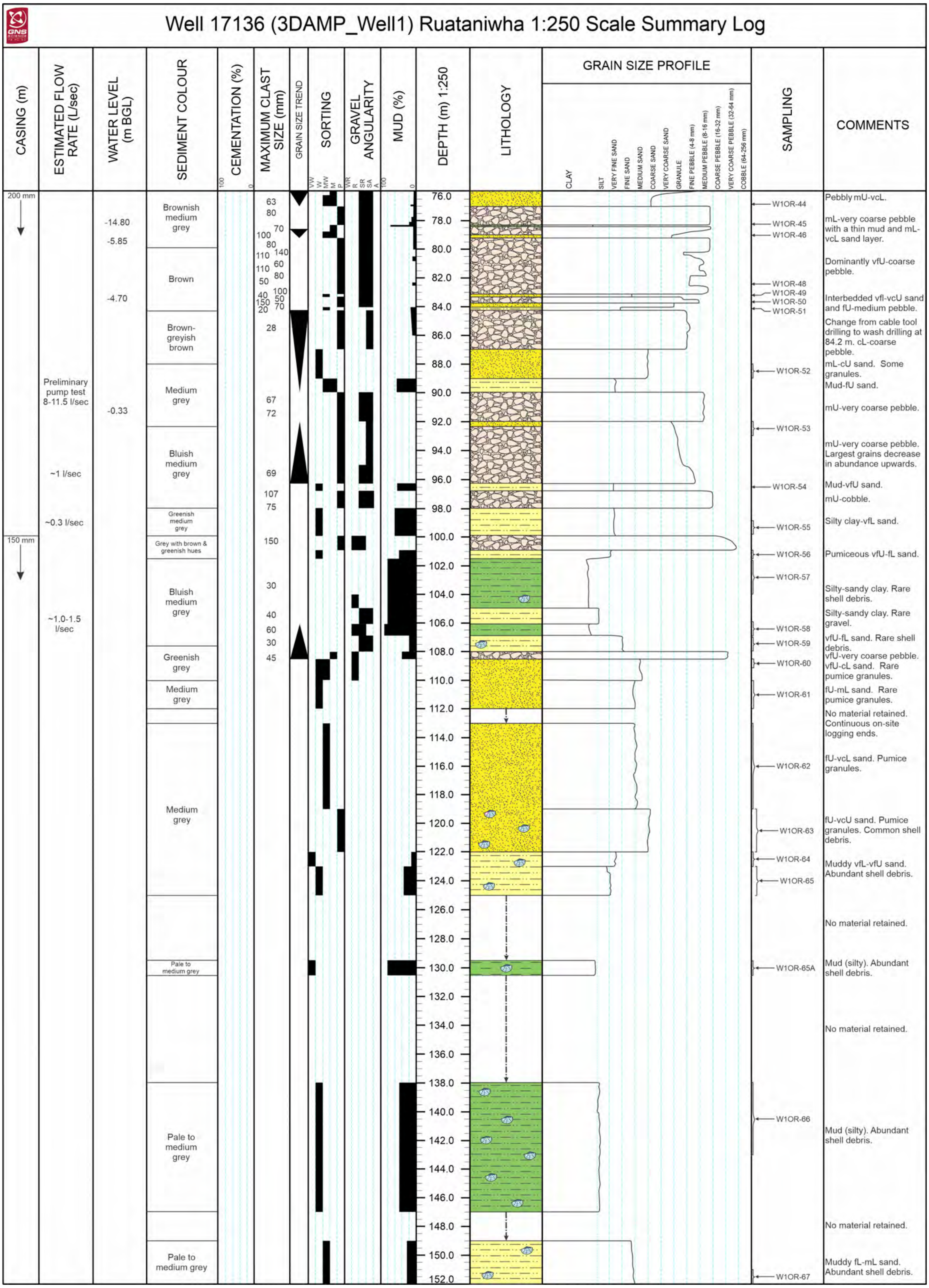


Figure 2.5 1:250-scale summary lithological log for well 17136 (3DAMP_Well1) (continued). Note: Sample W10R-47 missing due to depth recording error.

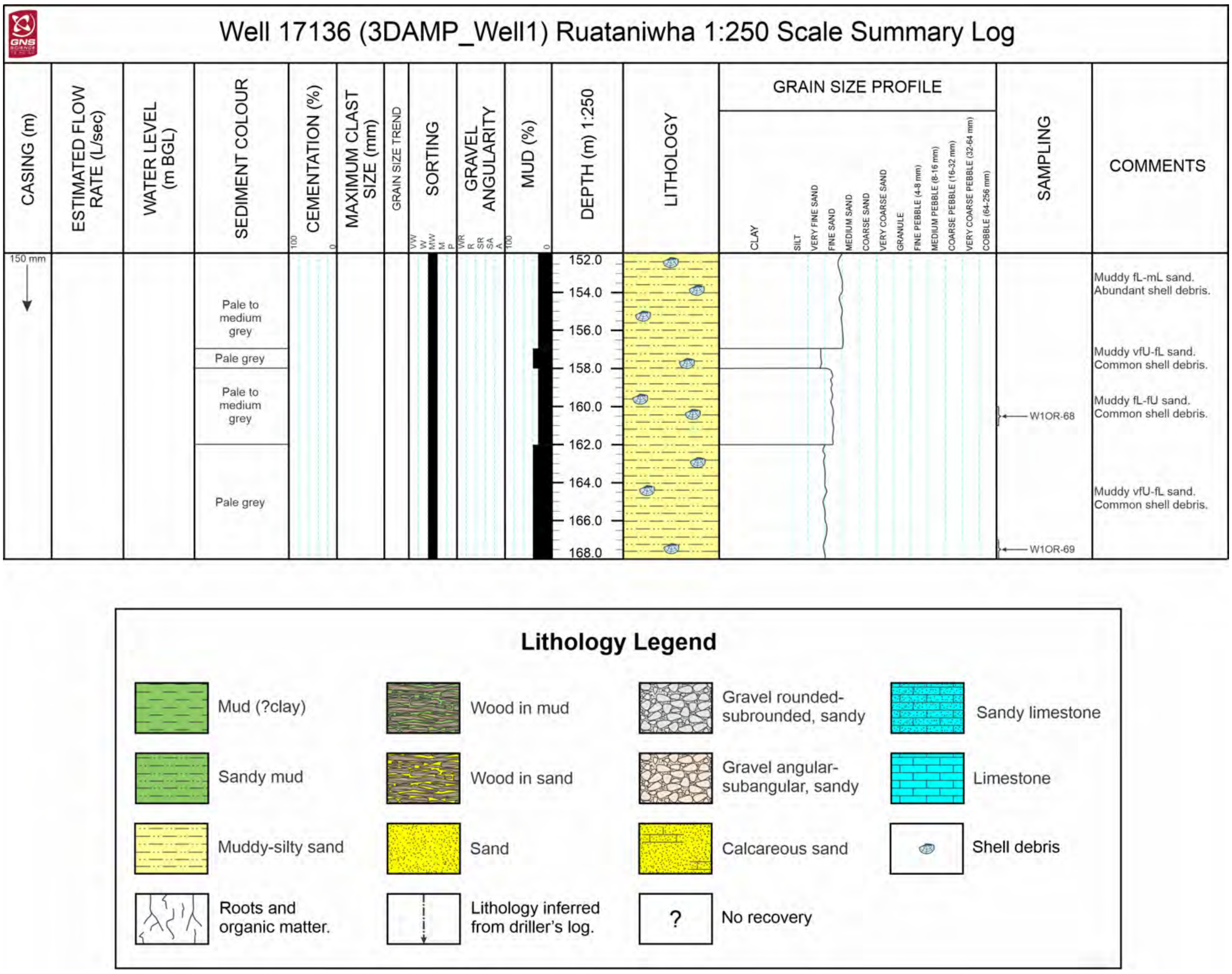


Figure 2.5 1:250-scale summary lithological log for well 17136 (3DAMP_Well1) (continued).

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

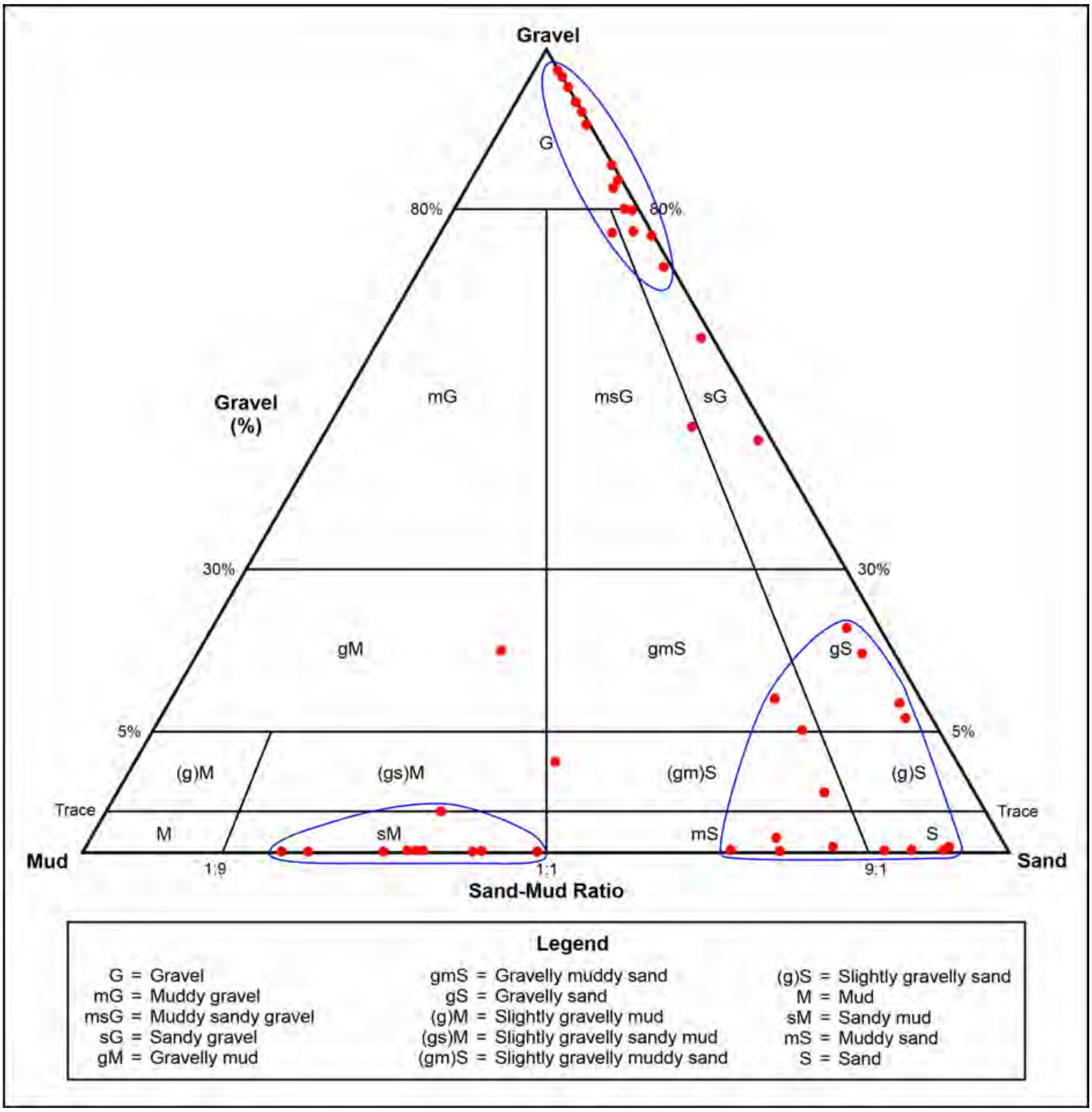


Figure 2.7 Ternary diagram summary of laboratory-derived grain-size results (after Folk et al. 1970).

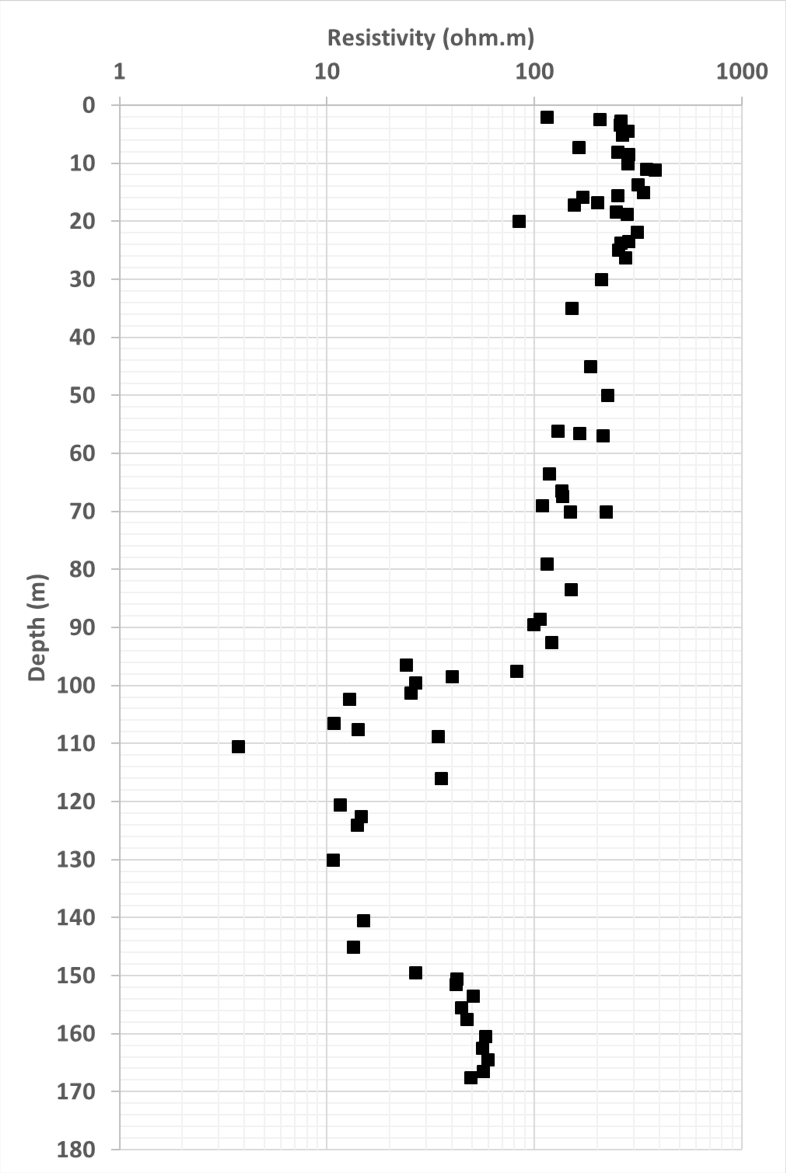


Figure 2.8 Resistivity measured on samples collected during drilling of the borehole.

2.2.6 Wireline Logs

Geophysical data can also be obtained using tools that are lowered into the borehole and measure physical properties of the formations in open boreholes or beyond the casing. In groundwater wells, the small diameter of the hole and 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.

Natural gamma 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) 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 calliper 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 20 July 2021. The hole was logged from ground level to 160.89 m BGL depth. The bottom 6 m were avoided to prevent the tool from getting stuck in the 100 mm slotted casing. Data gaps were observed in the logs due to tools getting stuck against the side of the well.

The detailed wireline logs are included as Appendix 5, with the raw data in the supplemental material in Log ASCII Standard (LAS) format. The wireline geophysical logs are also shown on the composite log in Figure 2.9.

Two different gamma logs were run to verify the reliability of the gamma ray measurement through the casing. Both tools yield similar gamma ray responses. The gamma ray log shows a general trend of moderate gamma ray signal (40–50 API) between 0 m BGL and 72 m BGL. There is a significant drop in gamma ray response between 72 and 82 m BGL, indicating the presence of a zone with lower clay content. The gamma ray signal increases rapidly at 100 m depth, indicating a sharp contact. Between 100 and 122 m BGL, the gamma ray signal is between 50 and 60 API, with variations that indicate thinly bedded geological units. At 122 m BGL, the gamma ray increases again to levels over 70 API. The clay content of these beds is likely to be higher than in the shallower units. There is a slight drop in gamma ray signal between 143 and 148 m BGL.

The density logs show similar changes with depth. The low gamma ray signal corresponds to high density values. There is a significant drop in density at 100 m depth. The density log is sensitive to poor borehole conditions behind the casing. Three main intervals of washouts are identified in the logs (54–57 m BGL, 96–97 m BGL, 156–158 m BGL).

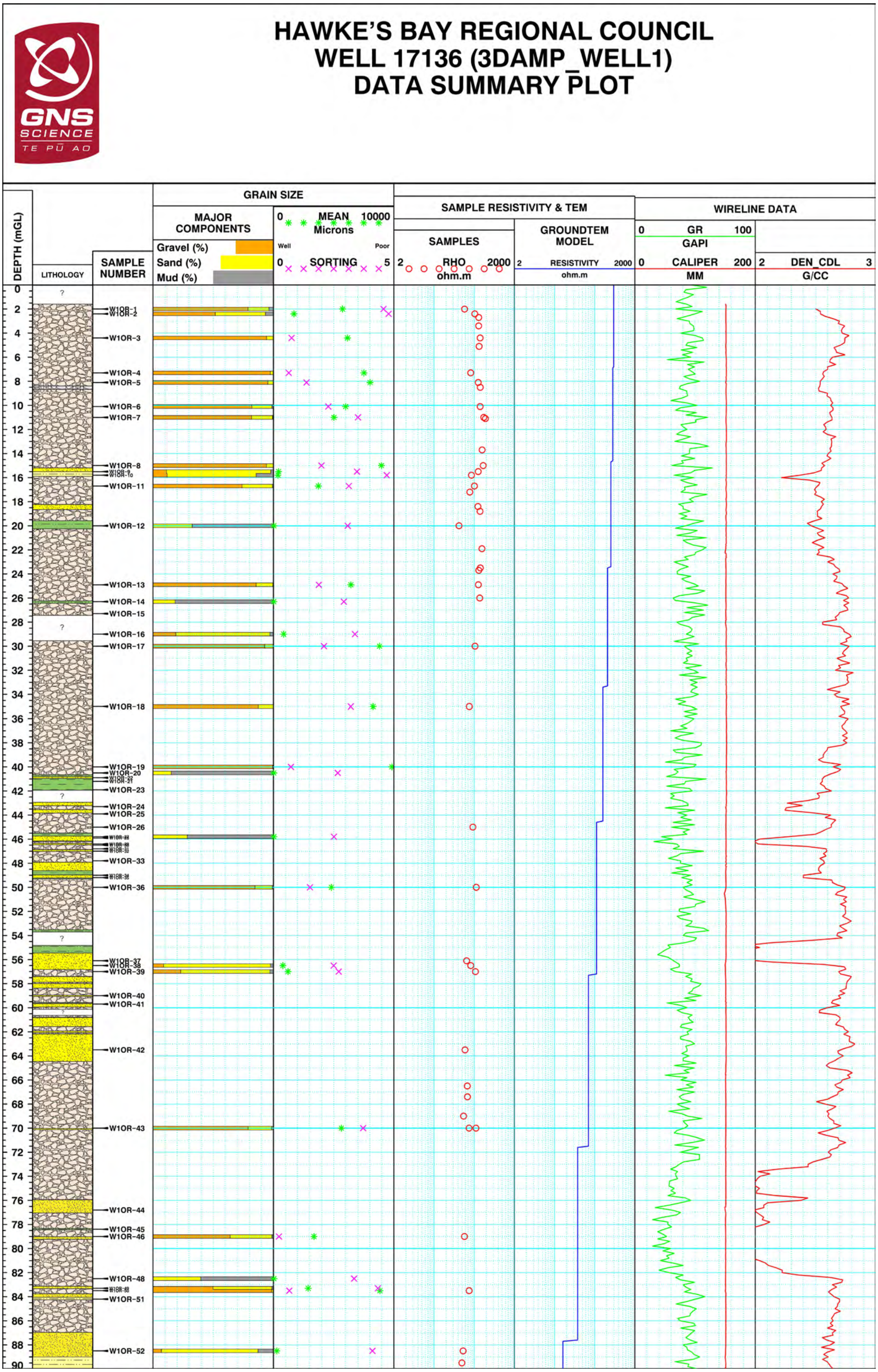


Figure 2.9 Composite summary log of lithology, sample locations, sample resistivity (RHO), groundTEM model (resistivity) and wireline logs (GR: gamma ray; DEN_CDL = compensated density). Note that the lithology here has been interpreted over intervals of poor recovery and where there is only information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

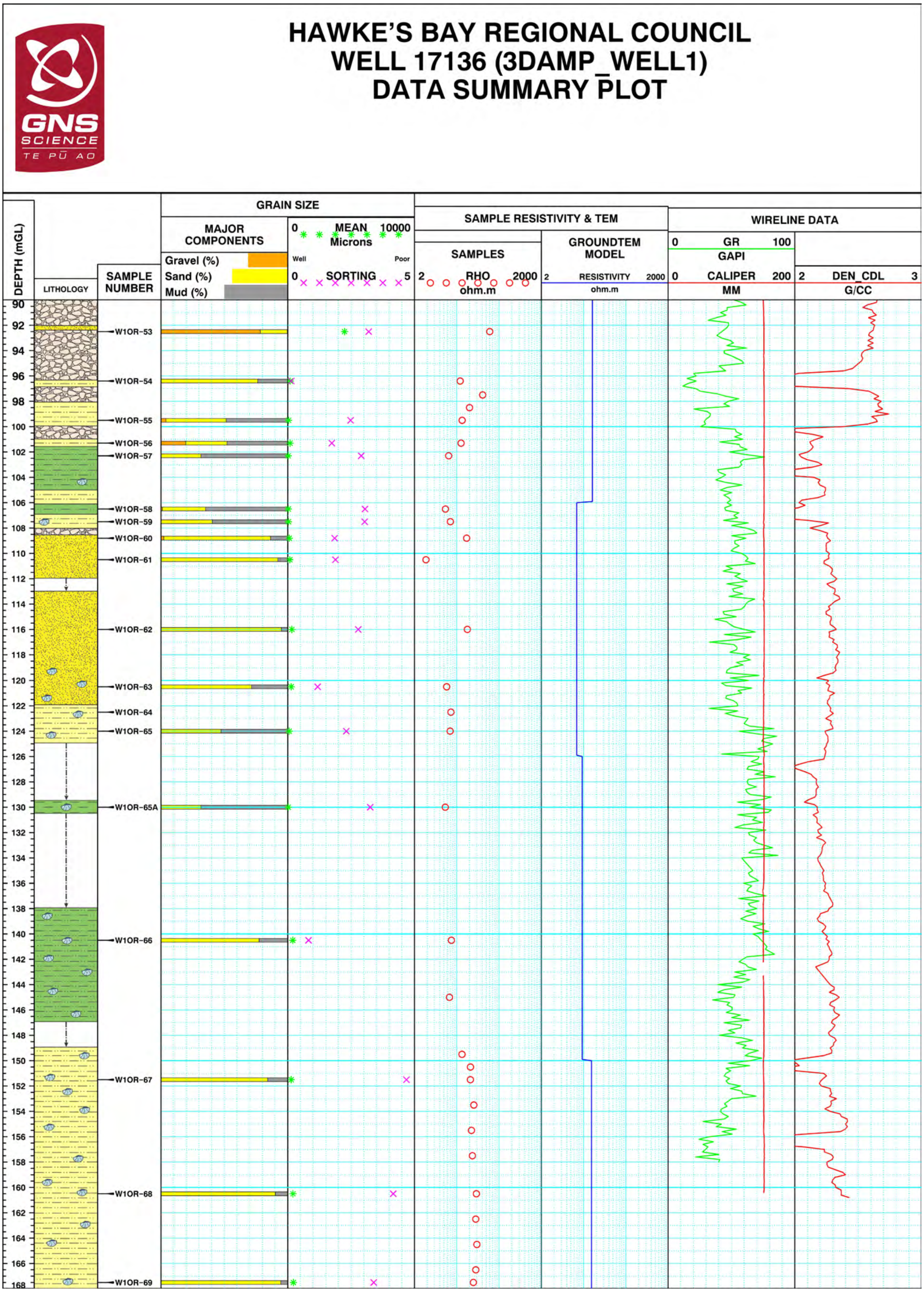


Figure 2.9 Composite summary log of lithology, sample locations, sample resistivity (RHO), groundTEM model (resistivity) and wireline logs (continued) (GR: gamma; DEN_CDL = compensated density). Note that the lithology here has been interpreted over intervals of poor recovery and where there is only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

2.2.7 Aquifer Testing

GNS conducted one 8-hour constant-rate pumping test at 92.0 m BGL and 10 slug test series at 10 different depth intervals during the drilling of well 17136 between March and June 2021. The two neighbouring wells 16713 and 16668, located right next to each other (2.5 m apart) 830 m from well 17136, were used as observation wells during the pumping test (Figure 2.10).

The exact depth of the pumping test was selected during drilling – once a layer with a suitable flow rate was encountered to undertake a test. The pumping test was undertaken under artesian conditions, with a static water level at 0.831 m above ground level (AGL). A total length of 1.686 m of casing above ground level was installed prior to the test to prevent groundwater flowing over the top of the casing, facilitating water level recording with data loggers and dip meters. Pumping rate was estimated and tested by the driller and approved by GNS prior to the start of the test. For the drawdown phase of the test, well 17136 was pumped at a constant flow of 8 L/s.

For the pumping test, well 17136 had a 1.2 m screen sitting between 88.8 and 90.0 m BGL with a casing diameter of 200 mm (8") above a 2 m open hole of 150 mm (6 ¼") in diameter between 90.0 and 92.0 m BGL. The screens of observation wells 16668 and 16713 were between 96.49 and 97.49 m BGL and 86.6 and 98.8 m BGL, respectively. These screens are at approximately similar depths as the screen/open interval of well 17136. Baylis provided pumping services for the pumping test. An 18.5 KW 3-phase submersible Grundfos pump lowered down to 42 m BGL (base of the pump) was utilised and connected to a 6" pipe with a 3" orifice controlling the flow (Figure 2.11). The flow was routinely checked on an orifice flow manometer during the test and found to be steady between 14" and 16", equivalent to 8 L/s (Figure 2.11). The flow was adjusted once during the drawdown period of the test, an hour after the beginning of the test, to maintain a constant 8 L/s flow. The discharge water was channelled to flow into a man-made stream, located on the edge of the field. The weather during the test was overcast with SSE winds and recurring showers.

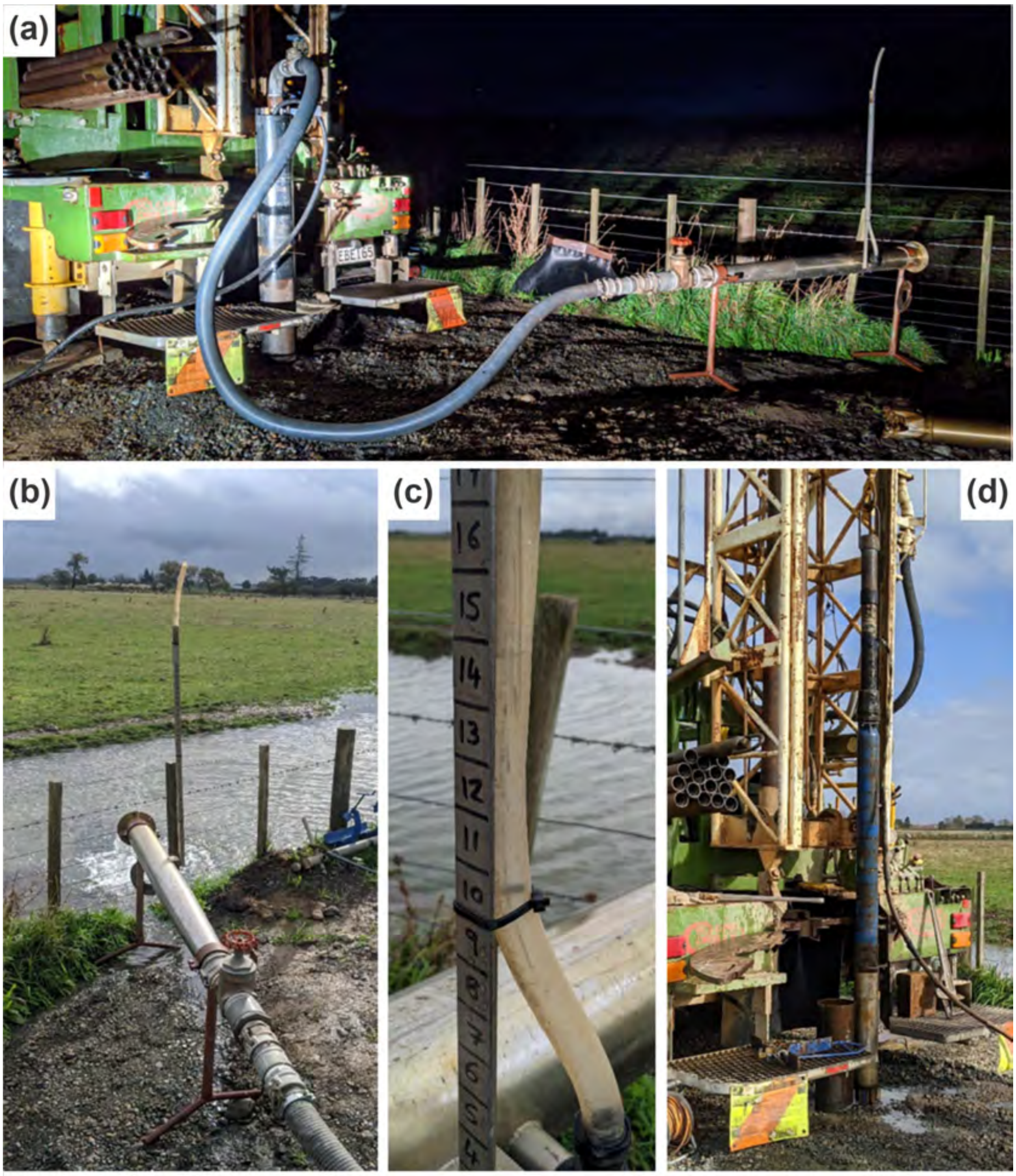
The driller from Baylis stayed on-site during the entirety of the test to control the pump and flow rate. Two GNS employees, one at the pumping well and one at observation well 16713, recorded water levels manually during both the drawdown and recovery phases of the test. The pumping well and two observation wells each had a data logger to record the water level.

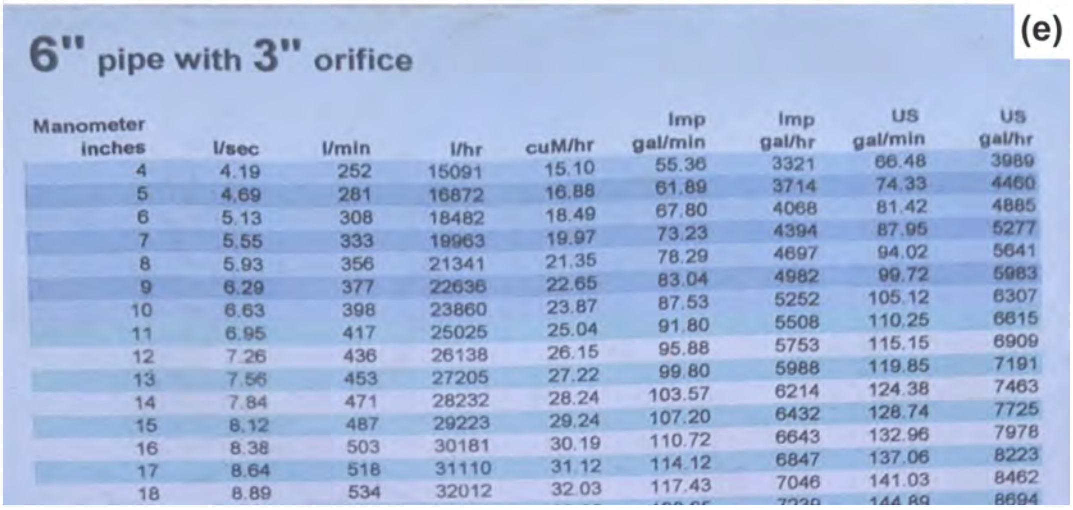
The constant-rate pumping test was analysed with AQTESOLV Pro software. A summary of the test analysis results is provided in Table 2.5. Additional test setting details, analysis and results are given in Appendix 6.

Table 2.5 Summary table of the constant-rate pumping test results.

Well	Pumping Test Screen / Open Interval (m BGL)	Aquifer Saturated Thickness (m)	Analysis Solution	T (Average) (m²/day)	K (Average) (m/day)
Pumping well 17136	88.8–92.0	11	Average between Theis, Theis recovery and Cooper-Jacob	52.34	4.76
Observation well 16668	96.49–97.49	12.7	Average between Theis, Theis recovery and Cooper-Jacob	170.80	13.45
Observation well 16713	87.0–98.82	12.7	Average between Theis, Theis recovery and Cooper-Jacob	227.27	17.90

Figure 2.10 Map showing the pumping well (17136) and the observation wells (16668 and 16713) used for the constant-rate pumping test.





6" pipe with 3" orifice

Manometer inches	l/sec	l/min	l/hr	cuM/hr	Imp gal/min	Imp gal/hr	US gal/min	US gal/hr
4	4.19	252	15091	15.10	55.36	3321	66.48	3989
5	4.69	281	16872	16.88	61.89	3714	74.33	4460
6	5.13	308	18482	18.49	67.80	4068	81.42	4885
7	5.55	333	19963	19.97	73.23	4394	87.95	5277
8	5.93	356	21341	21.35	78.29	4697	94.02	5641
9	6.29	377	22636	22.65	83.04	4982	99.72	5983
10	6.63	398	23860	23.87	87.53	5252	105.12	6307
11	6.95	417	25025	25.04	91.80	5508	110.25	6615
12	7.26	436	26138	26.15	95.88	5753	115.15	6909
13	7.56	453	27205	27.22	99.80	5988	119.85	7191
14	7.84	471	28232	28.24	103.57	6214	124.38	7463
15	8.12	487	29223	29.24	107.20	6432	128.74	7725
16	8.38	503	30181	30.19	110.72	6643	132.96	7978
17	8.64	518	31110	31.12	114.12	6847	137.06	8223
18	8.89	534	32012	32.03	117.43	7046	141.03	8462
				[illegible]	[illegible]	[illegible]	144.89	8694

Figure 2.11 Pictures of the pumping test set-up. (a) Complete set-up. (b) The 6" pipe with a 3" orifice controlling the flow and the manometer. (c) The manometer used to monitor the flow rate during the test (water level at 15", giving a flow rate of 8.12 L/s). (d) The submersible pump removed after the test. (e) The conversion sheet between measurement on the manometer (in inches) and the corresponding flow rate (in L/sec) for a 6" pipe with a 3" orifice set-up.

In addition to the constant-rate pumping test, a series of slug tests were conducted at multiple depth intervals (10.78 m, 26 m, 47.2 m, 53 m, 55 m, 79 m, 84.2 m, 92 m, 97 and 110.5 m BGL) at well 17136 between March and June 2021 at locations chosen as exhibiting potentially different hydraulic properties. An approximate depth of the slug tests was agreed 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 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 and repeatability of 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 for the water level to reach static level. Most slug tests were performed the morning after drilling was stopped.

For most tests, a Level TROLL 700 data logger was utilised to record water-level fluctuations at a 250 ms time interval. A total of six 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 first; however, in a gravel layer where a good permeability was expected the biggest slug was utilised first. Not all six slugs were selected at each depth; for example, in a low permeability layer, only the smallest slug was utilised for all repeats, decreasing the amount of time needed for the water level to recover back to static. Both slug and logger were attached to a non-moving part of the drilling rig to ensure good data-recording precision.

Each series of slug tests was individually analysed using AQTESOLV Pro software. A summary of the results is provided in Table 2.6. Individual description of the test conditions, setting details, analysis and results is given in Appendix 7.

Barometric data from the Waipawa electronic weather station was obtained from New Zealand's Climate Database web portal CliFlo (NIWA c2022) over a two-year time span between 05/2019 and 09/2021. This barometric data was combined with water-level data recording from HBRC monitoring wells 16879 and 16880 and observation wells 16668 and 16713 to calculate the barometric efficiency coefficient for each of the two aquifers encountered at well 17136. Barometric efficiency coefficients of 0.2458 and 0.5372 were estimated for the unconfined and confined aquifers, respectively. The corresponding barometric efficiency coefficient was utilised to correct the impact of barometric pressure on the water-level data recorded by data loggers for both the pump and slug tests. All water-level data that displayed a non-negligible impact of barometric pressure was corrected prior to analyses. Additional barometric correction details and results are given in Appendix A6.2.

Table 2.6 Summary table of the settings for each slug test series and the average hydraulic conductivity K per series. SWL: Static Water Level. A negative static water level indicates a water level below ground level, a positive static water level indicates a water level above ground level. Static water level prior to slug tests 6 and 10 was not reached, therefore no analysis was attempted for those tests (more detail is provided in Sections A7.6 and A7.10). No data could be recovered from the data logger for slug tests 7, therefore no analysis could be done.

	Slug Tests 1	**Slug Tests 2**	**Slug Tests 3**	**Slug Tests 4**	**Slug Tests 5**	**Slug Tests 6**	**Slug Tests 7**	**Slug Tests 8**	**Slug Tests 9**	**Slug Tests 10**
Bore Depth (m BGL)	10.78	26.00	47.20	53.00	55.00	79.00	84.20	92.00	97.00	110.50 *
Screen Interval (m BGL)	9.58 10.78	24.8 26.0	46.0 47.2	51.8 53.0	53.8 55.0	77.8 79.0	82.8 84.0	88.8 90.0	92.8 94.0	111 112
Open-Hole Interval (m BGL)	-	-	-	-	-	-	84.0 84.2	90.0 92.0	94.0 97.0	-
Depth Logger (m BGL)	10.72	6.43	20.15	20.39	19.5	19.85	19.48	9.85	9.05	14.21
Depth Slug (m BGL)	N/A **	6.05	7.62	8.18	8.2	10.15	N/A **	1.37	1.15	N/A **
SWL (m AGL)	-1.19	-3.62	-5.64	-5.43	-4.76	SWL not reached	-5.52	0.08	1.92	SWL not reached
Slug Number	2, 3, 5 ***	2, 3, 5 ***	2, 3, 5 ***	2, 3 ***	6 ***	2 ***	4, 6 ***	2, 3, 4 ***	1, 2 ***	3, 6 ***
Primary Lithology	Gravel	Gravel	Sandy gravel	Gravel	Silty clay	Gravelly sand	Sand	Gravel	Gravel	Running sand
Average K (m/day)	5.75	6.89	21.00	95.45	0.001	No analysis possible	No analysis possible	15.69	16.74	No analysis possible

* For slug tests 10, the sand moved back 500 mm above the top of the screen; therefore, the bottom of the well is higher than the base of the casing.

** The exact depth of the slug was not recorded for these slug tests; therefore, only the depth of the logger is reported here.

*** The corresponding volumes are: 11.88 L (slug 1), 5.76 L (slug 2), 5.43 L (slug 3), 4.19 L (slug 4), 1.55 L (slug 5) and 1.30 L (slug 6).

2.2.8 Groundwater Chemistry

Groundwater samples from well 17136 were collected at depths of 92.0 and 168 m BGL.

The samples at a depth of 92.0 m BGL were collected at the end of the drawdown phase of the pumping test, ensuring that a sufficient purge was undertaken prior to the sample collection. The water was colourless and odourless; the weather while sampling was cloudy with rain showers and SSE winds. The sampling set-up (following the pumping test set-up) could not ensure an air/bubble-free sample collection; hence, only tritium and the stable isotope samples were collected for age-tracer measurements.

The samples at depth of 168.0 m BGL, corresponding to the final total depth of the well, were collected after the well was allowed to free-flow for three days prior to the sampling, ensuring that three times the volume of the water column in the bore was purged prior to sample collection. The water was slightly brown but odourless; the weather while sampling was sunny with no clouds and no wind. The flow was estimated to be around 0.1 L/s. With a bore diameter of 150 mm and a static water level around 1.0 m AGL, the total volume of water in the well was calculated to be around 3 m^3. For a purge of three times the volume of water in the well with the estimated flow of 0.1 L/s, the estimated purging time was at least 25 hours. The purge started on Friday 16 March around midday, and the well was allowed to free-flow until the sampling started on Tuesday morning (20 March). Radon samples were not collected at this depth.

Samples were collected for water-quality analysis (i.e. alkalinity, ammonia-nitrogen, bromide, calcium, chloride, conductivity, dissolved reactive phosphorus, fluoride, dissolved iron, magnesium, dissolved manganese, nitrate-nitrogen, potassium, silica, sodium, sulphate) and age-tracer measurements and interpretation (tritium, chlorofluorocarbons, halon-1301, sulphur hexafluoride). Sample collection procedure followed the National Groundwater sampling protocol for State of the Environment monitoring (Daughney et al. 2006), which is consistent with the National Environment Monitoring Standards for Discrete Water Quality sampling (Milne et al. 2019). Field measurements of purge variables (including temperature, conductivity and pH) were measured prior to sampling (Table 2.7).

Table 2.7 Field measurements of purge variables.

	Depth Interval (m BGL)	pH	Electric Conductivity (µS/cm)	Temperature (°C)
Pumping Test 24/05/2021	89.0–92.0	6.91	401	14.4
Well Total Depth 20/07/2021	168	8.64	745	13.4

Samples collected for chemical analyses were refrigerated and dispatched to the IANZ-accredited New Zealand Geothermal Analytical Laboratory (NZGAL) in Wairakei (Taupō) for analysis the next day. Age-dating samples were sealed to prevent air ingress during transport and dispatched to the Tritium and Water Dating Laboratory in Lower Hutt. Chemical analyses were received back within 15 days for groundwater quality (Figure 2.12, Appendix 8). From the age-dating results, a mean residence time has been interpreted. The water from both samples is tritium-free and therefore has a mean residence time of over 200 years (Morgenstern 2022). Age-dating results are included in this report as a digital deliverable.

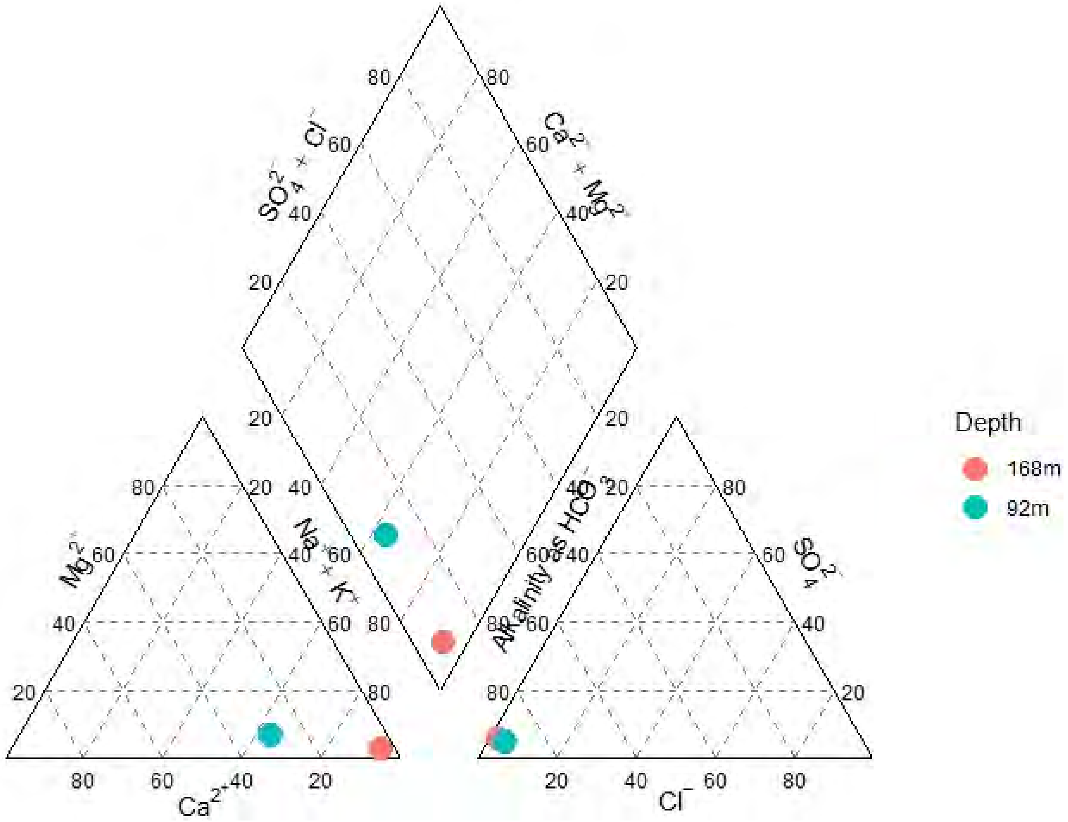


Figure 2.12 Groundwater quality Piper plot of groundwater samples collected at the flowing well 17136 at the end of the constant-rate pumping test at 92.0 m BGL and at well total depth at 168.0 m BGL.

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. Note that, although 10 slug tests were undertaken, the data for one test was not able to be downloaded from the logger due to a software connection problem, so only nine slug test datasets are supplied.

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

	File Names	**Data Format**
GroundTEM Data	S1_NTEM.usf S1_TEM.usf Site_1_groundTEM_Model.csv	ASCII tables of raw data in Universal File Format
Geophysical Logs	WELL1_ONGAONGA-WAIPUKURAU_RD_LOGS.las	Log Ascii Standard (LAS) format
Sample Resistivity	Appendix 4 Core Sample Resistivity.xlsx	EXCEL spreadsheet
Pumping Test Data	GNS_Data_92mAPT_AllData.xlsx Ruataniwha_Site1_Barometric_Efficiency_Estimation.xlsx	EXCEL spreadsheets
Pumping Test Analysis	AquiferTest92m_PW17136_CooperJacob.aqt AquiferTest92m_PW17136_Theis.aqt AquiferTest92m_PW17136_Recovery_Theis.aqt AquiferTest92m_OW16668_CooperJacob.aqt AquiferTest92m_OW16668_Theis.aqt AquiferTest92m_OW16668_Theis_Recovery.aqt AquiferTest92m_OW16713_CooperJacob.aqt AquiferTest92m_OW16713_Theis.aqt AquiferTest92m_OW16713_Theis_Recovery.aqt	AQTESOLV software analysis files
Slug Tests Data	SlugTests10m78_2021-03-18.xlsx SlugTest26m_2021-03-23.xlsx SlugTests47m20_2021-04-06.xlsx SlugTests53m_2021-04-08.xlsx SlugTests55m_2021-04-12.xlsx SlugTests79m_06-05-2021.xlsx SlugTests92m_25-05-2021.xlsx SlugTest97m_28-05-2021.xlsx SlugTests110m5_18-06-2021.xlsx	EXCEL spreadsheets
Slug Tests Analysis	10m78_Bluetooth_Slug2ain.aqt / 10m78_bluetooth_Slug2aOut.aqt / 10m78_bluetooth_Slug2bin.aqt / 10m78_bluetooth_Slug2bOut.aqt / 10m78_bluetooth_Slug3in.aqt / 10m78_bluetooth_Slug3out.aqt / 10m78_bluetooth_Slug5in.aqt / 10m78_bluetooth_Slug5Out.aqt 10m78_Slug2ain.aqt / 10m78_Slug2aOut.aqt / 10m78_Slug2bin.aqt / 10m78_Slug2bOut.aqt / 10m78_Slug3in.aqt / 10m78_Slug3out.aqt / 10m78_Slug5in.aqt / 10m78_Slug5Out.aqt 26m_Slug2in.aqt / 26m_Slug2out.aqt / 26m_Slug3in.aqt / 26m_Slug3out.aqt / 26m_Slug5in.aqt / 26m_Slug5out.aqt 47m20_Slug2in.aqt / 47m20_Slug2out.aqt / 47m20_Slug3in.aqt / 47m20_Slug3out.aqt / 47m20_Slug5in.aqt / 47m20_Slug5out.aqt 53m_Slug2ain.aqt / 53m_Slug2aout.aqt / 53m_Slug2bin.aqt / 53m_Slug2bout.aqt / 53m_Slug3in.aqt / 53m_Slug3out.aqt	AQTESOLV software analysis files

	File Names	Data Format
	55m_Slug6inCorrectedLogger2.aqt 79m_Slug2in.aqt / 79mSlug2out.aqt 92m_Slug2ain.aqt / 92m_Slug2aout.aqt / 92m_Slug2bin.aqt / 92m_Slug2bout.aqt / 92m_Slug3in.aqt / 92m_Slug3out.aqt / 92m_Slug4in.aqt / 92m_Slug4out.aqt 97m_Slug1in.aqt / 97m_Slug1out.aqt / 97m_Slug2ain.aqt / 97m_Slug2aout.aqt / 97m_Slug2bin.aqt / 97m_Slug2bout.aqt / 97m_Slug2cin.aqt / 97m_Slug2cout.aqt	
Groundwater Chemistry and Age Dating Results	2021052605_SkyTEM Site 17136.pdf 2021072103_SkyTEM Site 17136-168m.pdf Age_Dating_AllResults_WDL–GNS_17136.xlsx	PDF files EXCEL spreadsheet
Lithology Log	Digital_Lithology_Log_17136.xlsx	EXCEL spreadsheet
Grain Size Data	GrainSize_17136_Well1.xlsx	EXCEL spreadsheet

4.0 SUMMARY

1. Well 17136 was drilled as part of the 3D Aquifer Mapping Project in the Ruataniwha Plains, Hawke's Bay, with the objective to reduce uncertainty of hydrogeological interpretations of the SkyTEM-derived resistivity models.
2. A single groundTEM measurement and NanoTEM measurement were made at the drill site prior to spudding the well.
3. Prior to drilling, the proposed depth for well 17136 was 150–180 m BGL.
4. The well was spudded on 16 March 2021 and terminated at a depth of 168 m BGL (total depth) on 12 July 2021. The targeted low-resistivity feature was reached but was characterised by a gradual increase in shell debris in fine sands rather than a clear transition to limestone. Limestones in the area encountered in petroleum wells are typically referred to as 'coquinas', which refers to limestones formed entirely from shell fragments.
5. A continuous sedimentary log was produced to a depth of 112.0 m BGL. Below this depth, spot samples were provided by the drillers where changes in lithology were observed.
6. A total of 69 lithological samples were acquired, of which 46 were set aside for later laboratory analysis. The electrical resistivity of all of samples has been determined.
7. The majority of samples analysed for grain size fall into three distinct groups:
    - d. Gravels to sandy gravels
    - e. Sandy muds
    - f. Sands and gravelly to muddy sands.
8. Wireline logs (natural gamma, density) were acquired through casing to a depth of 160.89 m BGL. The well was not logged to total depth to avoid tool hang-up in the slotted casing at the bottom of the casing.
9. One 8-hour constant-rate pumping test was undertaken at 92.0 m BGL. Ten slug tests were undertaken at 10.78 m, 26 m, 47.20 m, 53.0 m, 55.0 m, 79.0 m, 84.20 m, 92.0 m, 97.0 and 110.5 m BGL. Groundwater chemistry, environmental tracer and water-age samples were collected at the end of the pumping test drawdown period and at well total depth.

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APPENDICES

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APPENDIX 1 TRANSIENT ELECTROMAGNETIC MEASUREMENT

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 72 μs, with the NanoTEM ramp time 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 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

TEM soundings were collected at borehole 17136 (centred on NZTM grid reference 1887198, 5567620) on 21 January 2021. The TEM data are generally of good quality, and both layered and smooth resistivity models have been generated for the site (Figures A1.1, A1.2). The NanoTEM data are very noisy and cannot be reliably modelled. The noise is probably due to localised electrical noise sources such as electric fences and poor earthing connections associated with electrical power systems. The TEM smooth model has been included in the composite log for the well.

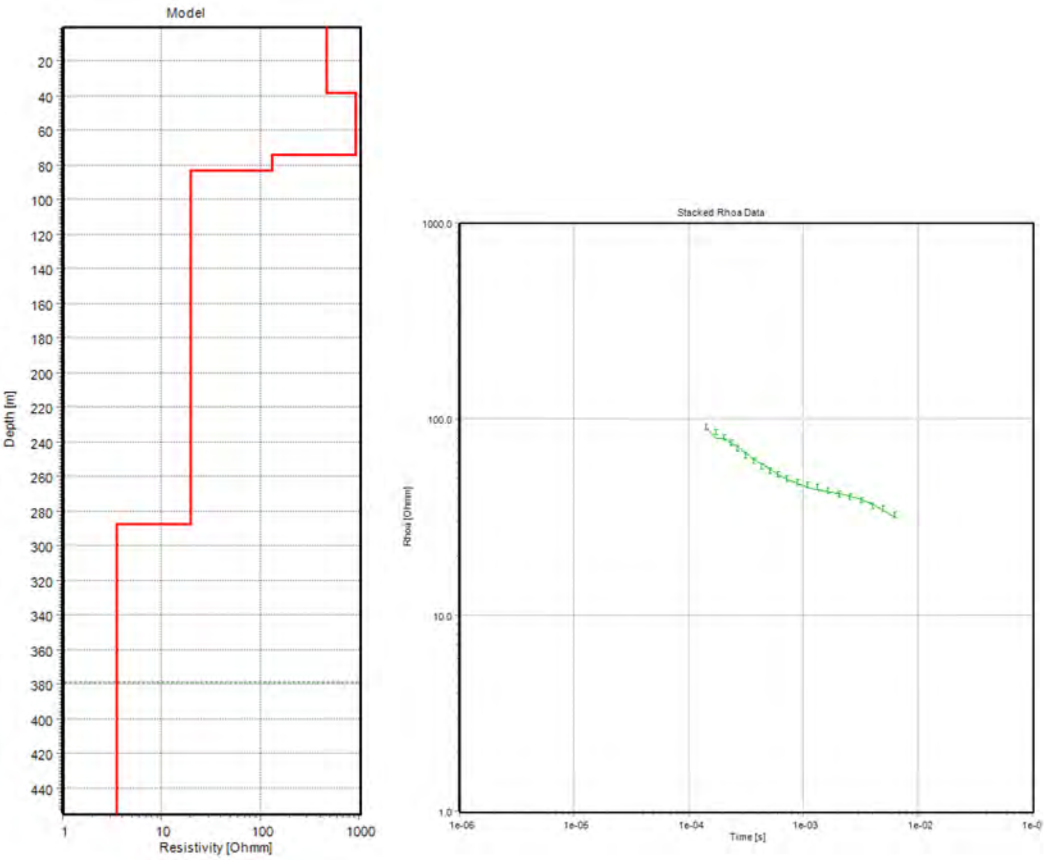

Figure A1.1 Left: Layered resistivity model for the TEM data. The green dashed line shows the calculated depth of investigation (depth to which the resistivity model is deemed valid). Right: TEM data (points) and model response (curve).

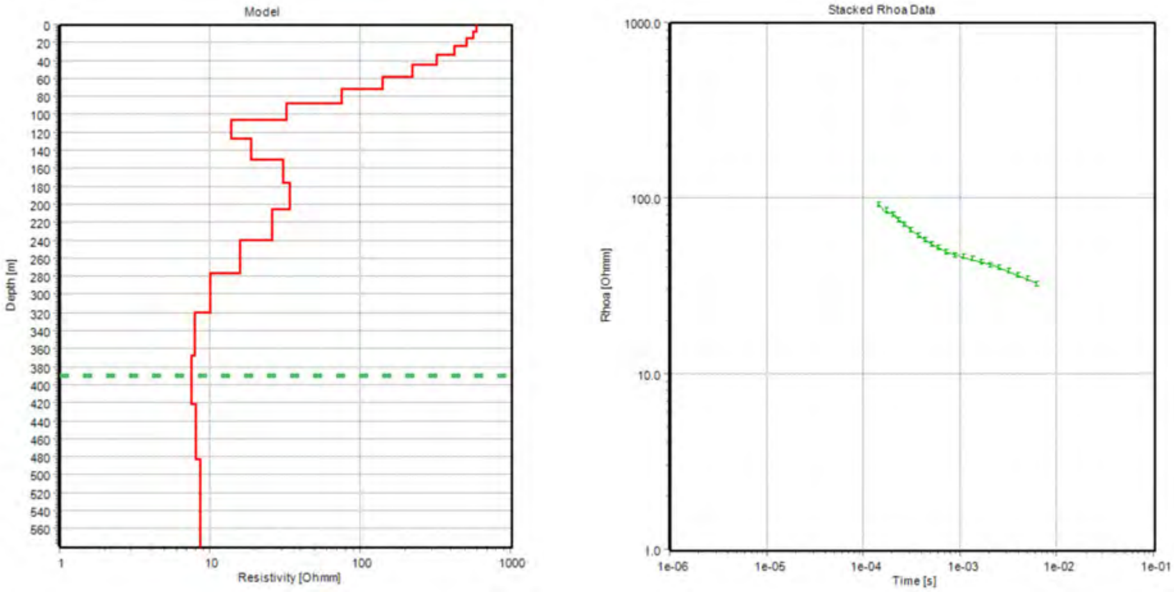

Figure A1.2 Left: Smooth resistivity model for the TEM data. The calculated depth of investigation is shown as a dashed green line. Right: TEM data (points) and model response (curve).

APPENDIX 2 DAILY DRILLING REPORTS AND WELL CONSTRUCTION

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 Limited Drilling. A well construction diagram has not been supplied.

A2.1 16 March 2021

Summary

At 3.7 m at end of day.

Details

Site set up Friday and this morning. Casing run a few metres and cable-tooling commenced after lunch. Sediments are poorly sorted muddy to sandy gravels. Lumps of clay also present and the deposits appear to be cemented, as pushing the casing in was very difficult. It finally became easier late in the day.

Additional Comments

Airlift tests require no GNS input – the drillers do it all themselves. The drillers said they will only be using cable tool for this well, no wash drilling it would seem. The site is not as easy to find, as I discovered to my cost. I will produce a detailed route description this week.

Collected all the equipment from site 2 yesterday but left a quantity of sample bags for the Honnor Drillers to collect designated samples, plus additional samples where they note that things change. Gavin (driller) was okay with the pump test being done on Friday.

Summary

At 8 m at end of day. A 3 m length of casing was welded and pushed in ready for bailing in the morning and slug testing later in the afternoon.

A2.2 17 March 2021

Details

There was a depth discrepancy yesterday; the length of casing protruding above ground may not been accounted for; we actually finished at 2.7 m (depth physically measured). Lithology was consistent all day comprising (very) poorly sorted gravels (range mU to very coarse pebbles) that are sub-rounded to sub-angular (more angular than well 2). Cementation (probably Fe) has caused slow penetration of casing and cable tool, although 5 m was managed by the days end.

Additional Comments

I left the site early as no more samples were to be obtained today. I said to Luke (driller) to let me know if there are any issues regarding tomorrow’s slug test. I have not heard anything so I assume it is all go. In addition, Russell was going to call Stewart as well.

Instructions on how to get to the rig site from Waipukurau. The rig is not easy to spot from the road but if you do it right it takes about 11 minutes.

1. Travel west from Waipukurau along SH2 for about 5 km.
2. Turn onto Ashcott Road.
3. Only a few hundred metres from the SH2 intersection you will cross a one-lane bridge.
4. Take the first right-hand turn immediately after the bridge – this is the Ongaonga–Waipukurau Road.
5. Cross the one-lane bridge on the Ongaonga–Waipukurau road (Tukituki River).
6. Travel northwest for nearly 3 km. After passing a small livestock loading yard on your right ,you will see a few hundred metres further two farmhouses and buildings on either side of the road. The farmhouse on the right has more buildings and equipment scattered about, along with a fairly obvious white barn/woolshed and a sign saying 'Braemar' on the gate.
7. Continue past the 'Braemar' gate for a few hundred metres more to the first farm track you see on the right. Turn onto this track, which is at the eastern end of a substantial roadside bank of toitoi and has recently been gravelled (a bit of care needed if you are not in a SUV). About 100 m along the track, you will pass a farmhouse set back from the track in a maize paddock (which has just been harvested).
8. The rig is at the very end of the track, about 500 m from the farmhouse.
9. If coming from the north, you could try SH50, travel south leaving SH50 to go through Onga Onga. Go along the main street to Herrick Street. The Ongaonga–Waipukurau Road should be the second street on your left.

A2.3 18 March 2021

Summary

At 11 m at end of day.

Details

Only a few metres logged today to get the well to the depth for the slug tests. The lithology was consistent and the same as yesterday, comprising (very) poorly sorted gravels (range mU to very coarse pebbles) that are sub-rounded to sub-angular (more angular than well 2). Slug tests were successfully completed during the afternoon.

Additional Comments

Nothing additional to report this time.

A2.4 19 March 2021

Summary

At 16.1 m at end of day.

Details

Pushed in a 6 m length of casing and logged to close to the base of it, certainly within the slotted liner. Few metres logged today to get the well to the depth for the slug tests. The lithology was he same as previous days (very poorly sorted gravels, range mU to very coarse pebbles that are sub-rounded to sub-angular). At about 15.5 m, we went into a mixture of sand and pale brown / buff-coloured clay that changed to sand and bluish-grey clay. The last two bails of the day were back into gravels with a similar grain size to gravels above the sand/clay but did not have the slightly reddish coating seen previously. In addition, the water coming up with last two bails was not the brown to tan colour it had been but greyer.

Additional Comments

There has been a significant amount of sand coming up in the gravels. It is possible that this may reflect fining-upward units, but there is no way of telling. Luke thinks it might also be possible that sand is being pulled in from the formation away from the well by the bailing action. Difficult to prove but, if true, it might be skewing the grain size toward the finer end. A working hypothesis about the sand/clay mixture we are getting is that they may be interbedded sands and clay – again, hard to verify.

The first pump test is proposed for 25–30 m, so progress on Monday will be critical.

A2.5 22 March 2021

Summary

At 21.5 m at end of day.

Details

Logged to the base of a 3 m length of casing and then attached a 6 m length to get to 26 m for pump testing. The lithology continues to be very poorly sorted gravels, range mU to very coarse pebbles that are sub-rounded to sub-angular.

Additional Comments

On track to get the well logged down to the pump test level on Tuesday (this) morning. That will leave the afternoon in which to develop the well for testing.

A2.6 23 March 2021

Summary

At 26.2 m at end of day.

Details

Logged to the base of the 6 m length of casing attached to 26 m for pump testing. The lithology continues to be very poorly sorted gravels, ranging from mU to very coarse pebbles that are sub-rounded to sub-angular. Local to moderately common very silty/fine sandy clay lumps were distributed throughout the formation, probably representing thin mudstone layers (stringers?) within the gravels. The flow in the well was insufficient to sustain a pump test (and an observation well was found to be pumping continuously, unbeknownst to us). Instead another slug test was successfully undertaken, during which Stewart rather joyfully completed some very small-scale civil engineering works on the site.

Additional Comments

The decision to not undertake the pump test was only made just before the Wairakei team (Maïwenn and Stewart) arrived. This is not optimal, so in future we have decided that the on-site geologist can make a call as to whether the test is likely to be viable or not before the team departs Wairakei (at very least, initiate the discussion with the groundwater team). Obviously, this will be based on the driller's assessment and experience and will be determined by the driller's observation of flow rate and also the presence of clay in the formation and general formation tightness.

A2.7 24 March 2021

Summary

A slow day, total depth at 28.4 m today.

Details

A 3 m section of casing was welded on in the morning and driven in. Initially, the lithology was the usual poorly sorted gravels, ranging from mU to very coarse pebbles that are sub-rounded to sub-angular. The well then intersected a c. 25-cm-thick silty clay that required a lot of effort to penetrate. Immediately below the clay layer were that same type of gravels found above the clay, which then passed into a mixture of clay and gravel. This mixed clay and gravel is very difficult to penetrate with the cable tool and required intermittent chiselling, hence the limited progress.

Additional Comments

The relatively thick clay layer just below yesterday's planned pump test level may have been a significant factor in the low flow in the well. This would have been exacerbated by the tight formation below the clay layer.

In a previous update, I noted that, in some cases, the sediment level came back up-hole when the casing was driven in. It has been noted so far that there is no linear relationship between casing length and the amount of up-hole movement. It is also noted that is does not always happen. Luke (driller) said one of his colleagues had noted similar movement in a well elsewhere, so it is not just this hole. Interesting depth control issue, still trying to assess the best way to deal with it.

On a more frivolous note, Stewart's civil engineering works are functioning well – see attached photos (below).

A2.8 25 March 2021

Summary

Another slow day but speeding up a bit; total depth at 30.0 m today.

Details

Intersected the usual poorly sorted gravels, ranging from mU to very coarse pebbles that are sub-rounded to sub-angular.

Additional Comments

My suspicion is that we may be drilling though layers that fine upward with gravels at the base and sands/clay toward the top, which would explain the variations in ROP. Some bails are full, then become negligible, then revert back to being full. The drillers tried a few changes of technique in order to speed up ROP. A combination of bailing beyond the end of the casing for short distances and chiselling specific hard layers once bailing returns become negligible. Checking returns after chiselling, there was not as much formation damage as expected in larger clasts. It is possible that the difficult layers are mainly clays and sands. This is something we will monitor.

Travelled up to well 2 to collect samples in the morning while they were welding and driving in casing and chiselling at well 1. This worked fine but is not something we should do on a daily basis. It requires timing but is eminently ‘do-able’.

A2.9 26 March 2021

Summary

Total depth at 32.2 m today.

Details

No change in lithology – poorly sorted gravels, ranging from mU to very coarse pebbles that are sub-rounded to sub-angular. Rare clay.

Additional Comments

The formation is still hard but it was found that better progress can be made by yet another technique change. Today, once the next casing string had been welded on, rather than driving it in fully it was driven in about 1 m then bailed with the cable tool. Drive another metre then bail and so on. This technique worked well today. Fiona is on site next week.

A2.10 29 March 2021

Summary

Cable-tooled to 35 m today.

Details

Drilling continued in very poorly sorted, sub-angular to sub-rounded sandy gravels ranging from cL sands to very coarse pebbles and rare cobbles. Minor variations in abundance of coarser pebbles occur over ~5–10 cm intervals. Up to ~20% tan brown clay (in several small ~2-cm-size and one large ~1015-cm-size clumps) at ~33.3 m.

Additional Details

Drilling was delayed this morning due to wet weather; otherwise, bailing with the cable tool was reasonably fast with no problems encountered. A further 3 m casing was welded in place at end of today, ready to be hammered in tomorrow morning. Luke (driller) noted that two nearby wells encountered a 1–2-m-thick blue clay layer: The well ~800 m WSW of this well logged 2-m-thick clay at 38 m depth, a farther well closer to Ongaonga–Waipukurau Rd logged 1-m-thick clay at 46 m. Following discussion with Stewart, the plan is to do a slug test if the blue clay is encountered at similar depths in this well and aim to undertake the planned ~40 m depth pump test below this clay layer if well conditions allow.

A2.11 30 March 2021

Summary

Cable-tooled to 41 m today.

Details

Drilling mainly continued in poorly sorted sandy gravels ranging from cL sands to very coarse pebbles and rare cobbles, with variably <5% to ~30% abundance of coarse to very coarse pebbles and overall average grain size gradually increasing with depth, except for a thin (~30 cm) interval of mainly angular gravels intersected at 39 m.

From 40.5 m, drilling intersected a dense tan brown silty clay mixed with poorly sorted gravels.

Additional Comments

Casing currently down to 41 m, with the shoe sitting in the brown clay. Following discussion with Stewart, the drillers will chisel through the clay at the start of operations tomorrow morning to determine the thickness of the clay. If it is > 1 m thick, the GNS hydro team will come down to carry out a slug test. If < 1 m thick, the plan is to drill ahead to either encounter the blue clay (and slug test then) or find a suitable interval to pump test.

We may have been the only part of the North Island to stay dry today (apart from a two-minute shower), but there is heavy rain forecast for tomorrow morning that may delay operations. I will keep Maïwenn and Stewart updated with progress in the morning with regards to the slug test.

A2.12 31 March 2021

Summary

Drilled to 46 m today – mostly cable tool but chiselled between 41 and 42 m and 42 and 43 m before bailing.

Details

Complex stratigraphy/lithology between 41 and 46 m, further complicated by heaving at the bottom of the hole after running in casing, resulting in skewed depths of lithology changes.

Based on depth retrieved by cable tool:

- 41 to ~41.10 m: thin interbedded layers of poorly to moderately sorted coarse sands, fine to coarse pebbles, cobbles and slightly silty tan brown clay.
- ~41.1 to ~43.3 m: blue clay matrix supporting rare sub-rounded fine to medium pebbles.
- ~43.3 to 45.8 m: brown gravels – variable average grain sizes with each bail – from medium sands to medium to coarse pebbles, rare small clumps of tan brown clay intermittently through this interval.
- 45.8 to 45.9 m: mainly dark orange-brown clay.
- 45.9 to ~46 m: possibly back into sandy gravels.

Additional Comments

Initially bailed to ~41.2 m to determine thickness of brown clay encountered at end of yesterday's drilling; however, only rare clay noted, along with fine to coarse sand and granules over three bailing runs. Smaller grain size and the absence of larger grains suggests this material came through the slots, but the driller did think he'd made new ground with the second and third bail, so this may indicate a sandy layer beneath the clay.

As the brown clay noted at 41 m yesterday is <1 m thick, decided against slug test (after consultation with Stewart), but, of note, the water level below the clay layer today was lower (approximately -5.2 to 5.7 m) compared to that above the clay layer (approximately -3.6 m), suggesting that this clay is a confining layer.

The next 6 m of casing (to reach 47 m depth) was welded in – while hammering this in, Luke (driller) noted that the hole was very tight between 43 and 44 m (possibly the blue clay bailed at 41 and 43.3 m) and again at 46 m (possibly the orange-brown clay bailed at 45.8 m). The casing was 'bouncing' at 46 m, so Luke stopped hammering the casing in at this depth.

After running casing in the bottom of the hole was at 40.7 m – 0.5 m shallower than the pre-casing bottom hole depth. As such, the post-casing depths/lithology are somewhat difficult to reconcile with pre-casing depths and suggested lithology-change depths based on conditions while running in casing (e.g. bailed depth of clays versus tight hole).

The thickness and lower boundary depth of the blue clay is somewhat ambiguous. Having chiselled then bailed to 42 m, where a large ~20–30 cm plug of blue clay was retrieved, no further clay was collected by the cable tool. Some blue clay was likely washed out while bailing – two bails at 42 m just collected blue, slightly viscous water – and some of the clay was likely compacted by chiselling, but, after chiselling another metre (to 43 m), the first bail collected brown gravels (and brown water). The measured bottom hole depth after this bail was 43.3 m. Luke noted that the chisel appeared to only reach gravel close to 43 m rather than at shallower depth.

Plan for Tomorrow

Originally planned to bail a little beyond the shoe (currently at 46 m) to determine thickness of the orange-brown clay, then drive in the last 1 m of casing to 47 m. BUT Stewart and Simon (HBRC) are in discussion to determine the feasibility (logistics and cost) of pulling the casing back up to the blue clay layer and performing a slug test at that depth. This will be discussed with drillers and decisions made first thing tomorrow.

A2.13 1 April 2021

Summary

Cable tool to 47.2 m.

Details

Drilling between 46 and 47.2 m encountered poorly sorted, sandy gravels – with variably rare (<1%) to common (up to ~30%) medium pebble to cobble-size grains – and interlayered clays.

A ~20-cm-thick layer of 'tight' red gravels was encountered at 46.3 m, overlying a thin (<10 cm) clay matrix-supported conglomerate of sub-rounded granules and fine pebbles at 46.5 m depth. Some medium to coarse pebbles below this depth (46.5–46.8 m) are coated by a very thin tan-brown clay, suggesting the presence of a clay matrix that possibly washed away with bailing.

A thin (<10 cm) layer of tan-brown clay was also encountered between 46.9 and 47 m underlain by poorly sorted coarse sands to gravels to 47.2 m.

Additional Comments

Following lots of discussion on Thursday morning, it was decided not to jack the casing back to the blue clay layer for a slug test, as the exact depth and thickness of the clay was uncertain. Drilling operations were suspended late Thursday morning after drilling to just below the casing shoe at 47 m, due to wet weather.

Plan for Tuesday

The Wairakei hydro team will conduct a slug test on Tuesday morning before drilling operations continue, after which the drillers will prepare, weld and run-in the next 3 m of casing. Depending on well conditions, the plan is to conduct a pump test before or at ~60 m depth. Giovanni will be on site this week.

A2.14 6 April 2021

Summary

Slug test this morning followed by drilling to 48.5 m today – cable-tooled to 48.5 m but encountering some clayey sand material, so will chisel through this with rotary drill tomorrow morning.

Details

Slug test completed this morning with Maïwenn and Estefania at ~47 m depth. Test completed early afternoon. Casing installed to 49.0 m, some material from below pushed up into casing to ~46.0 m.

47.2–48.0 m sandy gravel material with some pebbles up to very coarse pebbles encountered. Samples contained traces of clay.

48.0–48.5 m Gravelly sand with interbedded clay layers. Material very difficult to bail through, so will use rotary tool to break this material up before proceeding tomorrow morning.

Additional Comments

Luke (Baylis) mentioned that sometimes when using bailer the fine material can be sucked into the bailer with the up and down movement of the tool and can result in bias results of finer-grained material. Possible that we are over-estimating the sand content in the layer from 48.0 to 48.5 m.

A2.15 7 April 2021

Summary

Casing was installed this morning down to 53.0 m. Drilled to 53.0 m today mainly using cable tool but had to rotary one section out as the bailer was struggling to break through the layer.

Details

48.5–49.3 m: Used rotary tool to break through this layer, as bailer was unable to penetrate the material. Encountered a clay layer that was intermixed with fine to medium pebbles and sand. As we passed 49.0 m, the material become progressively more sandy.

49.3–53.0 m: Encountered sandy gravel with fine to coarse pebbles with the odd very coarse- to cobble-sized material. Material was rather consistent all the way down, with occasional changes in the quantity of pebble material returned. Occasionally would encounter some traces of clay that tended to slightly coat the outside of the pebbles in the returned material.

Additional Comments

Luke (Baylis) mentioned that other local wells encountered a blue clay layer around the 50-ish metre mark, so slowly advanced the casing from 52 to 53 m by knocking in ~500 mm then bailing. Discussed with Stewart about possibly running a pump test at 53.0 m, we will get an estimate of flow rate before deciding so drillers currently setting up an airlift test to get flow rate. Need a few extra pipes, so will begin test tomorrow morning. Once we have an estimate, we will decide to proceed or not with the pump test.

Farmers around the area have been using the irrigation systems, which is likely to affect the pump test results. Stewart has talked to the farmers and it appears that the irrigation systems should be finishing tonight, so should be a suitable time to do the pump test provided the flow rate is suitable. Will keep you updated with developments tomorrow.

A2.16 8 April 2021

Summary

No drilling completed today. Began airlifting test this morning followed by slug test at 53.0 m. Water level measured at 5.7 m below ground level this morning.

Details

Airlifting test – initial airlifting test resulted in a flow rate of approximately 2–3 L/s, left airlifting test run for approximately 1.5 hours with very little change in flow rate. Luke mentioned that developing this section we may be able to get up to 5 L/s but appeared to not be worth continuing doing pump test. Discussed results with Stewart and Russell (Baylis); it was determined that a pump test was not worthwhile at this depth but would be worth completing a slug test. Maïwenn contacted late morning to conduct slug test on site. After airlifting, water level re-measured around 1:45 pm and appeared to be relatively stable at 5.3 m.

Slug test – Maïwenn arrived on site at 3:00 pm and slug test set up and preformed. We noticed that one of the farmers to the east of the site was using their irrigation system, which may have impacted the results. Results appear to be recovering very quickly, possible as a result of the airlifting test clearing a lot of the finer material out, though the overall water level appears to be dropping overtime.

Additional Comments

Russell (Baylis) mentioned that with a 1 m slotted section it can be very difficult to get a true representation of the flow rate at depth. Developed wells around the area tended to have 6–9 m of slotted sections. It is possible that we are under-estimating the flow rate at some of the intervals.

Just for the written record regarding the rationale behind the decision not to pump test as all discussions were made via phone: we decided not to pump test because of the expense it would have incurred to install additional screen length – in the order of 3–4 days – and uncertainty around the likely pumping rate. Options considered were: jacking back the casing to install stainless steel casing; or drilling ahead and installing a longer section of perforated 150 mm diameter casing, which likely meant we would have to telescope the well from this depth.

A2.17 9 April 2021

Summary

Following from yesterday’s slug test at 53.0 m, drilled to 55.0 m today. Cable-tooled to 53.7 m followed by rotary tooling to 55.0 m and then bailing material out. Water level measured at 4.7 m this morning.

Details

53.0–53.5 m: Encountered sandy gravel with fine to coarse pebbles with the odd very coarse- to cobble-sized material. Similar to material encountered from 49.3–53.0 m.

53.5–53.7 m: Encountered an orange clay intermixed with sandy gravels and fine to medium pebbles. Material was very difficult to penetrate with the bailer so decided to rotary tool from 53.7 m onward.

53.7–55.0 m: Rotary tooled through this material then used bailer to recover material from this interval. Bailer sunk through the softer top material down to ~54.9 m and recovered dark bluish-grey clay intermixed with sandy gravels and minor fine to medium pebbles. Estimated that clay layer is currently around 1.5 m thick (53.5–55.0 m); based on other well logs, it appears this clay layer can be up to 4–5 m thick. Discussed findings with Stewart and Zara and it has been decided to undertake a slug test at this clay layer interval as we can’t be sure how thick it is and don’t want to penetrate slotted layers into the pebbles below clay layer. Slug test organised for Monday (12/04/2021).

Additional Comments

~2 m of pipe sticking up from the ground, so 1 m scaffold has been set up to safely undertake slug test on Monday. Water measured this morning at 4.7 m (53.0 m – 8:00 am) and re-measured after drilling at 5.23 m (55.0 m – 1:00 pm). Mark taking over from drilling supervision duties starting Tuesday.

A2.18 12–13 April 2021

Summary

Slug test completed Monday afternoon (12 May). Cable-tooled to 56.2 m today.

Details

Slug test: Minimal water-level response during the slug test on Monday, so it was decided to leave the data loggers and 'slug'-in overnight. Results to be downloaded during Maïwenn's next visit.

Very slow drilling progress. Passed through the clay layer into sand (mL-vcL, moderately sorted), which caused considerable difficulty for the cable tool, so had to alternate between cable-tooling and using the chisel.

Additional Comments

Virtually no progress was made by the cable tool, hence use of the chisel and driving in the casing about 1 m at a time. Unfortunately, this may be compacting the sediment, but there is no way of telling. Grains do not appear to be broken, so the effect of drilling will most likely be reduction in porosity if in fact we are compacting things. We are not sure how thick this sand is, as none was recorded at similar levels in adjacent wells. Another 2 m casing length was attached at the end of the day, so we will see what happens tomorrow when we continue. If this situation continues, it might be worth discussing the possibility of rotary air drilling for some intervals, as the budget will probably not stand an ROP of about 1 m/day.

A2.19 14 April 2021

Summary

No progress.

Details

The 2 m casing length that was attached yesterday was driven in first thing. The cable tool then deployed, but minimal sediment extracted and the chisel was then deployed. Some sand was extracted but, when the next chisel deployment occurred, the rig had an issue. It turns out that it had stripped a bearing (a spindle bearing if that means anything to anyone) on the winch motor (or one of the motors?). Russel Baylis came out to assist but his temporary fix did not work, thereby stopping play. Russell returned to base to check for spare parts and a mechanic has been called. Luke and co. commenced dismantling the appropriate bits in preparation for the mechanic's arrival. They hope to have it fixed this afternoon or tomorrow. If it is not fixable, my understanding is that they may swap the rig out. I will know more either later this evening or tomorrow morning.

Additional Comments

In motel, doing other work. Sorry, but s**t happens as they say!

From Baylis Bros Ltd:

To advise, we have had a breakdown today on the 22W drill rig – collapsed bearing in the clutch mechanism. Between our own crew and our mechanic, we are currently on-site starting the repair process. Realistically looking at Monday (19th) to be back up and running unfortunately.

It's also not an option at this stage to look at replacing the rig with a rotary unit, as we cannot lower the mast or lift the hydraulic jacks until we get the clutch mechanism repaired.

It's not often we get a major breakdown due to our constant servicing regime but, in this case, it's happened, nature of the beast! Apologies for the delays.

A2.20 19 April 2021

Summary

Cable-tooled to 58.0 m today.

Details

Slow drilling progress. Continued into the same sand layer Mark previously finished on (mL-vcU, moderately well sorted), which caused considerable difficulty for the cable tool, so had to alternate between cable-tooling and using the chisel. Got into a slightly coarser material from 56.9–57.5 m (mL – granules, moderately sorted) before returning into the sand layer.

Additional Comments

As per Mark's previous comments, the cable tool is making almost no progress, hence we are chiselling for around 0.5 m then using the cable tool to grab the chiselled section out, but this takes time swapping between each tool. Grains do not appear too damaged or broken but possibly compacting the material in front to some degree (can't really tell however). The next 3 m of casing is taking a significant amount of time to knock in, indicating that we are likely still in the sand material (as of the current time, we have knocked in 2 m of casing). We'll see how we go tomorrow – if this situation continues, it might be worth discussing the possibility of rotary air drilling for some intervals. Luke mentioned that the rotary drill would speed things up but as we get deeper having to place more rods and then taking them out takes longer and longer, so may be a trade off as we get deeper in the hole (something to consider) but would help greatly for these sections we are in where the cable tool is struggling.

A2.21 20 April 2021

Summary

Cable-tooled to 60.0 m today. Bit of an eventful day with a couple breakdowns; more details below.

Details

A mixture of lithologies encountered today. Managed to pass through the previous sand layer encountered yesterday at 58.5 m, where we moved into a fine to very coarse pebble poorly sorted layer to 59.0 m. From 59.0 to 59.6 m, we encountered a sandy gravel layer with some fine to very coarse pebbles. From 59.6–59.7 m, we entered into a thin sandy clay layer intermixed with pebbles before returning to a gravelly sand layer to 60.0 m.

Additional Comments

The drill rig was stalling at the end of Monday, so Tuesday morning a mechanic arrived to replace the fuel pump and filter and also a blocked pipe that appeared to do the trick. Managed to start drilling at 11:00 am with good progress now being made, with the bailer especially within the pebble layer described above. Unfortunately, late afternoon Luke noticed one of the belts was slipping and, after inspecting it, it was decided to replace the belt, so drilling operations ceased for the day. Luke is now getting a local company to replace the belt, with hopefully a late Wednesday morning start back onto drilling. Will keep you all updated with tomorrow's progress.

A2.22 21 April 2021

Summary

Slow day today; cable-tooled to 61.0 m today.

Details

From 60.0–60.2 m, encountered a sandy gravel layer with some pebble material and clay (10–20%). Chiselled down approximately 0.5 m, but bailer sunk through this material to 60.7 m, so no recovery of material from 60.2–60.7 m. Continued to recover the sandy gravel material from 60.7–60.8 m. 60.8 m: we transitioned into a sand layer intermixed with clay down to our end depth of 61.0 m. Next set of 3 m casing is currently being installed. Water level measured this morning was at 5.60 m.

Additional Comments

Belt replaced and set up this morning, which pushed drilling operations back; started drilling at around 11:30. Progress is again slow due to the sandy nature of the material; we are having to chisel then use the bailer, which is a time-heavy process. Only way to speed up the process is likely to get in the rotary drill rig, as these layers are very difficult to pass with the current process. Also currently within the zone (60–65 m) for the next slug test, we haven't encountered a decent aquitard material yet but may be calling up to organise a slug test in the next few days.

A2.23 22 April 2021

Summary

Cable-tooled to 62.5 m today.

Details

From 61.0–61.6 m, continued from yesterday into a sand layer with minor pebbles and clay. Transitioned to a fine to coarse pebble layer at 61.6–62.2 m, with a thin sand/gravel sequence in between at 62.0–62.1 m. From there, we transitioned back into a sand layer to our end depth of the day at 62.5 m.

Additional Comments

Still having to alternate between chiselling then bailing as we continue through the sand layer. Still have not encountered aquiclude material as identified on the resistivity profiles between 60.0 and 65.0 m, predominately drilling through sand material with minor clay encountered, but will keep you all updated if we hit something and organise the slug test.

A2.24 23 April 2021

As I'm sure you are aware, no drilling undertaken today so no update on drilling progress. Mark will be taking over drilling from Tuesday.

A2.25 27 April 2021

Summary

Cable-tooled to 63.4 m today.

Details

Things all started well with everyone back on deck. We continued through the sand reported by Giovanni on the 23rd. A combination of alternating between chiselling and bailing was used, but progress was slow. Then in late morning it started to rain, continuously and on occasion heavily causing issues with the winches (belts were slipping, etc).

Additional Comments

Regarding the winches, what might have happened is that the rain came in at significant angle (it was fairly windy), 'avoiding' the covers that would normally keep rain out. Hoping for better (and warmer) weather tomorrow.

A2.26 28 April 2021

Summary

Cable-tooled to 64.0 m today.

Details

Still in sand, so the combination of alternating between chiselling and bailing continued but progress was slow. Grain size is beginning to increase, suggesting we might be penetrating a fining-upward unit.

Additional Comments

There was an issue with the winch drive that continued from yesterday. This was fixed during the morning and drilling continued without incident in the afternoon. Lauren Coup was on-site for a few hours in the afternoon for training as an additional site geologist.

A2.27 29 April 2021

Summary

Cable-tooled to 66.0 m today.

Details

Finally penetrated the sand unit that had slowed ROP over the last few days. After cable-tooling and chiselling during the morning and driving in a new section of casing, we entered poorly sorted mL-coarse pebble, Fe-oxide stained (sandy) gravels.

Additional Comments

There is some evidence of breakage due to the drilling process in the upper part of the gravel succession, but the last few bails of material that breakage was less noticeable.

A2.28 30 April 2021

Summary

Cable-tooled to 69.5 m today.

Details

Sediments comprise poorly sorted mL- (very) coarse pebble, Fe-oxide stained (sandy) gravels. There were local intervals where finer grain sizes dominated, but these may be a function of the drilling process (e.g. winnowing of fines due to the bailing action).

Additional Comments

A good day and an increase in ROP. Sorry, Giovanni – did not quite make 70 m – you will have to do the sample at that depth.

A2.29 3 May 2021

Summary

Good progress today, cable-tooled to 73.0 m today.

Details

Sediments as per Mark’s last email. These comprised poorly sorted mL- (very) coarse pebble, Fe-oxide stained (sandy) gravels. We found localised intervals where finer grain sizes dominated, but these may be a function of the drilling process as previously mentioned by Mark in his last email.

Additional Comments

Sample taken at 70.0 m. Water level taken this morning showed a drop to 7.8 m; will see how it is tomorrow morning for comparison.

Casing was taking some time to go in from 70.0 to 71.0 m, but has since loosened up considerably, allowing us to make much better progress.

A2.30 4 May 2021

Summary

Cable-tooled to 75.9 m today.

Details

73.0–74.0 m: Sediments comprised poorly sorted, sub-angular to sub-rounded pebbles and sand with minor amounts of clay (<5%). Material was typically much sandier than that encountered yesterday. At 73.2–73.4 m, noticed an increase in clay content (10–20%).

74.0–75.9 m: Returned to material previously described yesterday comprising poorly sorted mL- (very) coarse pebble, Fe-oxide stained (sandy) gravels. Appeared to be fining slightly from 75.4 m.

At 75.9 m, bailer was struggling to push through at the end of the day. We returned a clump of clay, so suspect we may be passing a clay lense here. Will chisel this material tomorrow to see what we encounter.

Additional Comments

Water level this morning had risen to 5.9 m compared to yesterday. Discussed slug testing with Stewart this afternoon; however, due to the presence of clay in the returned samples it was decided to hold off for now. Will discuss with Stewart tomorrow about a slug test later in the week depending on returned material.

A2.31 5 May 2021

Summary

Cable-tooled to 77.6 m today.

Details

75.9–77.0 m: Sediments comprised moderate to moderately well sorted mL-vcL sand with minor gravels and pebbles and occasional clasts of clay.

77.0–77.6 m: Returned to material previous described yesterday comprising poorly sorted mL- (very) coarse pebble, Fe-oxide stained (sandy) gravels; minor clay encountered with these deposits.

Additional Comments

Water level this morning measured at 6.35 m. Slow progress when we encountered the sand layer this morning, as we were alternating between chiselling and bailing; fortunately the layer was only ~1 m thick. Once we moved into the gravels, we managed to make some ground late this afternoon; hopefully can continue this tomorrow morning.

Discussed slug testing in gravels with Stewart and Zara. Since we have not previously tested these particular gravels, it has been decided to perform a slug test tomorrow afternoon. We will continue drilling tomorrow morning with an idea to slug test early afternoon when Maïwenn arrives.

A2.32 6 May 2021

Summary

Cable-tooled to 79.0 m today.

Details

77.6–78.3 m: Continued into poorly sorted mL- (very) coarse pebble, Fe-oxide stained (sandy) gravels with minor clay. Clay began to increase from 77.8 m.

78.3–78.4 m: Encountered an intermixed clay (~60%), sand and pebble layer.

78.4–79.0 m: Transitioned back into the pebble layer that quickly fined into a gravelly sand.

Additional Comments

Strange water level this morning measured at 14.8 m, which was a significant drop from yesterday's measurement (6.35 m).

A2.33 7 May 2021

Summary

Relatively slow day, cable-tooled to 80.0 m.

Details

79.0–80.0 m: Continued into poorly sorted mL- (very) coarse pebble, Fe-oxide stained (sandy) gravels with minor clay (clasts and coating pebbles).

Additional Comments

Water level had returned to 5.85 m when measured in the morning.

Next set of casing was taking some time to knock in. Drillers have noted that the formation is significantly tighter, and as a result it is becoming increasingly difficult to knock the casing in. Managed to knock in 1 m and bail to the end. Fiona will be taking over drilling activities for next week.

A2.34 10 May 2021

Summary

Cable-tooled to 82 m today.

Details

Drilling continued in very poorly sorted sandy, brown gravels ranging from vfU sand to cobbles from 80 to 82 m. Rare to minor sandy (vfU) brown clay coats pebbles throughout the 80–82 m interval, with rare localised 'clasts' of a (sandy) clay matrix-supported breccia-conglomerate (with variably sub-angular to sub-rounded gravel to fine pebble-sized grains).

Additional Comments

Measured water level = 5.4 m at 08:00 this morning.

Running in casing remains relatively slow, with some localised resistance but overall slightly less issues than experienced last week. Tomorrow, drilling is likely to commence around mid-morning as a new length of casing will be prepared and welded up at the start of the day.

A2.35 11 May 2021

Summary

Cable-tooled to 83.5 m today.

Details

Drilling continued in very poorly sorted sandy, brown gravels ranging from vfU sand to cobbles (up to 100 mm size) , with rare to minor sandy (vfU) brown clay coating some pebbles. Lenses of dense brown silty-sandy (vfU) clay were encountered between 82.2 and 82.5 m (~5% vol.), with <1% 10–50-mm-size clumps of clay returned between 82.5 and 83.1 m. A 20-cm-thick layer of moderately well-sorted fU to mL sand with rare to minor granules to coarse pebbles was encountered from 83.1 to 83.3 m, which overlies poorly sorted sandy gravels of mainly granule to fine pebble size with rare very coarse pebbles and rare clay coating.

Additional Comments

- Measured water level = 5.6 m at 08:00 this morning.
- 3 m of casing welded up this morning and subsequently reasonably good progress was made ramming in casing and then bailing to 83 m.
- While hammering in the next 1 m of casing, the drive head sheered apart, halting casing progress at 83.7 m. The hole was cable-tooled to 83.5 m, but the tool was unable to progress further below this depth today.
- A replacement drive head has been located by Bayliss, which the drillers will bring to site in the morning to allow the remaining length of casing to be hammered in place.
- Going forward, the plan is to drive this length of casing in to 200 mm above ground (therefore down to 85.6 m hole depth), continuing to bail after every 1 m, which, barring any other complications, should be completed tomorrow afternoon. Then awaiting further decisions regarding possible rig change over and pump testing.
- Note, there is some wet weather forecast for tomorrow, which may delay operations.

A2.36 12 May 2021

Summary

Drilled to approximately 84.2 m today (from 83.5 m, yesterday’s total depth) using cable-tool, plus chiselling between 84 and 84.2 m.

Details

Drilling encountered several 100–150-mm-size, rounded cobbles (intact to partially fragmented) from 83.5 to 83.7 m, amongst poorly sorted sandy gravels (granules to medium pebbles) coated with rare brown clay. Below 83.7 m, sediments appear to be fining downwards:

- 83.7 to 84 m: ~50% vfL–vCU sand with ~40% granules to fine pebbles and ~5–10% medium to coarse pebbles.
- 84 to ~84.2 m: predominantly vfL–vCU sand with ~10% very silty/sandy brown clay, with very rare fine- to medium-size pebbles.

However, the increased abundance of sand may be due to substantial water/sediment displacement during chiselling (between 84 and 84.2 m), causing more fine material to be sucked in through the slots. Also, note that the water bailed out between 84 and 84.2 m appeared slightly more opaque and viscous than at shallower depths, suggesting higher clay/silt content.

Additional Comments

- Measured water level = 4.7 m at 08:00 this morning.
- Slow progress today, as it took some time to cable-tool through the large cobbles at 83.5–83.7 m.
- The plan was to run-in casing from 83.7 to 85 m; however, the hole got very tight at 84 m, so stopped and bailed to 84 m.
- After another unsuccessful attempt to run-in casing; the drillers tried chiselling, then bailing again. Only small amounts of sand and very fragmented pebbles were returned after several bails. After chiselling again, bailed down to approximately 84.2 m (mainly sand and some clay returned).
- Another attempt was made to run-in the casing, but unsuccessfully.
- TH60 rig also arrived on site this afternoon and will be swapped with the existing rig in the next few days.
- Meanwhile, Maïwenn and I will carry out a slug test tomorrow morning.

Currently, Mark will be back on-site for logging on 24 May and he will provide a geology update then.

From Baylis Bros:

From 13 May (tomorrow) until 21 May, Baylis will be:

- Demobilising the 22W.
- Mobilising the TH60
- Running and wielding 150 mm casing (to be telescoped).
- Spudding in the first length of 150 mm casing.
- GNS to decide whether they want to perform a slug test at the current depth by COB 13 May.
- HBRC will look to contact landowner on 13 May (tomorrow) to discuss site visit for 18 May (Tuesday). (Note: this refers to well 3.)
    - HBRC will look to change the drilling location as per discussions with Zara.

  - Baylis will discuss Health and Safety requirements with farmer.
  - GNS to discuss with HBRC their availability for TEM.
  - Potentially look to set up the 22W onsite during this week.

GNS geologists will not be needed until Monday May 24. Sites 1 and 3 maybe operational, so GNS to determine whether one or two geologists are needed.

From 24 May (Monday) onward:

- Drilling at Site 1 (Ongaonga-Waipukurau Road) will continue with the TH60.
- Rotary drilling will be used to penetrate through the cemented sands and then back to cable-tool (GNS to decide when).
- GNS will be looking for a zone between 90 and 110 m that can produce ~30 L/s for performing a pumping test.
- Drilling will potentially continue or start at Site 3 (Ratanui Farm).
- Should productive zones be encountered at both Site 1 and Site 3, Site 3 will go on standby until the pumping test at Site 1 is completed.

A2.37 20 May 2021

Summary

Well at 92 m.

Details

New rig now on-site. Casing down to 90 m with 2 m of open hole beyond. This is in the usual poorly sorted gravels, but these seem to have a bit less sand based on a quick look yesterday. Screen is in the gravels. These gravels underly a muddy fine sandstone that was probably an aquiclude. There is a metre or so of sand above the gravels. Stephen Baylis (driller) messaged the following results from the preliminary pump test:

- 8 L/s (assuming his ‘lps’ = litres per second) at 26 m.
- 10 L/s at 31 m.
- 11.5 L/s at 38 m drawdown and water is clear (not brown as it has been previously).

Additional Comments

None.

A2.38 26 May 2021

Summary

Well now at 95 m.

Details

Casing cleaned out after yesterday and a new length driven in. Wash-drilled (air-drilled) samples collected to total depth in the afternoon. Cold and windy again, but not as wet as Monday and Tuesday.

Additional Comments

1. Noted that the samples in well 1 grain size does not go above small to medium pebble size. This is probably due to damage to larger particles by the rotary bit. There are common broken fragments. The distribution of grain sizes below small pebble outwardly resemble those in gravels obtained by cable tool, which implies that the overall grain size may be similar to those obtained in gravel to about 83.4 m. However, this cannot be verified.
2. The water colour from the first metre of drilling was a bluish grey, then changed to a pale grey below. Not sure exactly what this means, but it could be a function of the grains being ground up by the bit. It was noted there where common pale-grey argillite grains, which are softer than the usual greywacke. Sadly, speculation only at this stage.
3. An impermeable layer is thought to occur at about 110 m, so at this stage it has been decided that on-site logging should continue to that depth (news to some but not all). At the projected rate of penetration, this means we will potentially be logging for the next two weeks. That will mean Lauren next week and Giovanni the week after (again – at this stage).
4. Lauren to pay another rig site visit this Friday.
5. In other news, most well 2 samples re-tested for resistivity – only six left to do.

A2.39 27 May 2021

Summary

Well now at 97 m.

Details

A 2 m length of casing was driven in and then drilled to 97 m. Initially gravels were as previously described but with a higher abundance of coarser material (slightly counter-intuitively perhaps). At 96.3 m, the well intersected a silt-vfU sand that was compacted. This sand was about 0.5 m thick. Once the bit had broken through into gravels similar to above the sand, the volume of water coming up the well significantly increased. Stevie pulled the drill string out of the well to see if the water level would re-equilibrate. The water level steadily rose up the well (approximately 10 cm in 10 seconds). By the end of the day, the well was flowing (estimated at approximately 1 L/s), containing abundant gas bubbles.

Additional Comments

The decision for Friday (28 May) is to either drill on or do a slug test. A pump test has been discounted at this stage.

A2.40 28 May 2021

Summary

Well now still at 97 m. Slug test completed.

Details

No further drilling, as the well was set up for a slug test. An additional stand of casing was attached to the top of the well to account for the increase in water level so the slug test could be undertaken. Good slug test results were acquired.

Additional Comments

The well was still flowing steadily in the morning, but there were no visible gas bubbles. Lauren Coup was on site to see how slug tests are done and also be re-acquainted with our lithological logging procedures. Lauren on-site for the week commencing 31 May.

A2.41 31 May 2021

Summary

Well is at 98 m. Casing is at 96 m.

Details

Lithology remained the same as at 97 m with gravels, cobbles and sand encountered. Another stand of casing was added in the afternoon.

Additional Comments

The well continued to flow steadily. The tape on the casing placed on Friday did not hold, so a groundwater level was unable to be measured. No gas bubbles were visible.

A2.42 1 June 2021

From Baylis Bros Ltd

We are probably coming to the end of the line as far as the 200 mm casing goes (98 m depth). If we are going deeper, we need to consider telescoping.

A2.43 16 June 2021

Summary

Yesterday (Tuesday 15th) casing was extended to 104 m. The drilled well remained at 101.5 m. Well 1 is now at 109 m with casing to 104 m. The well is steadily flowing at approximately 1–1.5 L/s.

Details

At approximately 102 m clay, silt, small shell fragments and rounded mudstone gravels were encountered. At 107 m, fine sands, silts and shell fragments with some siltstone gravels were present. At 108.5 m, running sands were encountered. A large volume of sand was expelled from the well with minor pumice gravels.

Additional Comments

A slug test has been scheduled for Friday.

A2.44 17 June 2021

Summary

Well is drilled to 110.5 m and is cased to 112 m.

Details

A large volume of sand has been removed from the well and the sand layer has continued; it has become slightly coarser-grained.

Additional Comments

Slug testing will be completed on Friday.

A2.45 18 June 2021

Slug testing performed. End of continuous on-site lithology logging.

A2.46 30 June 2021

From Mark Lawrence

Just had a call from Baylis (Hugh and Russell). Well 1 is now at 148 m depth (cased to 138 m). They have just passed out of a clay and are back into the running sands and it is artesian. They are putting in a 3 m casing string now. It sounds like they are making good progress and if the well is going to 170 m, they reckon they may get there perhaps by the end of next week. They also stated that, with current progress, the well 1 crew should be able to move to well 3 once well 1 has finished, which means not as much of a delay there as previously suggested. If another slug/pump testing is to be done on well 1, they would like to know as soon as possible – by the end of the day if we can. I also reminded them about the RDCL Ltd logging that needs to be done.

Further to this, Luke (driller) just called and said the sands were flowing at about 3 m/s. In addition, he said that well 1 was matching the lithology in a nearby well that indicated some more sand, but more clay under that to at least 170 m. Not sure if that changes the pump test decision or not but I thought you might like to know. I will be on-site tomorrow and can get back to you again then.

A2.47 6 July 2021

From Mark Lawrence

On Thursday last week, I travelled up to the rig site to collect samples obtained by the drillers since we stopped continuous on-site logging. The samples are all sands of one sort or another – I have yet to do the descriptions but have noted shell material in some that suggests we are into marine sediments. Thursday and Friday last week, there was no drilling progress as they were installing casing down to 149.8 m. On Monday, they ran (drill pipe) back in hole and drilled to 156 m. They are now in more pumiceous sand that also contains shell material (not sure if it is in the same or separate samples). Anyway, it sounds like the lithologies are the same as those I picked up last week.

The driller (Stevie) said that if it stays in this material, it looks like they will get to 170 m by about Friday next week. I shall now contact RDCL Ltd and let them know so they can start liaising with Baylis directly next week. Based on early communication with Hugh and Russell, and Stevie's comments this morning, there is a possibility of well 3 starting the week of 19 July if they shift their well 1 crew straight across. We will probably have a better idea on that next week.

Summary

Total depth still at 156 m.

Details

No further drilling on Tuesday (6 July) as they were casing down to Monday's drill depth of 156 m. The also ran drill pipe back in hole ready to drill ahead this morning (Wednesday).

Additional Comments

They hope to progress a further 6 m.

A2.48 7 July 2021

Summary

Total depth now at 162 m.

Details

They drilled to 162 m on Wednesday, but there is still some material in the casing from about 160 m. They appear to still be in the sands.

Additional Comments

After doing a few repairs on the cable, they will be drilling ahead today (Thursday). If they do another 6 m today, then they will be close to the 170 m mark (earlier than thought at the beginning of the week), so a decision or two will need to be made. My guess is that tomorrow they will be putting in casing. I have already contacted RDCL Ltd, but if we do stop at 170 m then we will need to get RDCL on-site early next week.

A2.49 9 July 2021

From Baylis Bros Ltd

Quick update on where we are at re: Well 1 Ongaonga-Waipukurau Road – cased to around 160 m, drilled out to 165 m, running sands. The sand issue is slowing progress, casing is also starting to tighten up. Appreciate we are within 5–10 m of proposed total depth, but we may have to consider a different approach along the lines of digging and lining a mud pit for recirculating. This would have cost implications, which we can price but may be worthwhile getting everyone's thoughts first.

Summary

Total depth now at 168 m.

Details

They managed a little under 3 m today and are still in the running sands. Drill rods were run back in hole ready to drill on.

Additional Comments

Stevie said they will not be on site on Monday – they have to be elsewhere for that day (not sure why) but will be back on Tuesday. This means that wireline logging could occur Thursday or Friday if we terminate at 170 m. If we got to 180 m, it will most likely be the following week. Next update will be on Tuesday.

A2.50 12 July 2021

Summary

Final total depth at 168 m.

Details

The well remains within the running sands formation. The decision this morning was made to stop drilling at the current total depth. A slug test will be undertaken, and a water sample taken either today or tomorrow prior to wireline logs being run by RDCL Ltd.

Additional Comments

The decision to terminate was based on the fact that nearby wells have the running sands to considerable depth below current well 1 total depth. The value of additional information gained from further drilling is unlikely to match the additional budget outlay. Bring on well 3 …

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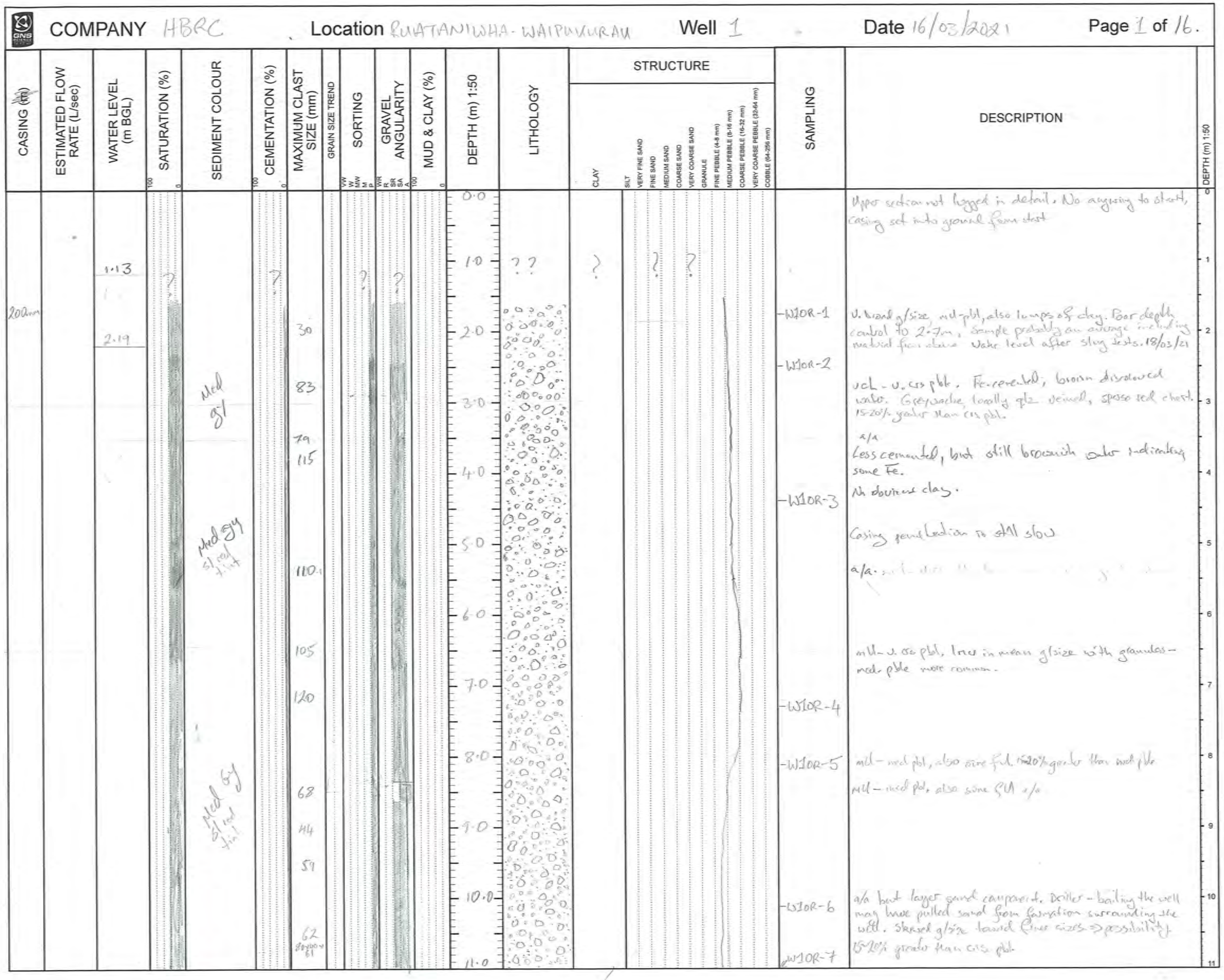
APPENDIX 3 LITHOLOGICAL LOGS

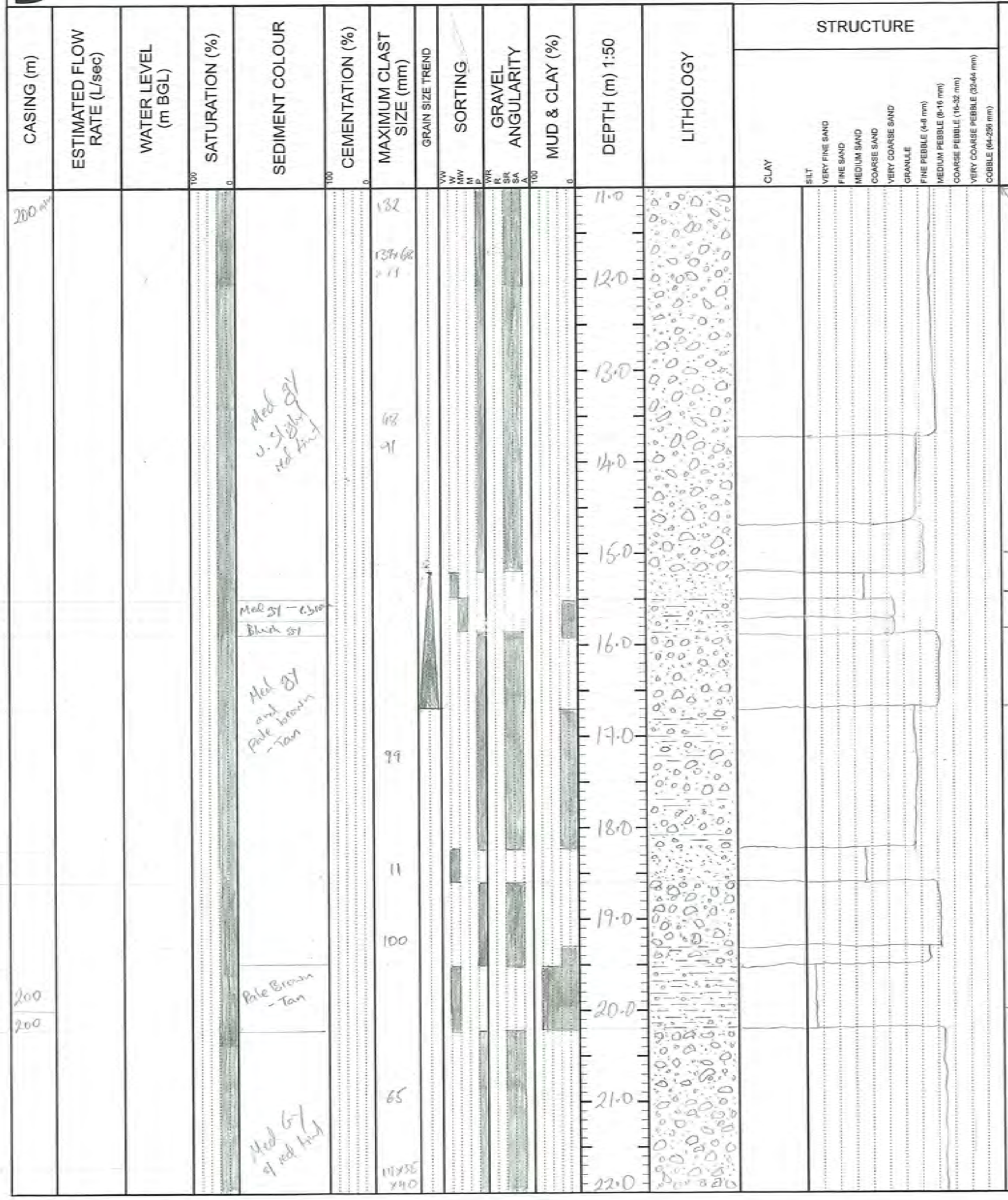


COMPANY HBRC Location RUATANIWHA-WAIPUKURAU Well 1 Date 16/03/2021 Page 1 of 16.

DEPTH (m) 1:50	CASING (m)	WATER LEVEL (m BGL)	SEDIMENT COLOUR	MAXIMUM CLAST SIZE (mm)	LITHOLOGY	SAMPLING	DESCRIPTION
0.0							Upper section not logged in detail. No augering to start, casing set into ground from start
1.0		1.13	?		? ?		
	200mm	2.19				W1OR-1	V. broad g/size, md-pbl, also lumps of clay. Poor depth control to 2.7m, sample probably an average including material from above. Water level after slug tests. 18/03/21
2.0				30		W1OR-2	
3.0			Med gy	83			vcL - v. crs pbl. Fe-cemented, brown discoloured water. Greywacke, locally qtz veined, sparse red chert. 15-20% greater than crs pbl.
				79 115			a/a Less cemented, but still brownish water indicating some Fe.
4.0						W1OR-3	No obvious clay.
5.0			Med gy sl red tint	110			Casing penetration is still slow
							a/a. [illegible]
6.0				105			md - v. crs pbl, lower in mean g/size with granules - med. pble more common.
7.0				120		W1OR-4	
8.0						W1OR-5	md - med pbl, also rare fcl. 15-20% greater than med pble
			Med gy sl red tint	68			md - med pbl, also some fcl a/a
9.0				44 59			
10.0				62 61		W1OR-6	a/a but larger sand component. Driller - bailing the well may have pulled sand from formation surrounding the well. Skewed g/size toward finer sizes => possibility. 15-20% greater than crs pbl.
11.0						W1OR-7	

Luke + Joe

COMPANY HBRC **Location** RUATANIWHA – WAIPUKURAU **Well** 1 **Date** 18/05/2021 **Page** 2 **of** 16.



SAMPLING

- W1OR-7
- W1OR-8
- W1OR-9
- W1OR-10
- W1OR-11
- W1OR-12

DESCRIPTION

DEPTH (m) 1:50

0 — W1OR-7: 6m casing inserted, sel level came back up to 10.2m. 0.8m difference. First bails contained more sand. 15-20% greater the crs pbl.

1 — Gravels becoming sandier but same grainsize range.

2 — Lithological contacts inferred.

vcL – m pble g/size range

3 — Small, scattered clay-silt lumps

4 — W1OR-8: vcL-crs pbl.

Inferred sharp contact

W1OR-9: mL-cL. Sparse small pbls. | Water coming up with seds is tan colour.

nL – med pbl, with moderately common, buff-tan coloured clay

5 — W1OR-10: lumps ← a/a but clay bluish grey ← | water coming up with bailer is greyish colour

mU – crs pbl. – Not as red tinted a/a sand layers.

W1OR-11: New casing length – Depth moved up hole to 16.0m

6 — cL – med pbl. Lumps of brown to tan coloured clay. Some bails contain the clay others do not. Possibly layers within the gravels. Clays are very silty to vF sand. | Water in bailer back to brown/tan

7 — fU-cL, sparse granules & fine pbls. Layer or washed in sands?

8 — mU – v.crs pble. 15-20% greater size than med pbl.

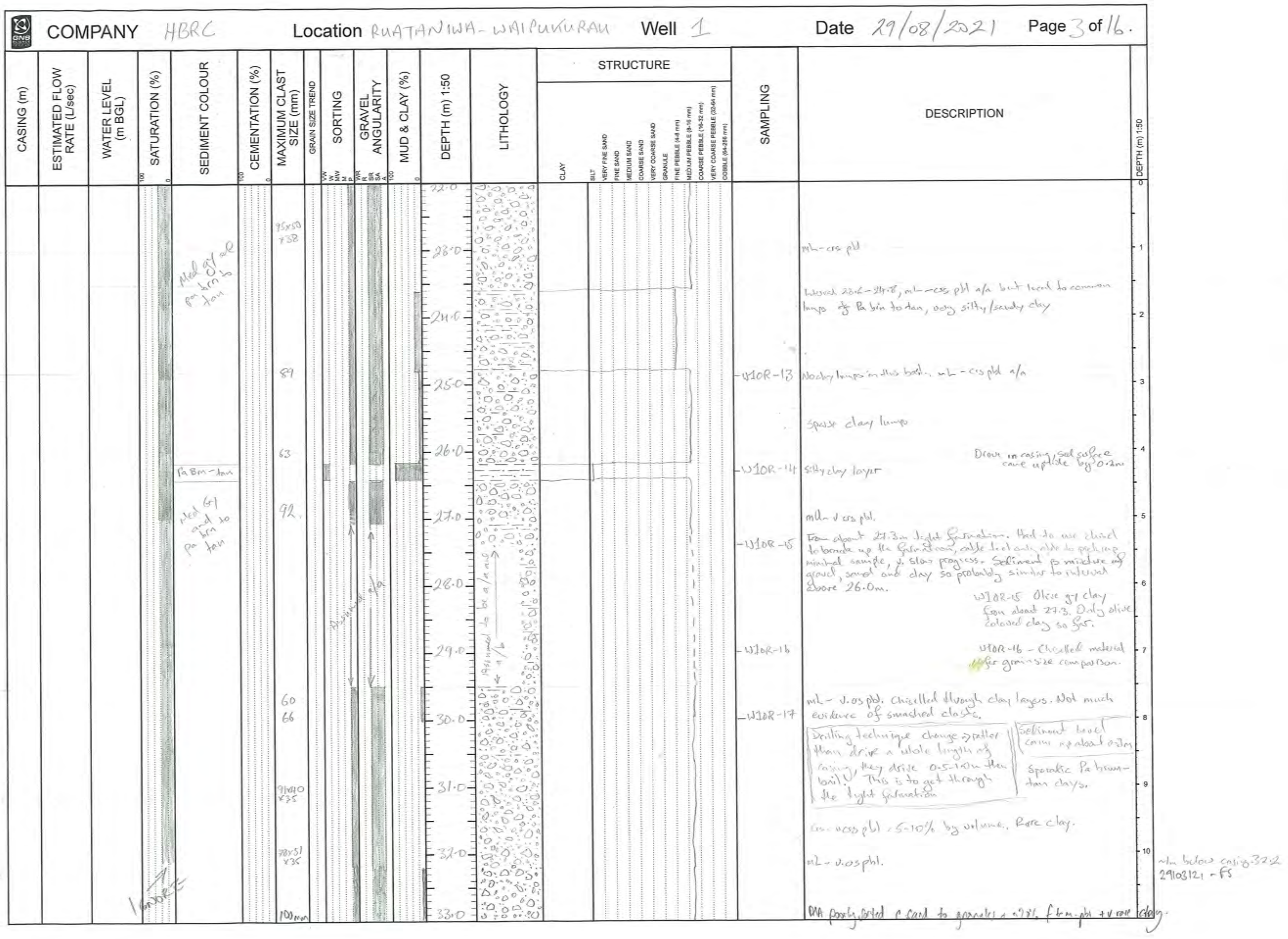
Basically a/a but with lumps of tan-brown v.silty clay.

9 — W1OR-12: About 10-50% crs material up to med pbl. Possibly thin pebble layers. Depth with new casing is OK this time.

10 — mU-crs pbl. About 10-15% coarser than crs pbl.

Tight gravels (Driller)

11



COMPANY HBRC Location RUATANIWA-WAIPUKURAU Well 1 Date 29/08/2021 Page 3 of 16.

W1OR-13
W1OR-14
W1OR-15
W1OR-16
W1OR-17

mL-crs pbl

Interval 23.6-24.8, mL-crs pbl a/a but local to common lumps of Pa brn to tan, very silty/sandy clay

No clay lumps in this batch. mL-crs pbl a/a

Sparse clay lumps

Drove in casing, sed surface came up inside by 0.2m

Silty clay layer

mL-v crs pbl.

From about 27.3m tight formation. Had to use chisel to break up the formation, cable tool only able to pick up minimal sample, v. slow progress. Sediment is mixture of gravel, sand and clay so probably similar to interval above 26.0m.

W1OR-15 Olive gy clay from about 27.3. Only olive coloured clay so far.

W1OR-16 - Chiselled material for grain size comparison.

mL-v.crs pbl. Chiselled through clay layers. Not much evidence of smashed clasts.

Drilling technique change → rather than drive a whole length of casing, they drive 0.5-1.0m then bail! This is to get through the tight formation

Sediment level came up about 0.3m

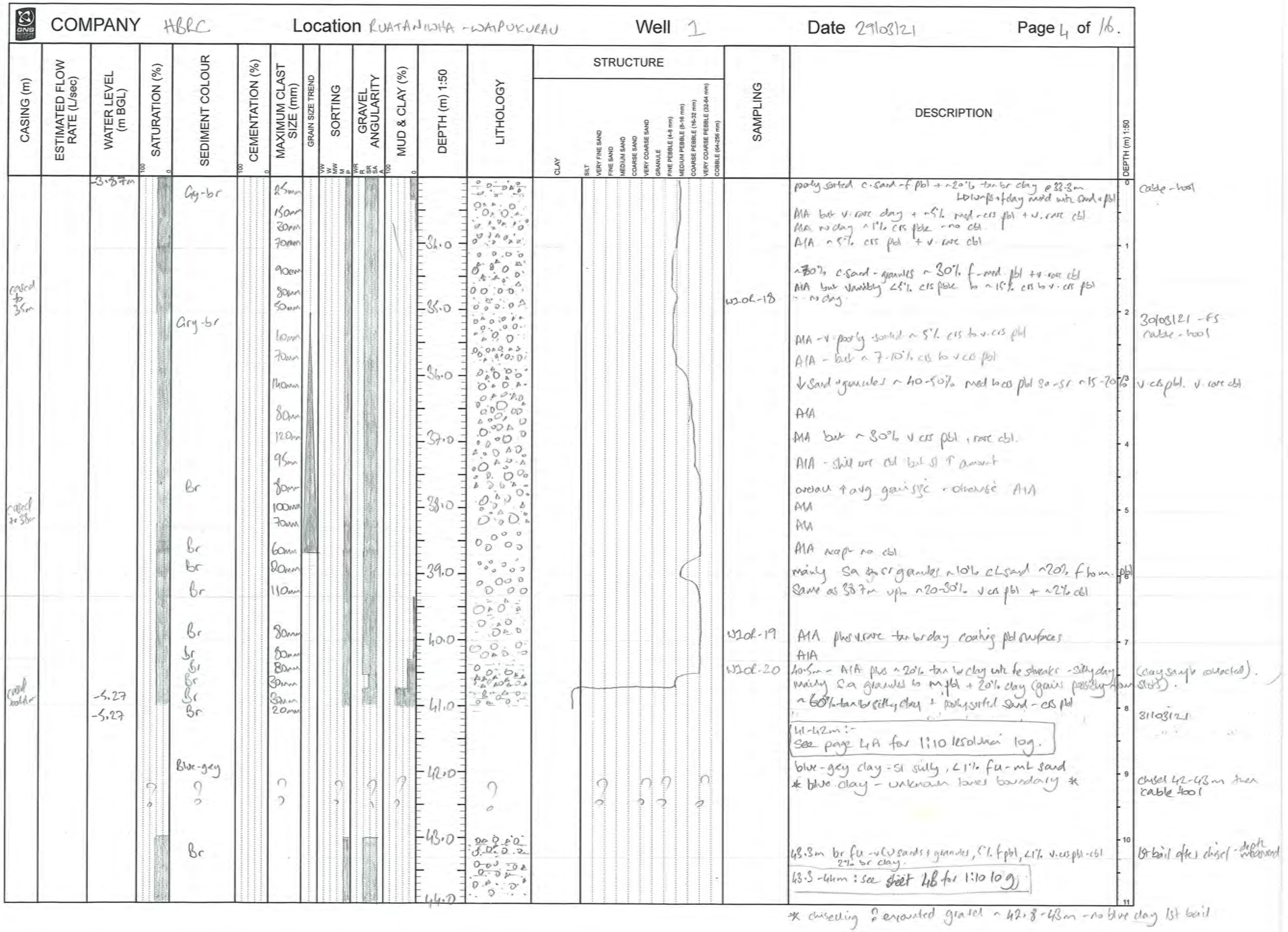
Sporadic Pa brown-tan clays.

Crs-vcrs pbl ~5-10% by volume. Rare clay.

mL-v.crs pbl.

MA poorly sorted c sand to granules ~?% f to m pbl + v rare clay.

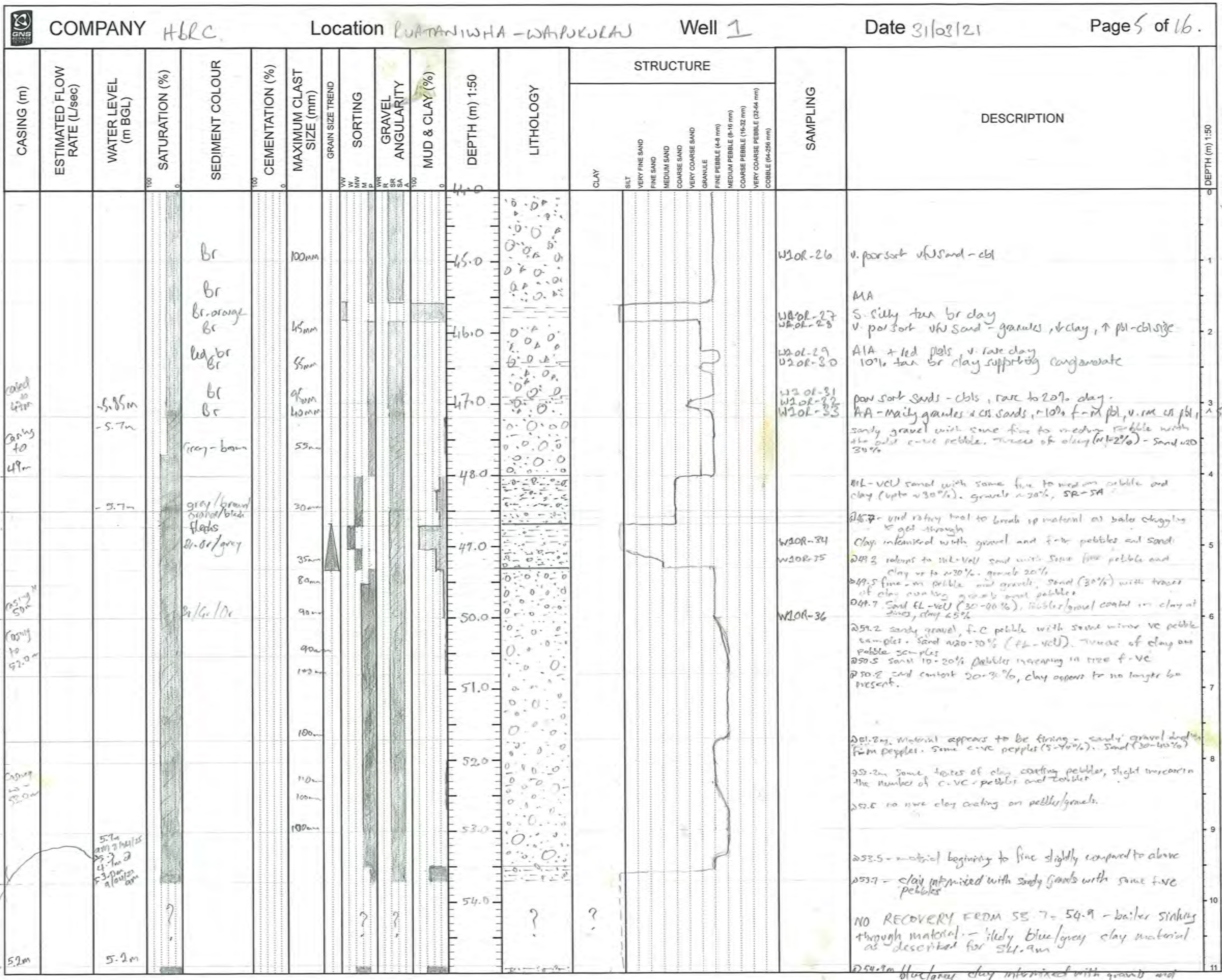
~1m below casing 32.2
29/08/21 - FS



COMPANY HBRC Location RUATANIWHA - WAIPUKURAU Well 1 Date 29/08/21 Page 4 of 16.

CASING (m)	WATER LEVEL (m BGL)	SEDIMENT COLOUR	MAXIMUM CLAST SIZE (mm)	DEPTH (m) 1:50	SAMPLING	DESCRIPTION	
	-3.87m	Gy-br	25mm			poorly sorted c.sand - f.pbl + ~20% tan br clay @ 33.3m └ lumps of clay mixed with sand & pbl	cable - tool
			150mm			A/A but v. rare clay + ~5% med - crs pbl + v. rare cbl	
			30mm			A/A no clay ~1% crs pble - no cbl	
			70mm	34.0		A/A ~5% crs pbl + v. rare cbl	
			90mm			~80% c.sand - granules ~30% f-med pbl + v. rare cbl	
cased to 35m			80mm		W1OL-18	A/A but variably <5% crs pble to ~15% crs to v. crs pbl -- no clay	
			50mm	35.0			30/08/21 - FS cable - tool
		Gry-br	60mm			A/A - v. poorly sorted ~5% crs to v. crs pbl	
			70mm			A/A - but ~7-10% crs to v crs pbl	
			140mm	36.0		↓ sand & granules ~40-50% med to crs pbl sa-sr ~15-20%	v. crs pbl. v. rare cbl
			80mm			A/A	
			120mm	37.0		A/A but ~30% v crs pbl, rare cbl.	
			95mm			A/A - still rare cbl but sl ↑ amount	
		Br	80mm			overall ↑ avg grain size - otherwise A/A	
cased to 38m			100mm	38.0		A/A	
			70mm			A/A	
		Br	60mm			A/A except no cbl	
		br	80mm	39.0		mainly sa to sr granules ~10% c.sand ~20% f to m. pbl	
		Br	110mm			Same as 38.7m up ~20-30% v crs pbl + ~2% cbl	
		Br	80mm	40.0	W1OL-19	A/A plus v. rare tan br clay coating pbl surfaces	
		br	80mm			A/A	
		Br	80mm		W1OL-20	40.5m - A/A plus ~20% tan br clay with fe streaks - silty clay	(clay sample collected).
		Br	30mm			mainly sa granules to m pbl + 20% clay (grains possibly from slots).	
cased holder	-5.27	Br	30mm			~60% tan br silty clay + poorly sorted sand - crs pbl	
	-5.27	Br	20mm	41.0			31/08/21
						41-42m :- See page 4A for 1:10 resolution log.	
		Blue-grey		42.0		blue-grey clay - sl silty, <1% fu-mL sand	chisel 42-43m then cable tool
		?	?			* blue clay - unknown lower boundary *	
				43.0			
		Br				43.3m br fu-vcU sands & granules, 5% f pbl, <1% v.crs pbl-cbl 2% br clay.	1st bail after chisel - depth measured
						43.3-44m : see sheet 4B for 1:10 log	
				44.0			

* chiselling ? encountered gravel ~42.8-43m - no blue clay 1st bail



COMPANY HBRC. Location RUATANIWHA – WAIPUKURAU Well 1 Date 31/03/21 Page 5 of 16.

DEPTH (m) 1:50	CASING (m)	WATER LEVEL (m BGL)	SEDIMENT COLOUR	MAXIMUM CLAST SIZE (mm)	SAMPLING	DESCRIPTION
44.0						
45.0			Br	100mm	W1OR-26	v. poor sort vfU sand – cbl
			Br			MA
			Br. orange Br	45mm	W1OR-27 W1OR-28	S. silty tan br clay v. por sort vfU sand – granules, ↓clay, ↑ pbl-cbl size
46.0			led br Br	55mm	W1OR-29 W1OR-30	A/A + led pbls, v. rare clay 10% tan br clay supporting conglomerate
47.0	cased to 47m	-5.85m	br Br	95mm 40mm	W1OR-31 W1OR-32 W1OR-33	poor sort sands – cbls, rare to 20% clay. AA – mainly granules & crs sands, ~10% f–m pbl, v. rare crs pbl, ^ 5% clay.
	Casing to 49m	-5.7m	Grey – brown	55mm		sandy gravel with some fine to medium pebble with the odd c–vc pebble. Traces of clay (~1–2%) – Sand ~20 30%
48.0						fL – vcU sand with some fine to medium pebble and clay (upto ~30%). gravels ~20%, SR – SA
		-5.7m	grey/brown/orange/black flecks	30mm		@48.7 – used rotary tool to break up material as bailer struggling to get through
49.0			Br-Or/grey		W1OR-34	Clay intermixed with gravel and f–m pebbles and sand
				35mm	W1OR-35	@49.3 returns to mL–vcU sand with some fine pebble and clay up to ~30%. gravels 20%
				80mm		@49.5 fine–m pebble and gravels, sand (30%) with traces of clay coating gravels and pebbles
	casing to 50m		Br/Gr/Or	90mm	W1OR-36	@49.7 Sand fL–vcU (30–40%), pebbles/gravel coated in clay at times, clay <5%
50.0						@50.2 sandy gravel, f–c pebble with some minor vc pebble samples. Sand ~20–30% (fL–vcU). Traces of clay on pebble samples
	Casing to 52.0m			90mm		@50.5 Sand 10–20% pebbles increasing in size f–vc
				140mm		@50.8 sand content 20–30%, clay appears to no longer be present.
51.0						
				100mm		@51.8m. Material appears to be fining – sandy gravel and f–m pebbles. Some c–vc pebbles (5–40%). Sand (30–40%)
52.0	Casing to 52.0m			110mm		@52.2m Some traces of clay coating pebbles, slight increase in the number of c–vc pebbles and cobbles
				100mm		@52.6 no more clay coating on pebbles/gravels.
53.0				100mm		
		5.7m am 8/04/21 5.3 4.7m @ 53.0m 9/04/21 am				@53.5 – material beginning to fine slightly compared to above
						@53.7 – clay intermixed with sandy gravels with some f–vc pebbles
54.0			?			NO RECOVERY FROM 53.7 – 54.9 – bailer sinking through material. – likely blue/grey clay material as described for 54.9m
	5.2m	5.2m				@54.9m blue/grey clay intermixed with gravels and f–m pebbles

Material pushed up to 49.5m

Water level 1:45pm after airlift test 08/04/21

cable tool.

See sheets 4b + 4C for detailed 1:10 scale log

@47.5 – some discrepancy with depth here

NOTE approx 1m of material pushed up casing to ~46.0m

@48.5 – driller note – bumping bailer up and down may be bringing in sand and clay so totally depth of clayey sand layer may not be very accurate.

Airlift test @53.0m

Slug test @ 53.0m

@53.7 – Rotary tool to break up clay layer

slug test @ 54.9m

check to sample taken

COMPANY HBRC **Location** RUATANIWHA - WAIPUKURAU **Well** 1 **Date** 9/04/21 **Page** 6 **of** 16.

Casing (m): 58.0m; 61.0m

Water level (m BGL):
8.85m @ 9:00am 20/04/21
5.60 @ 10:27 21/4/21
5.70m 22/4/21
6.40m @ 8:15am 23/4/21
- 6.30 09:15 24/4/21
- 6.20 0845 [illegible]

Sediment colour: Med gy; Grey/Brown; Grey/Brown; Grey/Brown; Reddish Brown/Grey; Grey/Brown; Reddish brown/Grey; Grey/Brown; Greyish brn; Brownish grey

Maximum clast size (mm): 2mm; 15-20mm; 25mm; 130mm; 80mm; 70mm; 85mm; 60mm; 25mm; 90mm; 56mm; 75mm; 21; 7; 26; 39; 97; 69; 109

Sampling: W1OR - 37; W1OR - 38; W1OR - 39; W1OR - 40; W1OR - 41; - W1OR - 42

Description:

a/a - chiselling thru' blue-gy clay. Silty

mL - vcU. Either sandy unit or mod. fied by chiselling the Tm. Rare granules - m pbl.

mL - vcL, sparse granules - f/m pbl. Cable tool & chiselling a/a. Sparse small brown clay pieces. 2m casing string added.

mL - vcU. Likely sandy unit or material modified by chiselling minor to trace of granules - m. pbl. Trace of clay (<5%)

@57.0m mL - granules. gravelly sand, material possibly modified by chiselling. some f-m pbl, Trace clay (<5%)

@57.6m mL - vcU. Likely sandy unit or material modified by chiselling minor to trace of granules - m. pbl -
@57.8m Traces of clay

@58.2m mL - m.pbl, granular sand with some f-m pebbles. traces of clay
@58.3 becomes mL - vcL, sand unit. Rare f-m pebbles traces of blue & brown clay
@58.5m f-VC pebbles, some ml - vcl sand (10-20%), traces of clay coating on pebbles, minor Cobbles
@59.1 mL - granules, sand gravel layer, some f-vc pbl Trace clay (<5%)
@59.3 minor clay coating pebbles.
@59.4 sandy f-c pbl, traces of clay coating pebbles clay increasing with depth
@59.7m sandy clay with minor granules - m. pbl, becoming sandier with depth.
@59.8 fu-vcL, sand layer with some granules - c. pbl. Rare vc pbl/cobbles. Traces of clay (brown)
@60.0m sandy granules layer. sand mL-vcU, some f-c pebbles. and clay (10-30%)

@60.8m mL-vcL, sand layer with some brown clay (~10%-20%) rare f-c pebbles
@61.2 becomes fu-vcL sand, rare pebbles, typically brown/grey in colour but the odd red pebble. trace clay

61.6m f-vc pebbles, some sand (20-30%). Rare Cobbles. material slightly broken due to chisel tool.

62.0m Sandy Gravel, sand (mu-vcU) - 20-30%. minor f-c pbl. Trace brown clay
62.1 becomes mL-vcU sand layer, minor f-m pebbles
62.2 - f-c pebbles, some sand (20-30%). Rare vc-cobbles, Trace of brown clay
@62.4m mL-vcU Sand layer, minor f-m pble, Trace clay

a/a, minimal clay. Pbls comprise 5-10% No clay

a/a but increase in pbl abundance ≈ 15-20%

a/a. Granules ≥ pbls ≈ 15-20%

mL - crs pbl. 10-20% are larger than crs pbl. Gravels are angular - possibly broken by drilling process. Possible thin clay stringers.

Broken large clasts - common in one bailed sample.

mL - crs pbl a/a

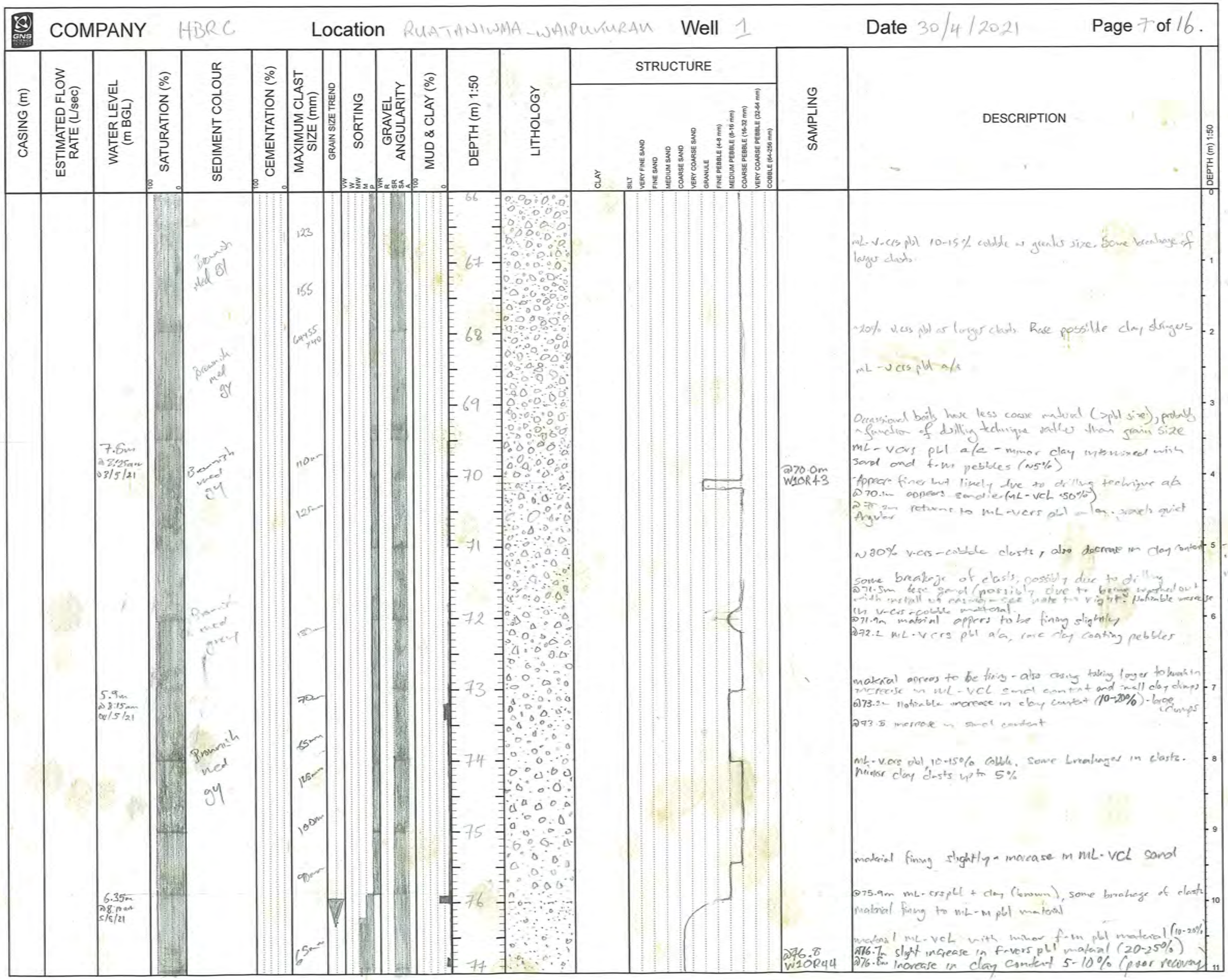
- 56.3m chiselling through material as bailer struggling to retrieve material.

Casing knocked from 57-56 material pushed up casing to ~56.5m

11am 57.7
Filter & pump replace pipe blocked - replaced all working now

- chiselled from 60.2 - 60.9 no recovery from this interval

COMPANY HBRC Location RUATANIWHA - WAIPUKURAU Well 1 Date 30/4/2021 Page 7 of 16.



Water level:
7.6m @ 8:25am 03/5/21
5.9m @ 8:15am 04/5/21
6.35m @ 8 pm 5/5/21

Sediment colour:
Brownish med gy
Brownish med gy
Brownish med gy
Brownish med grey
Brownish med gy

Maximum clast size:
123
155
64455 740
110mm
125mm
150mm
70mm
65mm
125mm
100mm
90mm
65mm

Sampling:
@70.0m W10R43
@76.8 W10R44

Description:

mL-v.crs pbl 10-15% cobble or granules size. Some breakage of larger clasts.

~20% v.crs pbl or larger clasts. Rare possible clay stringers

mL-v crs pbl a/a

Occasional bags have less coarse material (>pbl size), probably ~function of drilling technique rather than grain size
mL-vcrs pbl a/a - minor clay intermixed with sand and f-m pebbles (~5%)
-Appears finer but likely due to drilling technique a/a
@70.1m appears sandier (mL-vcL ~50%)
@70.3m returns to mL-vcrs pbl a/a, gravels quiet Angular

~30% v-crs-cobble clasts, also decrease in clay content

some breakage of clasts, possibly due to drilling
@71.5m less sand (possibly due to being washed out with install of casing - see note to right. Notable increase in v-crs-cobble material.
@71.9m material appears to be fining slightly
@72.2 mL-v crs pbl a/a, rare clay coating pebbles

material appears to be fining - also casing taking longer to knock in increase in mL-vcL sand content and small clay clumps
@73.2m notable increase in clay content (10-20%) - large clumps
@73.5 increase in sand content

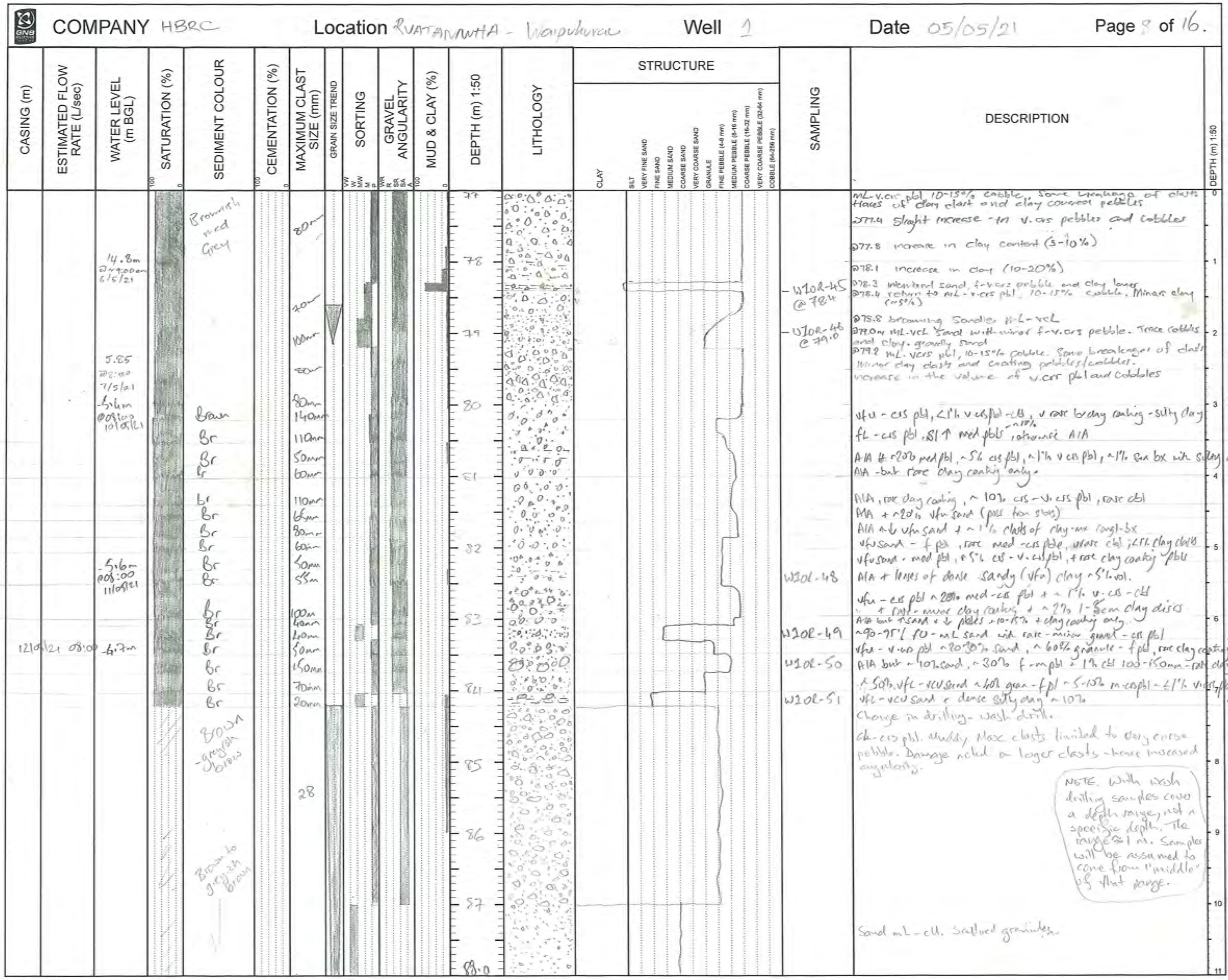
mL-v.crs pbl, 10-15% cobble. Some breakages in clasts. Minor clay clasts up to 5%

material fining slightly - increase in mL-vcL sand

@75.9m mL-crs pbl + clay (brown), some breakage of clasts
material fining to mL-m pbl material

material mL-vcL with minor f-m pbl material (10-20%)
@76.7m slight increase in f-vcrs pbl material (20-25%)
@76.8m increase in clay content 5-10% (poor recovery)

-Note casing knocked in from 71-72m material pushed up casing quiet sandy but possibly due to fine material being more easily flushed up the casing



COMPANY HBRC Location RUATANIWHA - Waipukurau Well 1 Date 05/05/21 Page 8 of 16.

CASING (m) | ESTIMATED FLOW RATE (L/sec) | WATER LEVEL (m BGL) | SATURATION (%) | 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

Water level:
14.8m @~9:00am 6/5/21
5.85 @8:00 7/5/21
-5.6m @08:00 10/05/21
-5.6m @08:00 11/05/21
12/05/21 08:00 5.7m

Sediment colour: Brownish and Grey; Brown; Br; Br; Br; br; Br; Br; Br; Br; Br; Br; Br; Br; Br; Br; Br; Br; Brown - greyish brow; Brown to greyish brown

Maximum clast size: 80mm; 70mm; 100mm; 50mm; 80mm; 140mm; 110mm; 50mm; 60mm; 110mm; 65mm; 80mm; 60mm; 50mm; 55mm; 100m; 40mm; 40mm; 50mm; 150mm; 70mm; 20mm; 28

Sampling:
- W1OR-45 @ 78.4
- W1OR-46 @ 79.0
W1OL-48
W1OR-49
W1OR-50
W1OR-51

Description:

mL-v.crs pbl, 10-15% cobble, some breakage of clasts traces of clay clast and clay covered pebbles
@77.4 slight increase in v.crs pebbles and cobbles
@77.8 increase in clay content (5-10%)
@78.1 increase in clay (10-20%)
@78.3 intermixed sand, f-v.crs pebble and clay layer
@78.4 return to mL-v.crs pbl, 10-15% cobble. Minor clay (~5%)
@78.8 becoming sandier mL-vcL
@79.0m mL-vcL sand with minor f-v.crs pebble. Trace cobbles and clay. gravelly sand
@79.2 mL-vcrs pbl, 10-15% cobble. Some breakages of clasts. Minor clay clasts and coating pebbles/cobbles.
increase in the volume of v.crs pbl and cobbles

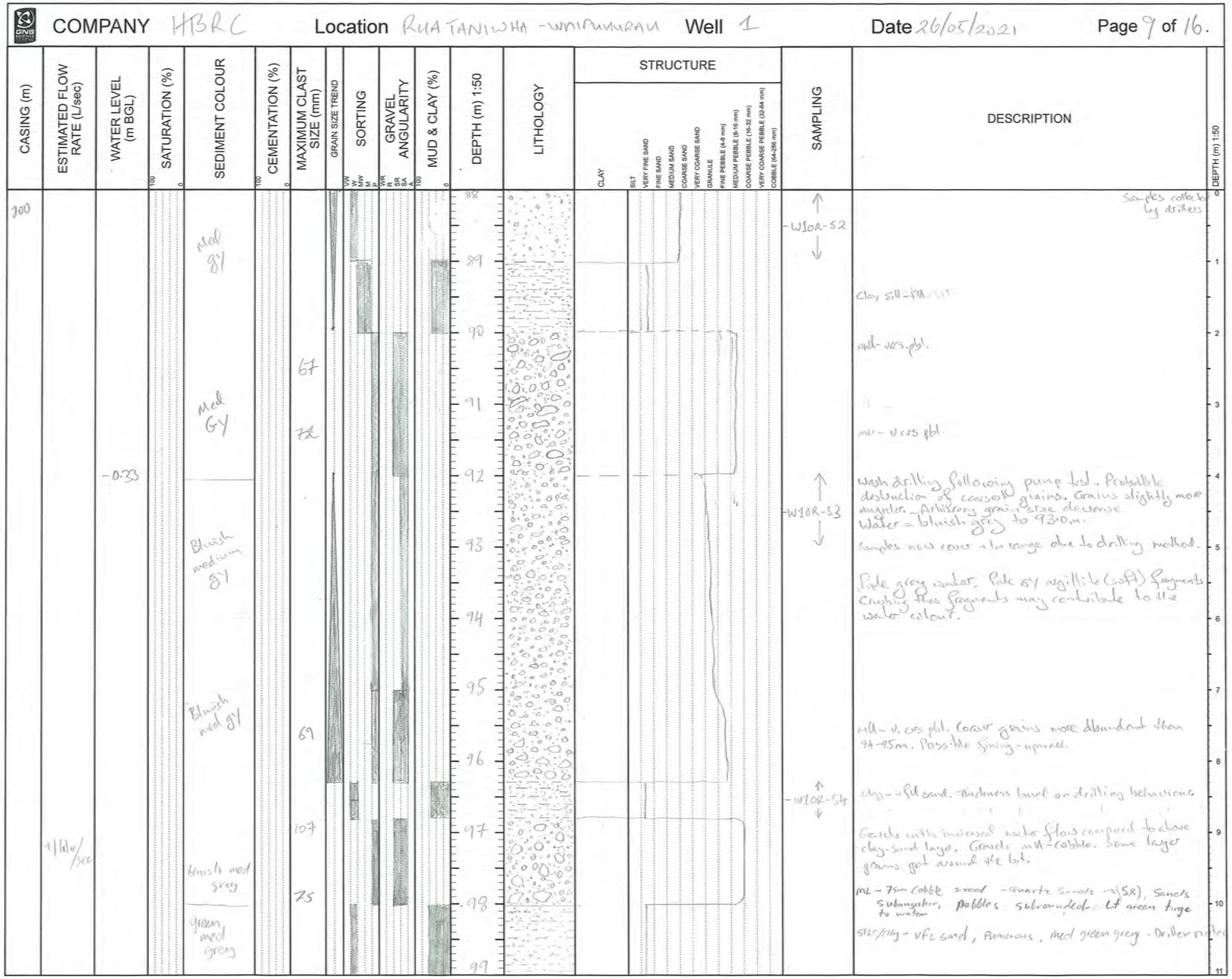
vfu - crs pbl, <1% v crs pbl - cbl, v rare br clay coating - silty clay
fL - crs pbl, sl ↑ med pbls ~10%, otherwise A/A
A/A ~20% med pbl, ~5% crs pbl, ~1% v crs pbl, ~1% sm bx with silty clay matrix
A/A - but rare clay coating only.

A/A, rare clay coating, ~10% crs - v. crs pbl, rare cbl
A/A + ~20% vfu sand (poss from slurry)
A/A ~↓ vfu sand + ~1% clasts of clay-mx congl-bx
vfu sand - f pbl, rare med - crs pble, v rare cbl; <1% clay clasts
vfu sand - med pbl, ~5% crs - v. crs pbl, + rare clay coating pbls
A/A + lenses of dense sandy (vfu) clay ~5% vol.
vfu - crs pbl ~20% med - crs pbl + ~1% v. crs - cbl + rare - minor clay coating + ~2% 1-3cm clay discs
A/A but ↑SAND + ↓ pbles ~10-15% + clay coating only.
~90-95% fU - mL sand with rare - minor gravel - crs pbl
vfu - v. crs pbl ~20-30% sand, ~60% granule - f pbl, rare clay coating
A/A but ~10% sand, ~30% f - m pbl + 1% cbl 100-150mm - rare clay coating
~50% vfL - vcU sand ~40% gran - f pbl ~5-15% m - crs pbl ~ ≤1% v crs pbl - cbl. v. rare clay coating
vfL - vcU sand + dense silty clay ~10%
Change in drilling - wash drill.
fL - crs pbl. Muddy. Max clasts limited to very coarse pebble. Damage noted on larger clasts - hence increased angularity.

NOTE. With wash drilling samples cover a depth range, not a specific depth. The range ≈ 1 m. Samples will be assumed to come from "middle" of that range.

Sand mL - cU. Scattered granules.

Slug test @79.9m
Cased to 81m - bottom of hole heaved ↑ by 1.5m
Cased to 82m
cased to 83m
cased to 83.7
cased to 84m
Slug test @84.2m



COMPANY HBRC Location RUATANIWHA - WAIPUKURAU Well 1 Date 26/05/2021 Page 9 of 16.

Samples collected by drillers

Clay silt - f sa silt

mdl - vcrs. pbl.

mdl - v crs pbl.

wash drilling following pump test. Probable destruction of coarsest grains. Grains slightly more angular. Arbitrary grain size decrease. Water = bluish grey to 93.0m.

Samples now cover ±1m range due to drilling method.

Pale grey water. Pale gy argillite (soft) fragments. Crushing these fragments may contribute to the water colour.

mdl - v. crs pbl. Coarser grains more abundant than 94-95m. Possible fining-upward.

clay - vf sand. Thickness based on drilling behaviours

Gravels with increased water flow compared to above clay-sand layer. Gravels mdl - cobble. Some larger grains got around the bit.

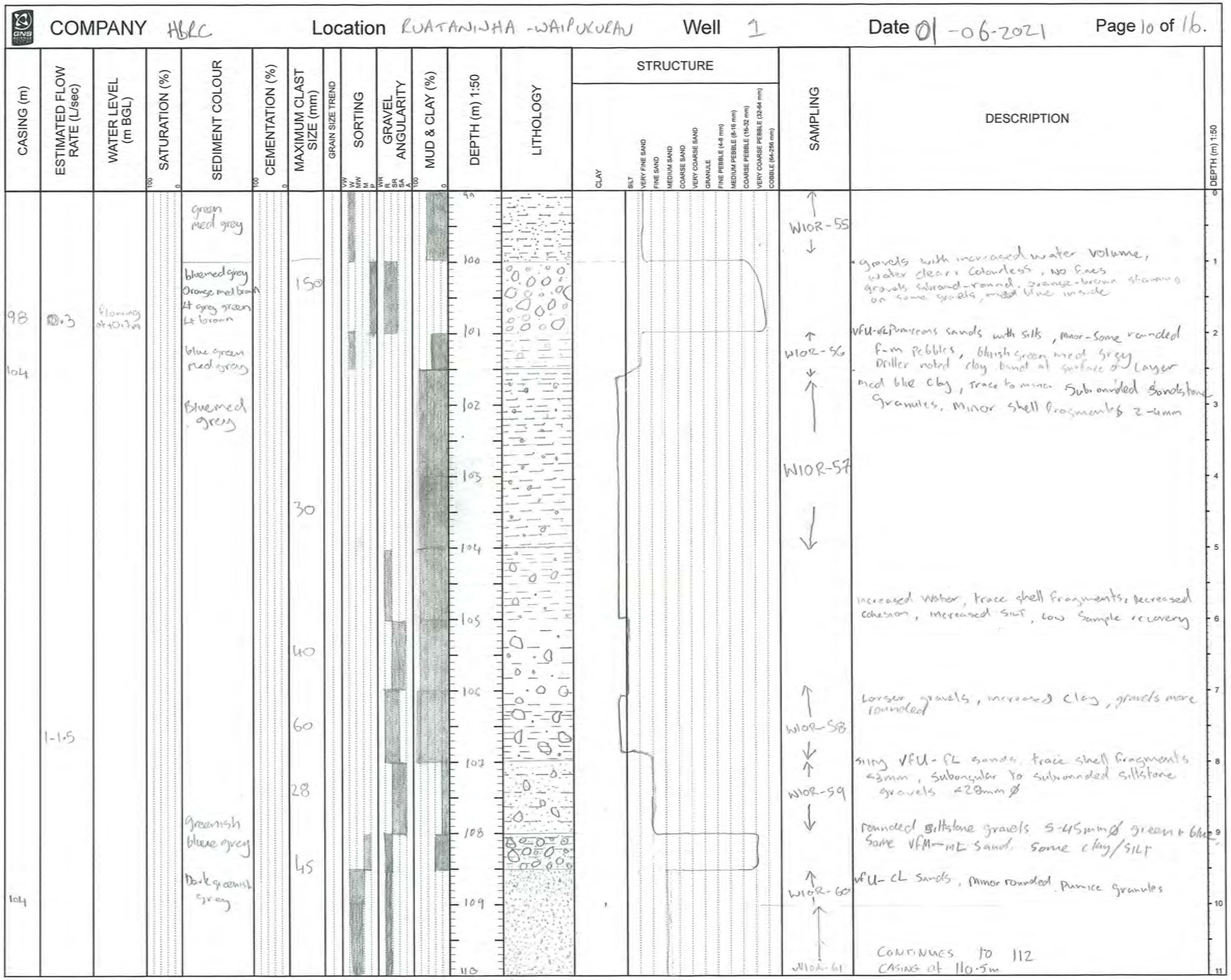
ML - 75mm Cobble sized - Quartz Sands ~(5%), Sands Subangular, pebbles subrounded. Lt green tinge to water

silt/clay - vfL sand, Pumiceous, med green grey - Driller noted sandy

50

Sand - [illegible] needed

← LC TAGGED IN 31-05-21 @ 97m



COMPANY HBRC Location RUATANIWHA -WAIPUKURAU Well 1 Date 01 -06-2021 Page 10 of 16.

Casing (m): 98; 104; 104

Estimated flow rate (L/sec): 0.3; 1-1.5

Water level: flowing at +0.7m

Sediment colour:
green med grey
bluemed grey
Orange med brown
Lt grey green
Lt brown
blue green med grey
Bluemed grey
Greenish bluee grey
Dark greenish grey

Maximum clast size (mm): 150; 30; 40; 60; 28; 45

Sampling: W10R-55; W10R-56; W10R-57; W10R-58; W10R-59; W10R-60; W10R-61

Description:

gravels with increased water volume, water clear + Colourless, no fines gravels subround-round, orange-brown staining on some gravels, med blue inside

VFU-VCL Pumiceous sands with silts, minor-Some rounded f-m pebbles, bluish green med grey Driller noted clay band at surface of Layer med blue clay, Trace to minor Subrounded Sandstone Granules, Minor shell fragments 2-4mm

increased Water, trace shell fragments, Decreased cohesion, increased SILT, Low Sample recovery

Larger gravels, increased Clay, gravels more rounded

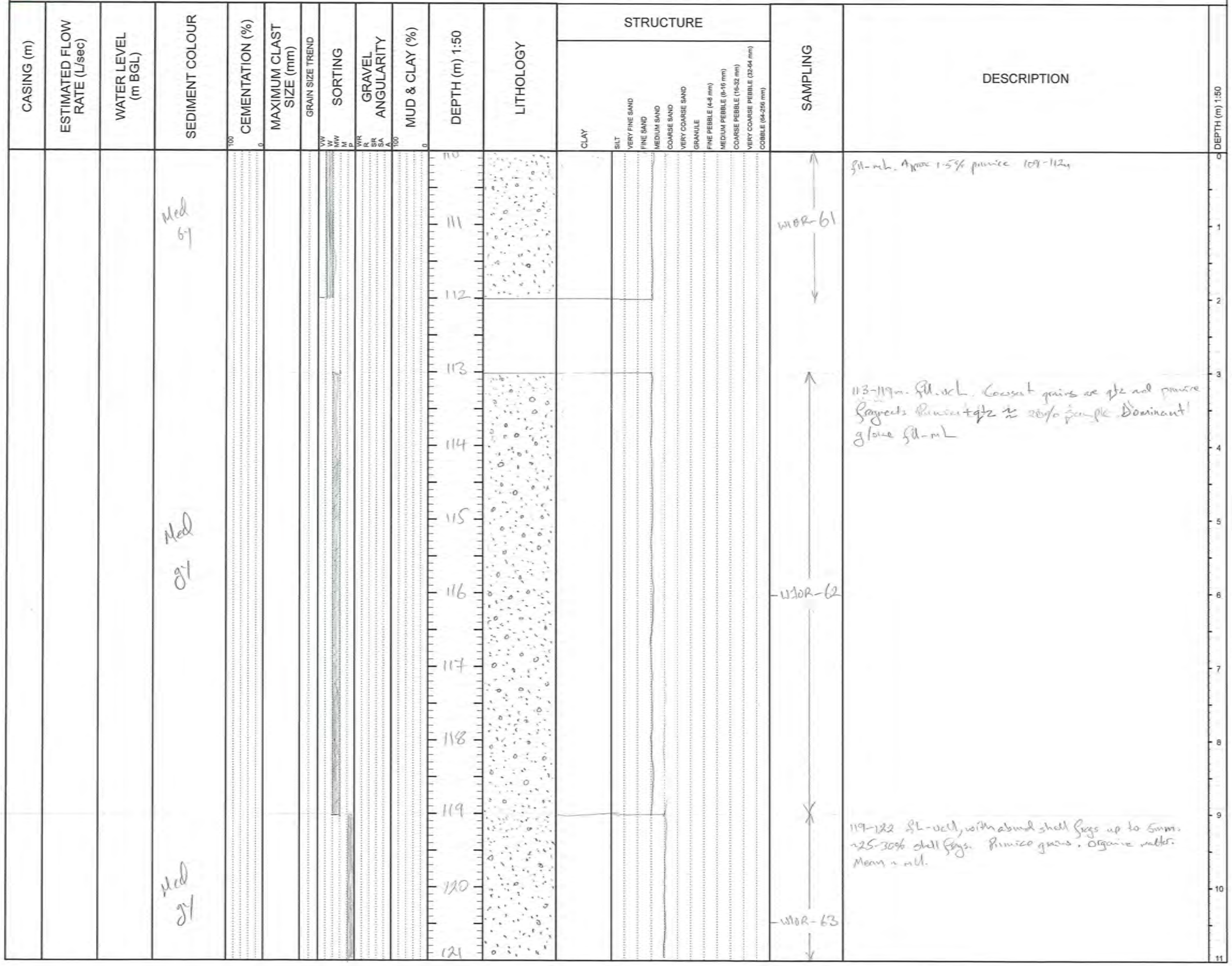
silty VFU-FL sands, trace shell fragments <3mm, Subangular to subrounded siltstone gravels <28mm Ø

rounded siltstone gravels 5-45mm Ø green + blue Some VFM-ML Sand. Some clay/SILT

VFU-CL Sands, minor rounded Pumice granules

CONTINUES TO 112
CASING at 110.5m

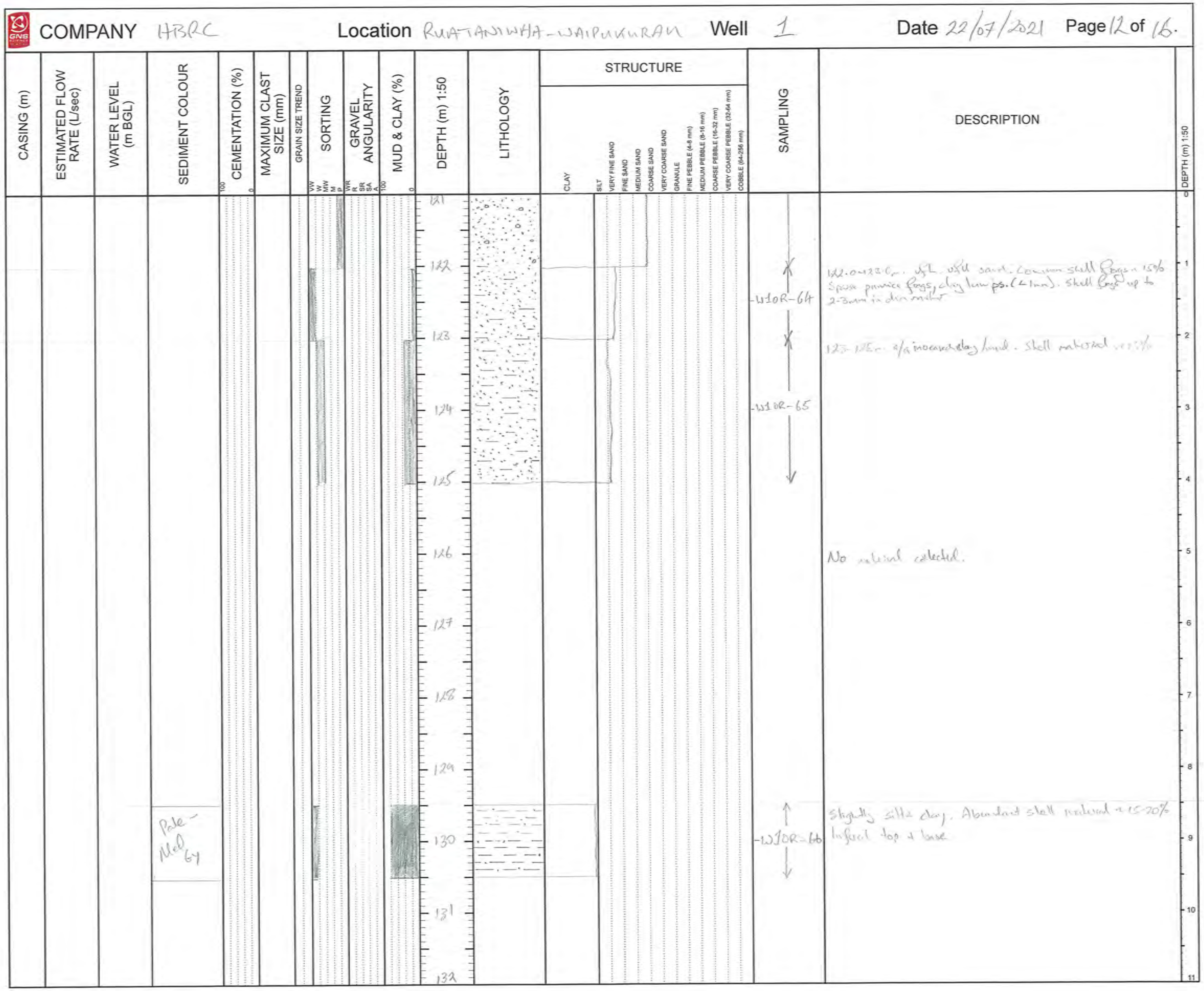
COMPANY HBRC Location RUATANIWHA – WAIPUKURAU Well 1 Date 22/07/2021 Page 11 of 16.



fll-mL. Approx 1-5% pumice 109-112m

113-119m. fU-vcL. Coarsest grains are qtz and pumice fragments. Pumice+qtz ≈ 20% sample. Dominant/glove fU-mL

119-122 fL-vcU, with abund shell frags up to 5mm. ~25-30% shell frags. Pumice grains. Organic matter. Mean ≈ mU.



COMPANY HBRC **Location** RUATANIWHA–WAIPUKURAU **Well** 1 **Date** 22/07/2021 **Page** 12 **of** 16.

W1OR-64

122.0–123.0m. vfL–vfU sand. Common shell frags ~15% Sparse pumice frags, clay lumps. (<1mm). Shell frags up to 2-3mm in diameter

123–125m. a/a increased clay band. Shell material ~15%

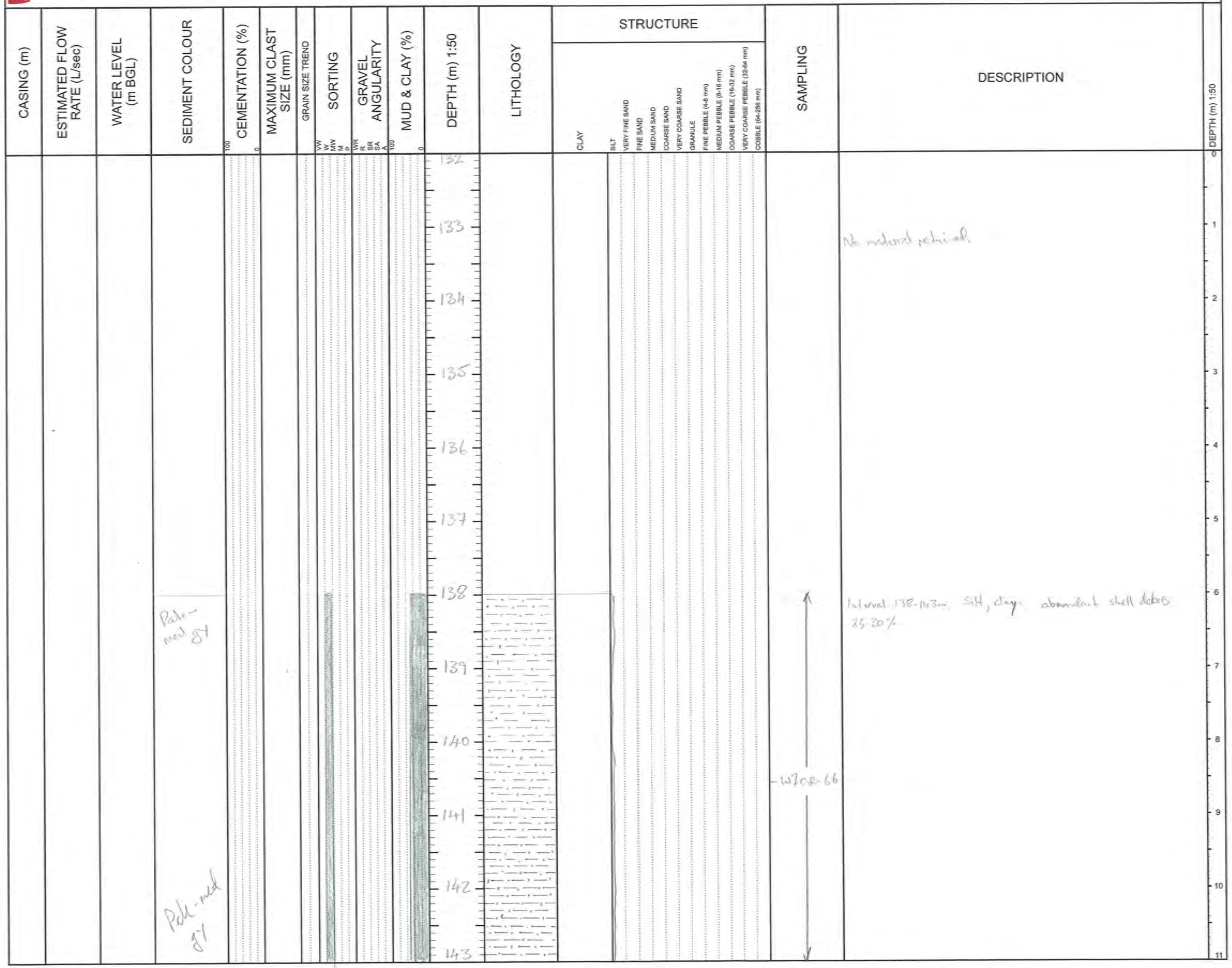
W1OR-65

No material collected.

W1OR-66

Slightly silty clay. Abundant shell material ~15-20% Inferred top + base

COMPANY HBRC Location RUATANIWHA – WAIPUKURAU Well 1 Date 30/07/2021 Page 13 of 16 .



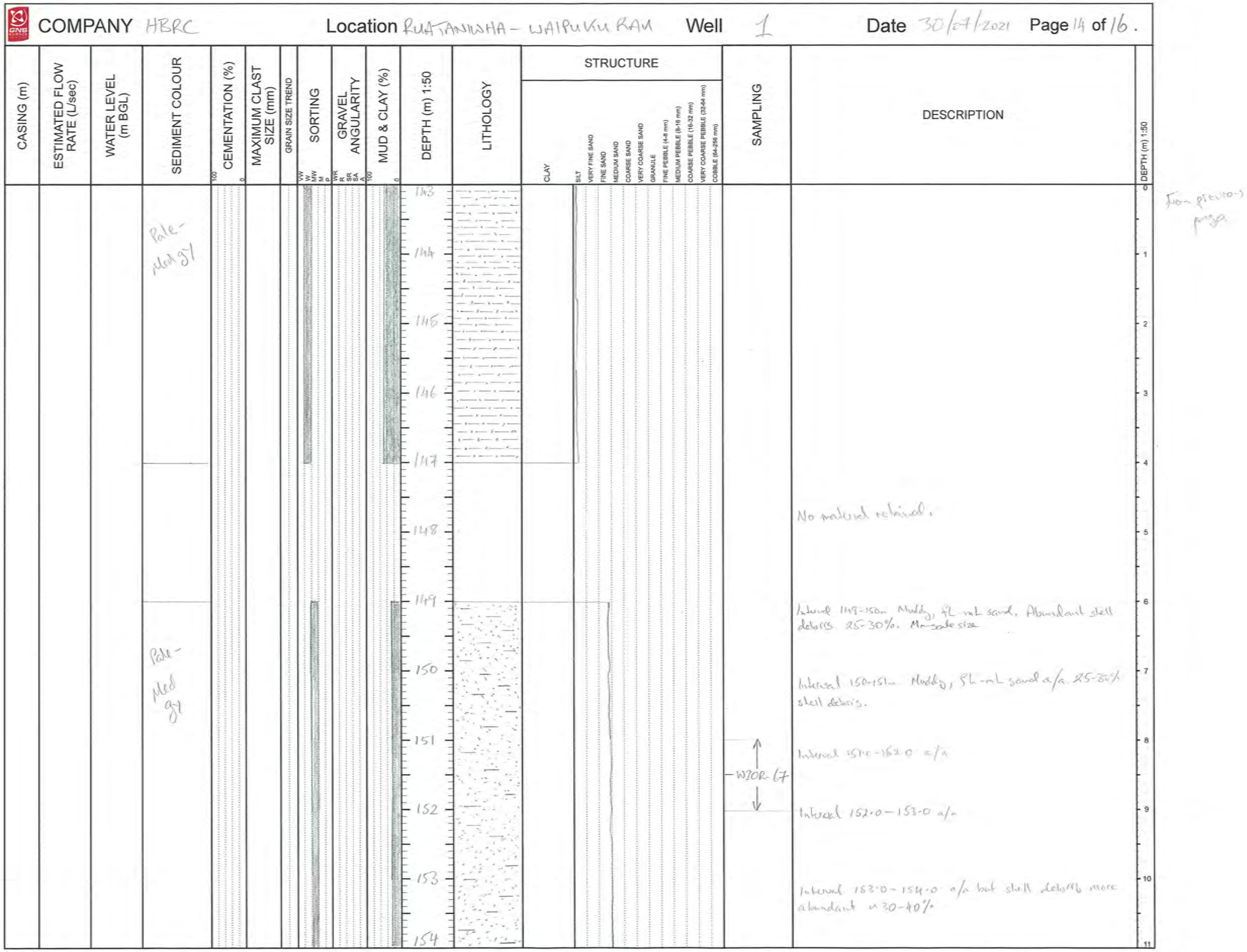
Pale–med gy

Pale-med gy

W70R-66

No material retrieved

Interval 138-143m, Silt, clay. abundant shell debris 25-30%



COMPANY HBRC Location RUATANIWHA – WAIPUKURAU Well 1 Date 30/07/2021 Page 14 of 16.

From previous page.

Pale-Med gy

No material retained.

Interval 149-150m Muddy, fL-mL sand. Abundant shell debris 25-30%. Mm-scale size

Pale-Med gy

Interval 150-151m. Muddy, fL-mL sand a/a. 25-30% shell debris.

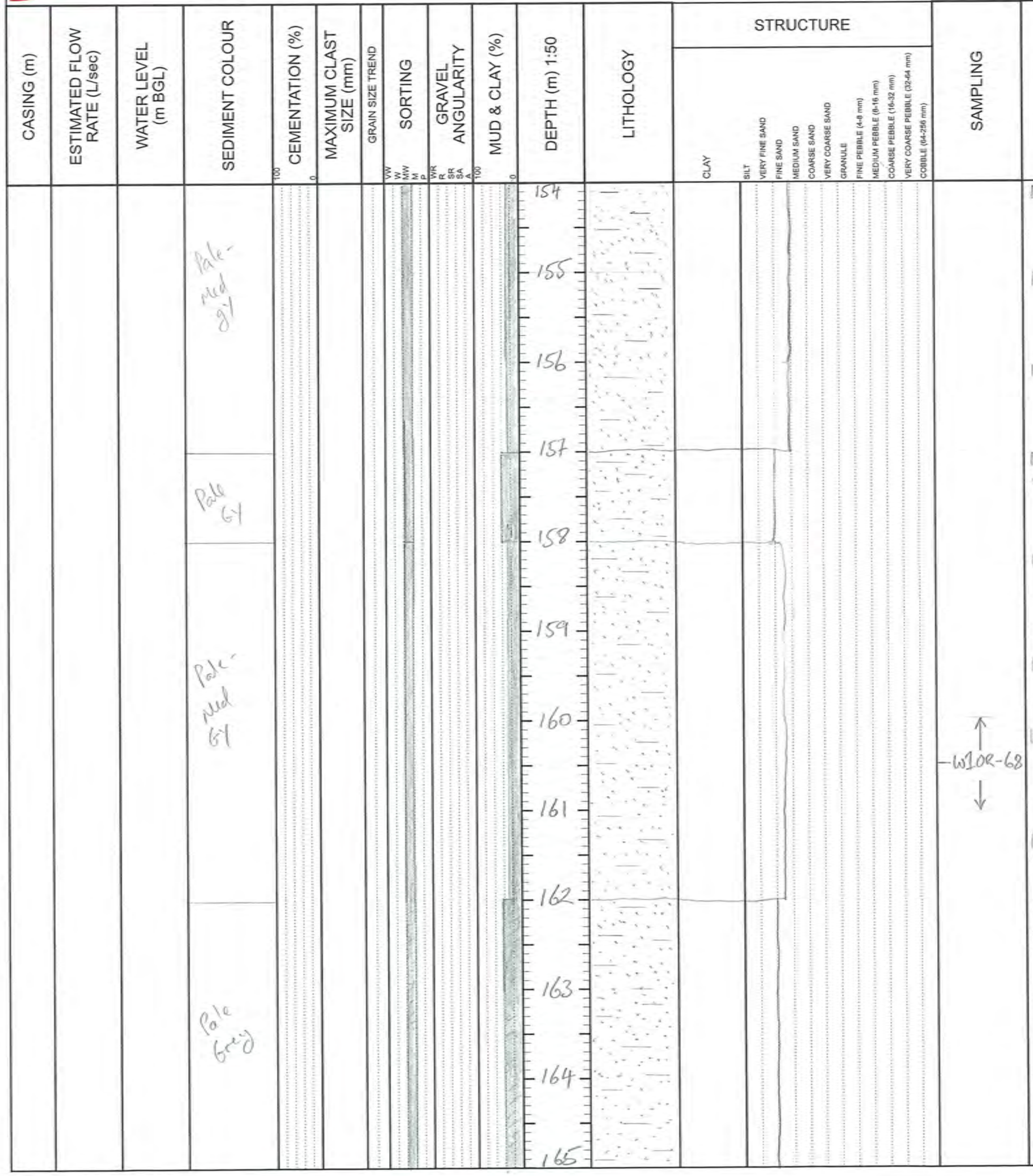
Interval 151.0-152.0 a/a

W20R-67

Interval 152.0-153.0 a/a

Interval 153.0-154.0 a/a but shell debris more abundant ~30-40%

COMPANY HBRC Location RUATANIWHA - WAIPUKURAU Well 1 Date OCTOBER (offsite) Page 15 of 16.



DESCRIPTION

Interval 154.0-155.0 a/a

Interval 155.0-156.0 a/a

Interval 156.0-157.0 a/a

Interval 157.0-158.0 vfL-fL, increased mud ppn. 15-20% shell debris

Interval 158.0-159.0. fL-fU. 15-20% shell debris.

Interval 159.0-160.0 a/a

Interval 160.0-161.0 a/a

Interval 161.0-162 a/a.

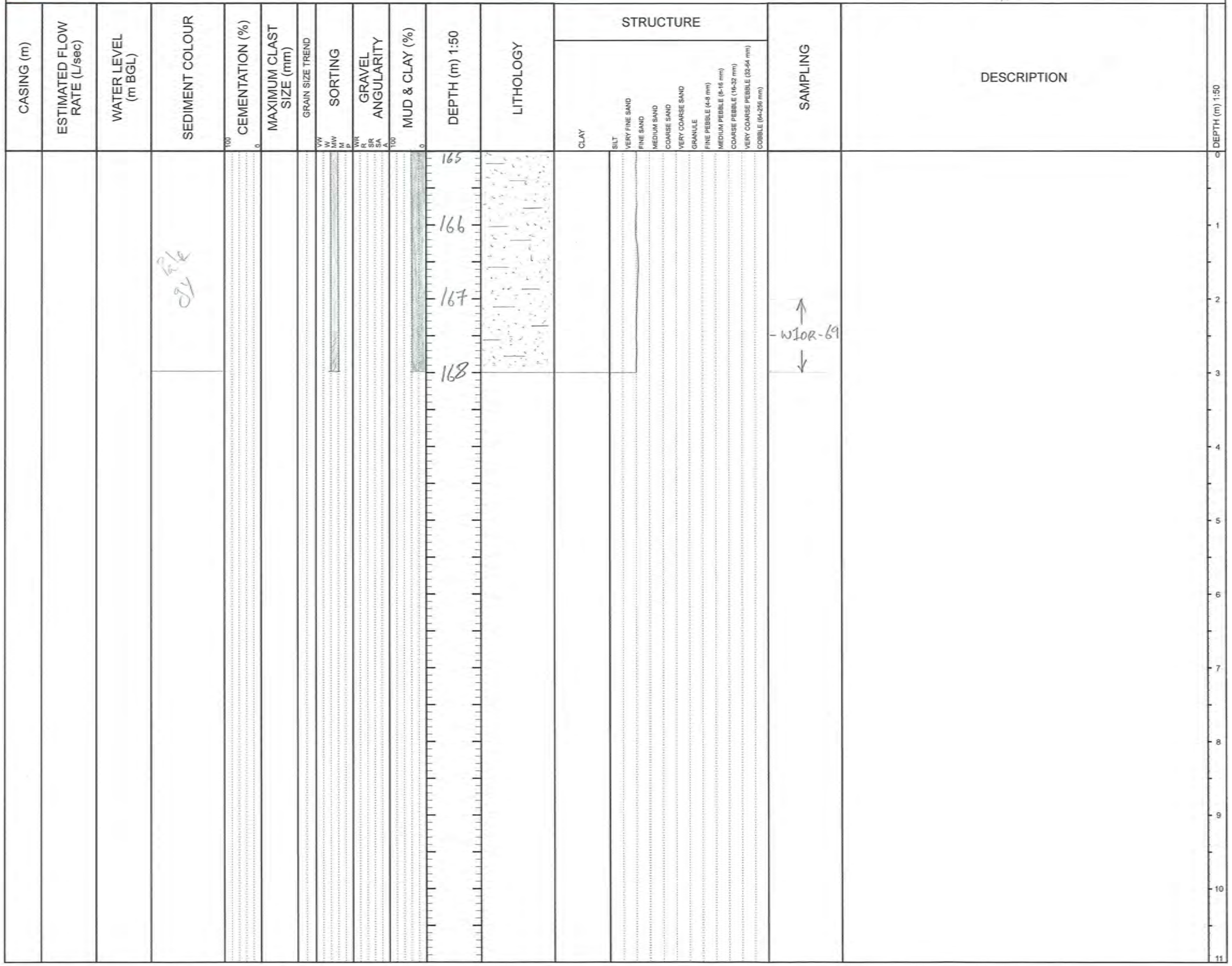
Interval 162.0-163. vfU-fL. Increased mud ppn 15-20% shell debris

Interval 163.0-164.0 a/a.

Interval 164.0-165.0 a/a

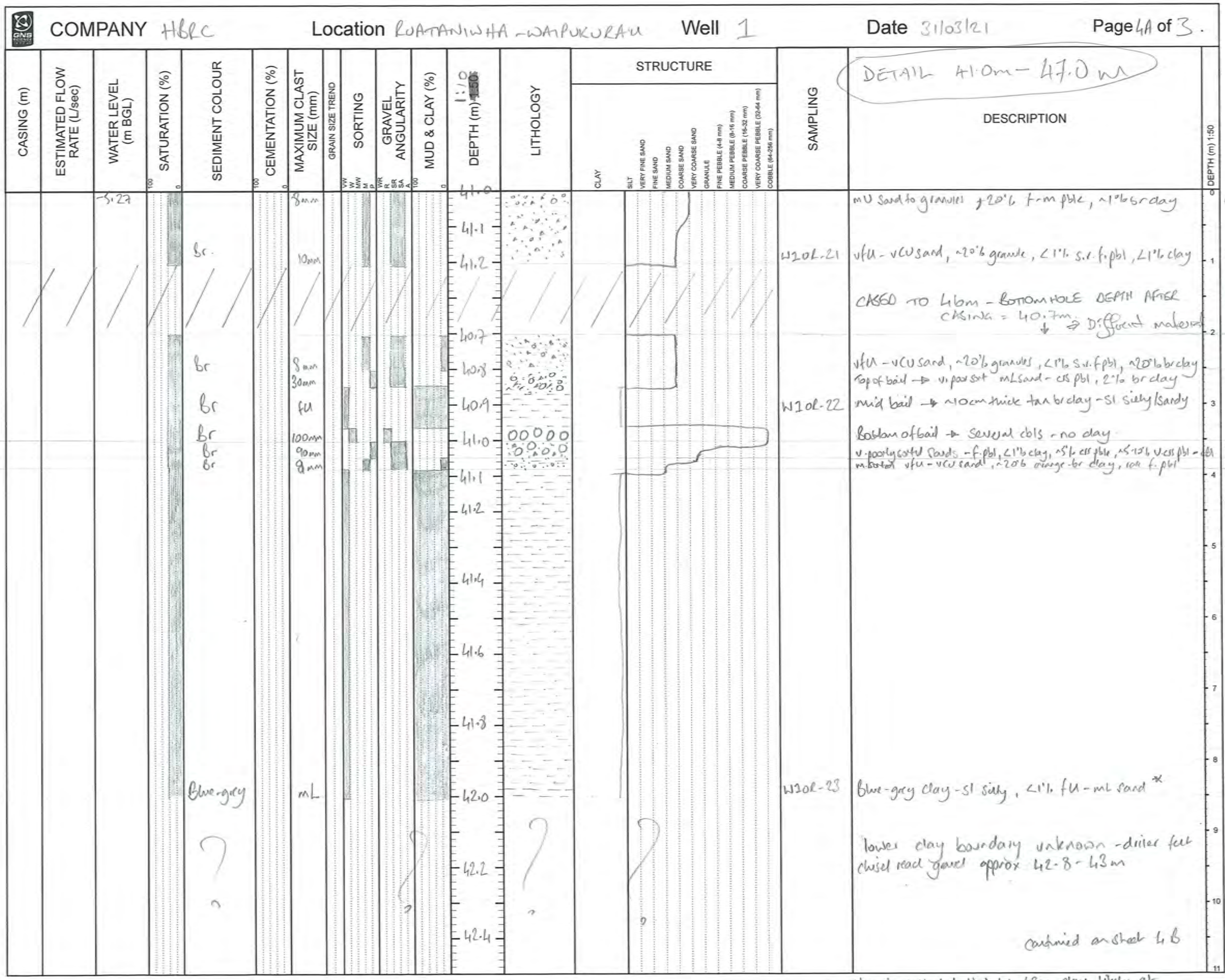
DEPTH (m) 1:50 0 1 2 3 4 5 6 7 8 9 10 11

COMPANY HBRC **Location** RUATANIWAH-WAIPUKURAU **Well** 1 **Date** OCTOBER (offsite) **Page** 16 **of** 16.



COMPANY HBRC Location RUATANIWHA - WAIPUKURAU Well 1 Date 31/03/21 Page 4A of 3.

DETAIL 41.0m – 47.0m

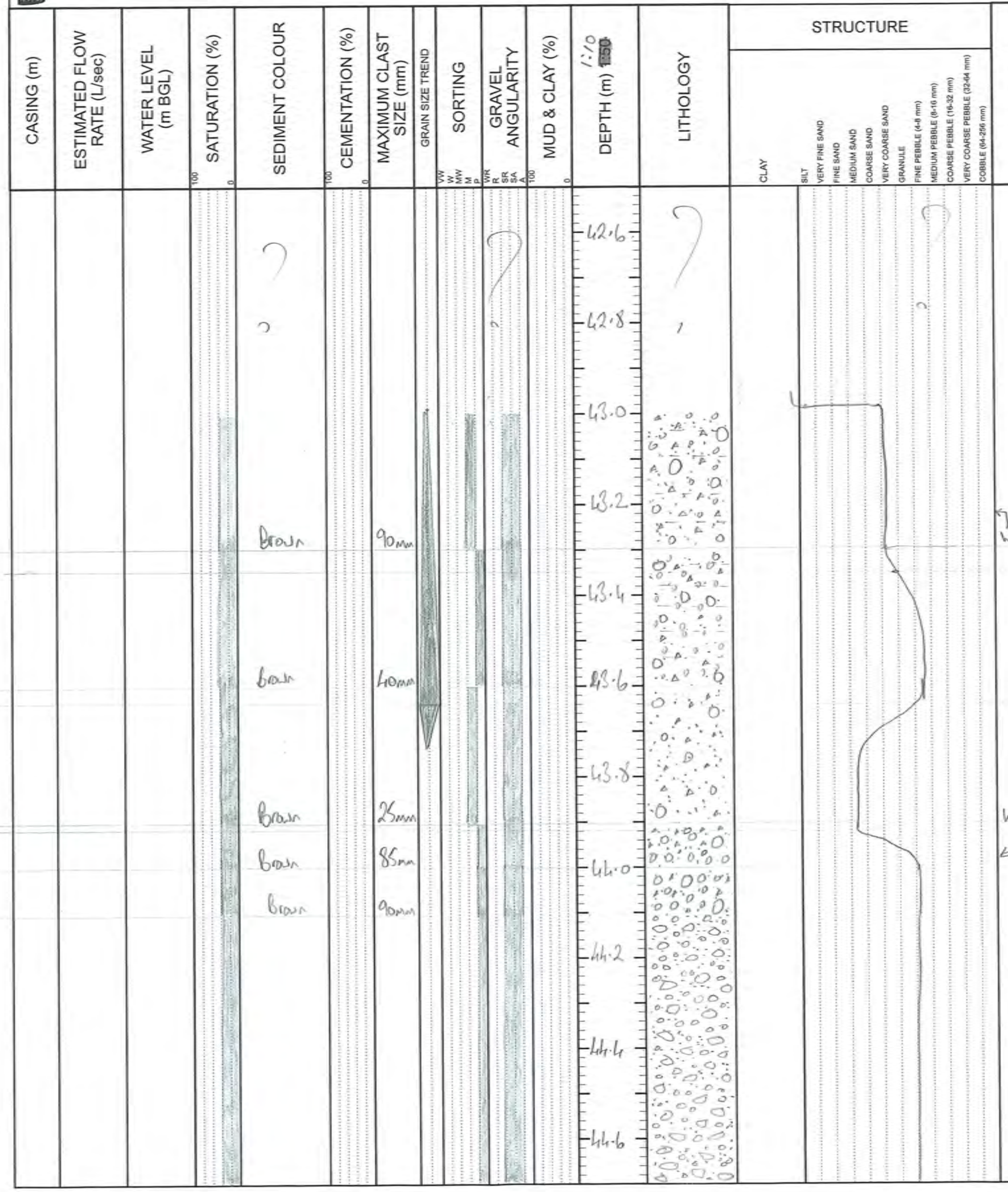


Sampling	Description	Notes
	mU sand to granules, ±20% f-m pble, ~1% br clay	cable-tool
W1OL-21	vfU - vcU sand, ~20% granule, <1% s.r. f.pbl, <1% clay	cable tool while running in casing tight hole @ 43-44m and @46m
	CASED TO 46m - BOTTOM HOLE DEPTH AFTER CASING = 40.7m. ↓ ⇒ Different material	
	vfU - vcU sand, ~20% granules, <1% s.r. f.pbl, ~20% br clay	cable-tool
	Top of bail → v. poor sort mL sand - crs pbl, 2% br clay	cable tool
W1OL-22	mid bail → ~10cm thick tan br clay - Sl silty/sandy	1 bail
	Bottom of bail → several cbls - no clay	
	v. poorly sorted sands - f. pbl, <1% clay, ~5% crs pble, ~5-10% v.crs pbl - cbl	cable tool 1 bail
	m. sorted vfU - vcU sand, ~20% orange-br clay, rare f. pbl	cable tool 1 bail
		chisel to 42m then cable-tool
		x2 bails = clay x2 bails = blue-grey silty water washed away - no solid returns. x4 bails
W1OL-23	blue-grey clay - Sl silty, <1% fU - mL sand *	bottom of hole sludgy i.e. uncertain depth
	lower clay boundary unknown - driller felt chisel reach gravel approx 42.8 - 43m	chisel to 43m then cable tool - see log sheet 4

continued on sheet 4B

* although collected b/w 41-42m, clay likely at 43-44m in situ based on tight hole while casing

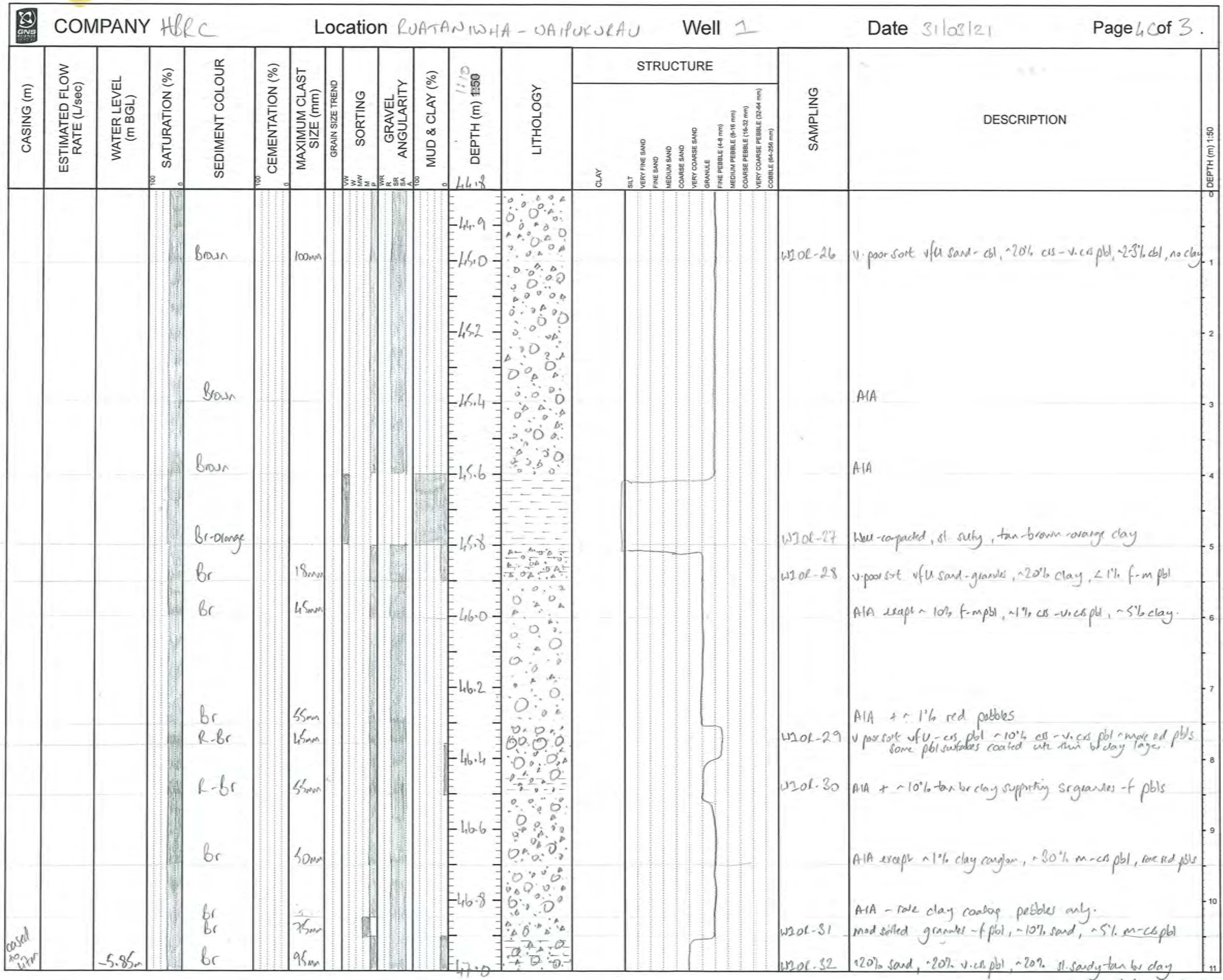
COMPANY HBRC Location RUATANIWHA - WAIPUKURAU Well 1 Date 31/08/21 Page 4b of 3.



SEDIMENT COLOUR	MAXIMUM CLAST SIZE (mm)	SAMPLING	DESCRIPTION	
				chisel 42-43 then cable tool
			lower blue clay boundary unknown - driller felt chisel reach gravel approx 42.8 - 43 m	x1 bail
Brown	90mm	W10R-24	mod-sort. brown fu-vcu sands & granules, ~5% fine pbl ~2% br clay, <1% v. crs pbl - cbl	bottom of hole measured after this bail cable tool
brown	40mm		v. poor sort fu sand - crs pbl - mainly f-m pbl, <5% br clay	cable tool
Brown	25mm	W10R-25	mod-sort vfu - cu sand, ~20% granule, <1% f-crs pbl, <1% br. clay	cable tool
brown	85mm		AIA but ~20% f-crs pbl, ~1% v.crs pbl - cbl, <1% clay.	cable tool
brown	90mm		AIA except no. clay	

DEPTH (m) 1:50 0 1 2 3 4 5 6 7 8 9 10 11

continued on sheet 4C



COMPANY HBRC Location RUATANIWHA - WAIPUKURAU Well 1 Date 31/03/21 Page 4 of 3 .

CASING (m)	WATER LEVEL (m BGL)	SEDIMENT COLOUR	MAXIMUM CLAST SIZE (mm)	SAMPLING	DESCRIPTION	
						cable tool
		Brown	100mm	W1OR-26	v. poor sort vfU sand - cbl, ~20% crs - v.crs pbl, ~2-3% cbl, no clay	
		Brown			AIA	
		Brown			AIA	
		Br-orange		W1OR-27	Well-compacted, sl. silty, tan-brown-orange clay	
		Br	18mm	W1OR-28	v.poor sort vfU sand-granules, ~20% clay, <1% f-m pbl	chisel next 10cm then cable tool
		Br	45mm		AIA except ~10% f-m pbl, ~1% crs - v.crs pbl, ~5% clay.	01/04/21 - cable tool ran in next 0.5m casing
		br	55mm		AIA + ~1% red pebbles	v. tight bailing
		R-Br	45mm	W1OR-29	v poor sort vfU - crs pbl ~10% crs - v. crs pbl ~more red pbls Some pbl surfaces coated with thin br clay layer.	
		R-br	55mm	W1OR-30	AIA + ~10% tan br clay supporting sr granules - f pbls	ran in 0.5m casing to 47m
		br	50mm		AIA except ~1% clay coating, ~30% m-crs pbl, rare red pbls	
		br			AIA - rare clay coating pebbles only.	
		br	75mm	W1OR-31	mod sorted granules - f pbl, ~10% sand, ~5% m-crs pbl	
cased to 47m	-5.85m	br	95mm	W1OR-32	~20% sand, ~20% v.crs pbl, ~20% sl.sandy tan br clay	

continued on sheet 5

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APPENDIX 4 CORE RESISTIVITY MEASUREMENTS

A4.1 Resistivity Measurements

Figure A4.1 shows the equipment used on well HBRC 17136. The raw data are attached to this report in an Excel file as an electronic supplement. Figure A4.2 shows the trends of the resistivity as a function of depth in the borehole.

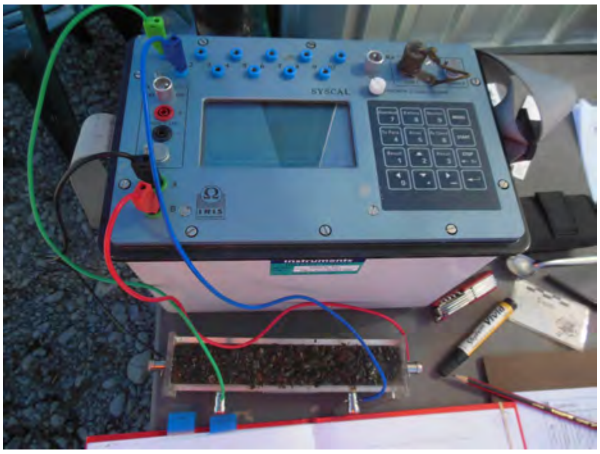

Figure A4.1 Resistivity measurements on a sample from borehole 17136 (Photo: Mark Lawrence).

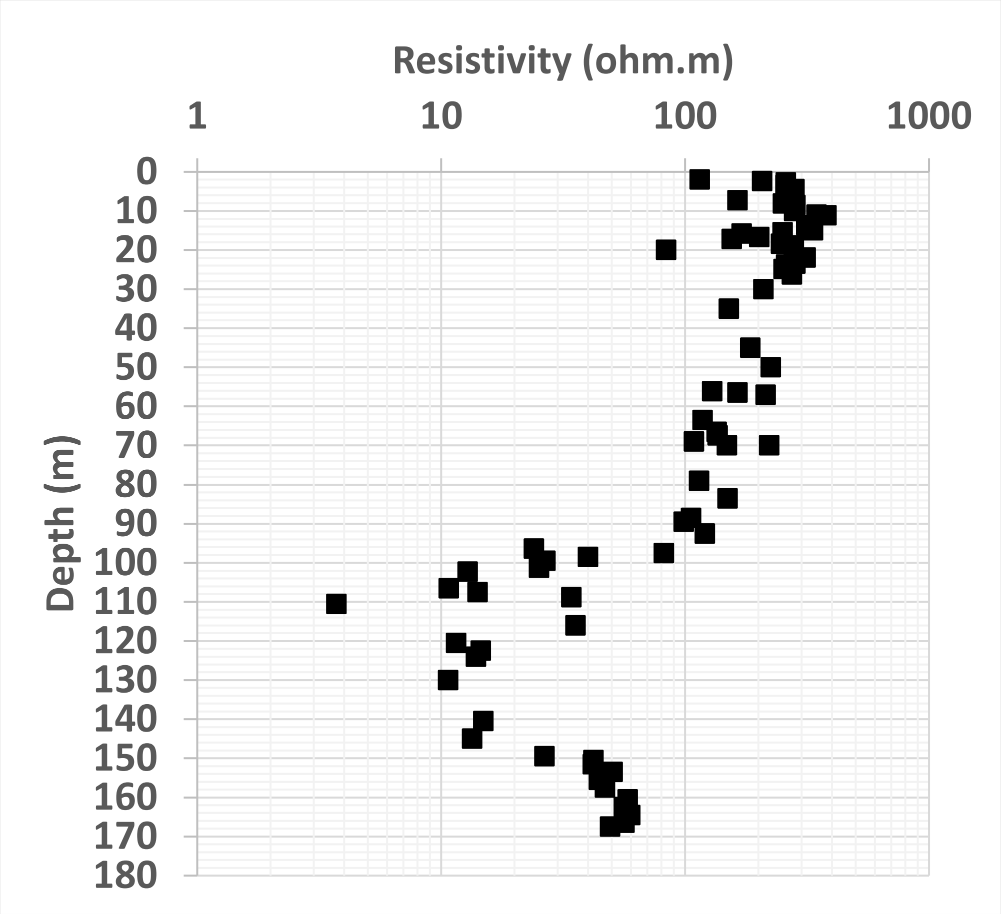

Figure A4.2 Plot of sample resistivity versus depth.

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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 1 (Well ID 17136)
Client:	Hawke's Bay Regional Council
Run Number(s):	02 - 13
Tool Type(s):	Century Coal Combination Sonde CCS QL40-GR Natural Gamma
Service Company:	RDCL
Operator:	O Gibson
Date Logged:	20/07/2021
Field:	Waipukurua
State / Province:	Hawke's Bay
Country:	New Zealand

Location Description:

North of the 382 Ongaonga Waipukurua Road. Approximately 980 m from the road.

Drillhole Information:

Log interval from (m):	-0.59	Log interval to (m):	160.89
Depth Driller (m):	162 (casing)	Depth Logger (m):	166.65 (sump)
Fluid Type:	Water	Fluid Level (m):	Artesian
Easting:	1896477.322	Northing:	5572972.328
Elevation:	Unknown	Coord Ref System:	N/A
Hole Azimuth:	N/A	Hole Inclination:	-90°
Magnetic Declination:	+22° 9'	Magnetic Inclination:	65° 4'
Drill Company:	Baylis Bros.		

Printing Information:

Depth Unit:	Metres	Log Scale:	1:100	Log Version:	Final
Processed:	O Gibson			Log Reviewer:	L McLennan

Bit Size Record:

Size (mm):	From (m):	To (m):
200	0.00	166.65
##.#	##.#	##.#
##.#	##.#	##.#
##.#	##.#	##.#

Casing Record:

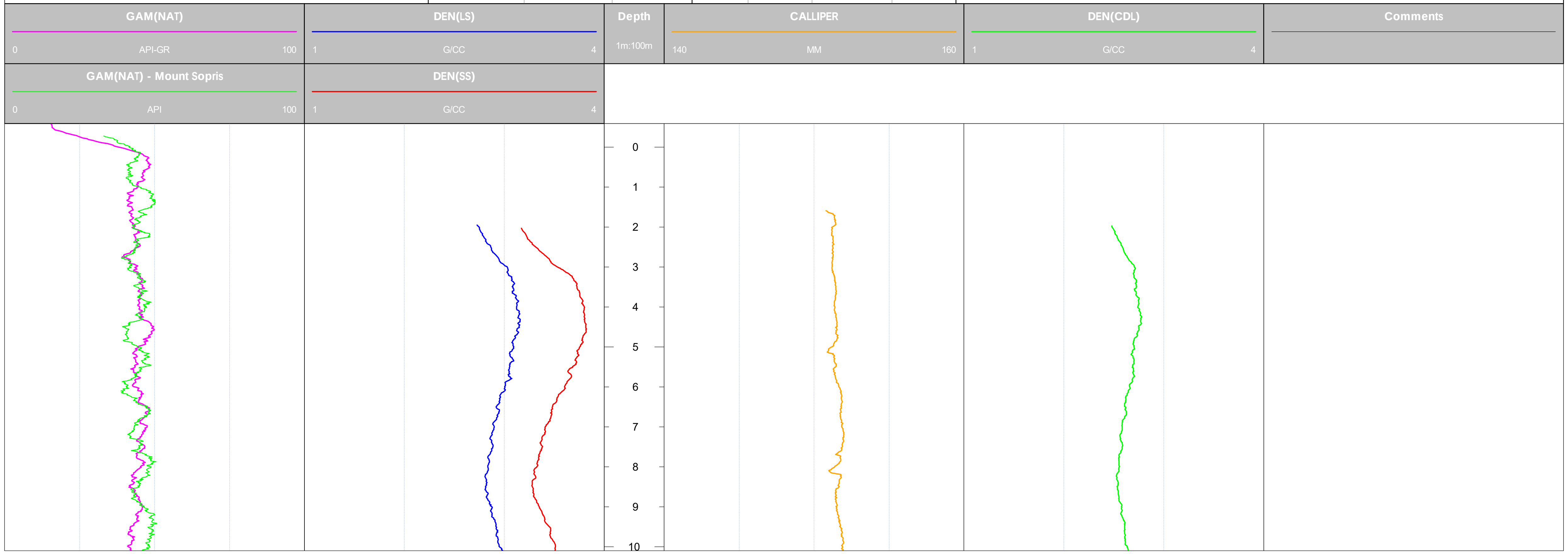
Type:	Size:	From (m):	To (m):
Well	150 mm	-0.7	162
XX	##.#	##.#	##.#
XX	##.#	##.#	##.#
XX	##.#	##.#	##.#

Log Nomenclature:

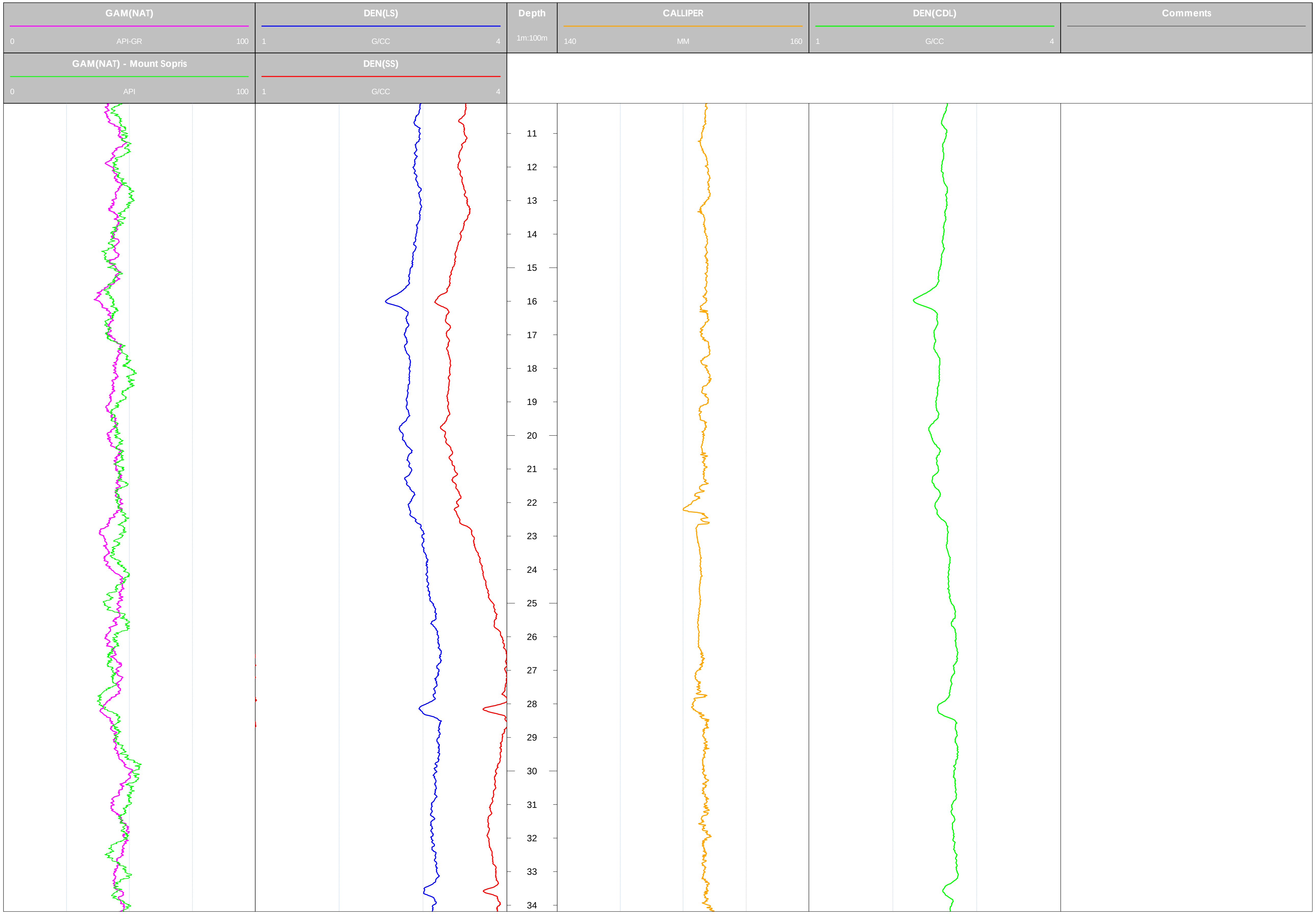
DEN(SS) = Short-Spaced Density
DEN(LS) = Long-Spaced Density
DEN(CDL) = Compensated Density
GAM(NAT) = Natural Gamma
CALIPER = Single Arm Mechanical Calliper

Comments:

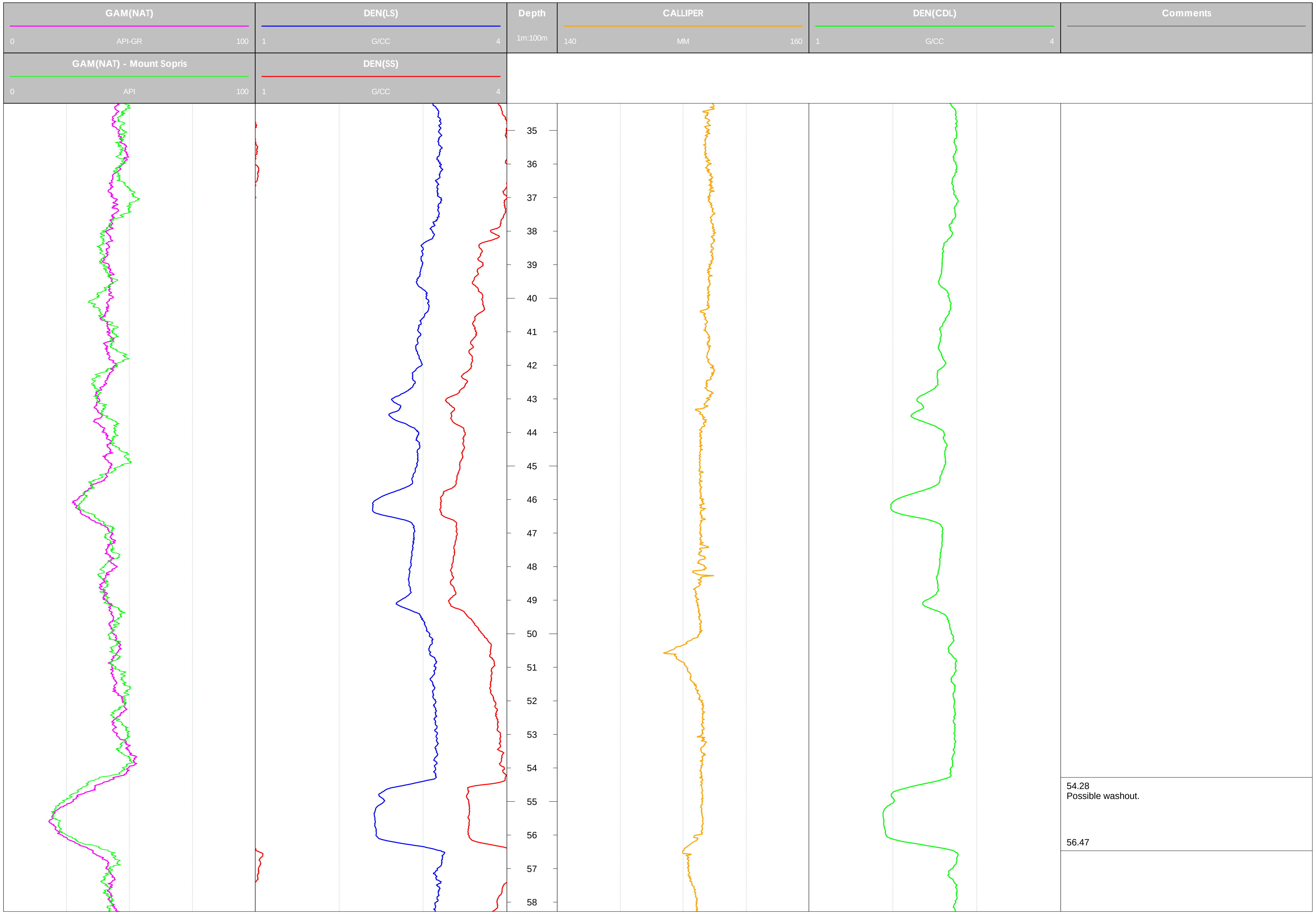
1. Log started at 160.89 m bgl to avoid hangup in open hole.
2. Data gaps caused by tool hangups on the inside of the well casing.
3. Density values are relative not absolute due the presence of metal casing.
4. GAM(NAT) - Mount Sopris run deployed to provide gap less natural gamma data in hole. This probe is centralised in hole (unlike the 9239C Century probe) but there is good agreement between runs.



Page 1


GAM(NAT)
0
API-GR
100
GAM(NAT) - Mount Sopris
0
API
100
DEN(LS)
1
G/CC
4
DEN(SS)
1
G/CC
4
Depth
1m:100m
CALLIPER
140
MM
160
DEN(CDL)
1
G/CC
4
Comments
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34

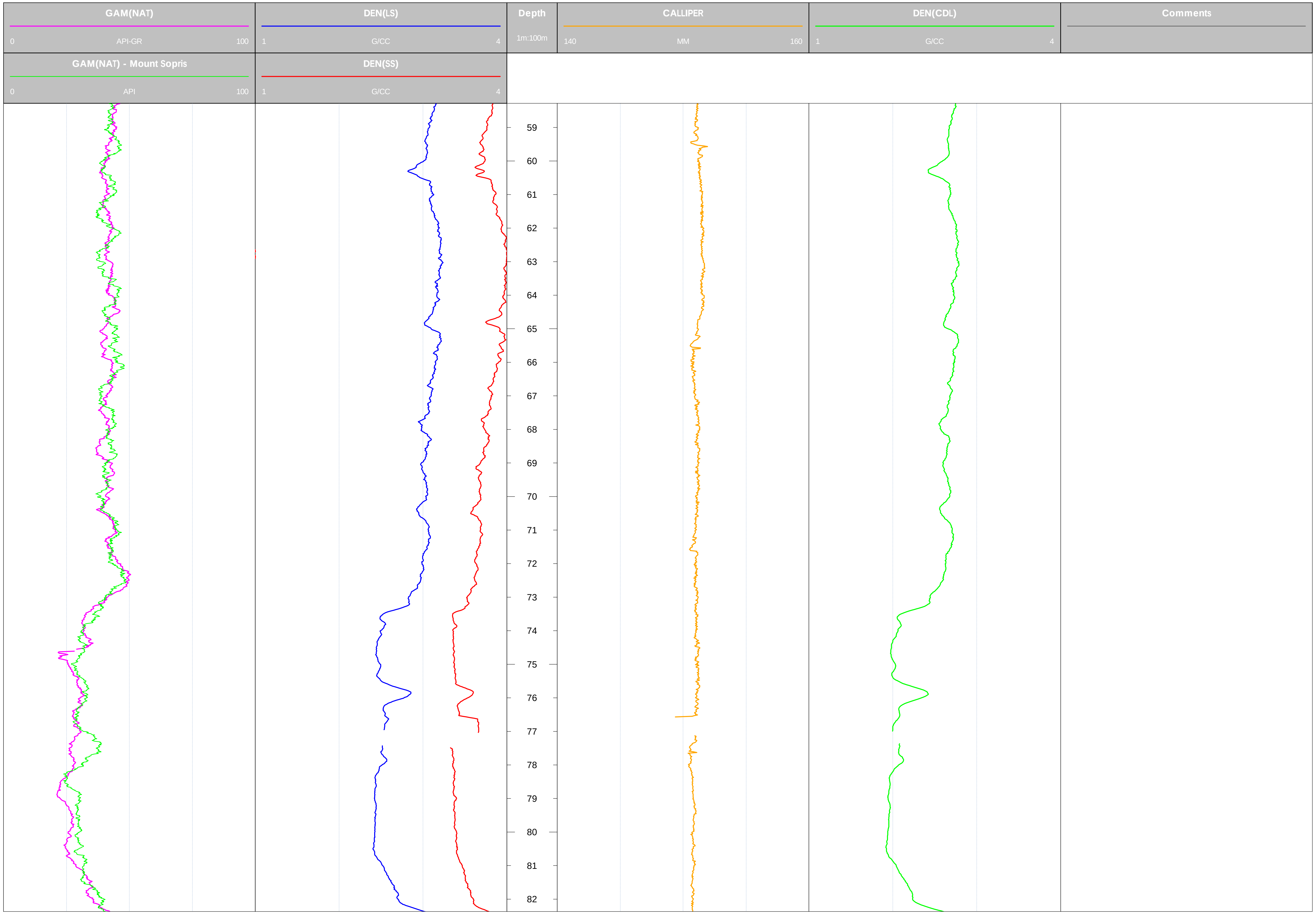
Page 2



54.28
Possible washout.

56.47

Page 3


GAM(NAT)
0
API-GR
100
GAM(NAT) - Mount Sopris
0
API
100
DEN(LS)
1
G/CC
4
DEN(SS)
1
G/CC
4
Depth
1m:100m
CALLIPER
140
MM
160
DEN(CDL)
1
G/CC
4
Comments
59
60
61
62
63
64
65
66
67
68
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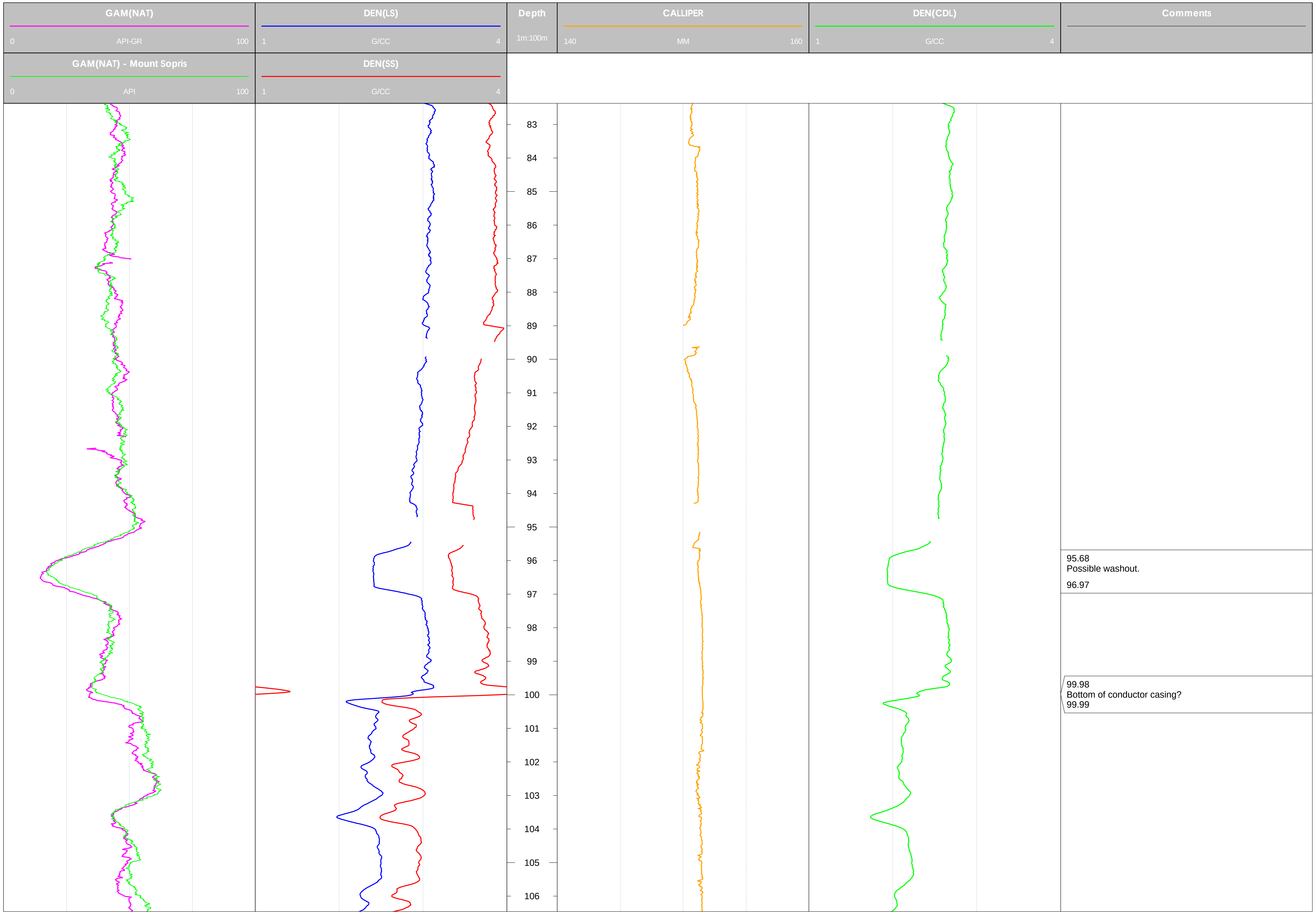
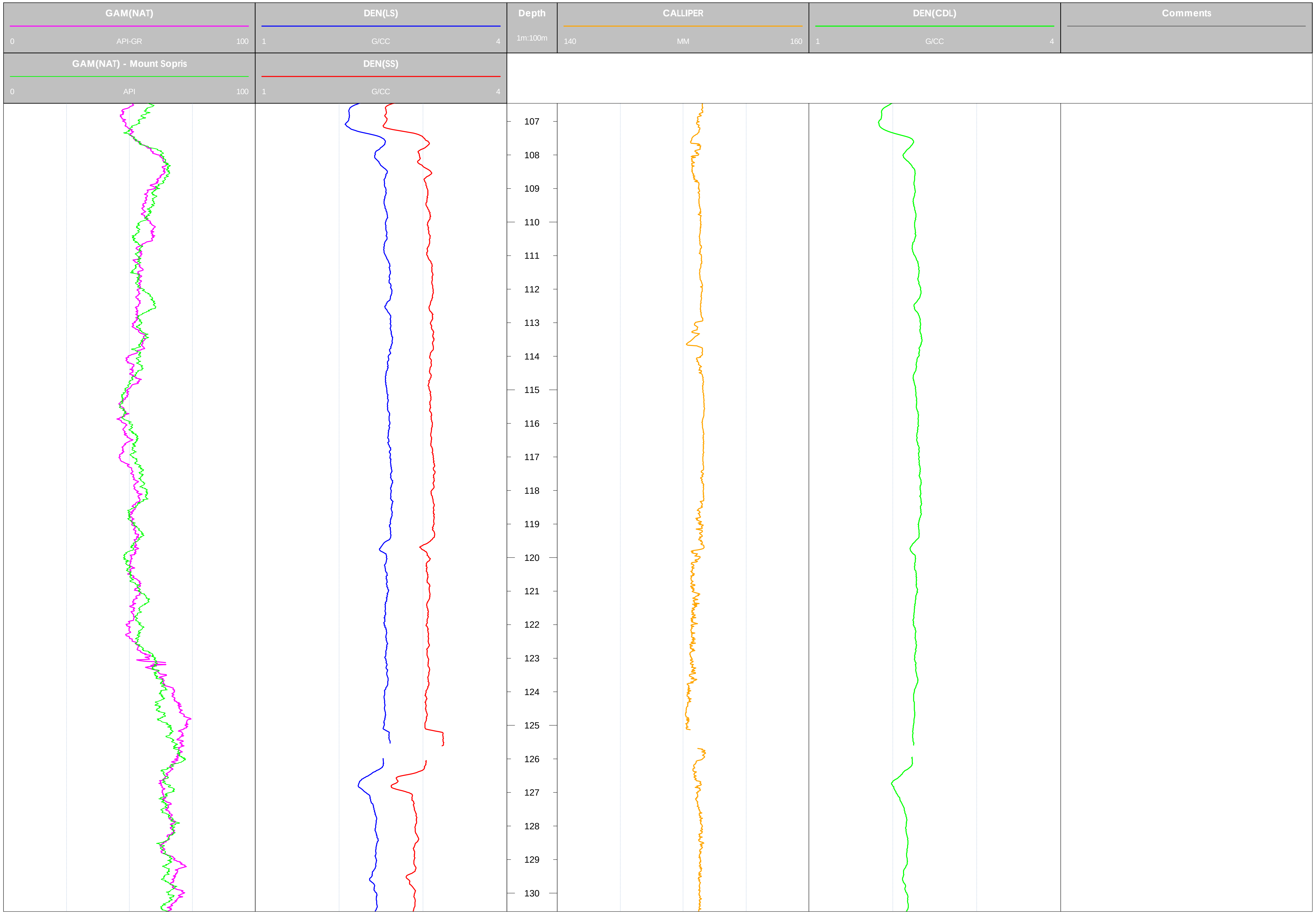
77
78
79
80
81
82



95.68
Possible washout.
96.97

99.98
Bottom of conductor casing?
99.99


GAM(NAT)
0 API-GR 100
GAM(NAT) - Mount Sopris
0 API 100
DEN(LS)
1 G/CC 4
DEN(SS)
1 G/CC 4
Depth
1m:100m
CALLIPER
140 MM 160
DEN(CDL)
1 G/CC 4
Comments
107
108
109
110
111
112
113
114
115
116
117
118
119
120
121
122
123
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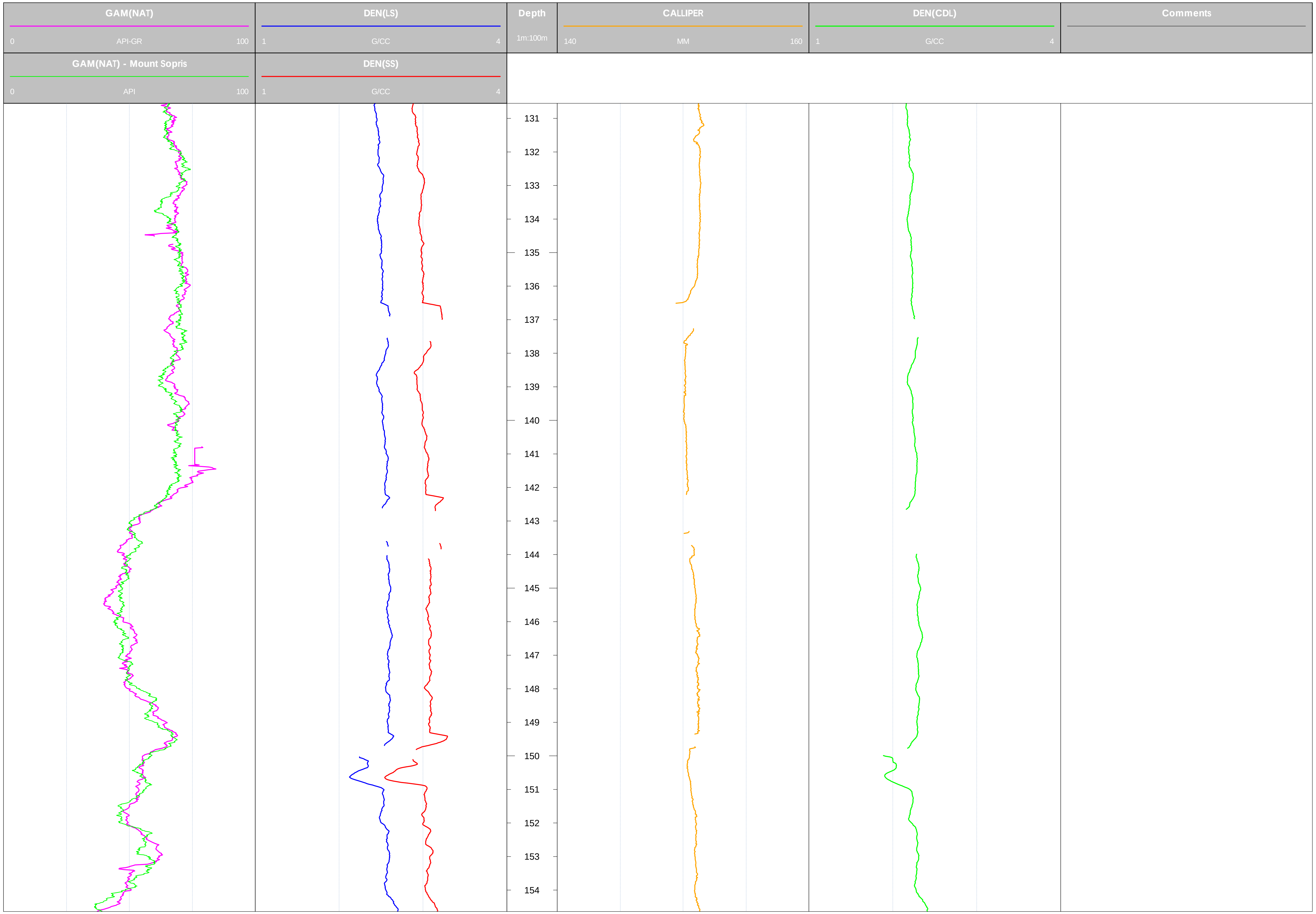
125
126
127
128
129
130


GAM(NAT)
0
API-GR
100
GAM(NAT) - Mount Sopris
0
API
100
DEN(LS)
1
G/CC
4
DEN(SS)
1
G/CC
4
Depth
1m:100m
CALLIPER
140
MM
160
DEN(CDL)
1
G/CC
4
Comments
131
132
133
134
135
136
137
138
139
140
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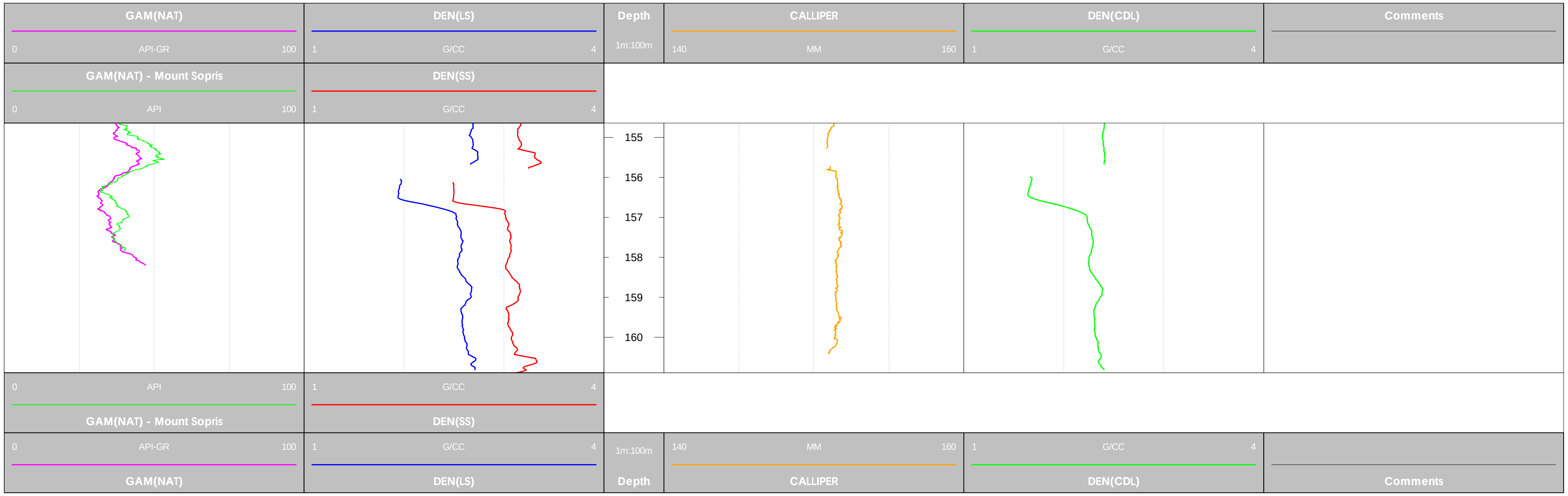
149
150
151
152
153
154


GAM(NAT)
0
API-GR
100
DEN(LS)
1
G/CC
4
Depth
1m:100m
CALLIPER
140
MM
160
DEN(CDL)
1
G/CC
4
Comments
GAM(NAT) - Mount Sopris
0
API
100
DEN(SS)
1
G/CC
4
155
156
157
158
159
160
0
API
100
GAM(NAT) - Mount Sopris
1
G/CC
4
DEN(SS)
0
API-GR
100
GAM(NAT)
1
G/CC
4
DEN(LS)
1m:100m
Depth
140
MM
160
CALLIPER
1
G/CC
4
DEN(CDL)
Comments

APPENDIX 6 PUMPING TEST

One 8-hour constant-rate pumping test was undertaken at well 17136 at 92.0 m BGL in May 2021. Groundwater level was monitored at the two observation wells 16668 and 16713 located right next to each other (2.5 m apart) 830 m from well 17136 (Figure 2.10).

A6.1 Setting Details

The lithology at the screen interval of the two observation wells was similar to the lithology of the tested aquifer (Table A6.1). The pumps in the neighbouring fields were turned off three days prior to the test, allowing the water table to reach a static level by the beginning of the test. An episode of heavy rain occurred in the week prior to the test. The water level measured immediately prior to the start of the test was assumed to be the static water level.

Table A6.1 Screen interval and lithology for each well utilised during the pumping test at 92.0 m BGL.

Well Number	Distance to Well 17136 (m)	Screen Interval (m BGL)	Lithology at the Screen
Pumping well 17136	0	88.8–90.0 Open hole 90.0–92.0	87.0 –89.0: Sand 89.0–90.0: Muddy-silty sand 90.0–92.0: Gravel
Observation well 16668	830	96.49–97.49	83.5–87.0: Blue/brown siltstone* 87.0–99.7: Red gravel*
Observation well 16713	830	86.6–98.8	83.5–87.0: Blue/brown siltstone* 87.0–99.7: Red gravel*

* Lithology extracted from HBRC database (Harper 2019).

Prior to the test, a Level TROLL 700 data logger was installed in both observation wells 16668 and 16713 to monitor the water-level fluctuations for a period of two and a half weeks. A Level TROLL 700 data logger was also installed in the pumping well on the evening prior to the test to monitor the water level and inform a static water level for the test.

For the pumping test, the two loggers were kept in the observation wells, and manual measurements were read from a dip meter at observation well 16713. A Level TROLL 700 data logger was lowered into the pumping well at around 30 m BGL, 7 m above the top of the pump. Manual measurements were also read from a dip meter at the pumping well. A summary of the loggers used and time interval used for each logger is described in Table A6.2.

For the drawdown phase of the test, well 17136 was pumped at a constant flow rate of 8 L/s for eight hours, from 9:00 am on 24 May 2021 until 5:00 pm the same day. Flow rate was controlled by a valve and routinely checked on an orifice flow manometer and found to be steady between 14" and 16", equivalent to 8 L/s (Figure 2.11). A maximum drawdown of 25.2 m was recorded during this test. The recovery started once the pump was turned off at 5:00 pm on 24 May 2021 and was monitored continuously for 17 hours until 10:00 am on 25 May 2021.

Table A6.2 Logging details for each well during the pumping test at 92.0 m BGL.

Well Number	Distance to Well 17136 (m)	Logging Characteristics	Time Interval
Pumping well 17136	0	Level TROLL 700	**Step interval** (drawdown and recovery): • 250 milliseconds for 4 hours • 30 seconds for 4 hours • 250 milliseconds for 4 hours • 30 seconds for 13 hours
		Dip meter	**Semi-logarithmic interval** (drawdown and recovery): • Manual measurements, reading from the dip meter
Observation well 16668	830	Level TROLL 700	**Constant interval** (drawdown and recovery): • 1 second for 24 hours
Observation well 16713	830	Level TROLL 700	**Step interval** (drawdown and recovery): • 15 seconds for 15 hours • 30 seconds for 9 hours
		Dip meter	**Semi-logarithmic interval** (drawdown and recovery): • Manual measurements, reading from the dip meter

A6.2 Barometric Correction

No barometric pressure was recorded during the pumping and slug tests, therefore barometric data from the Waipawa electronic weather station recorded every hour were obtained from New Zealand’s Climate Database web portal CliFlo (NIWA c2022) over the two-year period from 05/2019 to 09/2021. Groundwater-level telemetered data recorded every 15 minutes were obtained from the Hawke’s Bay Regional Council wells 16879 and 16880 over a similar two-year period from 07/2019 to 09/2021. A piezometer is set at 30 m BGL in well 16880 and at 90 m BGL in well 16879 (Figure A6.1). The water-level data in well 16879 showed a recovery of the aquifer during most of winter period with no stable level being reached before the beginning of the test, therefore the water-level data from this well could not be utilised in the estimation of the barometric efficiency coefficient.

Data loggers were lowered into neighbouring wells 16668 and 16713 (Figure A6.1) two and a half weeks prior to the constant-rate pumping test to monitor what impact the surrounding pumping/irrigation had on the deeper aquifer. It rained for a few days before the start of the test, showing no significant impact on the monitored water level, and, after observation by drillers and on-site geologists, it was confirmed that irrigation did not occur during those days, providing for a four-day monitored stable water level.

The estimation of the barometric efficiency of the aquifer coefficient was based on barometric pressure data from the Waipawa weather station (NIWA c2022) and groundwater levels from well 16880 for the unconfined aquifer layers (Table A6.3) and from wells 16713 and 16668 for the confined aquifer layers (Table A6.4).

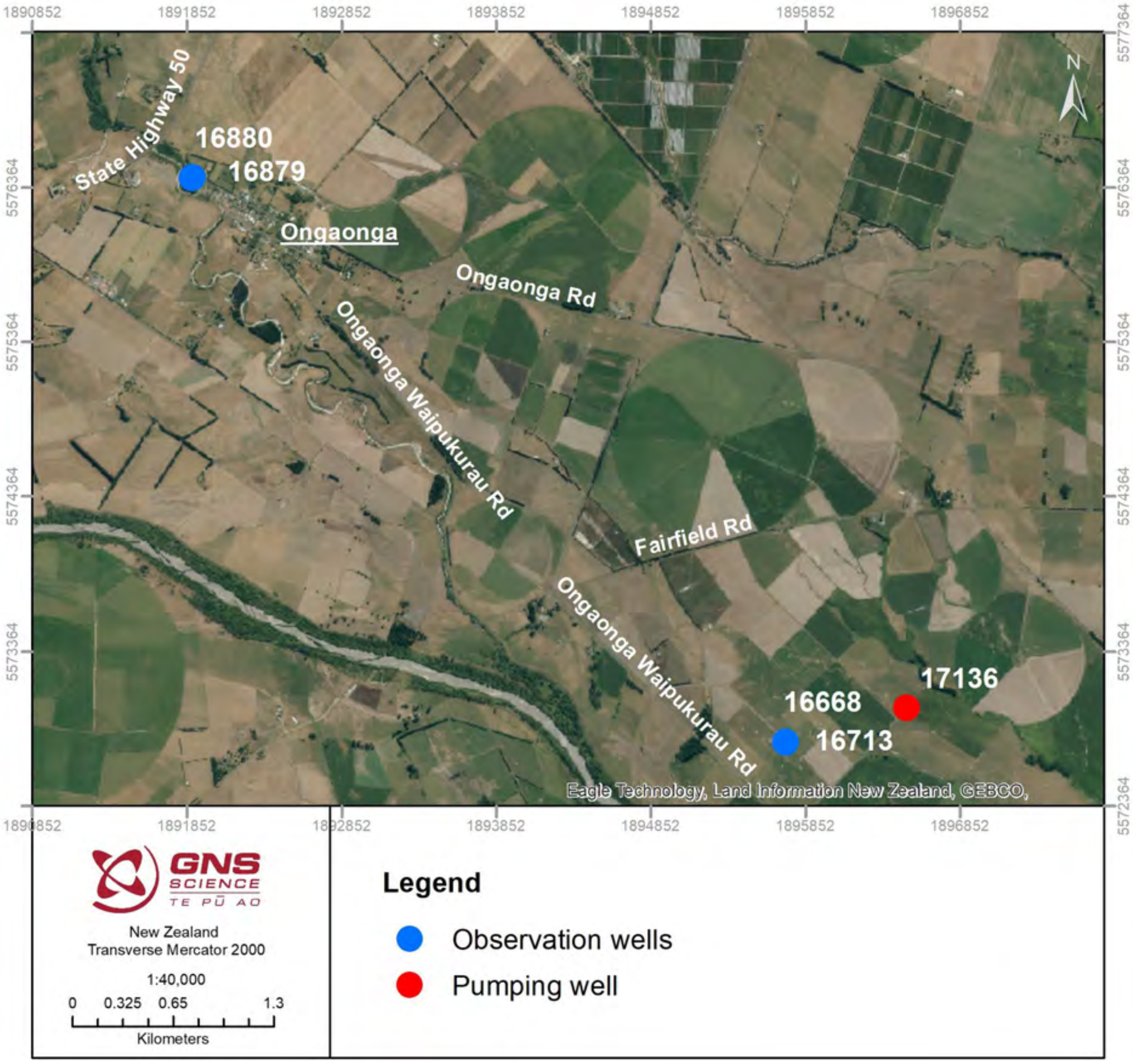


Figure A6.1 Map showing the distance between the different wells used in this analysis. The drilled well 17136 was used as the pumping well in the constant-rate pumping test. The wells 16668 and 16713 were used as observation wells for the pumping test and for the calculation of the barometric efficiency of the deeper confined aquifer. The HRBC monitoring wells 16879 and 16880 were used as observation wells for the calculation of the barometric efficiency of the upper unconfined aquifer.

Winter data between June 2019 and August 2021 from well 16880, monitoring data prior to the pumping test from wells 16668 and 16713 and data from the Waipawa weather station were combined using the graphical method of Gonthier (2007) to estimate the barometric efficiency coefficient of both aquifers. The estimated results are summarised in Tables A6.3 and A6.4. The water levels recorded during each test were corrected for barometric effects using the following Equation A6.1 (Gonthier 2007):

$$WL_{(t)corr} = WL_{(t)uncorr} - BE(B_0 - B_{(t)}) \qquad \text{Equation A6.1}$$

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.

A barometric efficiency coefficient of 0.2458 was used for all slug tests occurring above 89.0 m BGL corresponding to the unconfined aquifer layer. A barometric efficiency coefficient of 0.5372 was used for all slug tests and the pumping test occurring below 89.0 m BGL corresponding to the confined aquifer layer.

Table A6.3 Barometric efficiency of the aquifer (BE) estimation results for the unconfined aquifer layer. An estimation was first made for each timeframe with the graphic method. The timeframes were chosen to be primarily in winter, where it is assumed that groundwater levels will be less impacted by surrounding irrigation/pumping. The piezometer in well 16880 is at 30 m BGL. The average value of all estimations was used as the BE coefficient in the barometric correction of the groundwater levels recorded during the slug tests above 89.0 m BGL.

Timeframe		**BE Correlation Well 16880**
From	**To**	
20/07/2019	19/08/2019	0.1782
7/09/2019	6/10/2019	0.1846
1/07/2020	30/07/2020	0.4856
1/08/2020	31/08/2020	0.1729
1/09/2020	30/09/2020	0.1475
1/07/2021	31/07/2021	0.1868
1/08/2021	31/08/2021	0.3649
Average All Timeframe		**0.2458**

Table A6.4 Barometric efficiency of the aquifer (BE) estimation results for the confined aquifer layer. An estimation was first made for each timeframe with the graphic method. The timeframes were chosen in the monitoring period prior to the start of the pumping test. It is uncertain if irrigation occurred during the period between 13/05 and 19/05. However, it is certain that no irrigation occurred during the period between 20/05 and 24/05. The screens in wells 16668 and 16713 are at a similar depth to the screen at well 17136 during the pumping test. The average value of all estimations was used as the BE coefficient in the barometric correction of the groundwater levels recorded during the pumping test and the slug tests below 89.0 m BGL.

Timeframe		**BE Correlation Well 16668**	**BE Correlation Well 16713**
From	**To**		
13/05/2021	19/05/2021	0.5733	0.6392
20/05/2021	24/05/2021	0.5574	0.3787
Average All Timeframe		0.5654	0.5090
		0.5372	

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

- Water level above ground level (artesian conditions) is noted by positive values and 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: $\Delta H = H_{t+1} - H_t$ (Gonthier 2007).
- All drawdown calculations are based on this relation.
- An increase in the barometric pressure is considered a negative change and gives the following relation:

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

All data utilised in the pumping test analysis was corrected for barometric pressure before any analysis was made. Manual water-level measurements were neither corrected nor analysed.

A6.3 Results and Analysis

AQTESOLV Pro software was used for the analysis of the pumping test data.

Based on the lithological log of well 17136 (Figure 2.5), the thickness of the confined aquifer is assumed to be 11.0 m (Figure A6.2 and Table A6.5). The top of the confined aquifer is assumed to be at 90.0 m BGL corresponding to the base of the muddy-silty sand layer, while the aquifer base is assumed to be at 101.0 m BGL, where a significant change in the lithology occurs corresponding to the base of the gravel layers.

Both observation wells have their screens located in a similar lithology to the one encountered at the pumping well, a gravel layer located below a blue siltstone layer (Table A6.1). It is assumed that the thickness of the confined aquifer at observation wells 16668 and 16713 is 12.7 m (Figure A6.2 and Table A6.5). Raw pumping test data is provided as a digital file with this report.

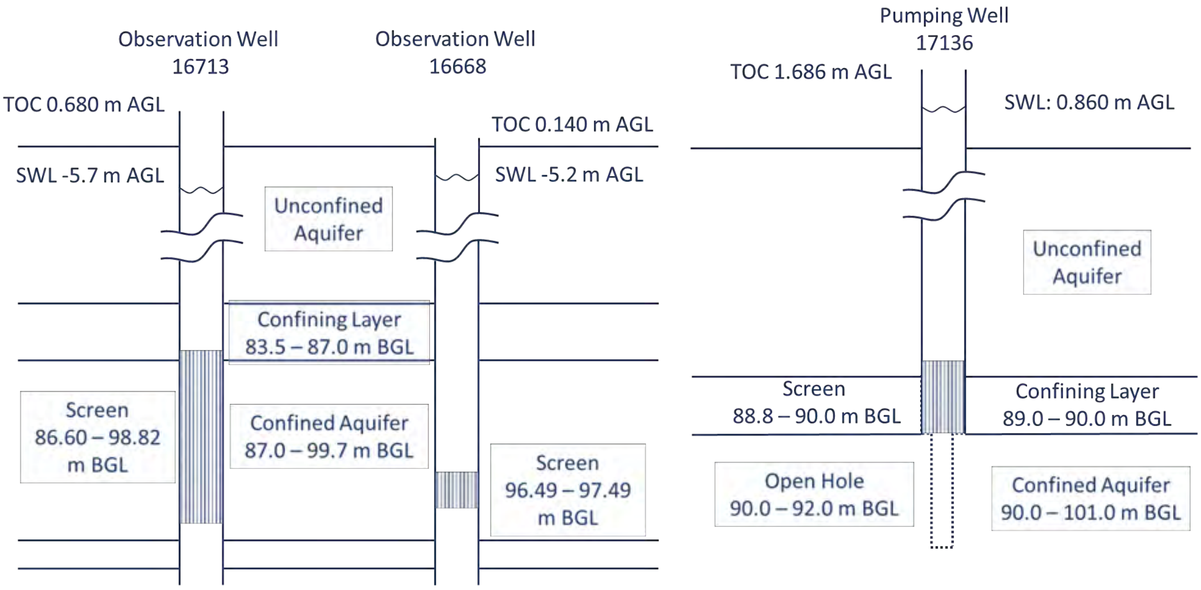


Figure A6.2 Schematic of the aquifers and bore construction details as utilised for this analysis for the two observation wells 16668 and 16713 on the left and for the pumping well 17136 on the right. AGL: Above Ground Level, BGL: Below Ground Level, TOC: Top of Casing, SWL: Static Water Level.

Table A6.5 Parameters used for the pumping tests analysis in AQTESOLV.

Well		Distance to Pumping Well (m)	Screen Depth (m BGL)		Screen Length (m)	Aquifer Saturated Thickness (m)	Top of Aquifer (m BGL)	Base of Aquifer (m BGL)
			Top	Bottom				
Pumping well 17136	Flow rate of 8 L/s	0	90*	92*	2 *	11	90	101
Observation well 16668		830	96.49	97.49	1	12.7	87	99.7
Observation well 16713			86.6	98.82	11.8 **			

* For the pumping well, since the well screen was fully in the confining layer, the open-hole section was considered as part of the screen for the analysis.

** For observation well 16713, only the section of the screen in the aquifer layer is accounted for in the screen length.

Table A6.6 summarises the results of the AQTESOLV pumping test analysis for all wells. The hydraulic conductivity (K) estimation is based on the assumption that the confined aquifer thickness at the pumping well is 11.0 m and 12.7 m at both observation wells.

Figures A6.3, A6.4 and A6.5 show the manual measurements and data logs acquired during the pumping test. Figures A6.6–A6.14 show the results of the AQTESOLV analysis.

Table A6.6 Summary of the pumping test solution analysis for each well. T is the transmissivity and K is the hydraulic conductivity.

Well	Pumping Test Screen Interval (m BGL)	Aquifer Saturated Thickness (m)	Analysis	Solution Used	T (m^2/day)	K (m/day)
Pumping well 17136	90.0–92.0	11	Drawdown/ Recovery	Theis	75.06	6.82
			Drawdown	Cooper-Jacob	40.99	3.73
			Recovery	Theis (Recovery)	40.96	3.72
Observation well 16668	96.49–97.49	12.7	Drawdown /Recovery	Theis	136.30	10.73
			Drawdown	Cooper-Jacob	235.80	18.57
			Recovery	Theis (Recovery)	140.30	11.05
Observation well 16713	87.0–98.82	12.7	Drawdown /Recovery	Theis	179.30	14.12
			Drawdown	Cooper-Jacob	363.60	28.63
			Recovery	Theis (Recovery)	138.90	10.94

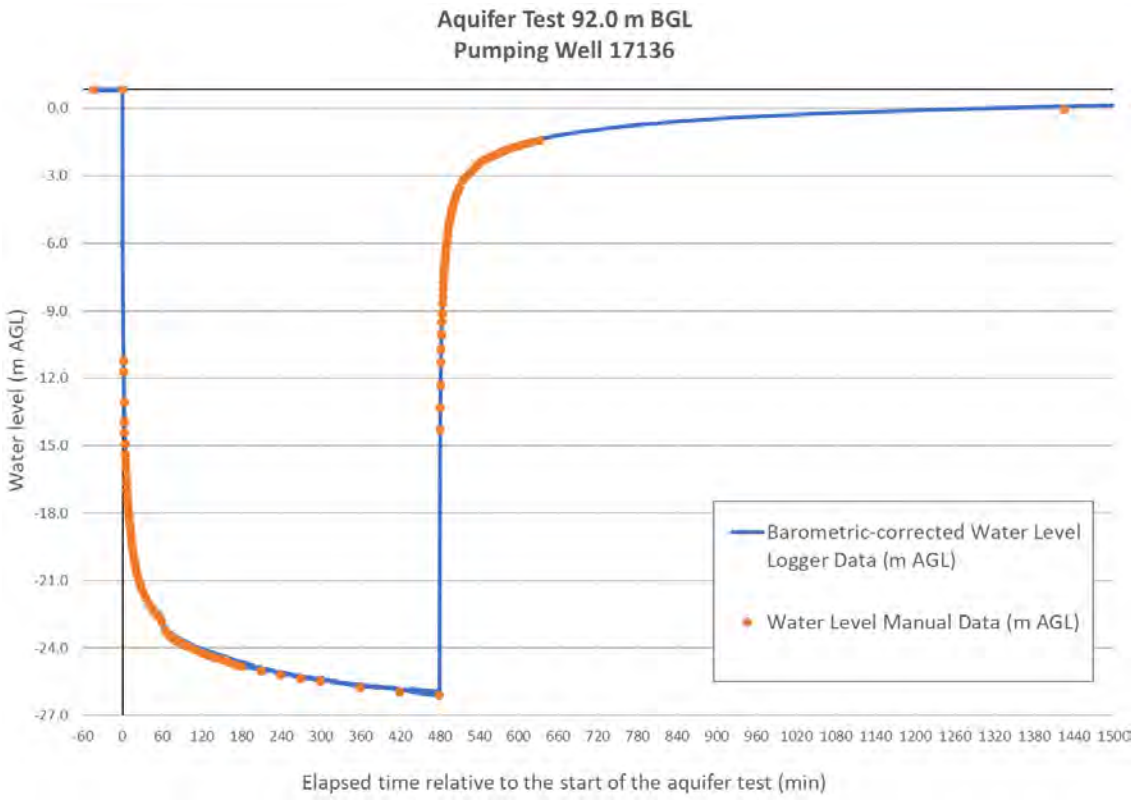


Figure A6.3 Manual measurements and barometric-corrected data log for the pumping well 17136 during the pumping test at 92.0 m BGL.

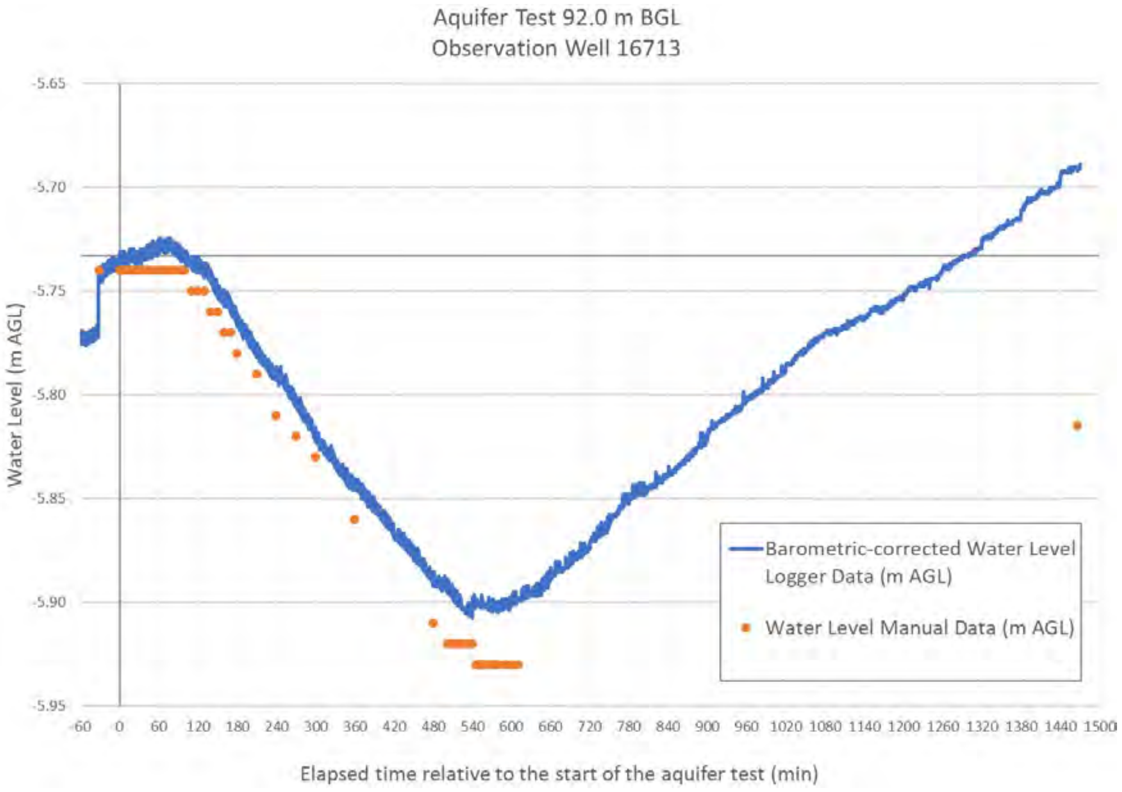


Figure A6.4 Manual measurements and barometric-corrected data log for the observation well 16713 during the pumping test at 92.0 m BGL. Note: The manual measurements have not been analysed and therefore have not been corrected for barometric pressure in this graph.

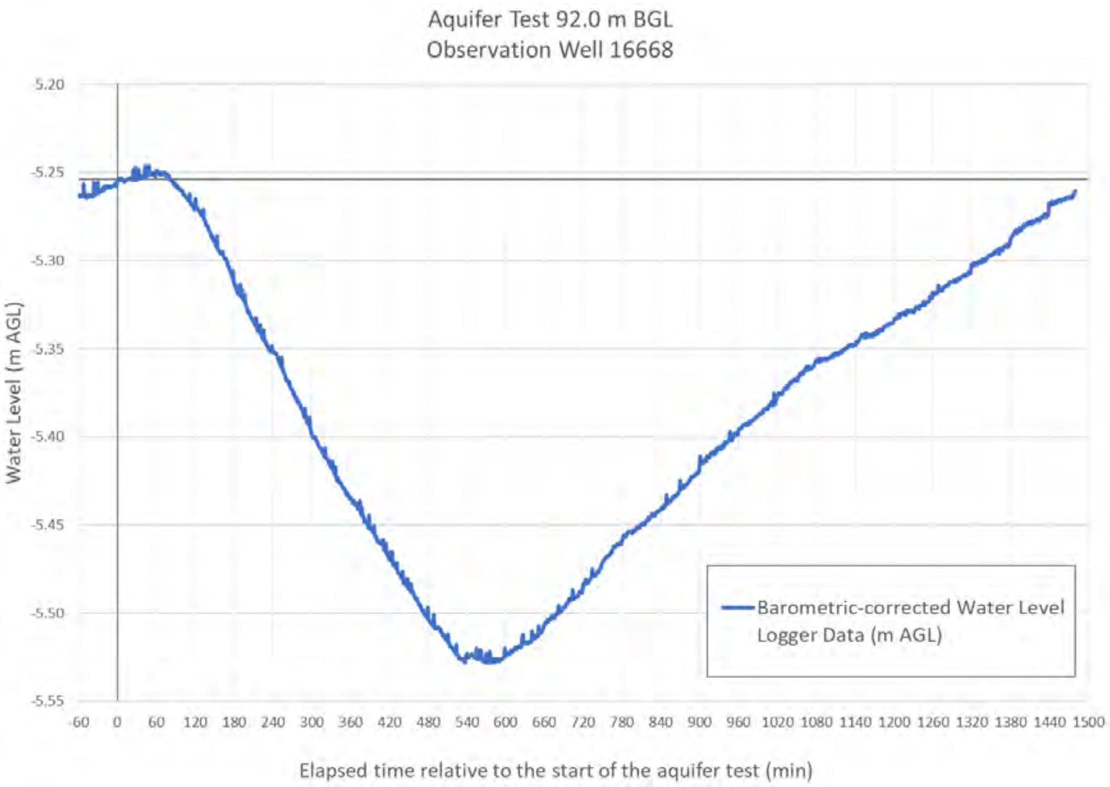


Figure A6.5 Barometric-corrected data log for the observation well 16713 during the pumping test at 92.0 m BGL. No manual measurements were acquired at this well.

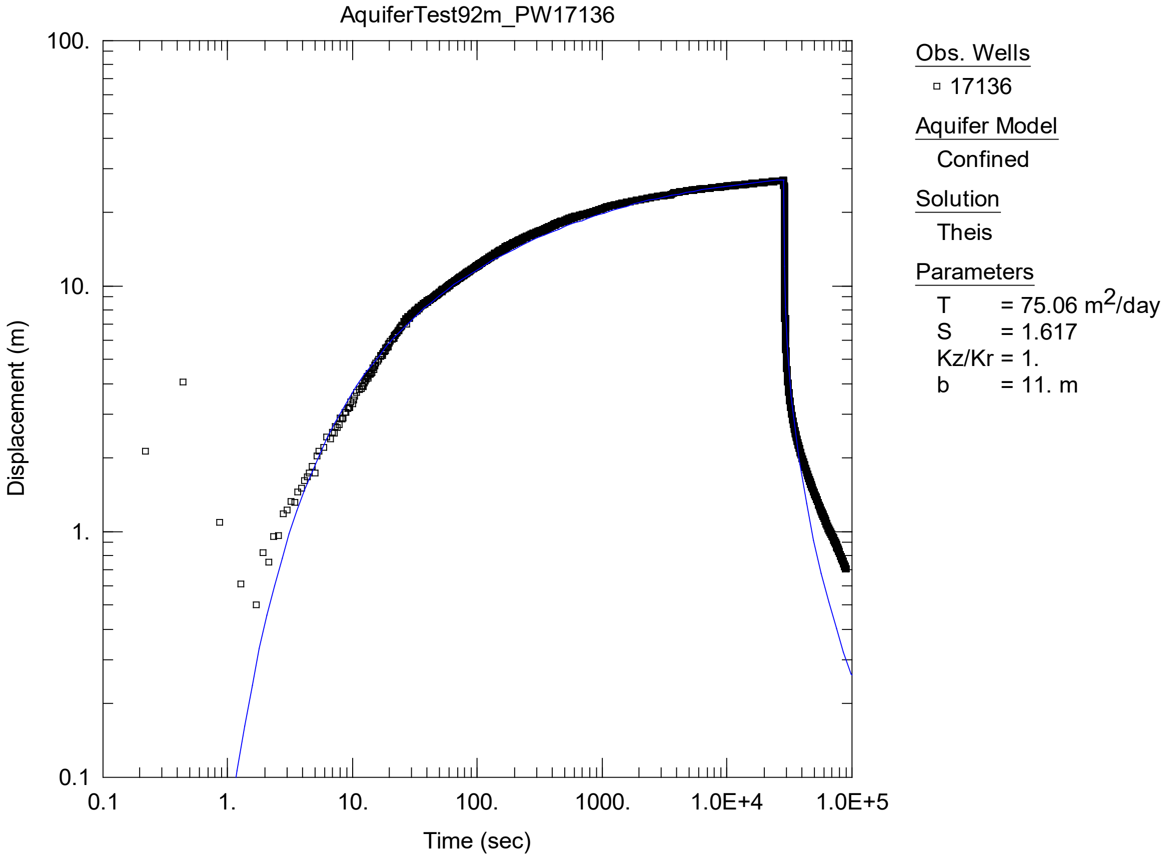


Figure A6.6 Drawdown and recovery analysis using the Theis solution in AQTESOLV on the pumping well 17136 during the pumping test.

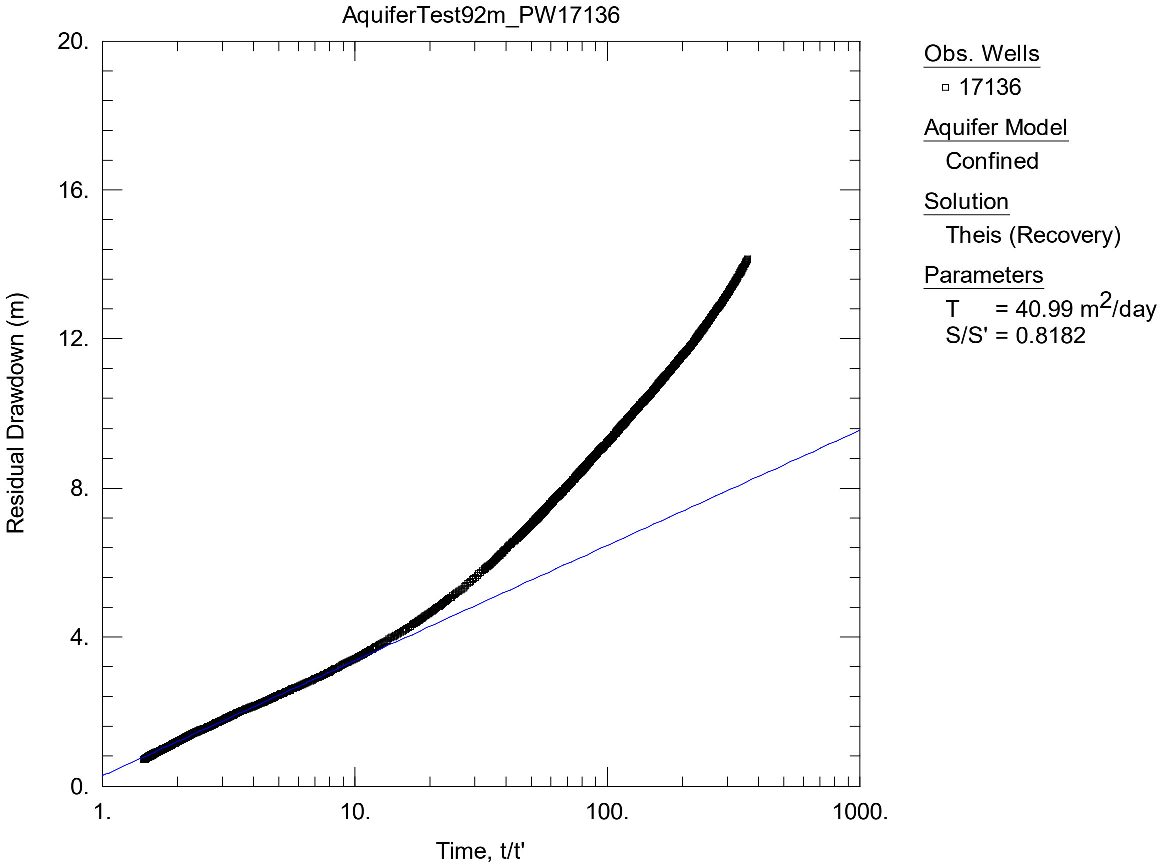


Figure A6.7 Recovery analysis using the Theis recovery solution in AQTESOLV on the pumping well 17136 during the pumping test.

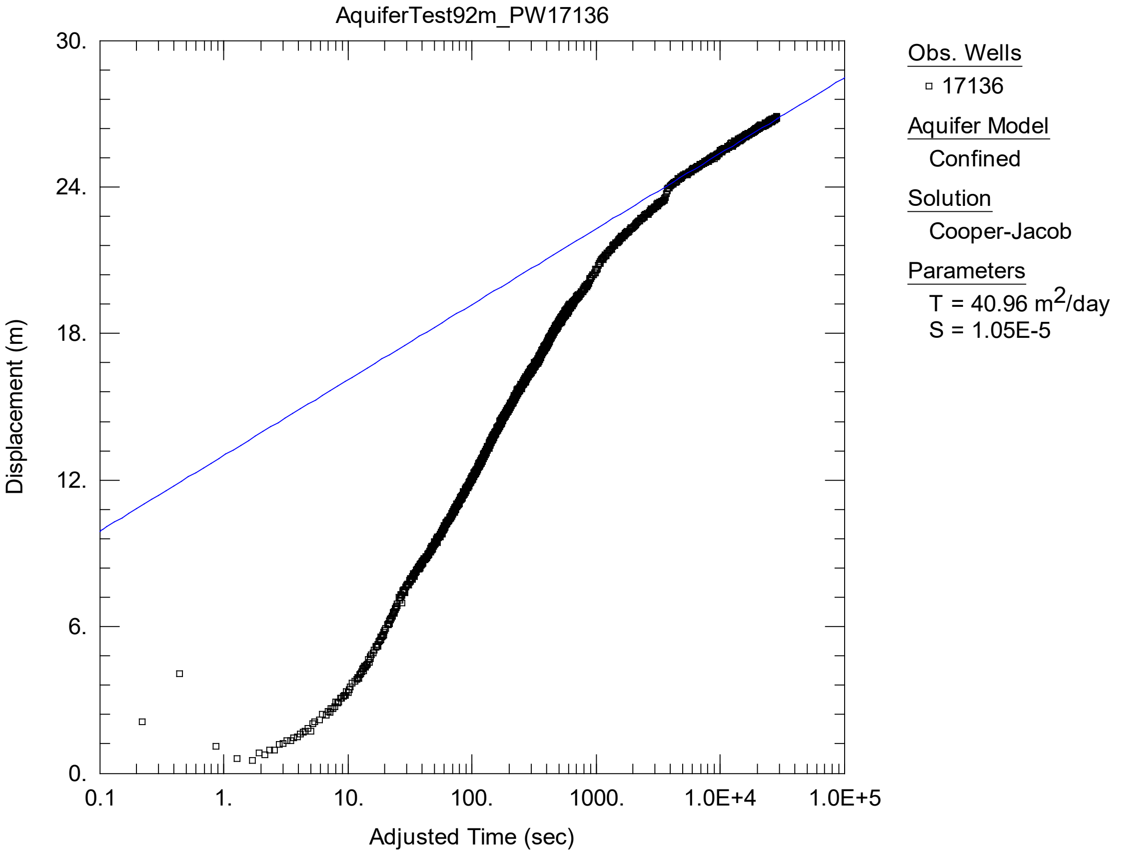


Figure A6.8 Drawdown analysis using the Cooper-Jacob solution in AQTESOLV on the pumping well 17136 during the pumping test.

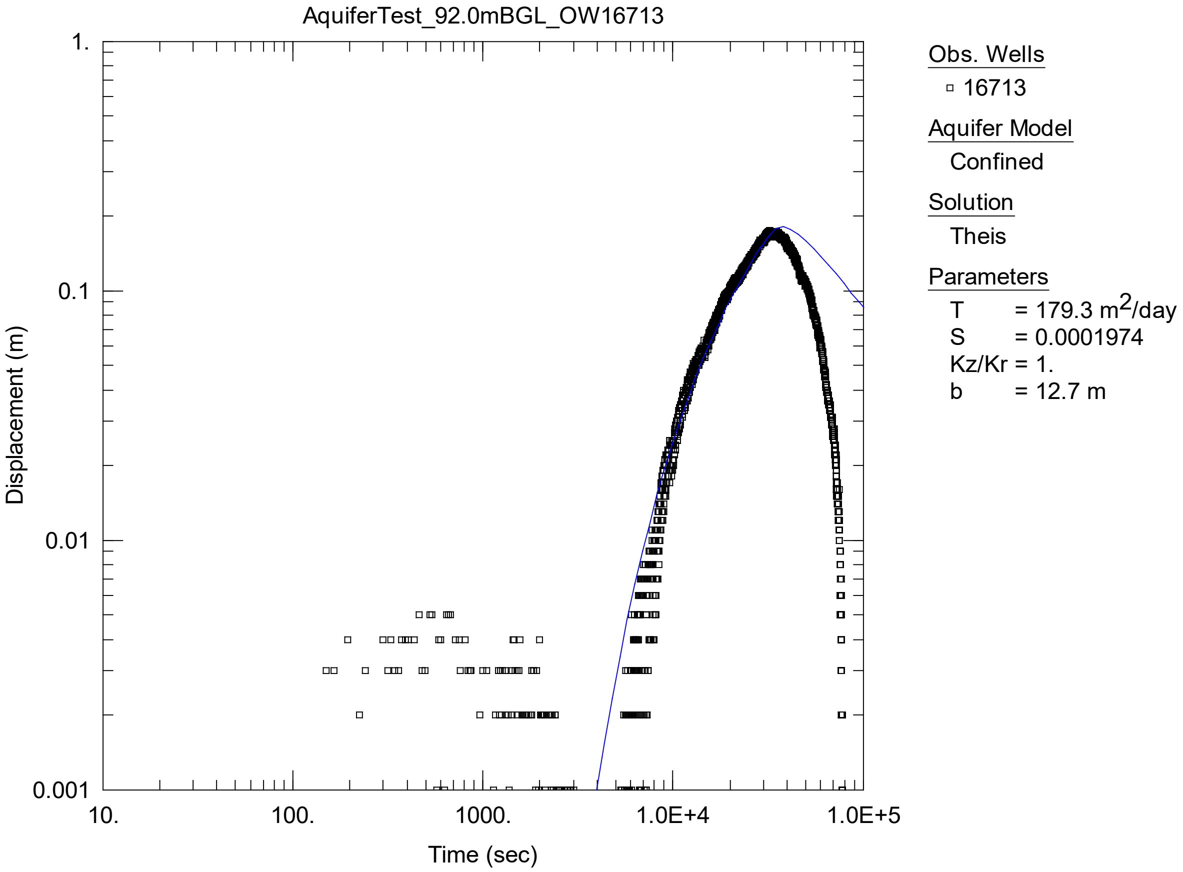


Figure A6.9 Drawdown and recovery analysis using the Theis solution in AQTESOLV on the observation well 16713 during the pumping test.

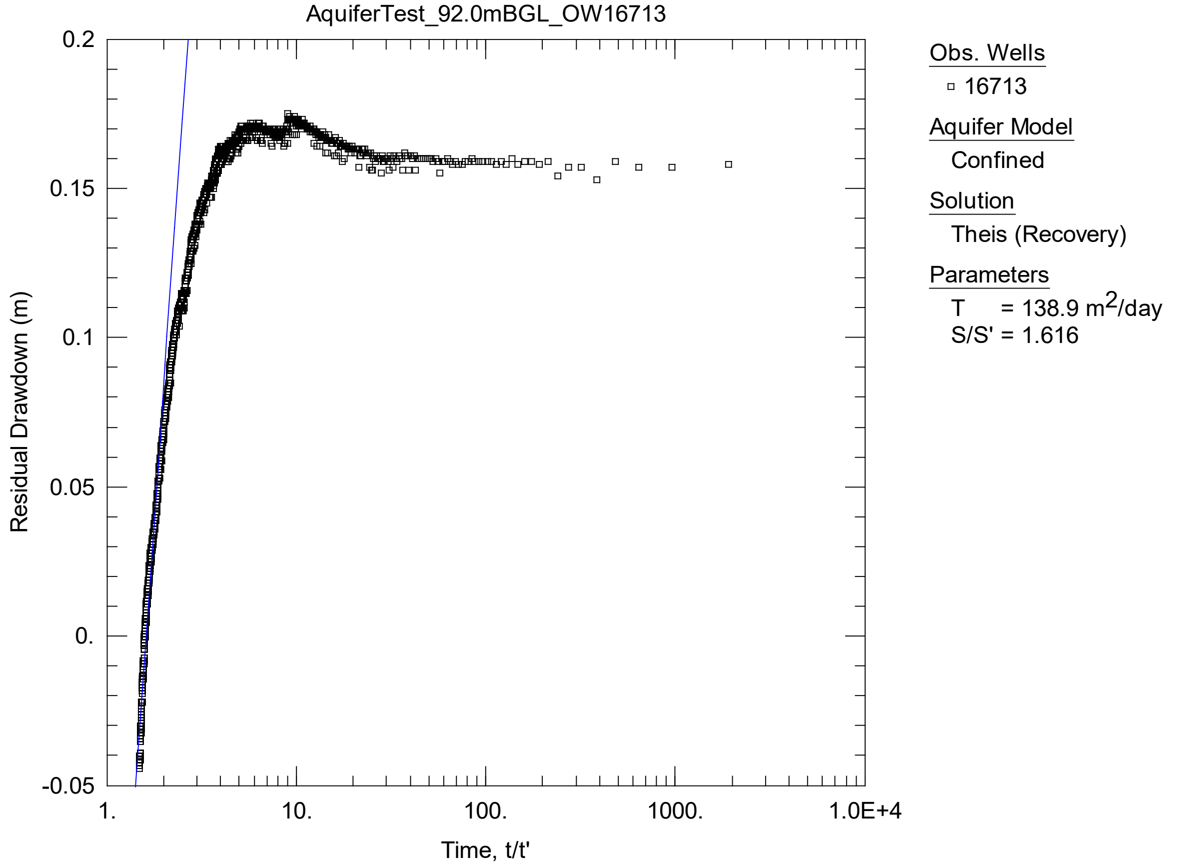


Figure A6.10 Recovery analysis using the Theis recovery solution in AQTESOLV on the observation well 16713 during the pumping test.

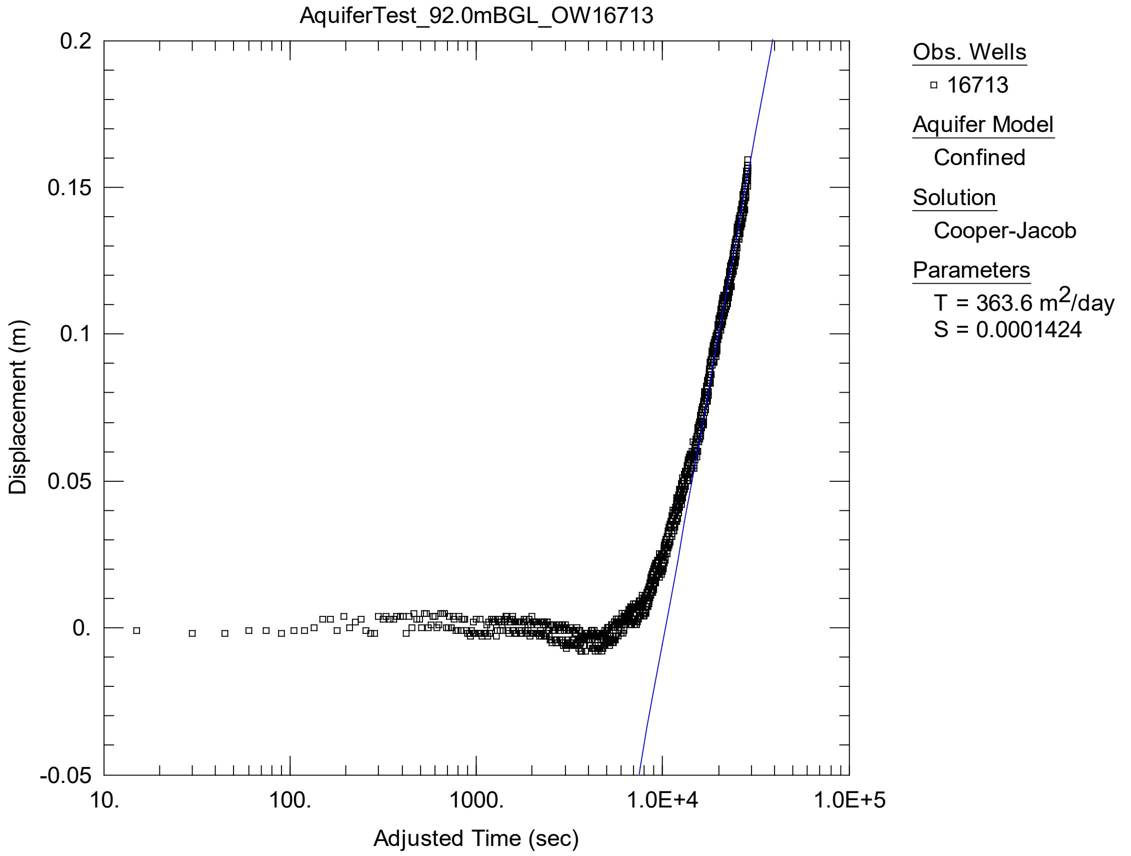


Figure A6.11 Drawdown analysis using the Cooper-Jacob solution in AQTESOLV on the observation well 16713 during the pumping test.

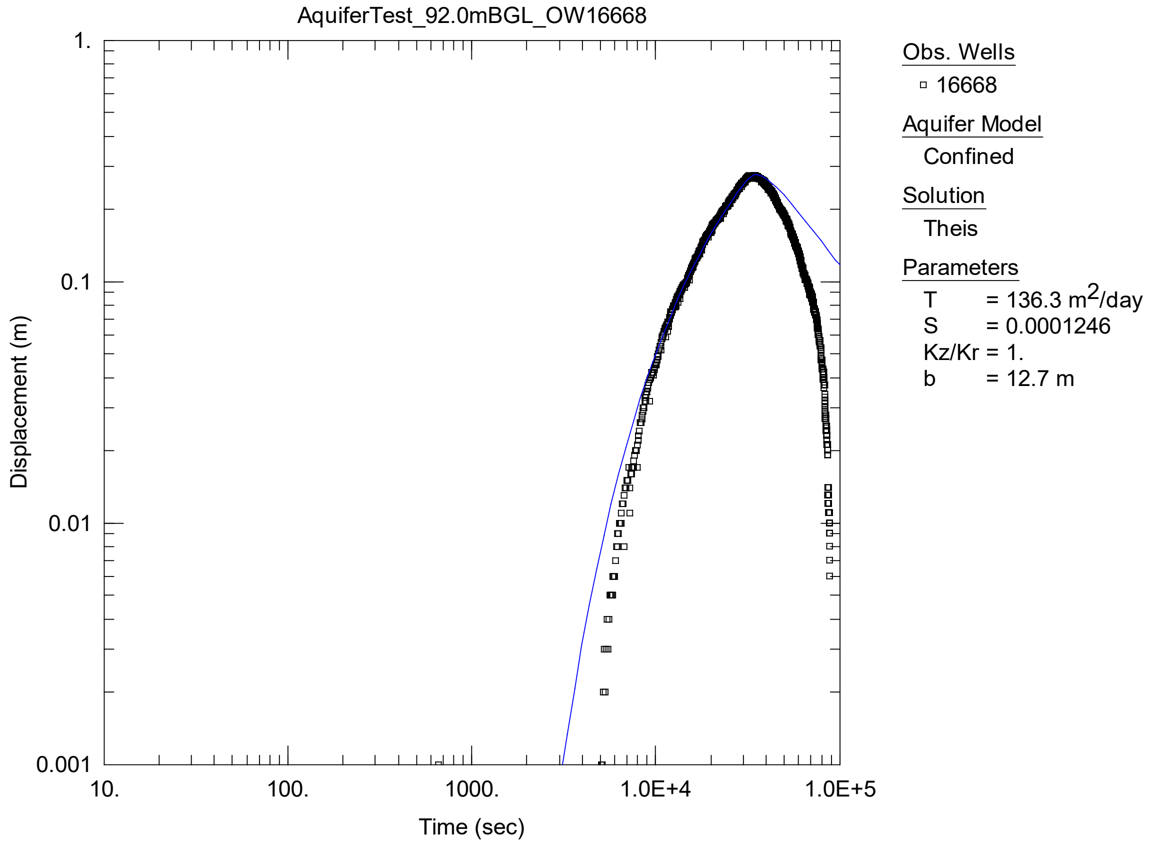


Figure A6.12 Drawdown and recovery analysis using the Theis solution in AQTESOLV on the observation well 16668 during the pumping test.

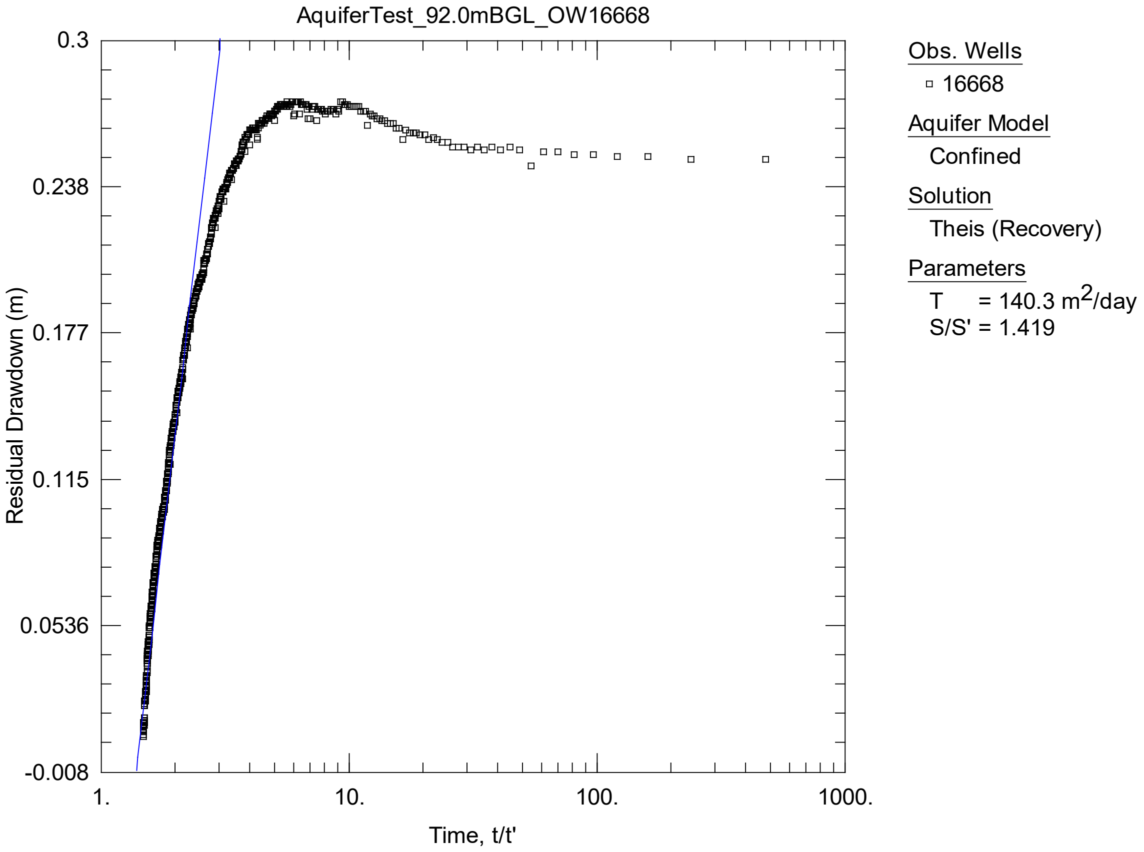


Figure A6.13 Recovery analysis using the Theis recovery solution in AQTESOLV on the observation well 16668 during the pumping test.

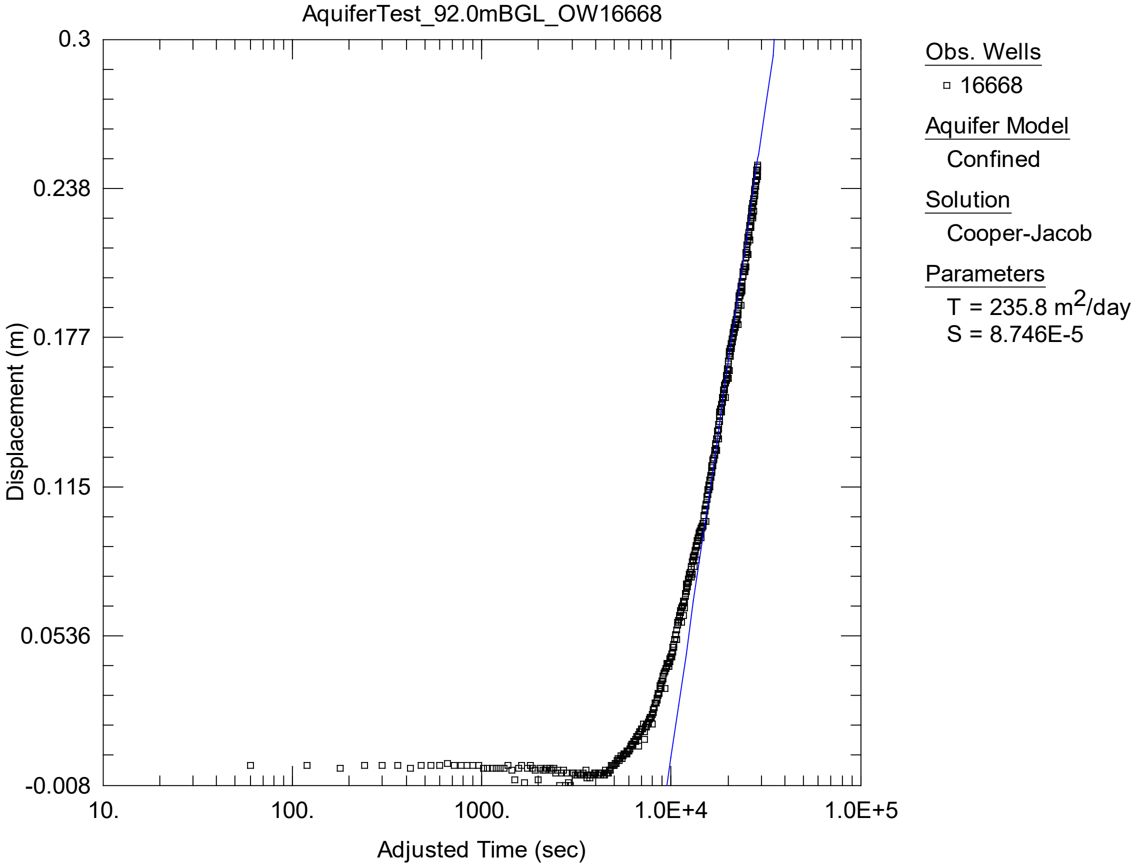


Figure A6.14 Drawdown analysis using the Cooper-Jacob solution in AQTESOLV on the observation well 16668 during the pumping test.

APPENDIX 7 SLUG TESTS

A series of 10 slug tests was performed at different depths at well 17136. Based on the lithology encountered while drilling (Figure 2.5) and the static water level measured at the beginning of each slug test (Table A7.1), we assume a confining layer is present between 89.0 and 90.0 m BGL. More detail of each of the slug tests, their analysis and results are presented in Sections A7.1 to A7.10.

Table A7.1 Summary of the depth of each slug test and the static water level of each layer encountered. A negative static water level indicates a water level below ground level, a positive static water level indicates a water level above ground level.

	Date	Depth (m BGL)	SWL (m AGL)	Recovery
Slug test 1	18/03/2021	10.78	-1.190	Yes, good
Slug test 2	23/03/2021	26.00	-3.621	Yes, good
Slug test 3	6/04/2021	47.20	-5.640	Yes, good
Slug test 4	8/04/2021	53.00	-5.430	Yes, good
Slug test 5	12/04/2021	55.00	-4.764	No recovery
Slug test 6	6/05/2021	79.00	-7.834*	Slug test recovery overshadowed by aquifer recovery
Slug test 7	13/05/2021	84.20	-5.515	Yes, very slow
Slug test 8	25/05/2021	92.00	0.082	Yes, very good
Slug test 9	28/05/2021	97.00	1.920	Yes, very good
Slug test 10	18/06/2021	110.50	0.587*	Slug test recovery overshadowed by aquifer recovery

* The water level prior to slug tests 6 and 10 was not static; more detail is provided in Sections A7.6 and A7.10.

The initial water level measured for slug tests 6 and 10 were not at static (more details in Sections A7.6 and A7.10), hence were not directly included in the assumption made about the top and bottom aquifer boundary estimation. From the water-level measurements, a negative hydraulic gradient with depth can be noted, with no indication of a lithological barrier acting as a confining layer for the first seven slug tests, meaning that the vertical groundwater movement is downward over these depths and the shallow groundwater is recharging the deeper layers. However, a positive hydraulic head is observed during slug tests 8, 9 and 10, meaning that the vertical groundwater movement is upward over these depths and the deeper groundwater is recharging the shallower layers, which suggests confined aquifer conditions at these depths.

The lithological log (Figure 2.5) shows a muddy-silty sand layer between 89.0 and 90.0 m BGL, which is assumed to be the confining layer for the aquifer tested during the pumping test at 92.0 m BGL and the slug tests at 92.0 m, 97.0 and 110.5 m BGL. It is assumed for the analysis of the pumping test and slug tests in these layers that the base of the aquifer is at 101.0 m BGL, where a significant change in lithology is observed. It is also assumed for the analysis of the slug tests in the unconfined layer that the base of the aquifer is the top of the confining unit at 89 m BGL.

A total of six different slugs have been utilised for the slug tests at well 17136; a summary of their volume and potential water displacement is presented in Table A7.2.

Table A7.2 Summary of the volume of the slugs used for the slug tests and the expected water displacement in the well. The casing inner diameter was 0.203 m (8") during slug tests 1 to 7 and 0.155 m (6 ¼") during slug tests 8 to 10 and the pumping test.

	Volumes		**Expected Water Displacement in the Well**			
Slug Number	**Volume (m^3)**	**Volume (L)**	**Well Inner Diameter (m)**	**Water Displacement (m)**	**Well Inner Diameter (m)**	**Water Displacement (m)**
1	0.0119	11.88	0.203	0.367	0.155	0.629
2	0.0058	5.76		0.178		0.305
3	0.0054	5.43		0.168		0.288
4	0.0042	4.19		0.129		0.222
5	0.0015	1.55		0.048		0.082
6	0.0013	1.30		0.040		0.069

A7.1 Slug Tests at 10.78 m BGL

A7.1.1 Settings Details

A series of slug tests were performed on 18 March 2021 at a depth of 10.78 m BGL in a poorly sorted sub-angular to sub-rounded gravel layer. Three different sizes of slugs (slugs 2, 3 and 5) were used to undertake slug-in and -out tests. Slug tests were repeated 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 and every second using a HOBO Bluetooth water-level data logger. The weather was constant with no rainfall recorded over the length of the test. No barometric pressure correction was made for this slug test, as the barometric pressure data remained stable for the entire duration of the test, meaning the effect on the water level is considered negligible.

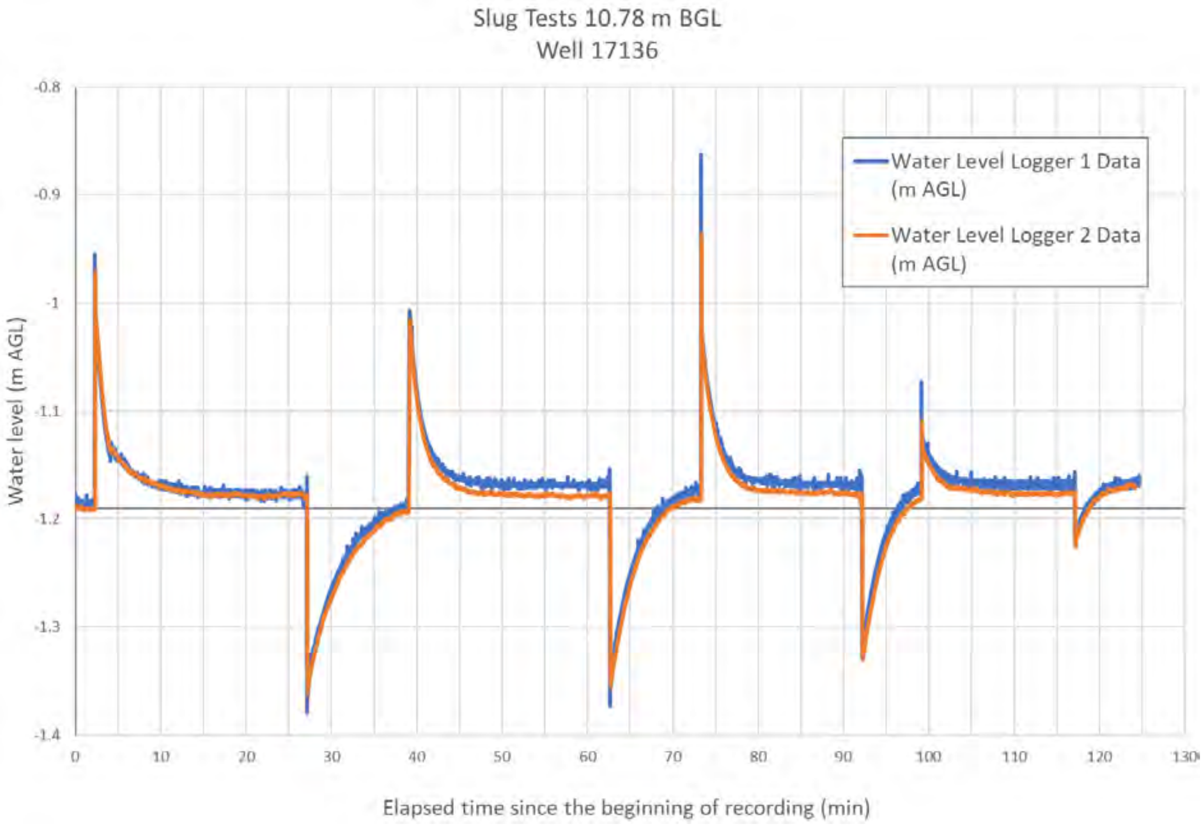


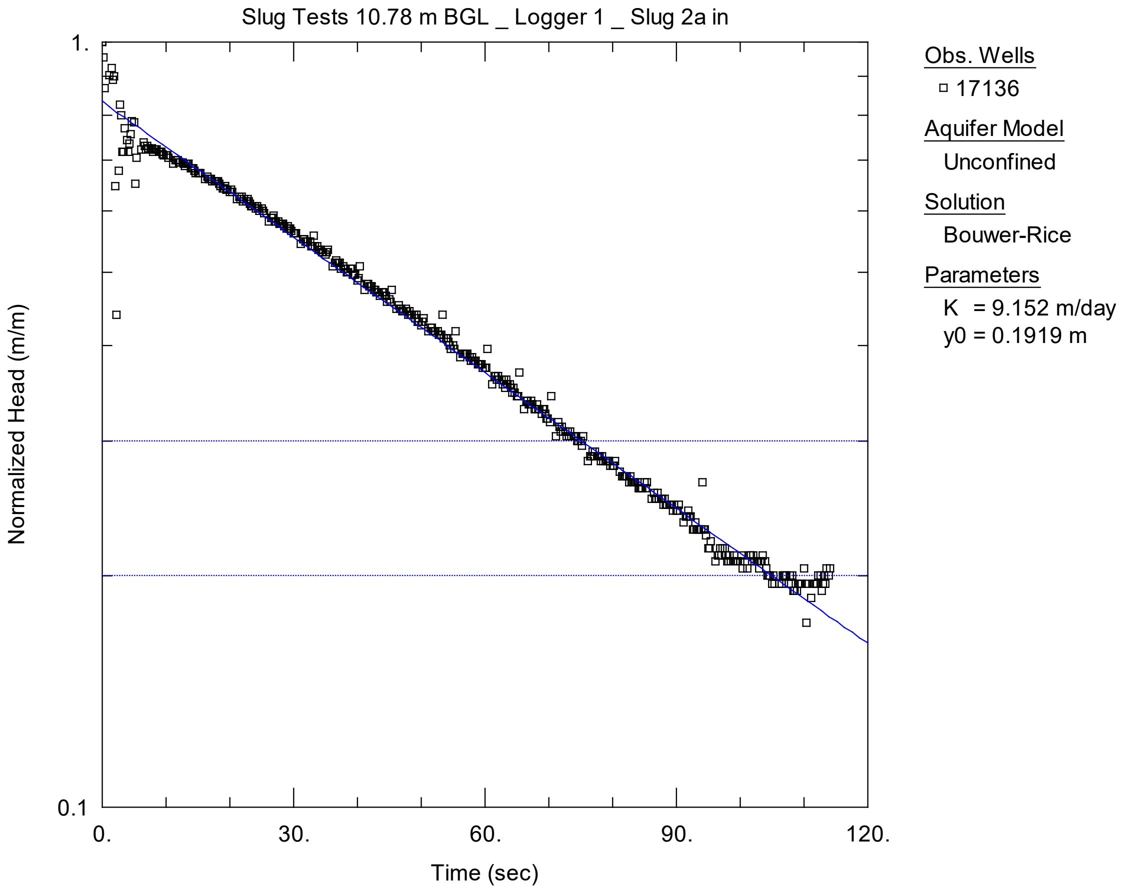
Figure A7.1 Fluctuation of the water level during the slug tests at 10.78 m BGL. Four slug tests were undertaken with the following slugs in order: slug 2, slug 2, slug 3 and slug 5. Logger 1 is a Level TROLL 700 data logger and logger 2 is a HOBO Bluetooth data logger.

A7.1.2 Results and Analysis

The slug-test data was analysed using AQTESOLV Pro software. Each slug in and slug out were analysed on their own, and a Bouwer-Rice solution was fitted to the curves (Figures A7.2–A7.9). From this solution, a hydraulic conductivity (K) was calculated and summarised in Table A7.3. A hydraulic conductivity average of 5.8 m/day was estimated for this layer. Assumptions made on the different parameters for this analysis (e.g. saturated thickness of the aquifer) might impact the results as they may be under- or over-estimated.

Table A7.3 Summary of the hydraulic conductivity calculated for each slug-in and slug-out test.

		Slug Test 2a		**Slug Test 2b**		**Slug Test 3**		**Slug Test 5**	
		In	**Out**	**In**	**Out**	**In**	**Out**	**In**	**Out**
K (m/day)	Calculated from the Level TROLL 700 logger data	9.2	3.2	5.7	3.9	6.2	5.1	6.3	7.5
	Calculated from the Bluetooth logger data	8.6	2.5	5.7	3.9	6.0	5.2	5.4	7.9
	Test average	**5.9**		**4.8**		**5.6**		**6.8**	
	Total	**5.8**							



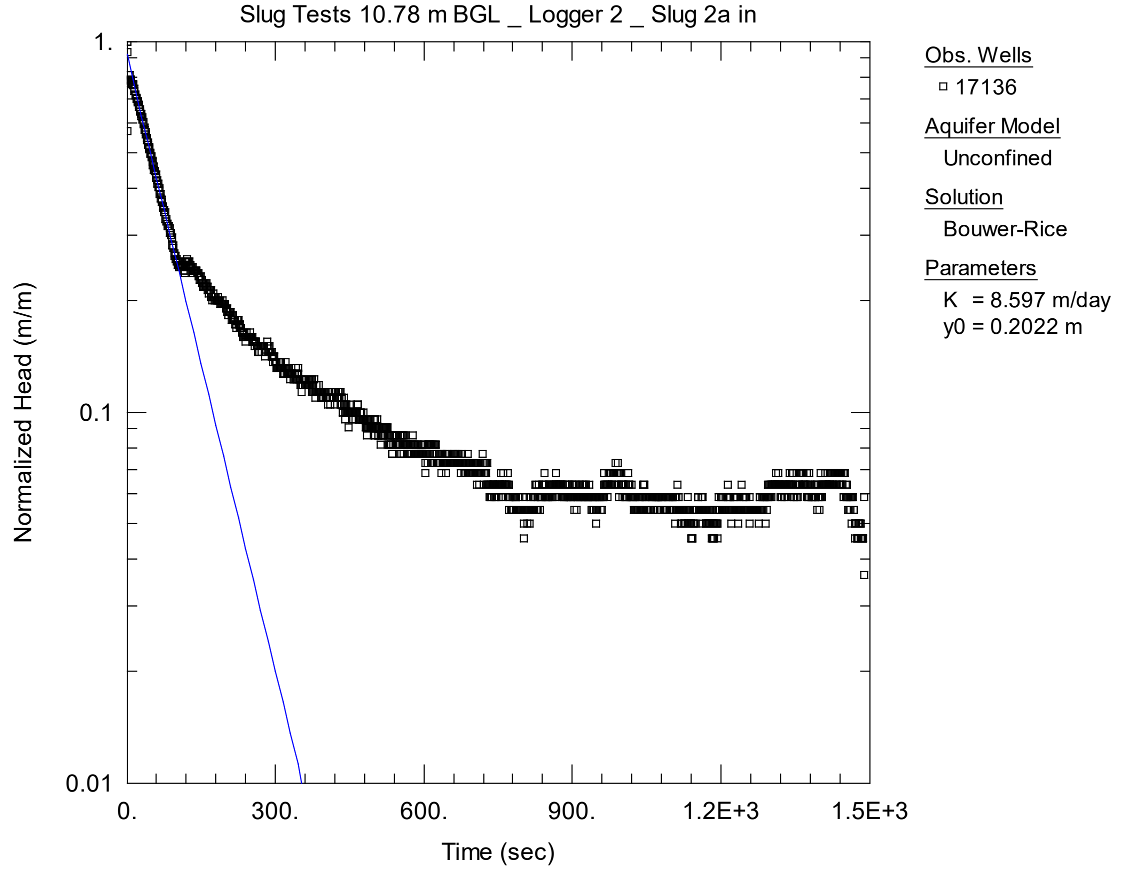
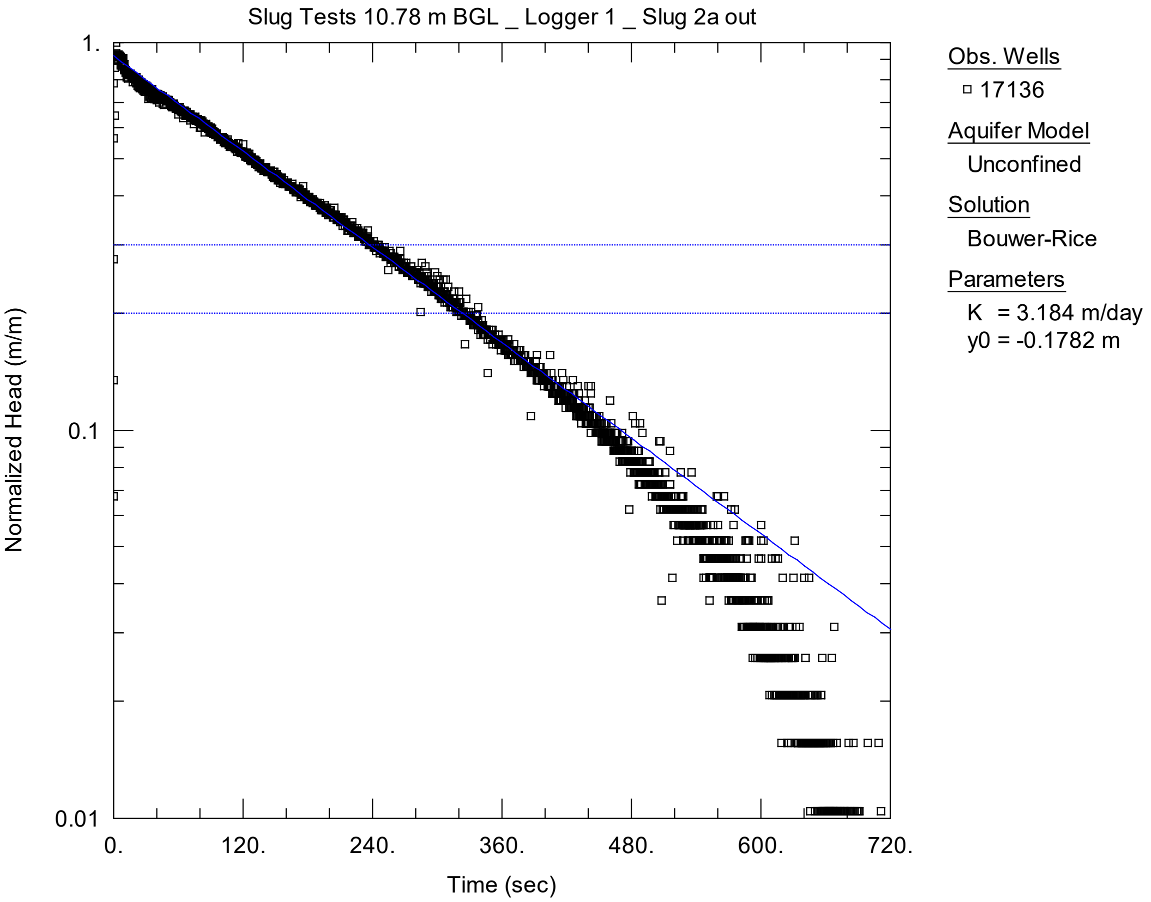


Figure A7.2 Results of the analysis for the first slug-in test, with slug 2 undertaken at 10.78 m BGL for both loggers. Logger 1 is a Level TROLL 700 data logger; logger 2 is a HOBO Bluetooth data logger.



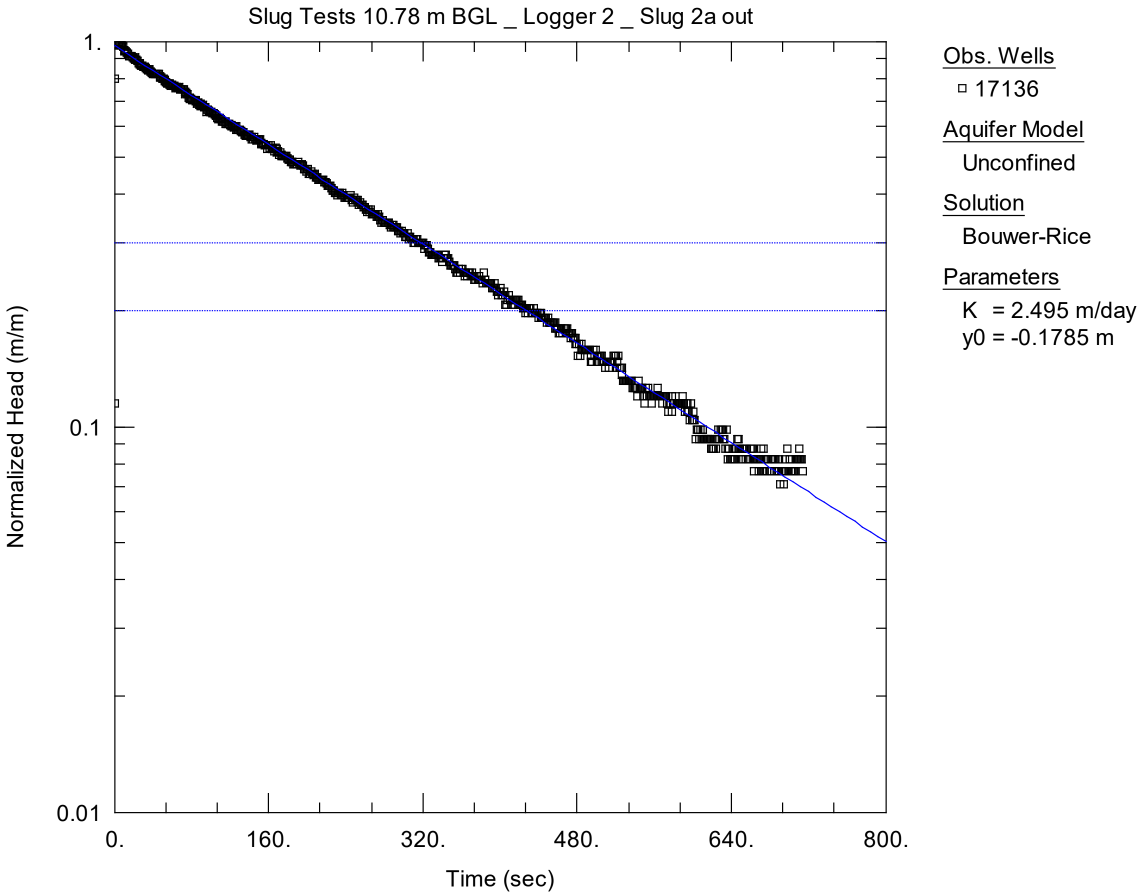
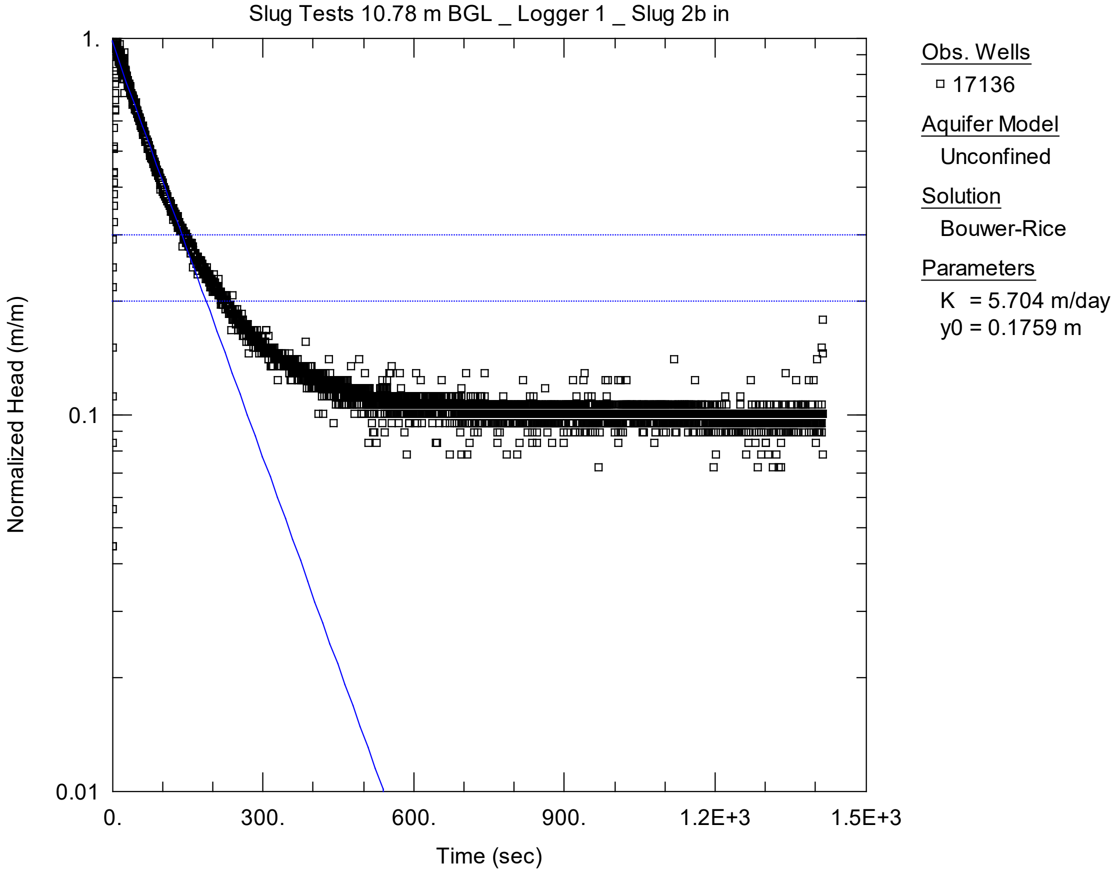


Figure A7.3 Results of the analysis for the first slug-out test with slug 2 undertaken at 10.78 m BGL for both loggers. Logger 1 is a Level TROLL 700 data logger; logger 2 is a HOBO Bluetooth data logger.



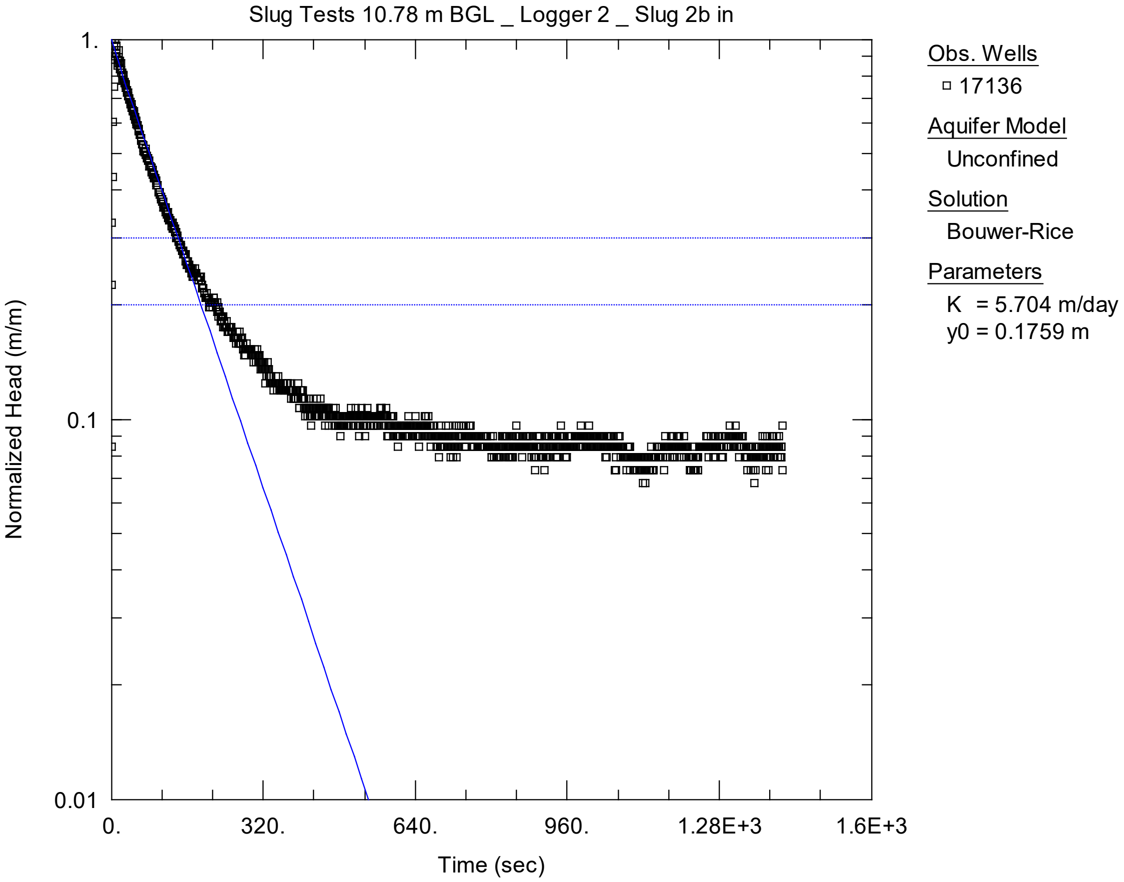
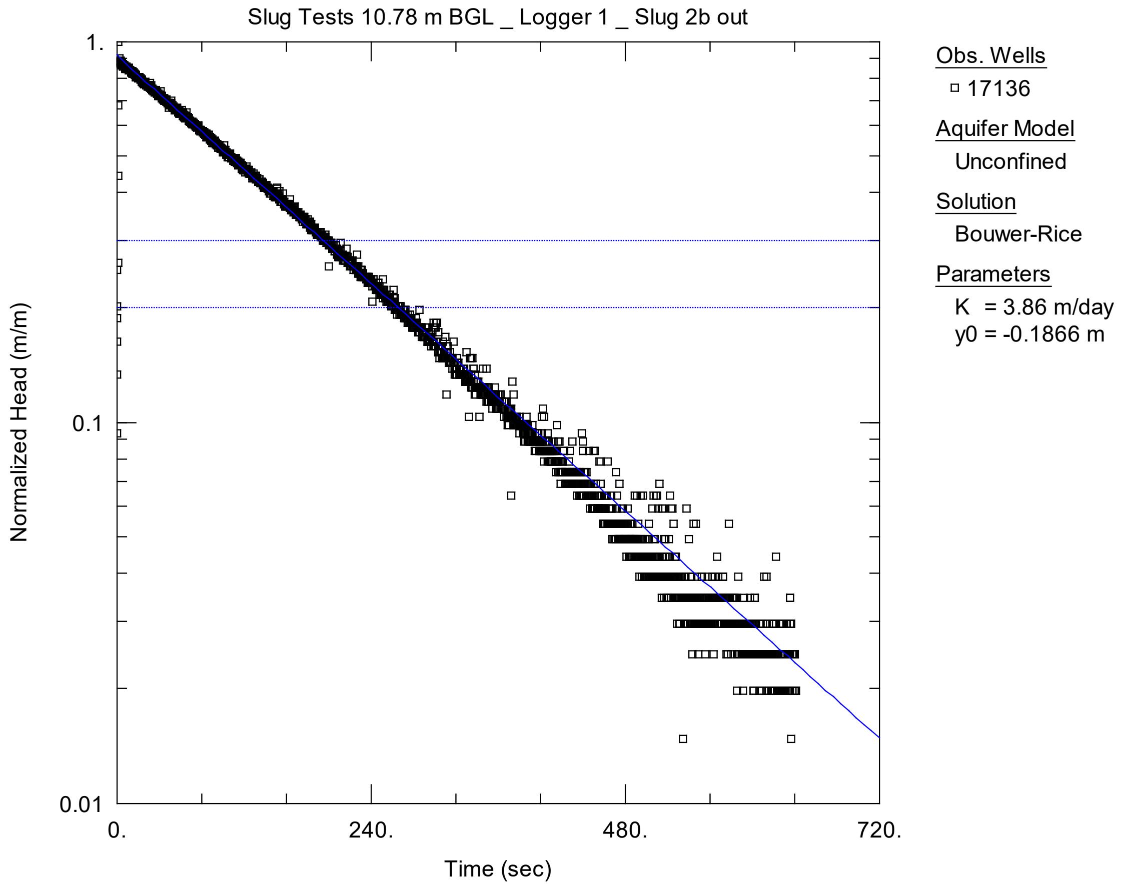


Figure A7.4 Results of the analysis for the second slug-in test with slug 2 undertaken at 10.78 m BGL for both loggers. Logger 1 is a Level TROLL 700 data logger; logger 2 is a HOBO Bluetooth data logger.



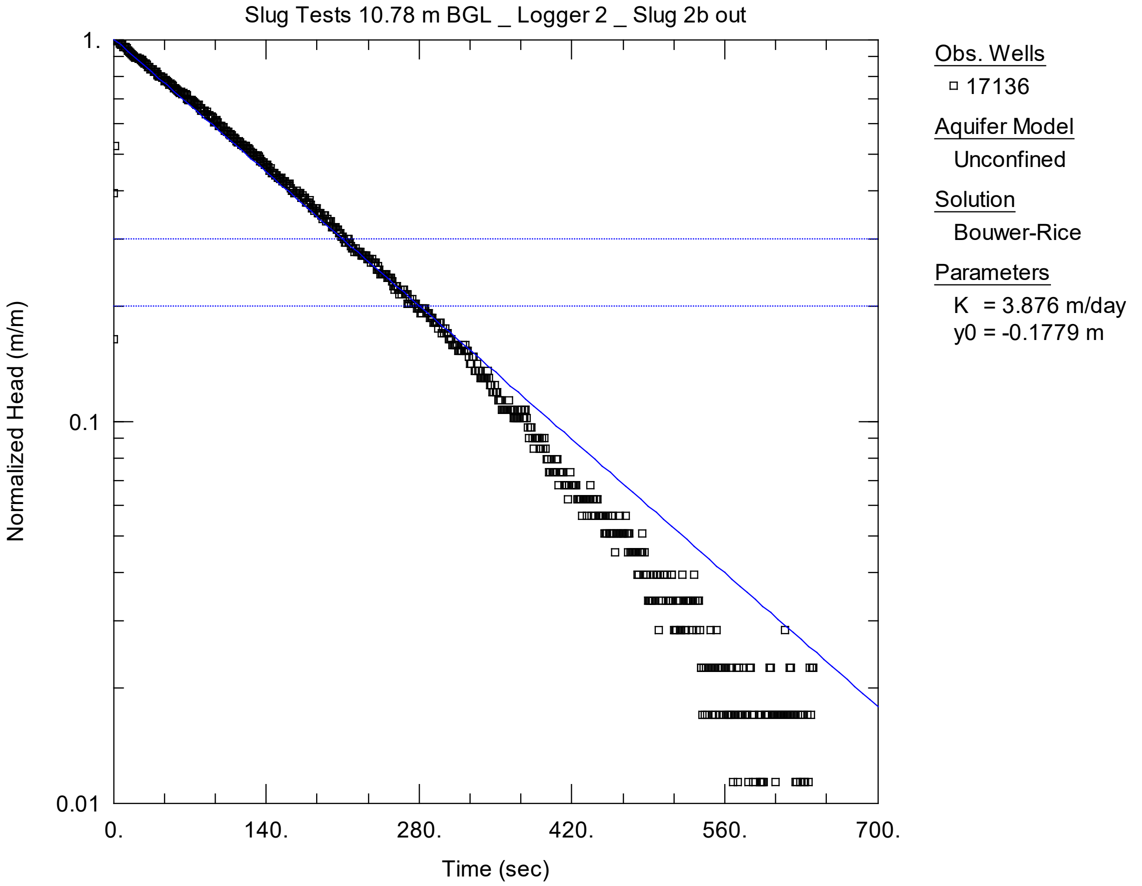
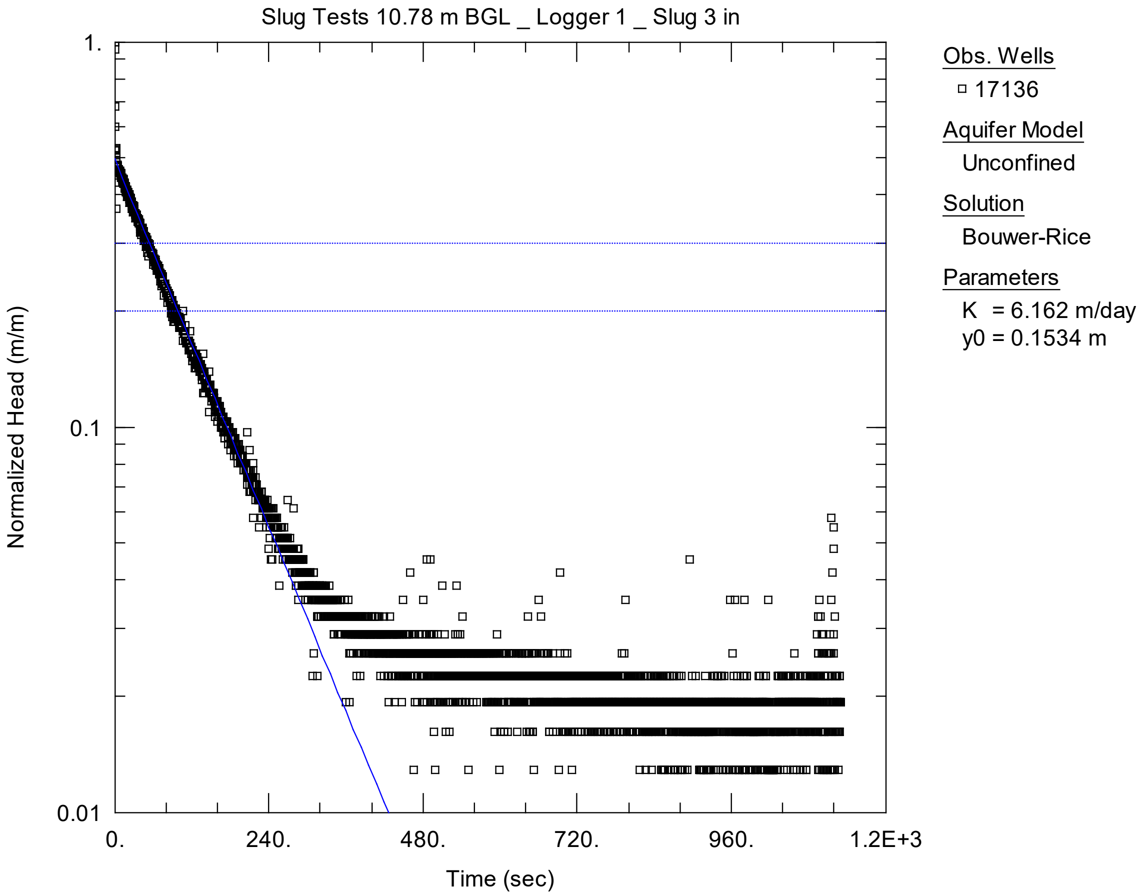


Figure A7.5 Results of the analysis for the second slug-out test with slug 2 undertaken at 10.78 m BGL for both loggers. Logger 1 is a Level TROLL 700 data logger; logger 2 is a HOBO Bluetooth data logger.



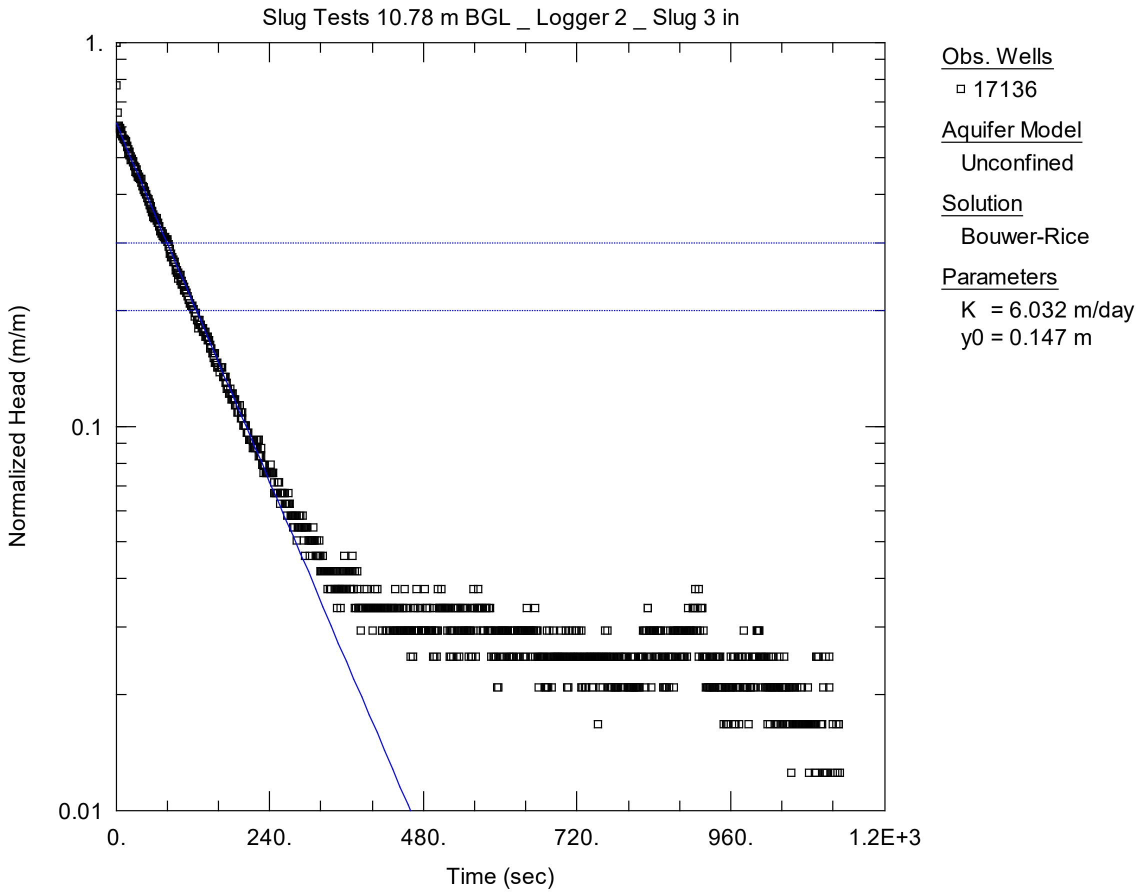
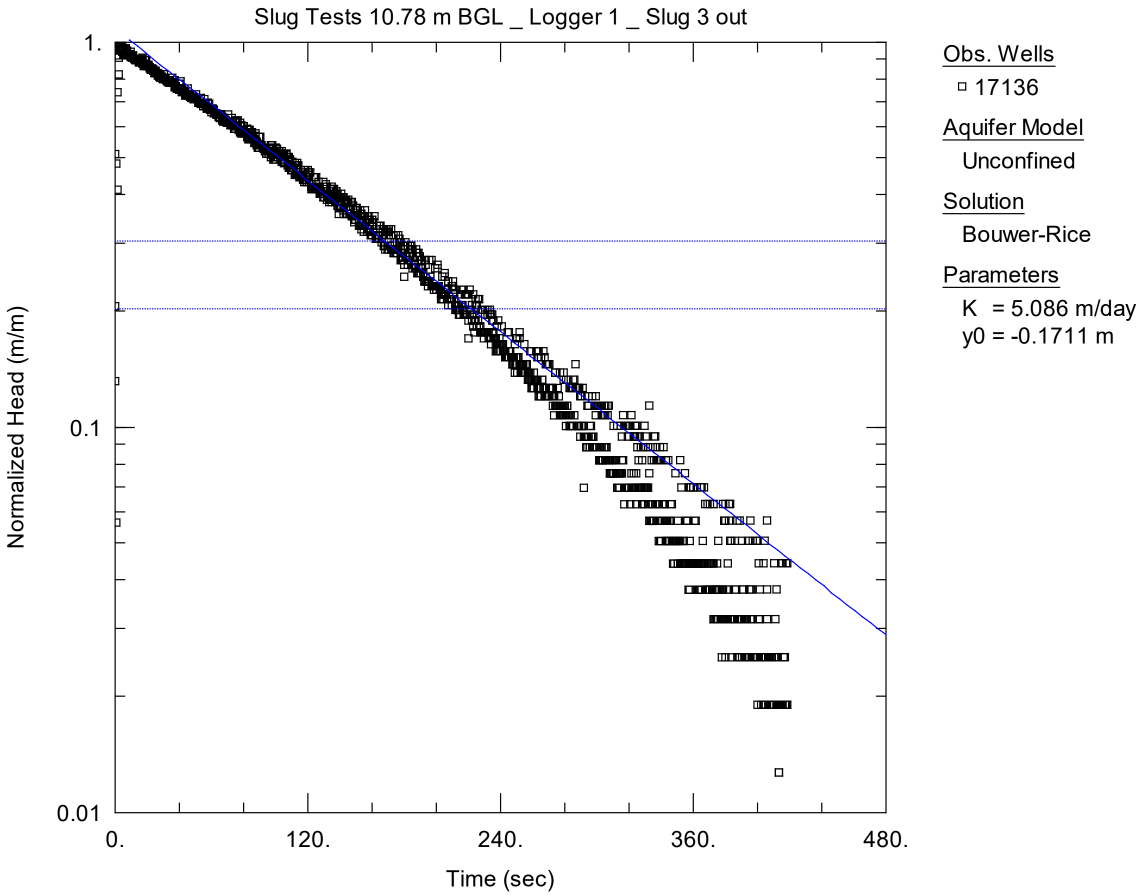


Figure A7.6 Results of the analysis for the slug-in test with slug 3 undertaken at 10.78 m BGL for both loggers. Logger 1 is a Level TROLL 700 data logger; logger 2 is a HOBO Bluetooth data logger.



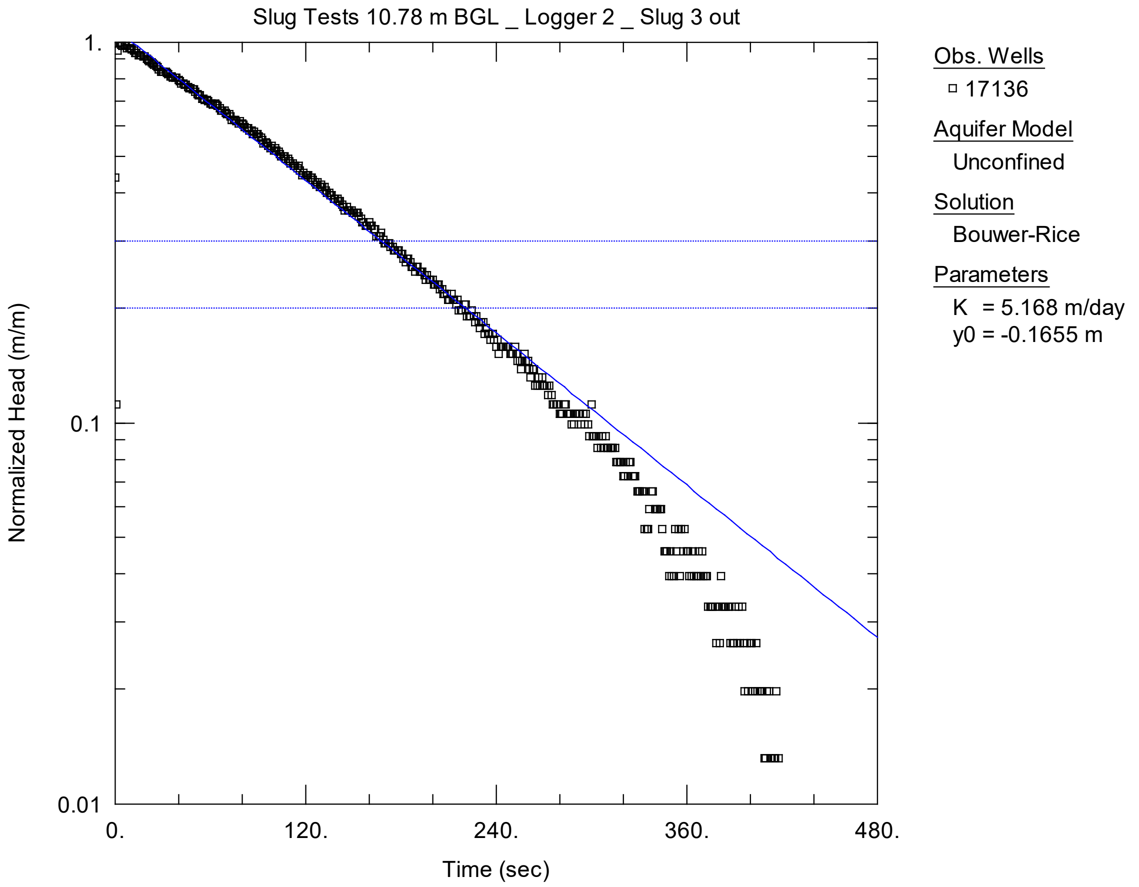
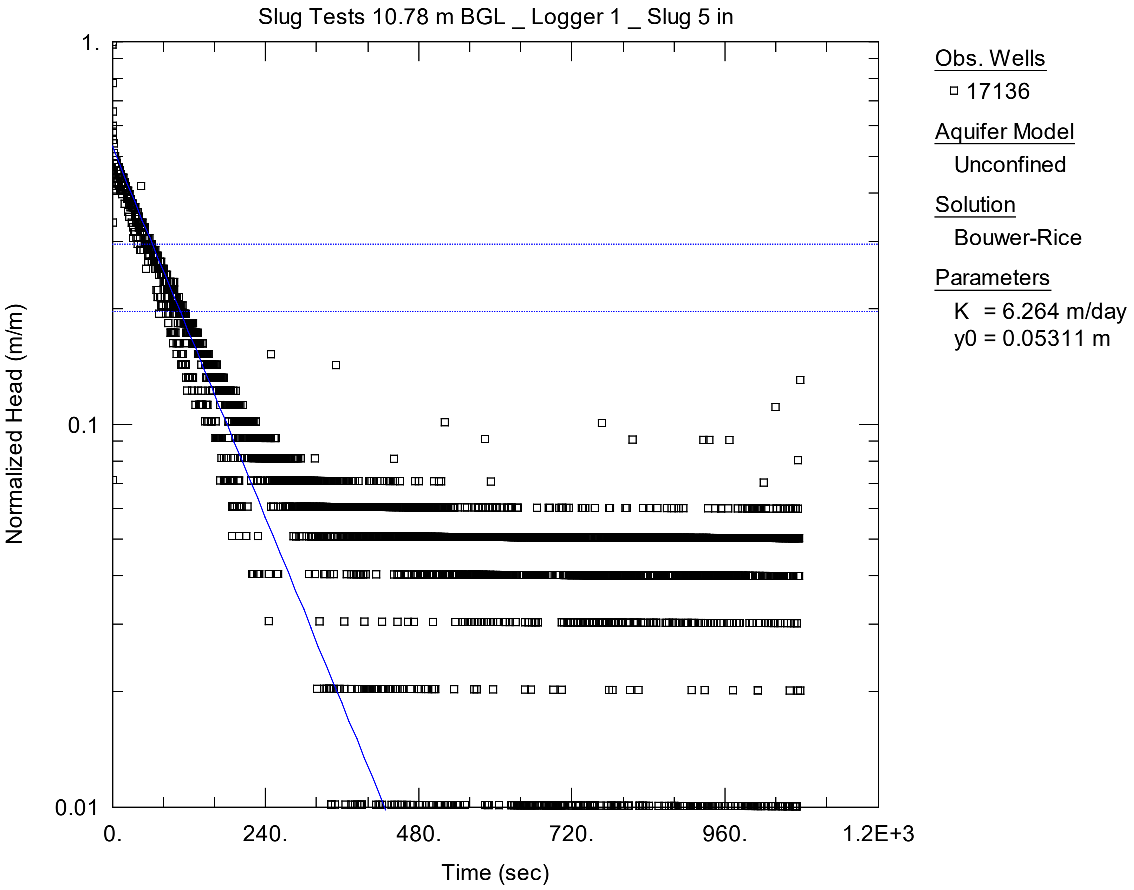


Figure A7.7 Results of the analysis for the slug-out test with slug 3 undertaken at 10.78 m BGL for both loggers. Logger 1 is a Level TROLL 700 data logger; logger 2 is a HOBO Bluetooth data logger.



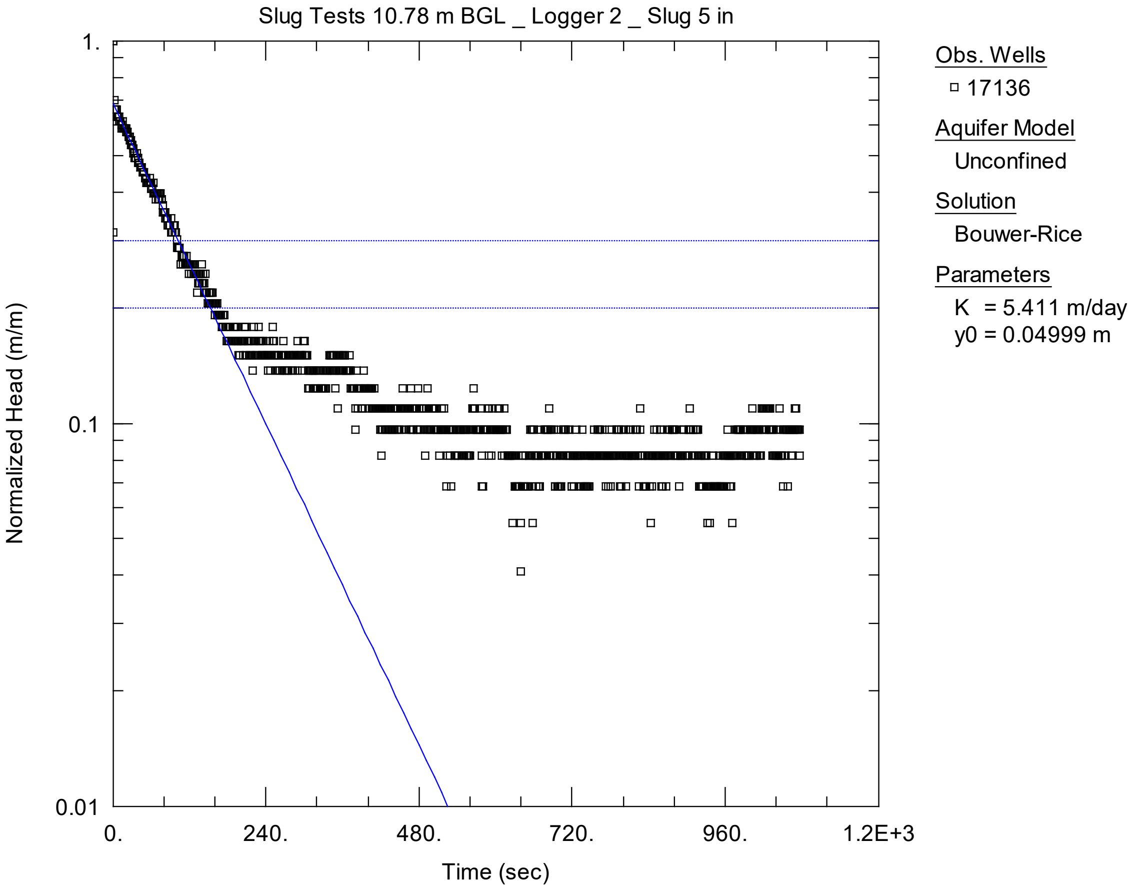
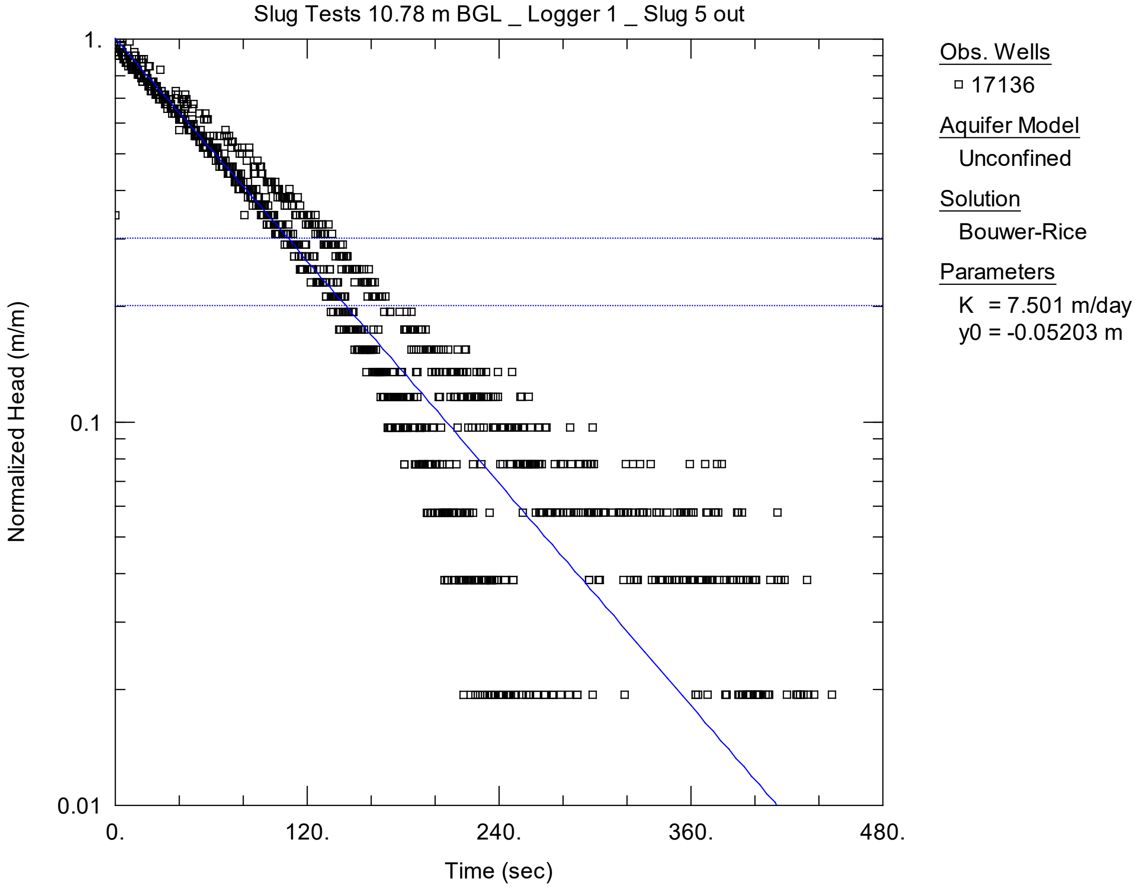


Figure A7.8 Results of the analysis for the slug-in test with slug 5 undertaken at 10.78 m BGL for both loggers. Logger 1 is a Level TROLL 700 data logger; logger 2 is a HOBO Bluetooth data logger.



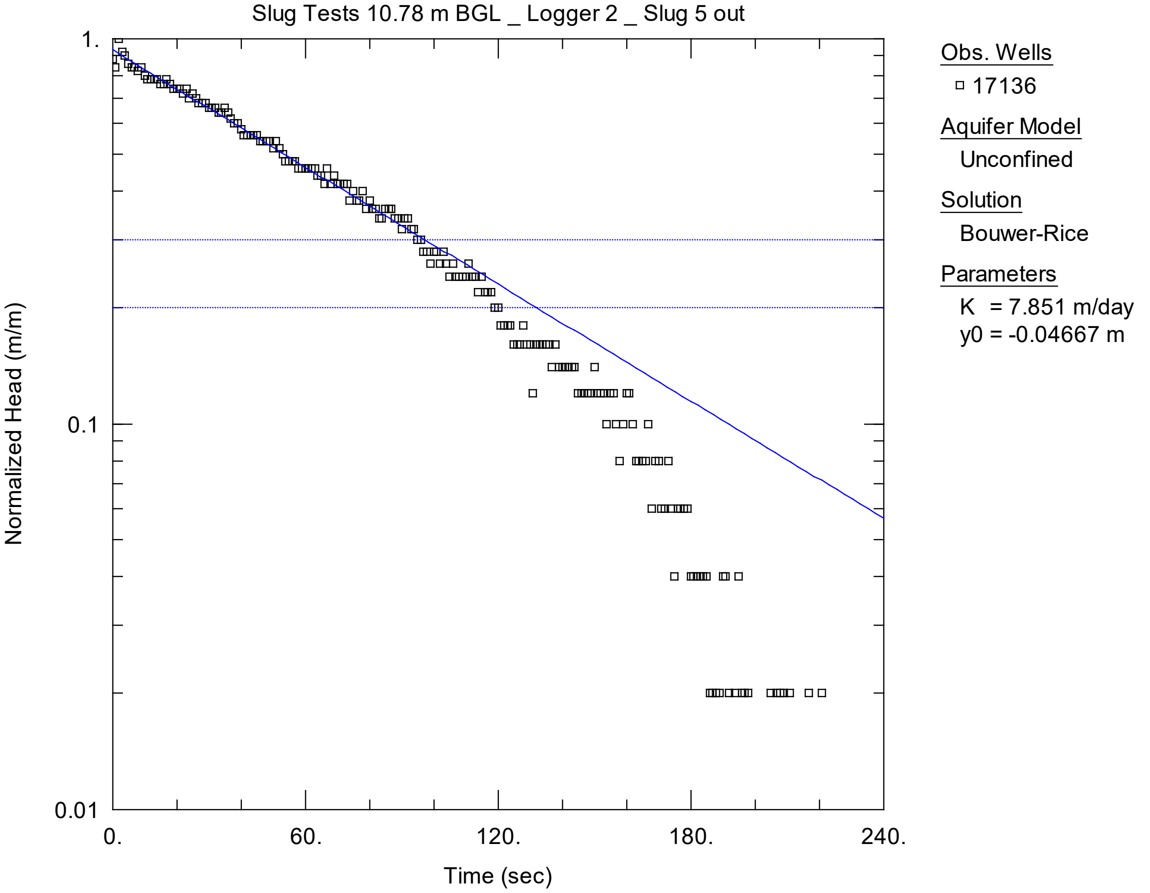


Figure A7.9 Results of the analysis for the slug-out test with slug 5 undertaken at 10.78 m BGL for both loggers. Logger 1 is a Level TROLL 700 data logger; logger 2 is a HOBO Bluetooth data logger.

A7.2 Slug Tests at 26.0 m BGL

A7.2.1 Settings Details

A series of slug tests were performed on 23 March 2021 at a depth of 26.0 m BGL in a poorly sorted sub-angular to sub-rounded gravel layer. Three different sizes of slugs (slugs 2, 3 and 5) were used to undertake slug-in and slug-out tests. Slug tests were repeated for quality assurance (Figure A7.10).

Water levels were recorded at 250 millisecond intervals using an In-Situ Level TROLL 700 data logger. The weather was constant, with no rainfall recorded over the length of the test.

No barometric pressure correction was made for this slug test, as the barometric pressure data remained stable for the entire duration of the test and its effect on the water level is considered negligible.

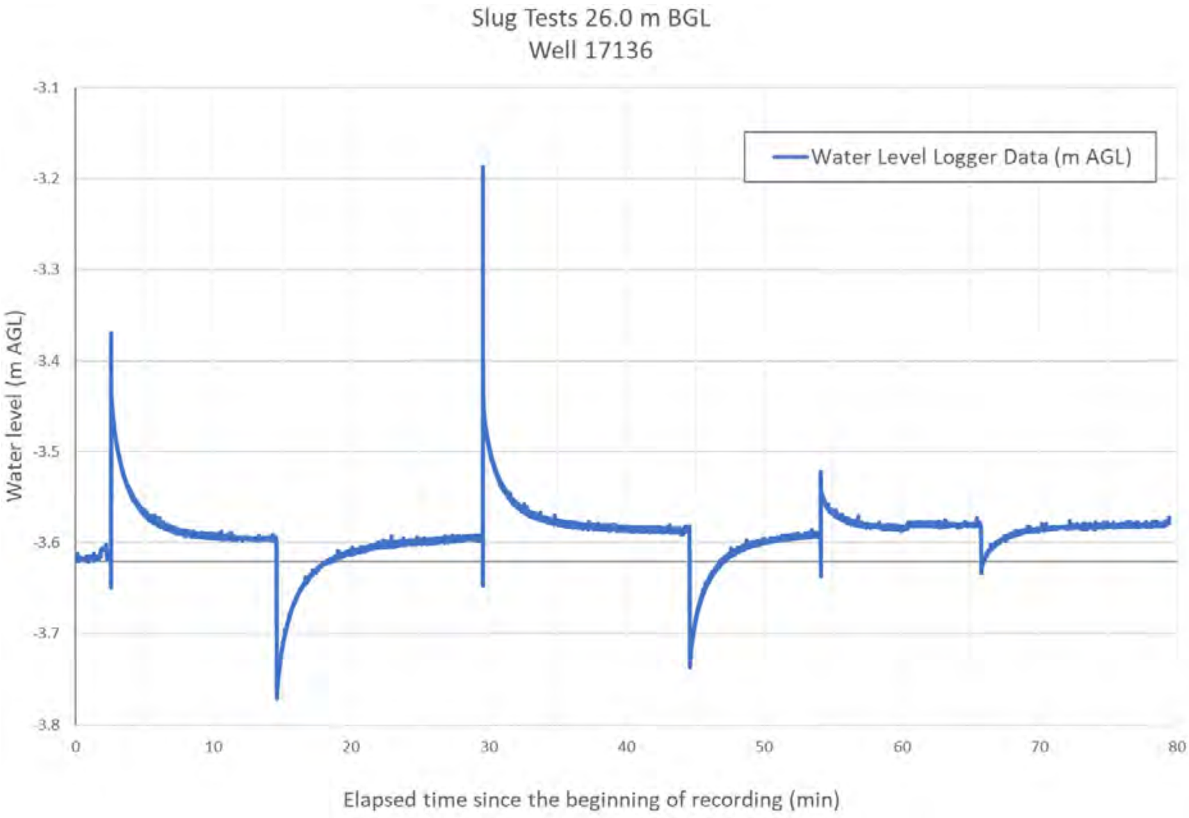


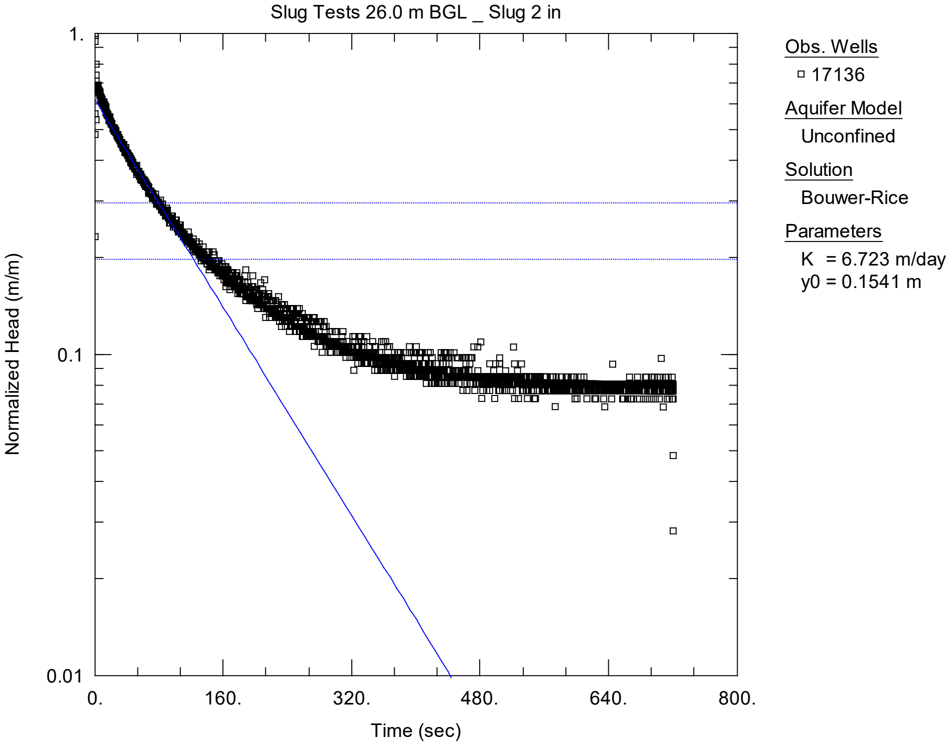
Figure A7.10 Fluctuation of the water level during the slug tests at 26.0 m BGL. Three slug tests were undertaken with the following slugs in order: slug 2, slug 3 and slug 5.

A7.2.2 Results and Analysis

The slug-test data was analysed using AQTESOLV Pro software. Each slug in and slug out were analysed on their own, and a Bouwer-Rice solution was fitted to the curves (Figures A7.11, A7.12 and A7.13). From this solution, a hydraulic conductivity (K) was calculated and summarised in Table A7.4. A hydraulic conductivity average of 6.9 m/day was estimated for this layer. Assumptions made on the different parameters for this analysis (e.g. saturated thickness of the aquifer) might impact the results, as they may be over- or under-estimated.

Table A7.4 Summary of the hydraulic conductivity calculated for each slug-in and slug-out test.

		Slug Test 2		Slug Test 3		Slug Test 5	
		In	**Out**	**In**	**Out**	**In**	**Out**
K (m/day)	Calculated from the Level TROLL 700 logger data	6.7	7.0	6.8	6.7	6.9	7.1
	Test average	**6.9**		**6.8**		**7.0**	
	Total	**6.9**					



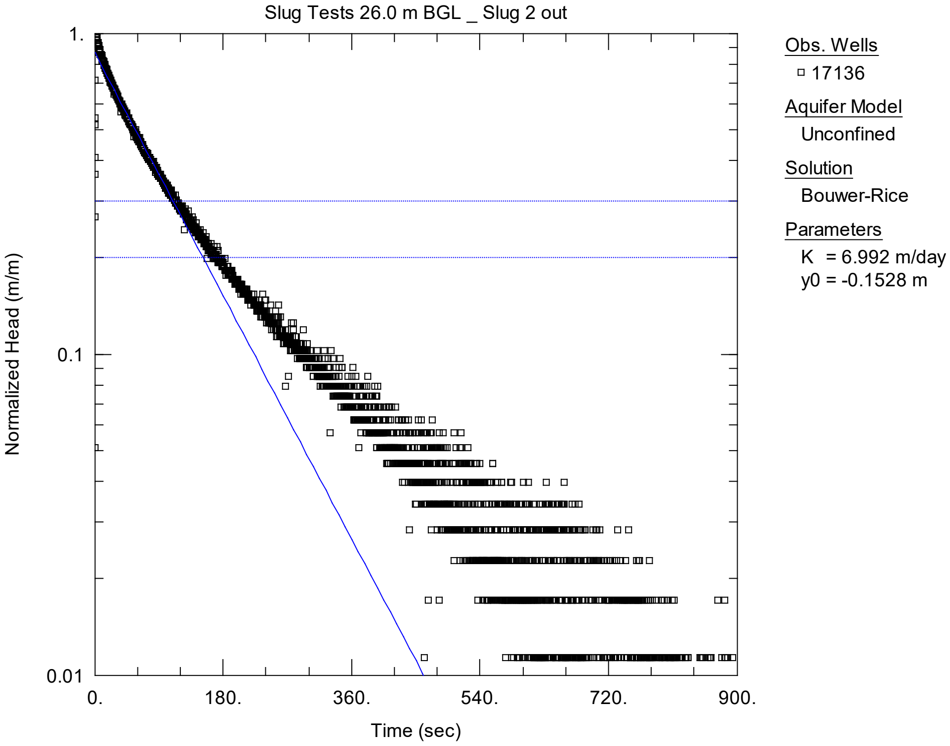


Figure A7.11 Results of the analysis for the slug-in and slug-out tests with slug 2, undertaken at 26.0 m BGL.

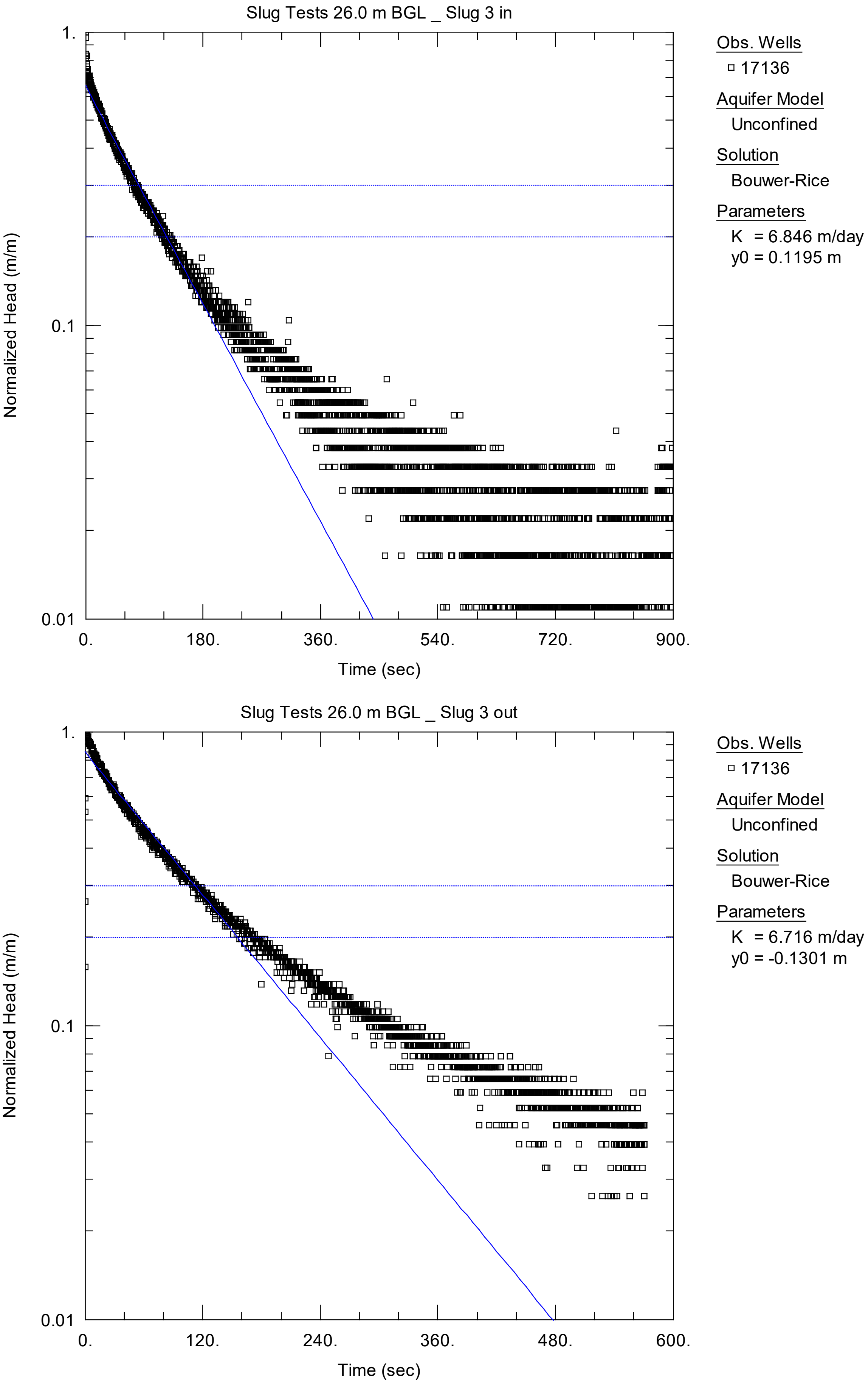
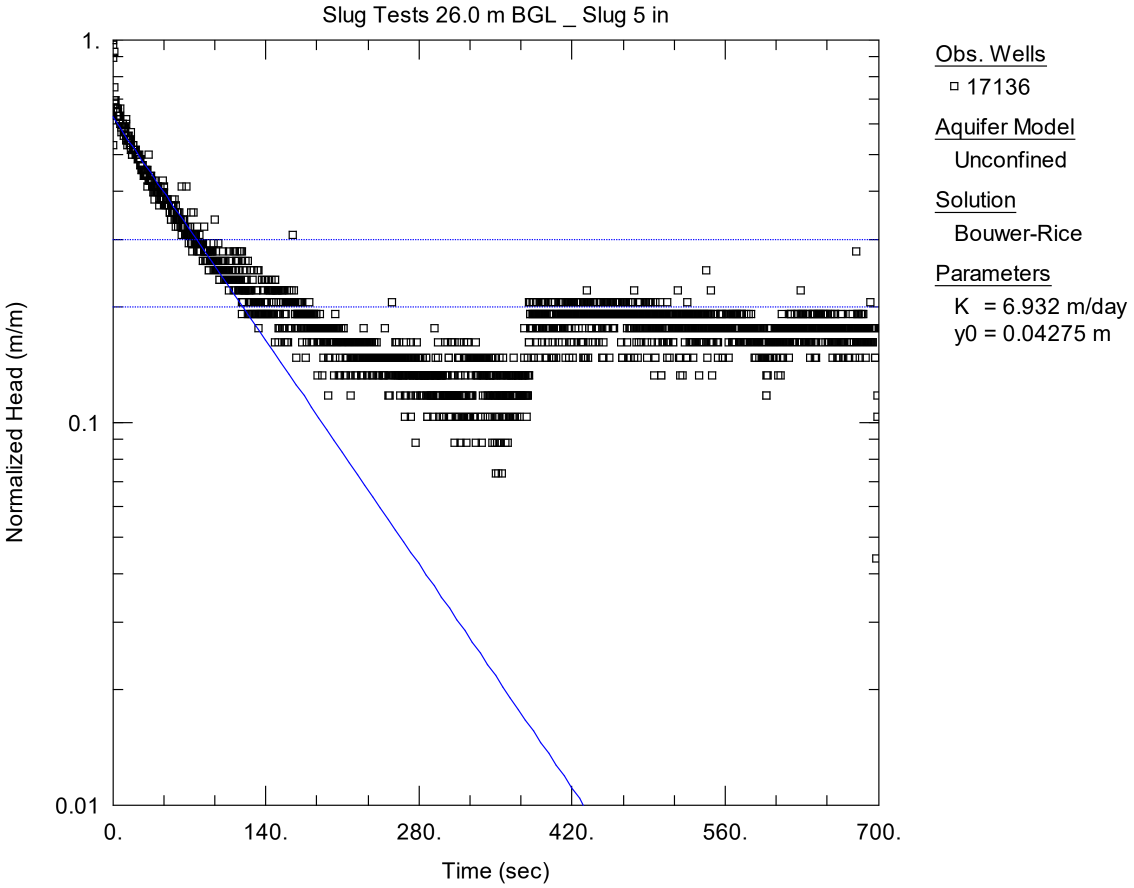


Figure A7.12 Results of the analysis for the slug-in and slug-out tests with slug 3, undertaken at 26.0 m BGL.



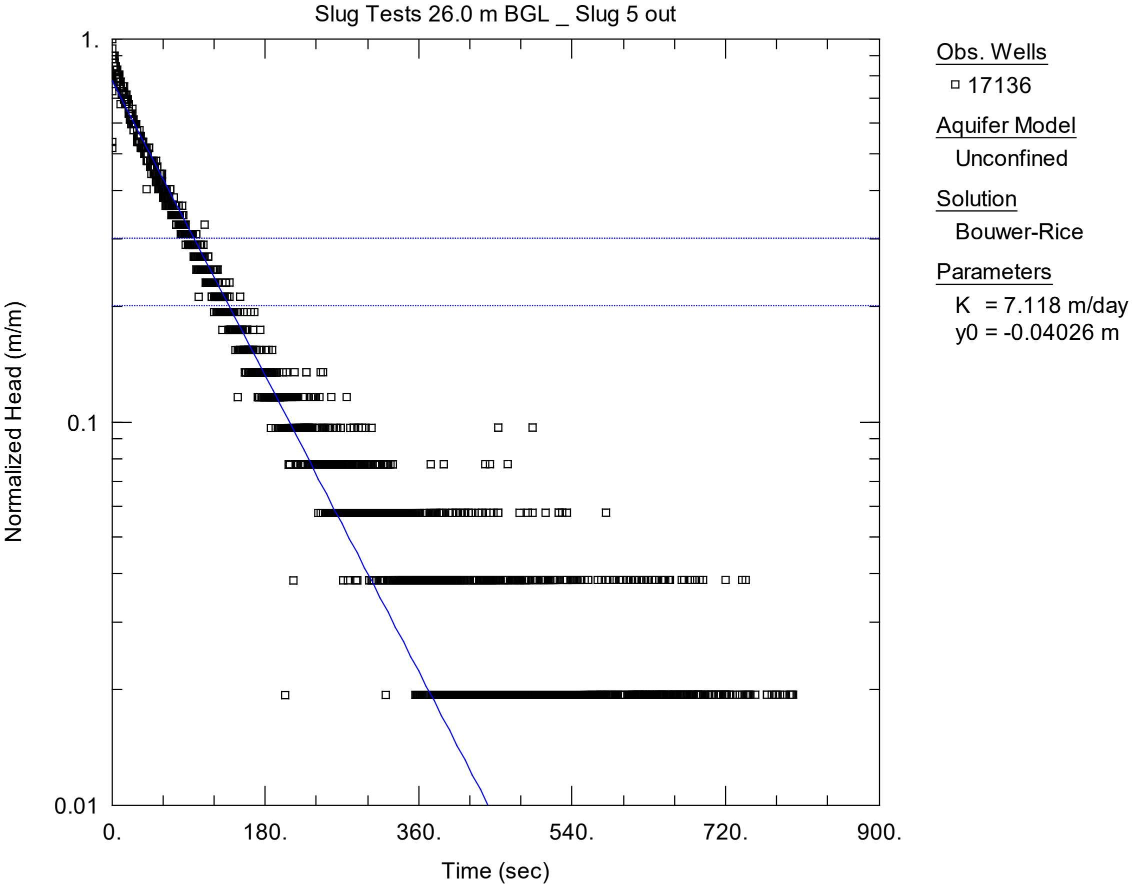


Figure A7.13 Results of the analysis for the slug-in and slug-out tests with slug 5, undertaken at 26.0 m BGL.

A7.3 Slug Tests at 47.2 m BGL

A7.3.1 Settings Details

A series of slug tests were performed on 6 April 2021 at a depth of 47.2 m BGL in a poorly sorted sub-angular to sub-rounded sandy gravel layer. Three different sizes of slugs (slugs 2, 3 and 5) were used to undertake slug-in and slug-out tests. Slug tests were repeated for quality assurance (Figure A7.14).

Water levels were recorded at 250 millisecond intervals using an In-Situ Level TROLL 700 data logger. The weather was constant, with no rainfall recorded over the length of the test.

The water level was static prior to the start of the tests and remained stable during the tests with slug 2; however, the water level decreased during the tests with slugs 3 and 5. Farmers in fields surrounding the well site might have started to irrigate, impacting the water level in the tested well.

No barometric pressure correction was made for this slug test, as the barometric pressure data remained relatively stable for the entire duration of the test and the effect on the water level is considered negligible.

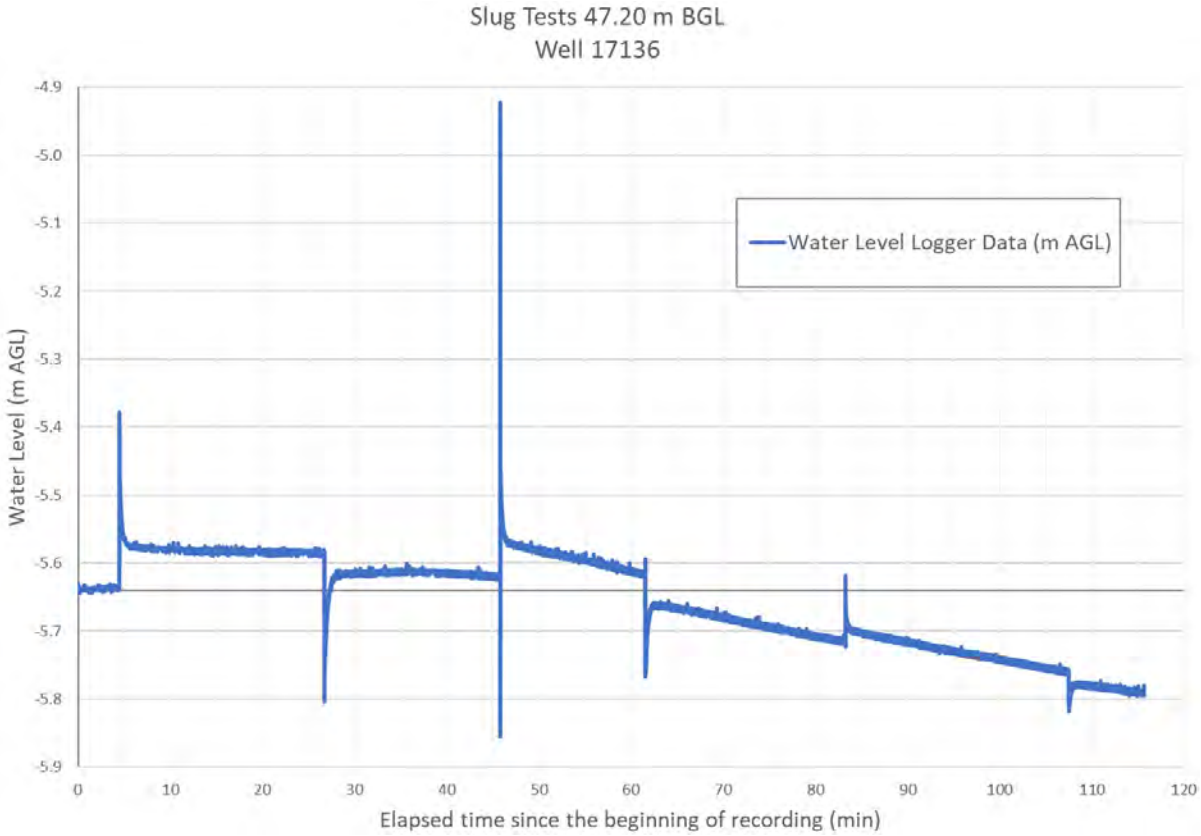


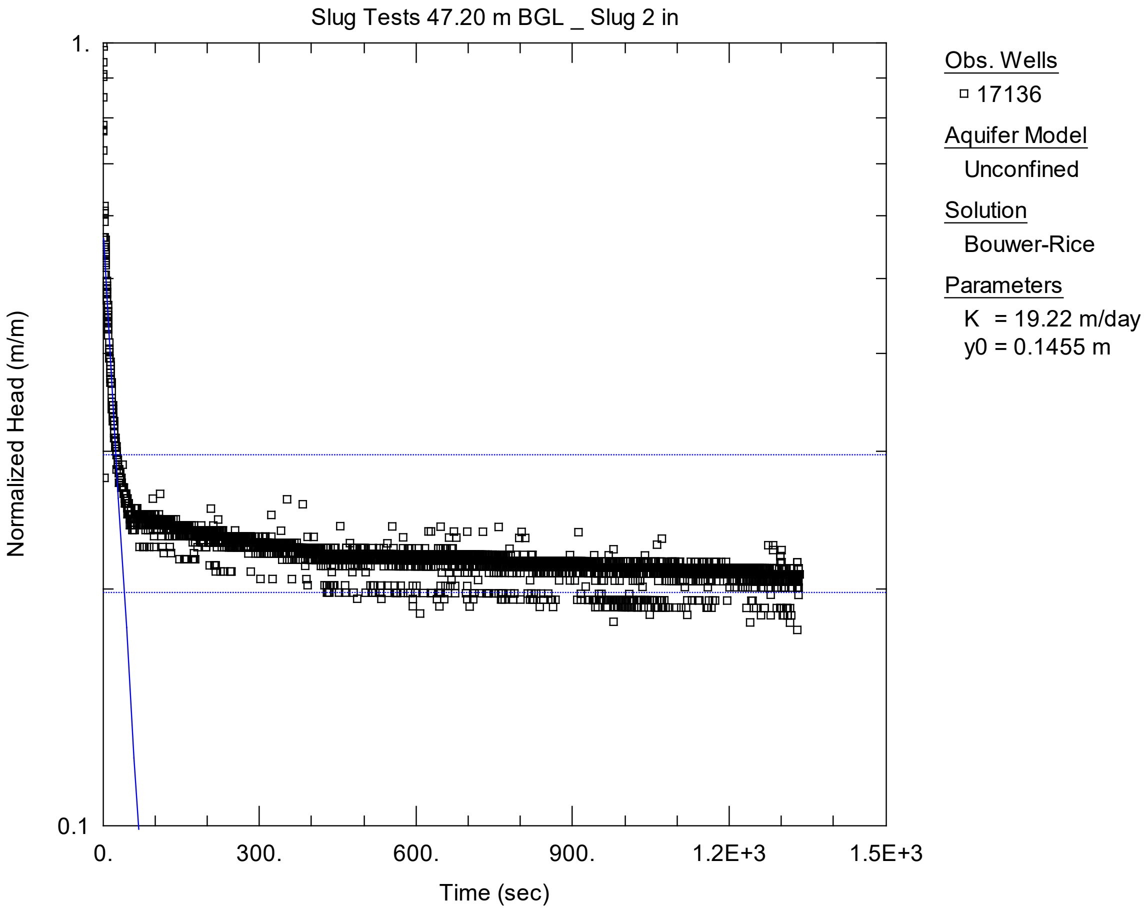
Figure A7.14 Fluctuation of the water level during the slug tests at 47.2 m BGL. Three slug tests were undertaken with the following slugs in order: slug 2, slug 3 and slug 5. The water level remained stable during the tests with slug 2; however, it started to decrease for the tests with slugs 3 and 5. The water level was potentially affected by irrigation in nearby fields.

A7.3.2 Results and Analysis

The slug-test data were analysed using AQTESOLV Pro software. Each slug-in and slug-out were analysed on their own, and a Bouwer-Rice solution was fitted to the curves (Figures A7.15, A7.16 and A7.17). From this solution, a hydraulic conductivity (K) was calculated and summarised in Table A7.5. A hydraulic conductivity average of 21.0 m/day was estimated for this layer. Assumptions made on the different parameters for this analysis (e.g. saturated thickness of the aquifer) might impact the results, as they may be over- or under-estimated.

Table A7.5 Summary of the hydraulic conductivity calculated for each slug-in and slug-out test.

		Slug Test 2		**Slug Test 3**		**Slug Test 5**	
		In	**Out**	**In**	**Out**	**In**	**Out**
K (m/day)	Calculated from the Level TROLL 700 logger data	19.2	20.6	18.5	19.6	27.0	21.1
	Test average	**19.9**		**19.0**		**24.0**	
	Total	**21.0**					



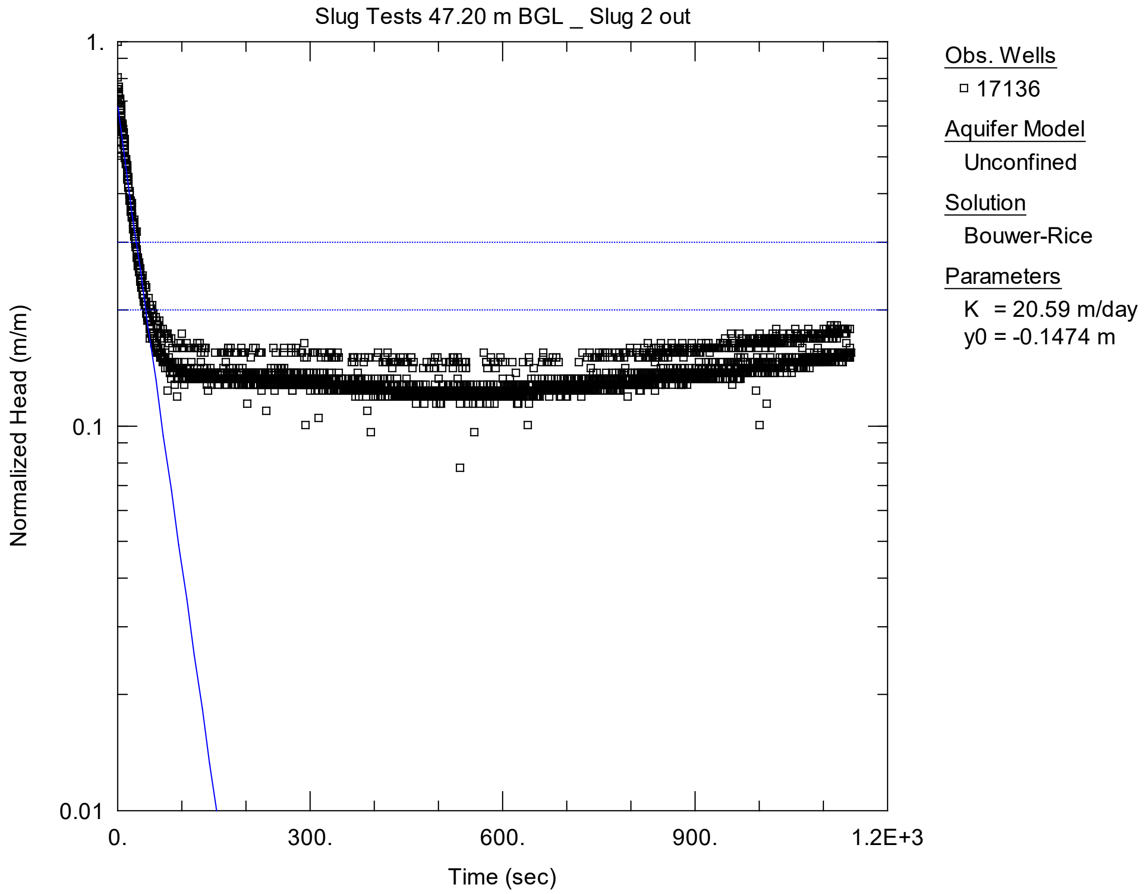
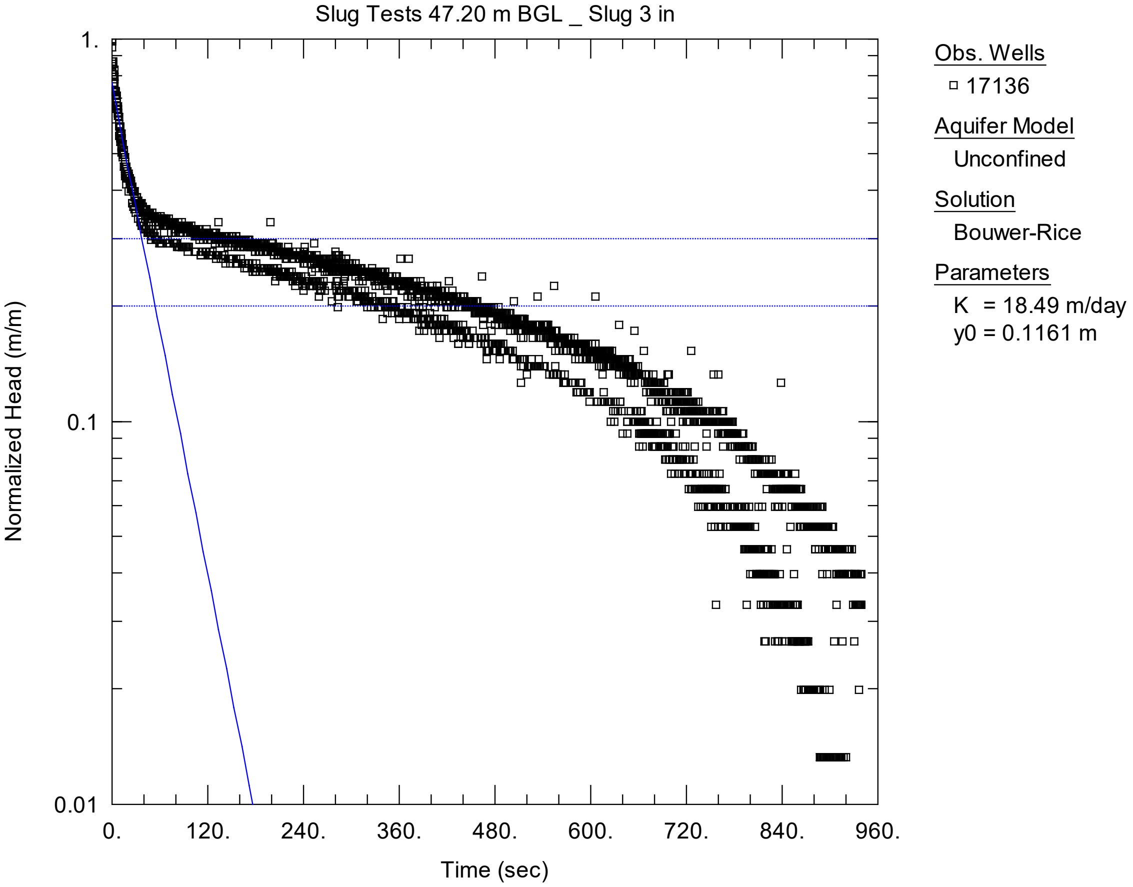


Figure A7.15 Results of the analysis for the slug-in and slug-out tests with slug 2, undertaken at 47.20 m BGL.



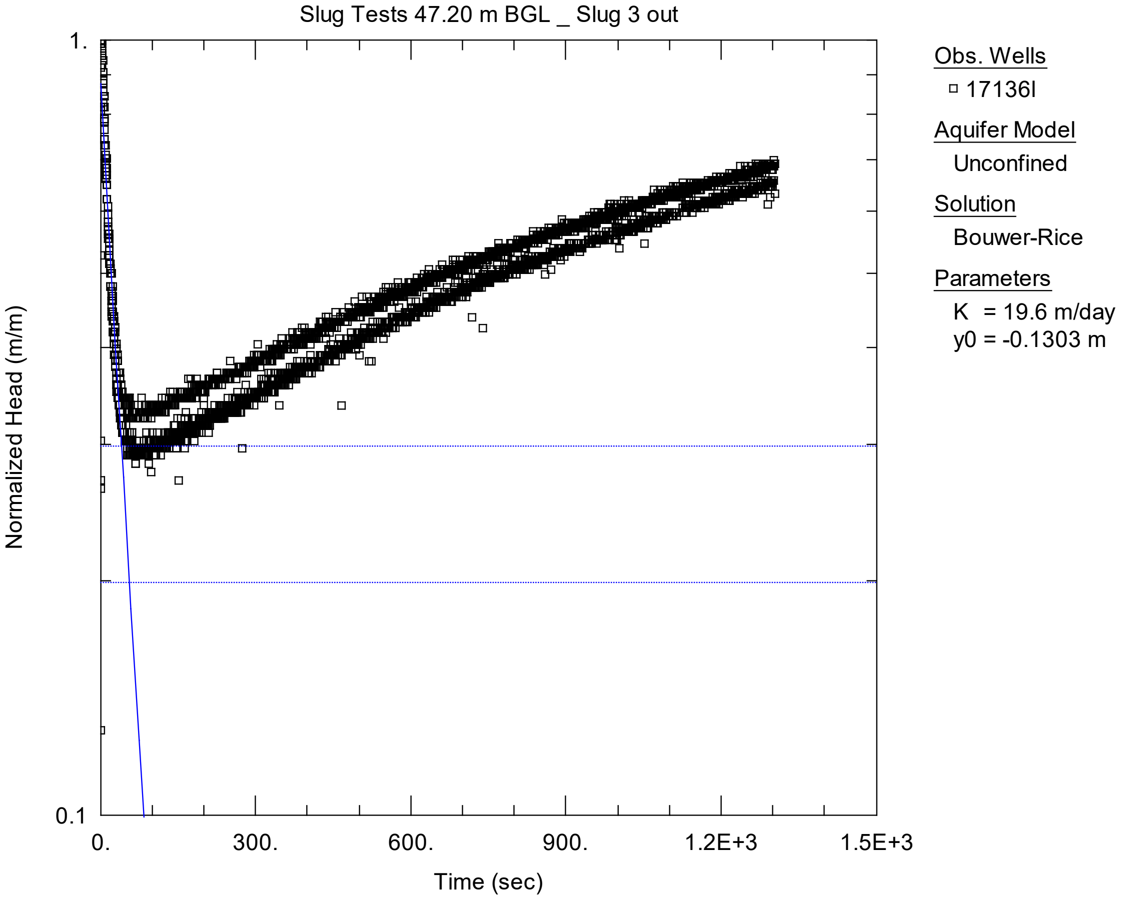
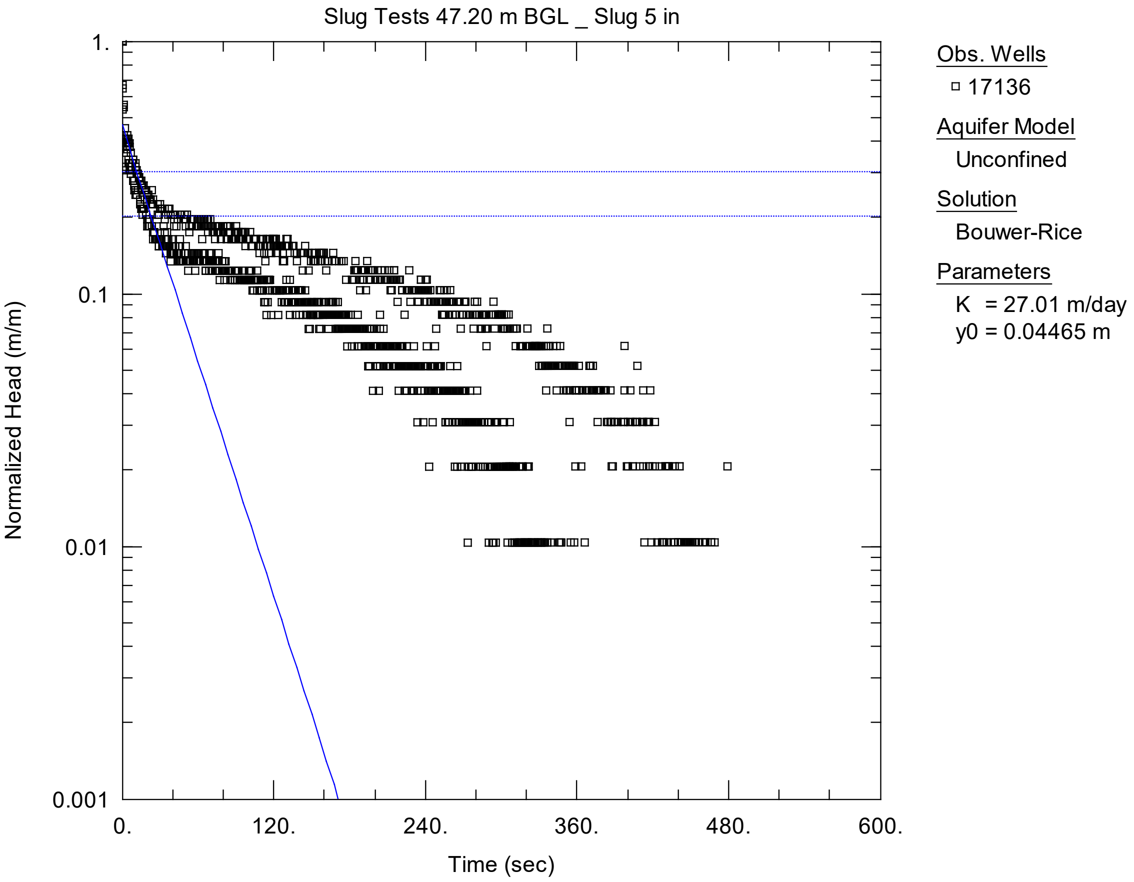


Figure A7.16 Results of the analysis for the slug-in and slug-out tests with slug 3, undertaken at 47.20 m BGL.



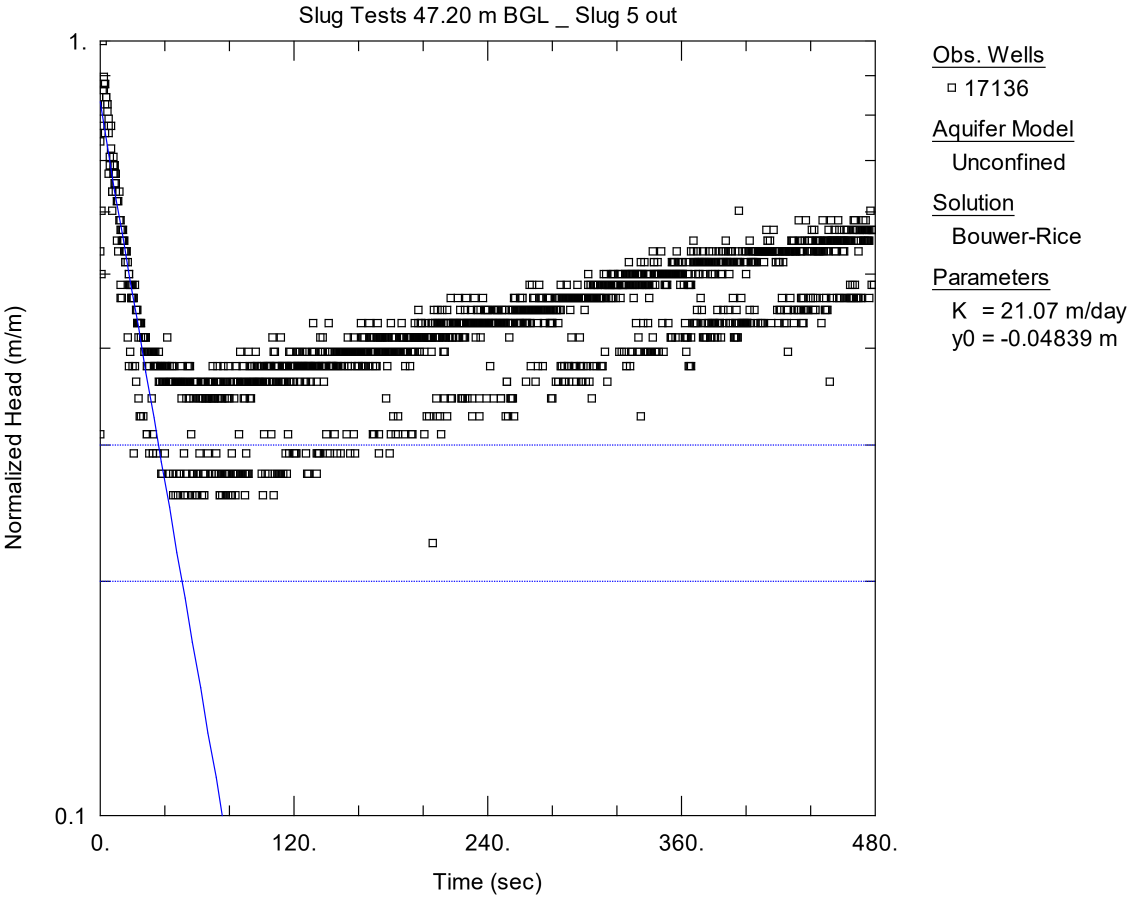


Figure A7.17 Results of the analysis for the slug-in and slug-out tests with slug 5, undertaken at 47.20 m BGL.

A7.4 Slug Tests at 53.0 m BGL

A7.4.1 Settings Details

A series of slug tests were performed on 8 April 2021 at a depth of 53.0 m BGL in a poorly to moderately sorted sub-angular to sub-rounded gravel layer. Two different sizes of slugs (slugs 2 and 3) were used to undertake slug-in and slug-out tests. Slug tests were repeated for quality assurance (Figure A7.18).

Water levels were recorded at 250 millisecond intervals using an In-Situ Level TROLL 700 data logger. The weather was constant, with no rainfall recorded over the length of the test.

The water level seemed static prior to the start of the tests; however, a slow increase of the water level became noticeable during the first two tests with slugs 2 and 3. As the increase seemed to slow down toward the end of the tests with slug 3; it was decided to repeat the tests with slug 2. Farmers in fields surrounding the well site probably stopped irrigating for the day, causing the water level to recover and affect the level in the tested well.

No barometric pressure correction was made for this slug test as the barometric pressure data remained relatively stable for the entire duration of the test, meaning that the effect on the water level is considered negligible.

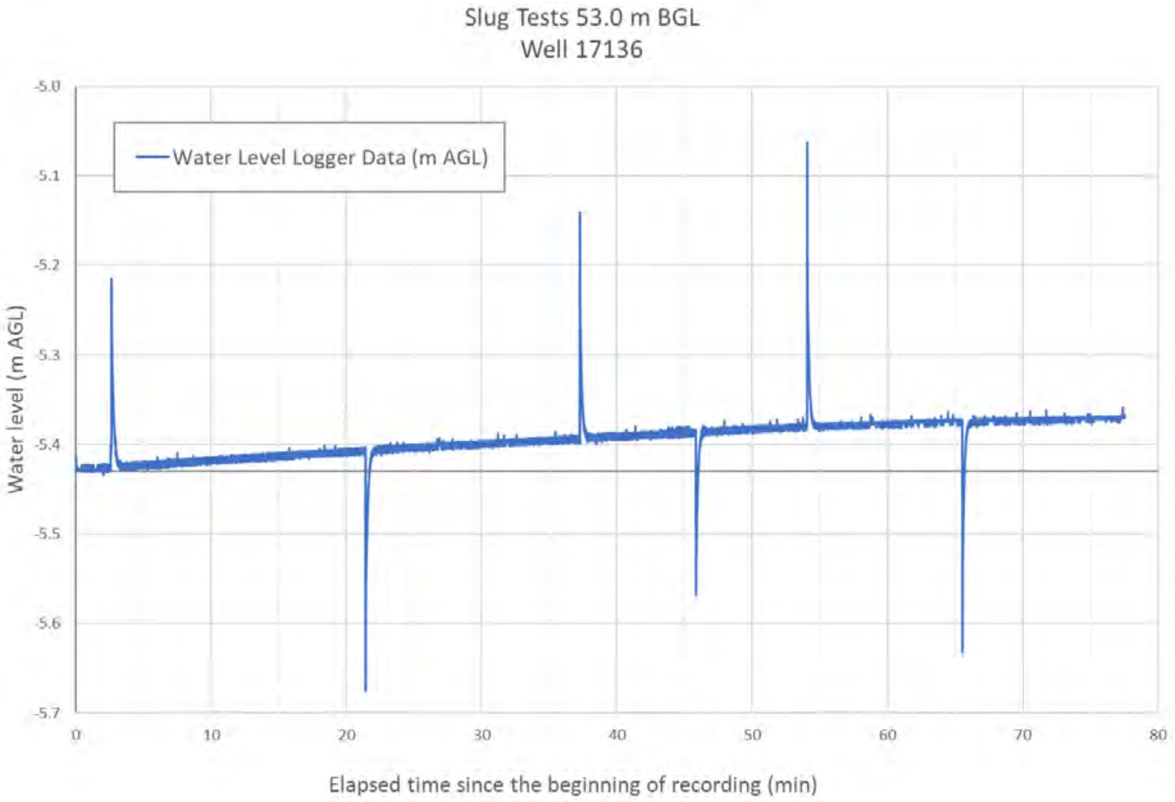


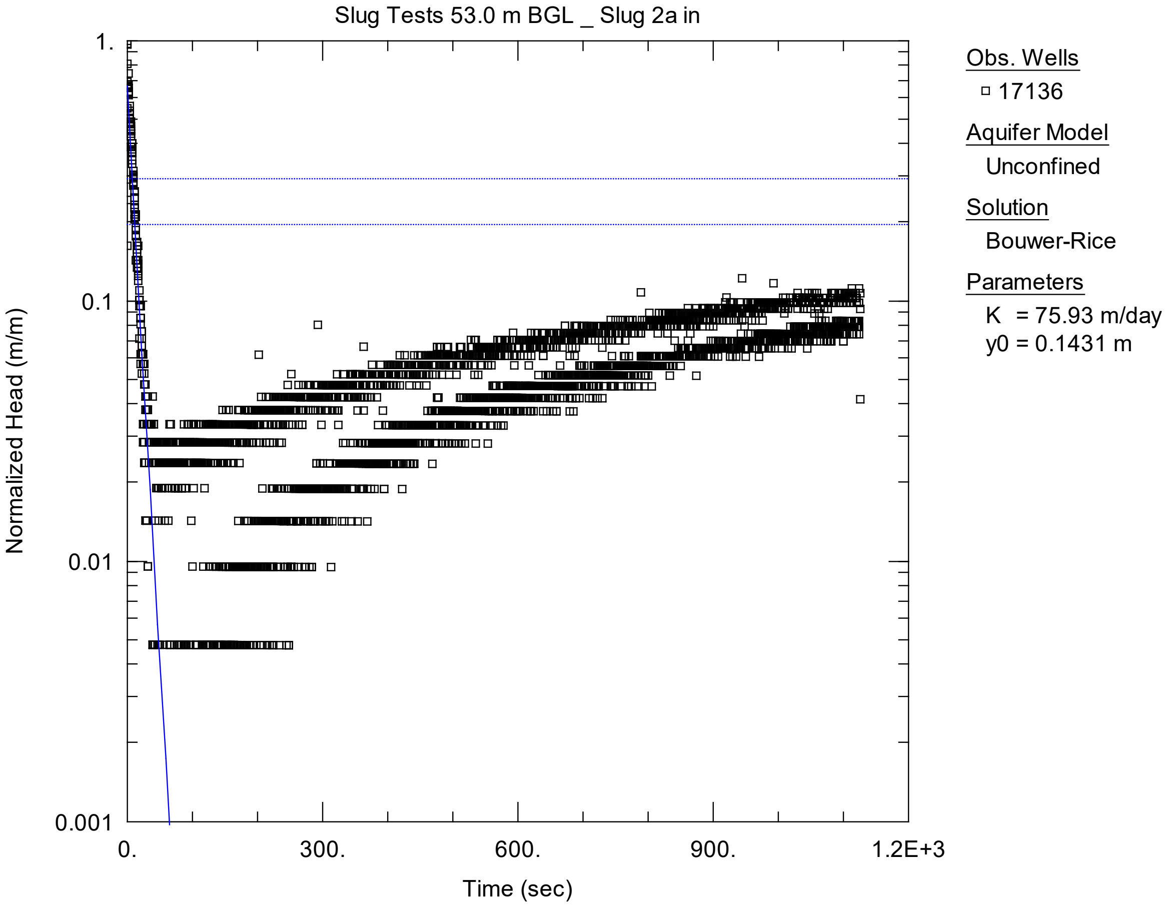
Figure A7.18 Fluctuation of the water level during the slug tests at 53.0 m BGL. Three slug tests were undertaken with the following slugs in order: slug 2, slug 3 and slug 2. The tests were carried out at the end of the afternoon; therefore, one possible explanation for the water level increasing during the tests is that the irrigation in neighbouring fields stopped and the aquifer was recovering.

A7.4.2 Results and Analysis

The slug-test data was analysed using AQTESOLV Pro software. Each slug in and slug out were analysed on their own, and a Bouwer-Rice solution was fitted to the curves (Figures A7.19, A7.20 and A7.21). From this solution, a hydraulic conductivity (K) was calculated and summarised in Table A7.6. A hydraulic conductivity average of 95.5 m/day was estimated for this layer. Assumptions made on the different parameters for this analysis (e.g. saturated thickness of the aquifer) might impact the results, as they may be over- or under-estimated.

Table A7.6 Summary of the hydraulic conductivity calculated for each slug-in and slug-out test.

		Slug Test 2a		**Slug Test 3**		**Slug Test 2b**	
		In	**Out**	**In**	**Out**	**In**	**Out**
K (m/day)	Calculated from the Level TROLL 700 logger data	75.9	85.2	88.0	118.2	100.2	105.2
	Test average	**80.6**		**103.1**		**102.7**	
	Total	**95.5**					



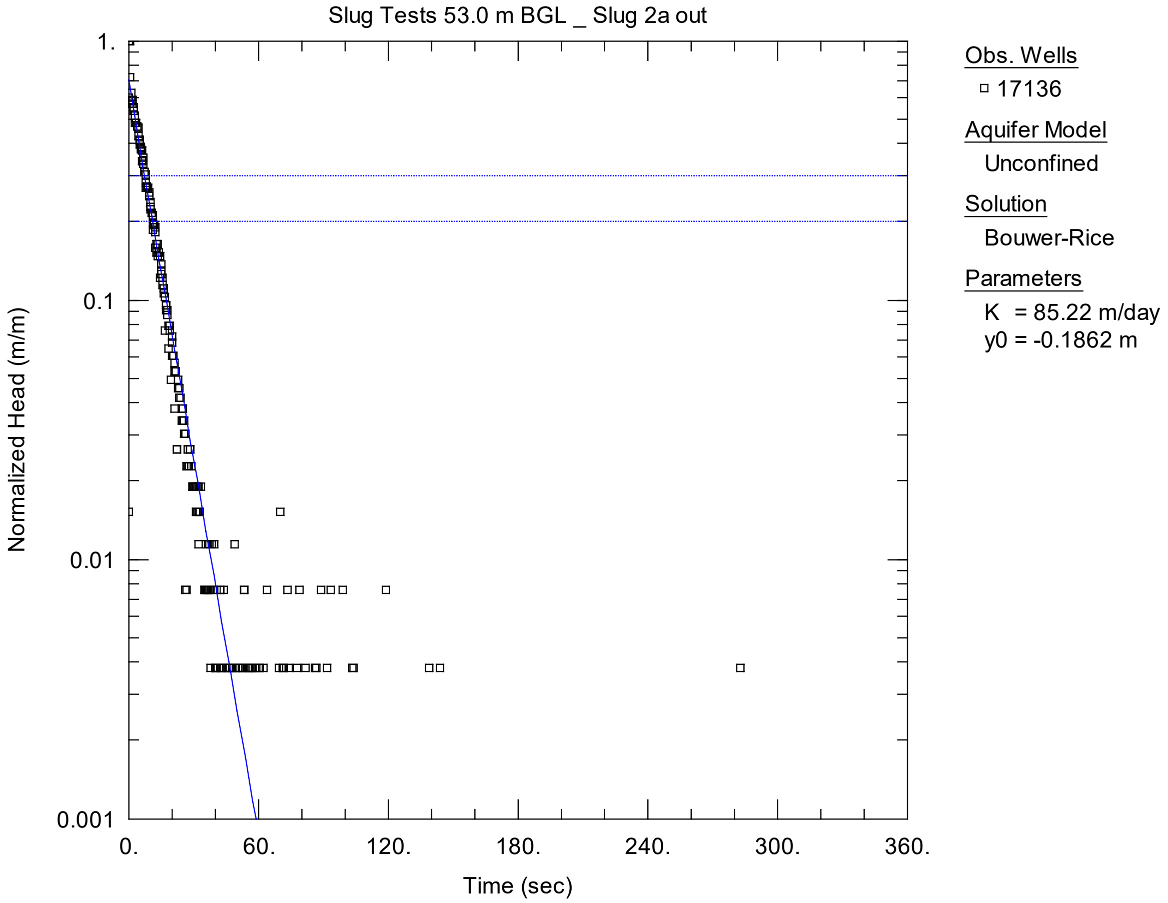
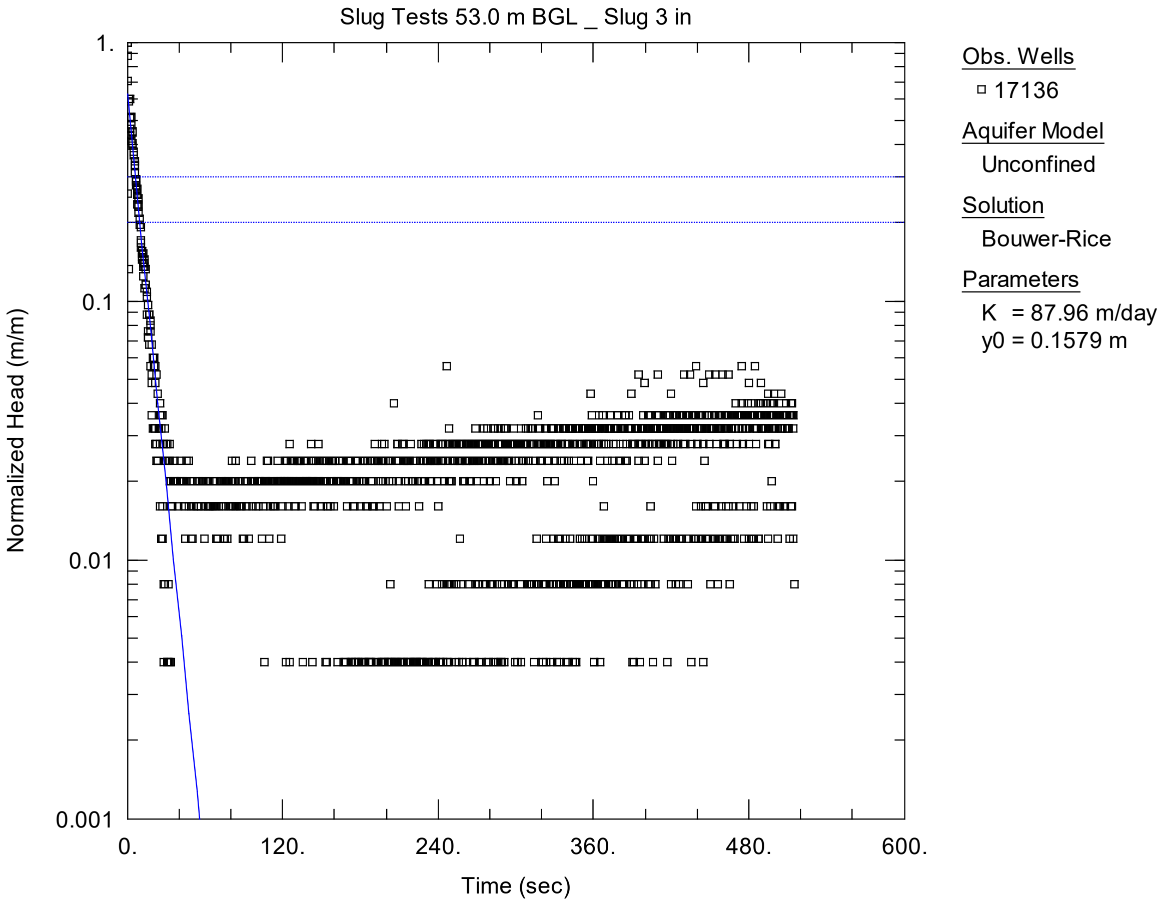


Figure A7.19 Results of the analysis for the first slug-in and slug-out tests with slug 2, undertaken at 53.0 m BGL.



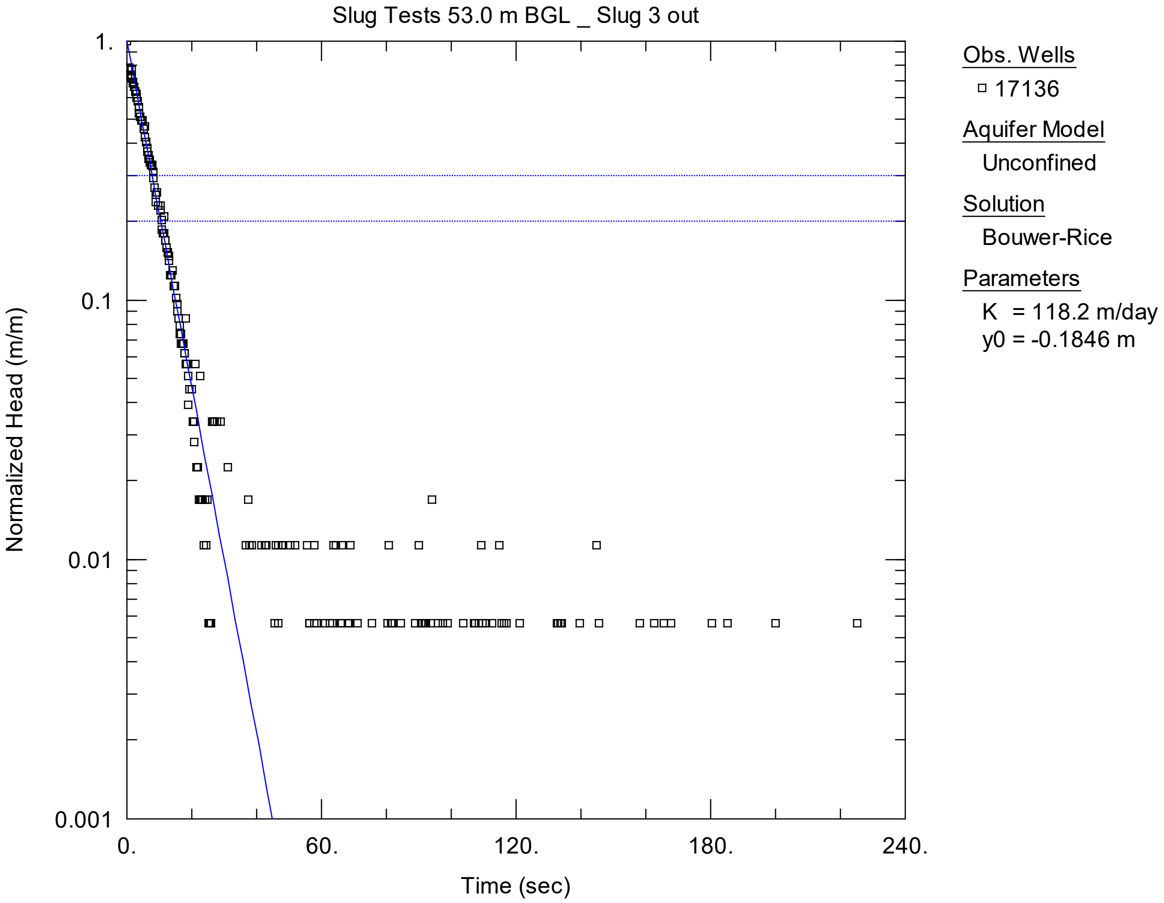
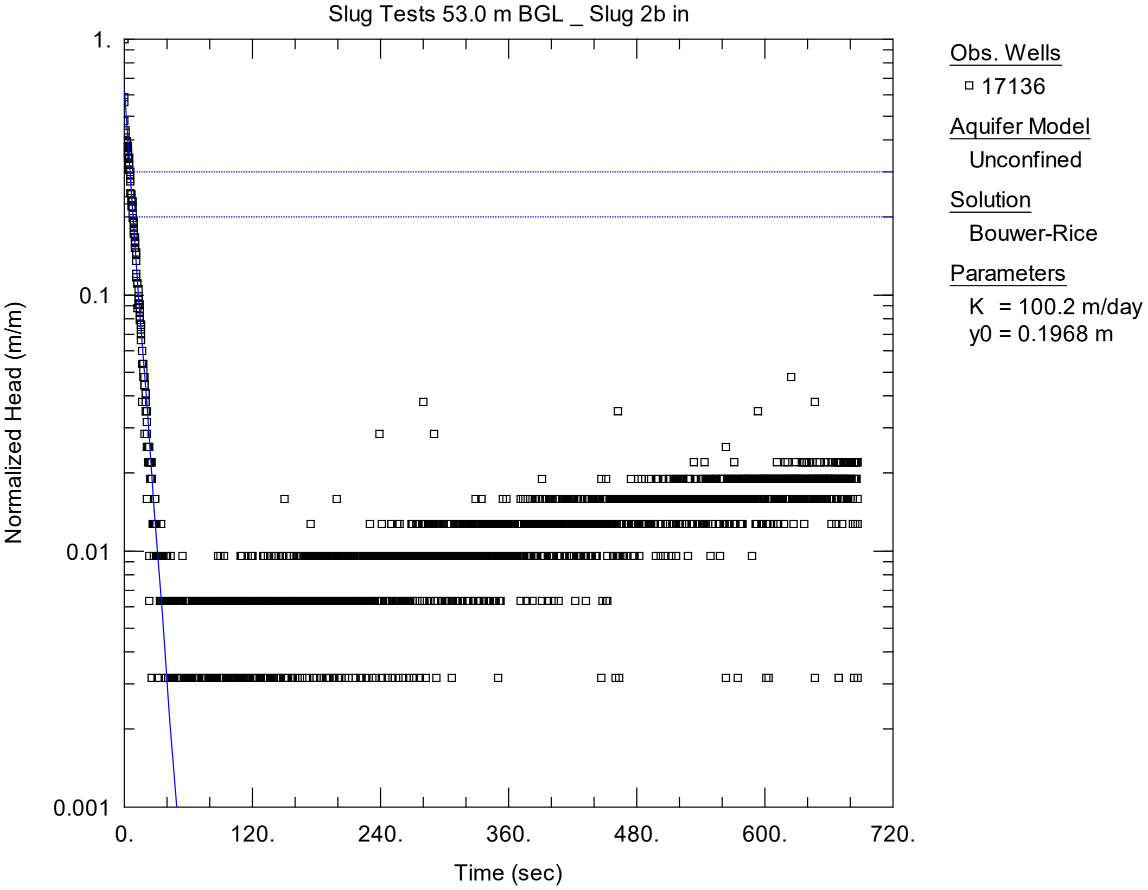


Figure A7.20 Results of the analysis for the slug-in and slug-out tests with slug 3, undertaken at 53.0 m BGL.



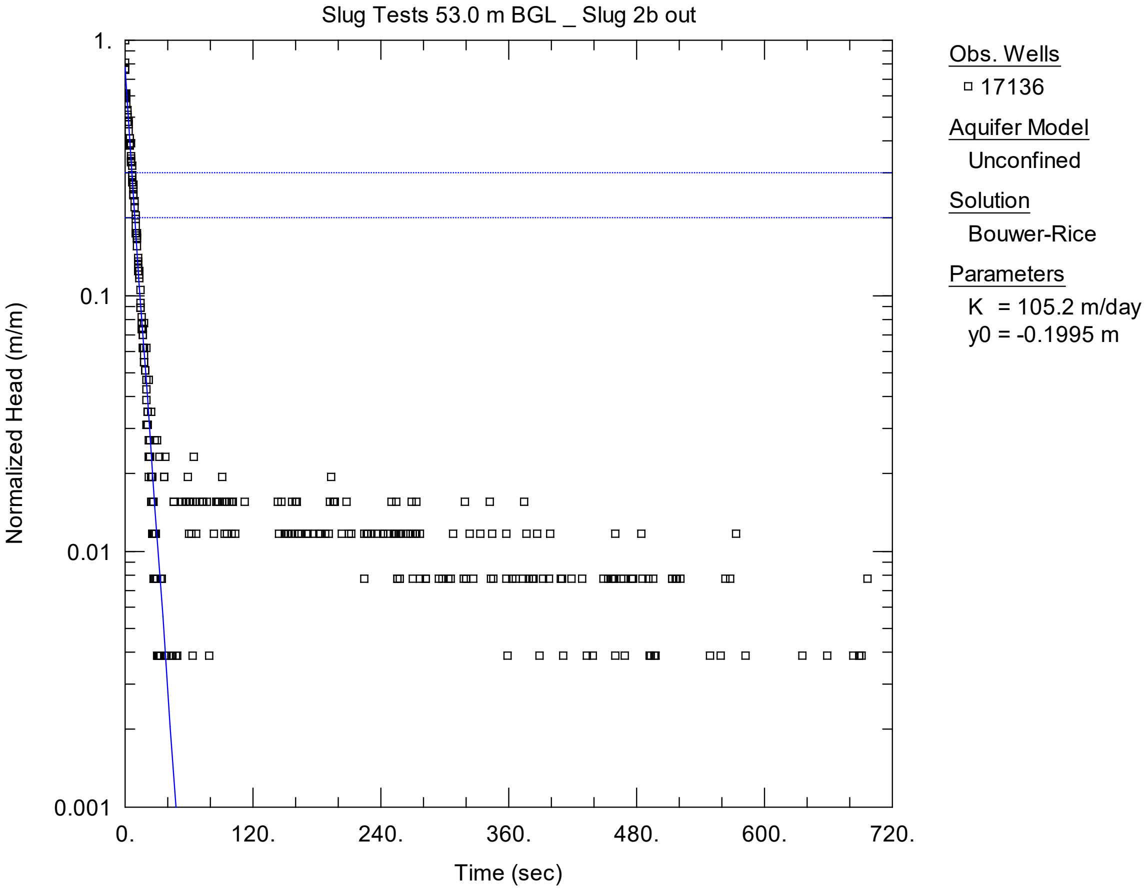


Figure A7.21 Results of the analysis for the second slug-in and slug-out tests with slug 2, undertaken at 53.0 m BGL.

A7.5 Slug Test at 55.0 m BGL

A7.5.1 Settings Details

A slug test was performed over two days on 12 and 13 April 2021 at a depth of 55.0 m BGL in a poorly to moderately sorted silty clay layer. The tested layer was a clay layer, so the smallest size of slug, slug 6, was used to undertake a single slug-in test (Figure A7.22).

Thirty minutes after the start of the slug-in test, the water level remained stable and no clear indication of a recovery was observed. It was decided to lower a second data logger to record the water level overnight. No slug-out test was undertaken the next morning, and both slug and data logger were removed prior to the start of drilling, still showing no signs of recovery.

Water levels were initially recorded at a 250 millisecond interval using an In-Situ Level TROLL 700 data logger. However, a second In-Situ Level TROLL 700 was lowered before leaving the well site to record the water level change overnight with a 30 second interval. The weather was constant, with no rainfall recorded over the length of the test.

A few corrections have been made on the data prior to the analysis (Figure A7.22), i.e. a correction was applied to remove the effect of installing the second logger and dip meter, and a barometric pressure correction with a barometric efficiency coefficient of 0.2458 was applied thereafter. While the second logger was lowered into the well, the dip meter was lowered simultaneously to guide the depth of the logger and brought back to surface once the logger was set up, both of which impacted the water level.

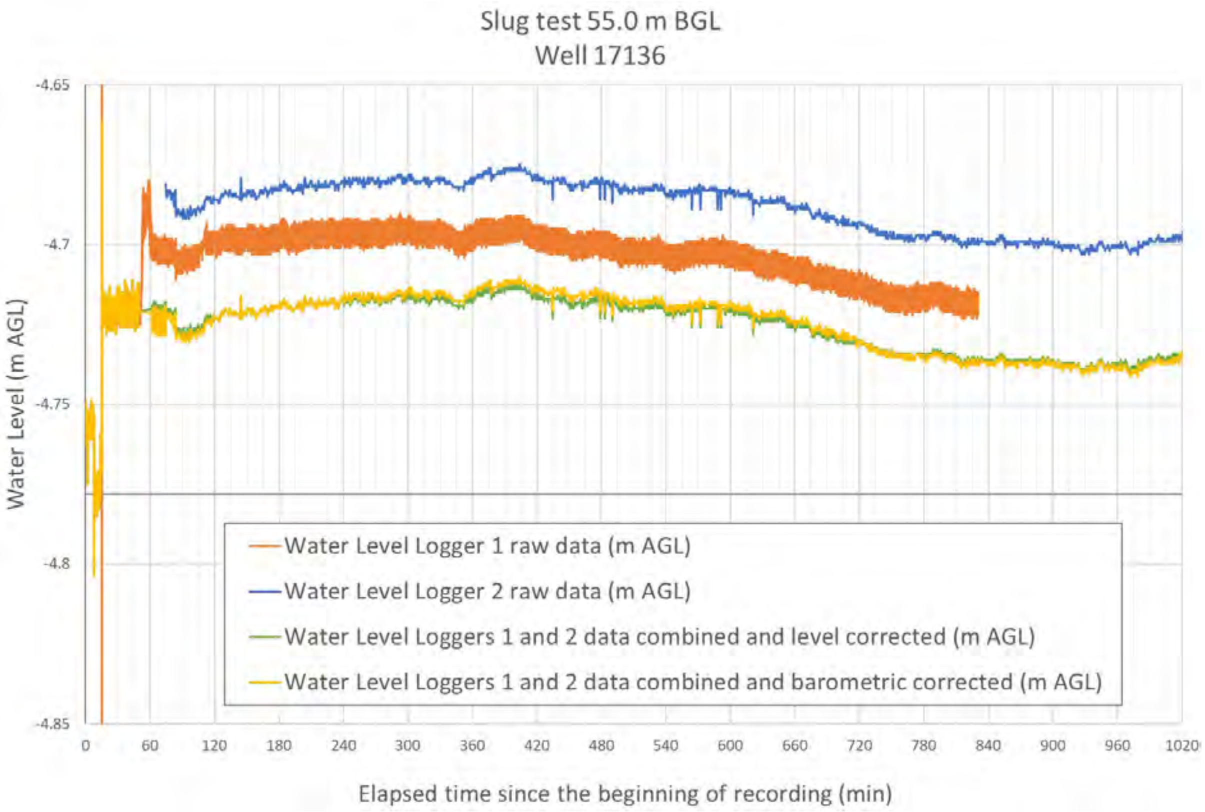


Figure A7.22 Fluctuation of the water level during the slug test at 55.0 m BGL. A single slug-in test with slug 6 was undertaken. Logger 1 recorded with a time interval of 250 milliseconds until 5:00 am (orange curve), while logger 2 recorded with a time interval of 30 seconds and was stopped at 8:00 am the next morning (blue curve). A level correction was applied to remove the impact of lowering logger 2, and the two datasets were combined to create a uniform dataset to analyse (green curve). Finally, a barometric correction was applied with a barometric efficiency coefficient of 0.2458 (yellow curve).

A7.5.2 Results and Analysis

The slug-test data was analysed using AQTESOLV Pro software. A Bouwer-Rice solution was fitted on the curve (Figure A7.23). From this solution, a hydraulic conductivity K of 0.001 m/day was estimated for this layer. Assumptions made on the different parameters for this analysis (e.g. saturated thickness of the aquifer) might impact the results, as they may be over- or under-estimated.

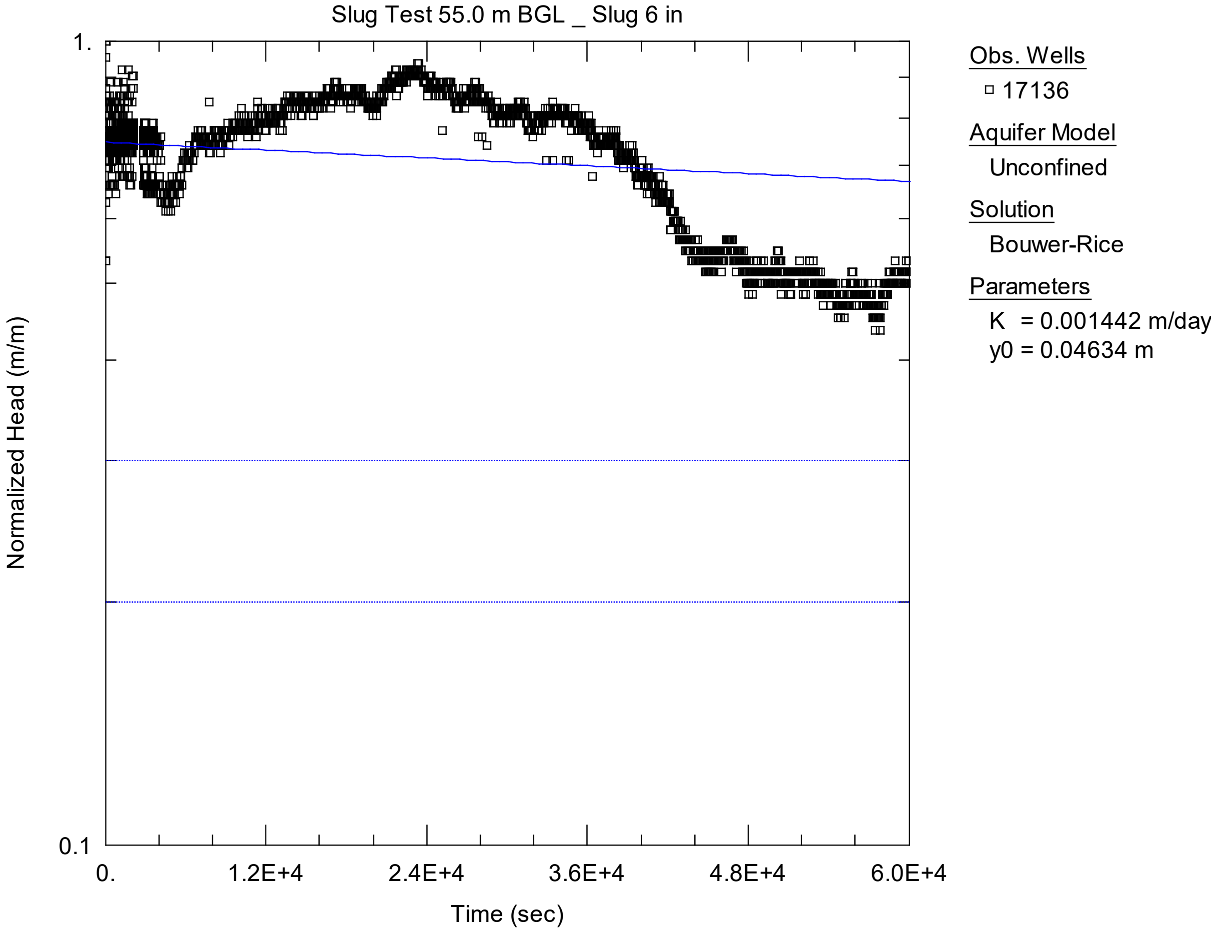


Figure A7.23 Results of the analysis for the slug-in test with slug 6, undertaken at 55.0 m BGL.

A7.6 Slug Test at 79.0 m BGL

A7.6.1 Settings Details

A slug test was performed over two days on 6 and 7 May 2021 at a depth of 79.0 m BGL in a moderately well to moderately sorted gravelly sand layer. Slug 2 was utilised to undertake a slug-in and slug-out test.

Water levels were recorded at 250 millisecond intervals using an In-Situ Level TROLL 700 data logger. The data logger was left overnight to record the water-level recovery. The weather was constant with no rainfall recorded over the length of the test. Since the recorded data spans over several hours, a barometric pressure correction with a barometric efficiency coefficient of 0.2458 was applied on the data.

The water level on 5 May morning was -6.35 m AGL, and on 6 May morning, it was -14.8 m AGL. After drilling on the 6^{th} in the morning (stopped around 11:00 am), the water level was down to -25.0 m AGL. When arriving on site at 15:20 on the 6^{th}, the water level had partially recovered to -10.113 m AGL and was still rising significantly: around 10 cm every 5 minutes (-9.41 m AGL at 15:50, -8.185 m AGL at 17:05 and -7.98 m AGL at 17:20). Most surrounding fields were irrigating on both 5 and 6 May, hence both the drilling and irrigation impacted the water level in the tested well. One slug test was performed, but, as predicted, the results were overshadowed by the overall recovery of the aquifer from the irrigation (Figure A7.24).

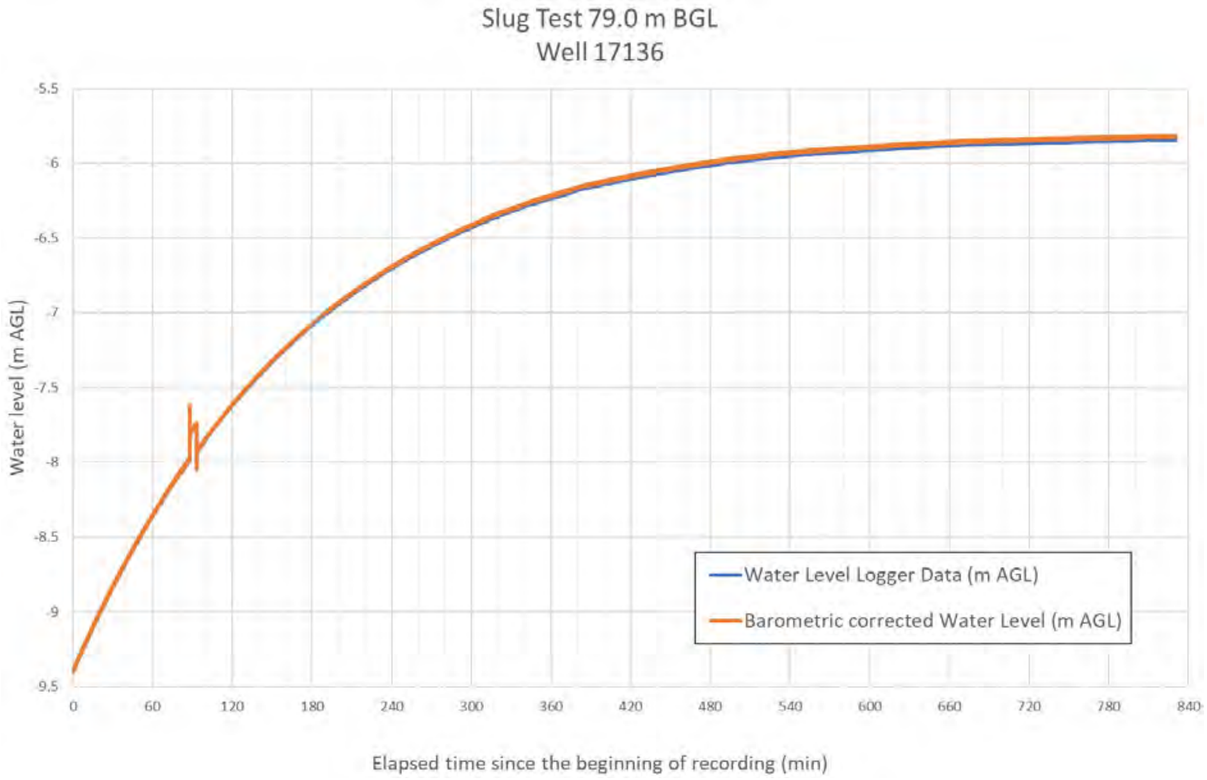


Figure A7.24 Fluctuation of the water level during the slug test at 79.0 m BGL. One slug test was attempted with slug 2; however, the response of the test was overshadowed by the recovery of the aquifer from the drilling and irrigation in neighbouring fields. The logger was left in the well to record overnight to attempt a reading of the static water level at this level. The data was corrected for barometric pressure.

A7.6.2 Results and Analysis

An analysis using AQTESOLV was attempted with this slug-test data. However, since the test was overshadowed by the aquifer recovery, only a few data points could be utilised for the analysis, which did not give conclusive results that could be interpreted.

A7.7 Slug Tests at 84.2 m BGL

A7.7.1 Settings Details

A slug-test series was performed on 13 May 2021 at a depth of 84.2 m BGL in a moderately well-sorted fine sand layer. The bottom of the casing screen was at 84.0 m BGL with 0.2 m of open hole beneath the casing shoe. Two different sizes of slugs (slugs 4 and 6) were used to undertake slug-in and slug-out tests. Slug tests were repeated for quality assurance.

Water levels were recorded at 250 millisecond intervals using an In-Situ Level TROLL 700 data logger. The data logger was left overnight to record the water-level recovery. However, the logger could not be reconnected to any computer in the morning, and the data was unable to be recovered. The weather was constant, with no rainfall recorded over the length of the test.

Some manual data were recorded, a measure at the beginning and end of each slug test. During the slug-in tests with slugs 4 and 6, it took respectively 50 minutes and one hour for the water level to recover. During the slug-out test undertaken with slug 4, it took close to 1.5 hours to recover (Table A7.7).

Table A7.7 Manual measurements of the water level during the slug tests at 110.5 m BGL.

		Slug 4		**Slug 6**	
		Time	**Water Level (m AGL)**	**Time**	**Water Level (m AGL)**
Reference water level before slug in-(m AGL)		-5.49		-5.493	
Slug in	Start	13:27	-5.362	15:49	-5.447
	Finish	14:17	-5.455	16:52	-5.469
Slug out	Start	14:17	-5.578	16:53	-5.52
	Finish	15:45	-5.493	Logger left overnight	

A7.7.2 Results and Analysis

Too few data points were taken manually to be analysed in AQTESOLV. However, from field observation during the slug tests, the layer reacted similarly to a semi-impermeable layer.

A7.8 Slug Tests at 92.0 m BGL

A7.8.1 Settings Details

A series of slug tests were performed on 25 May 2021 at a depth between 88.8 and 92.0 m BGL following the eight-hour constant-rate pumping test. The casing screen sat between 88.8 and 90.0 m BGL in a moderate to moderately well-sorted fine muddy-silty sand layer above a 2 m open hole between 90.0 and 92.0 m BGL in a poorly sorted sub-angular to sub-rounded medium to very coarse gravel (Figure A7.25). Three different sizes of slugs (slugs 2, 3 and 4) were used to undertake slug in and slug out tests. Slug tests were repeated for quality assurance (Figure A7.26).

Water levels were recorded at 250 millisecond intervals using an In-Situ Level TROLL 700 data logger. The weather was overcast and windy, with some light rainfall recorded during the test.

A barometric pressure correction with a barometric efficiency coefficient of 0.5372 was applied to the data prior to its analysis.

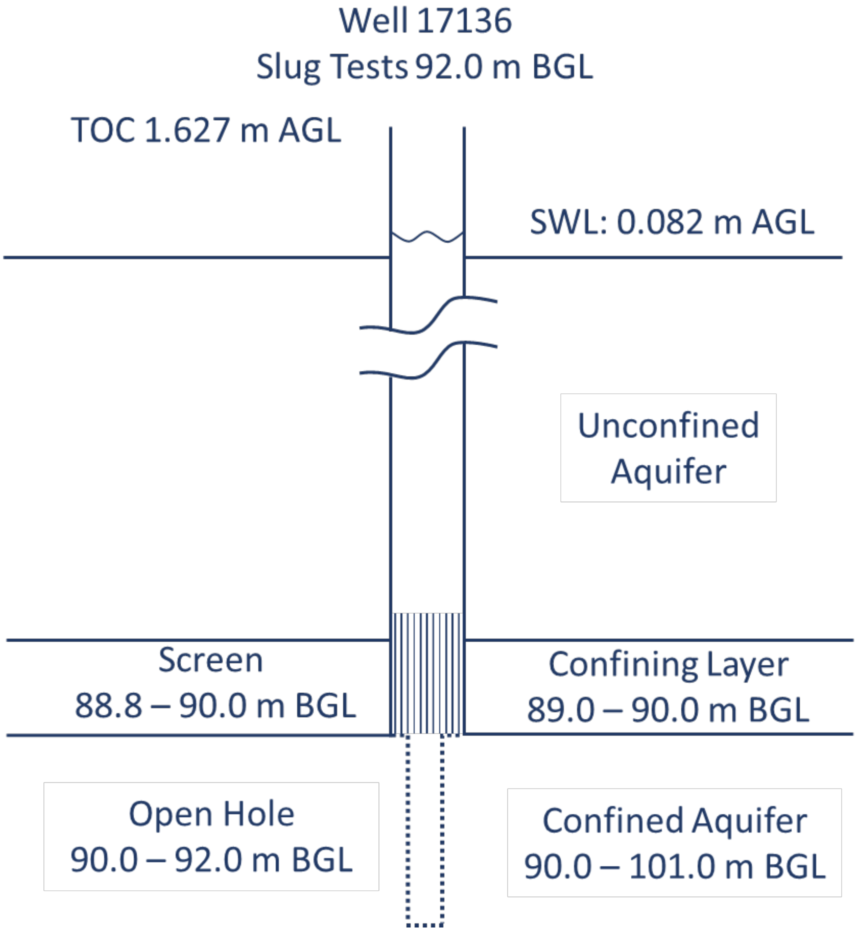


Figure A7.25 Schematic showing the well during the slug tests at 92.0 m BGL. The well was drilled to a depth of 92.0 m BGL, with an open hole between 90.0 and 92.0 m BGL. The bottom of the casing sits at 90.0 m BGL with the screen between 88.8 and 90.0 m BGL in the confining layer, with the latter being the top of the confined aquifer. TOC: Top Of Casing; SWL: Static Water Level.

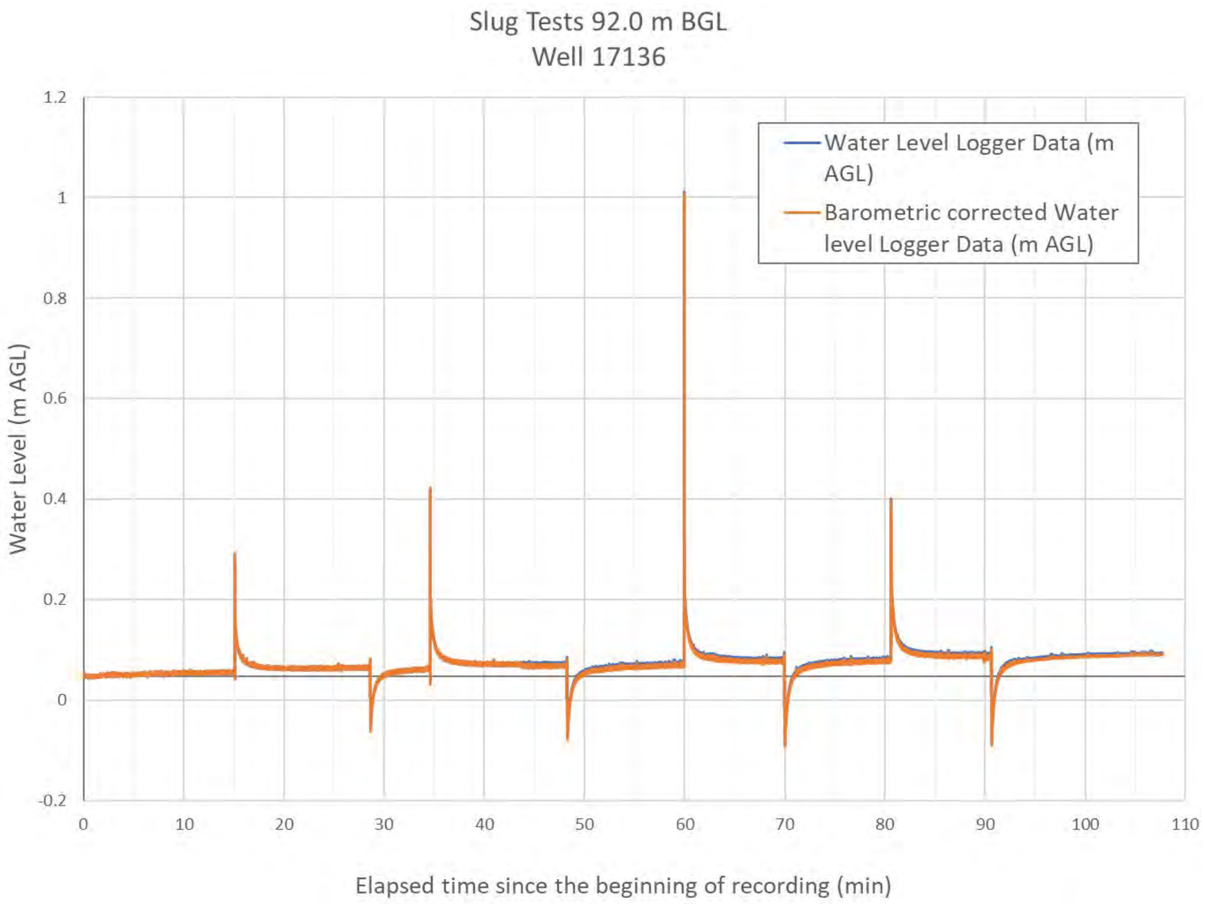


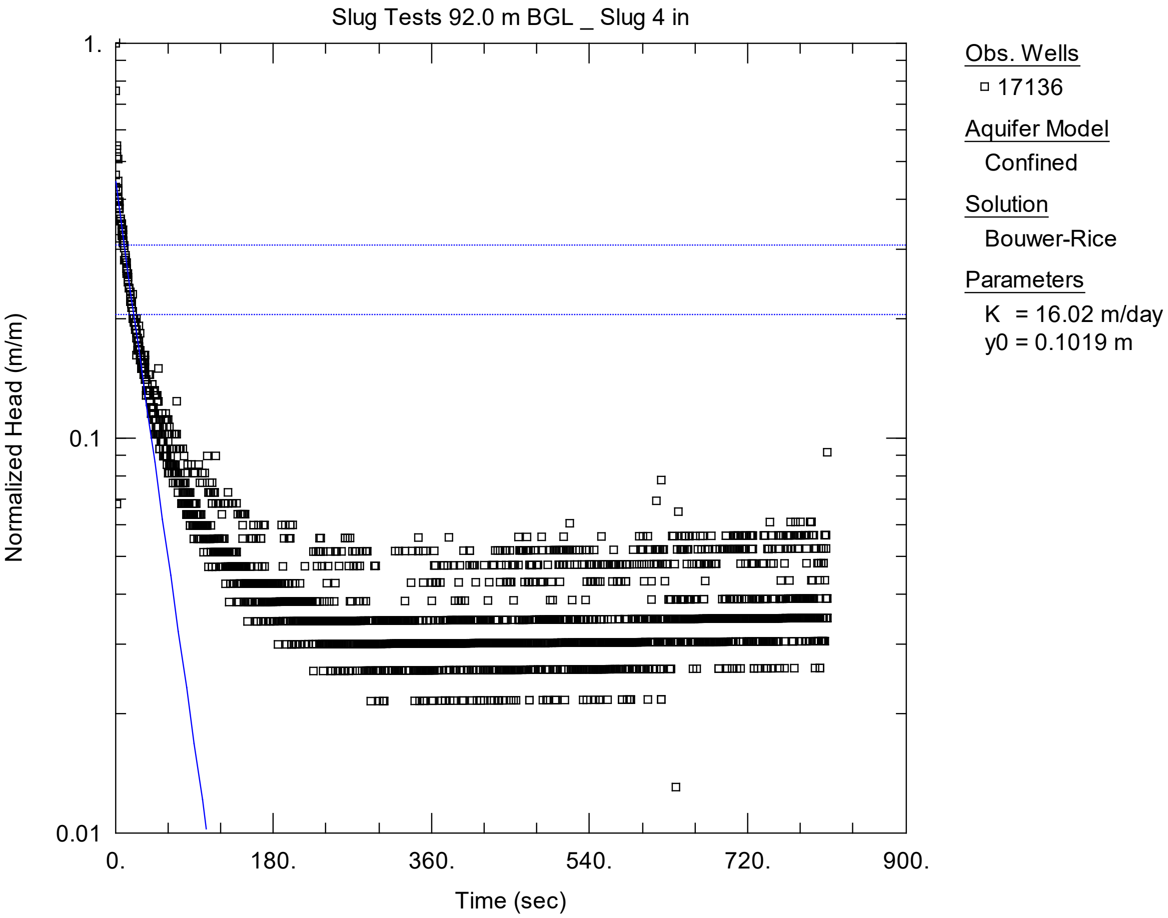
Figure A7.26 Fluctuation of the water level during the slug tests at 92.0 m BGL. Four slug tests were undertaken with the following slugs in order: slug 4, slug 3 and slug 2 twice.

A7.8.2 Results and Analysis

The slug-test data was analysed using AQTESOLV Pro software. Each slug-in and slug-out were analysed on their own, and a Bouwer-Rice solution was fitted to the curves (Figures A7.27–A7.30). From this solution, a hydraulic conductivity (K) was calculated and summarised in Table A7.8. A hydraulic conductivity average of 15.7 m/day was estimated for this layer. Assumptions made on the different parameters for this analysis (e.g. saturated thickness of the aquifer) might impact the results, as they may be over- or under-estimated.

Table A7.8 Summary of the hydraulic conductivity calculated for each slug-in and slug-out test.

		Slug Test 4		**Slug Test 3**		**Slug Test 2a**		**Slug Test 2b**	
		In	**Out**	**In**	**Out**	**In**	**Out**	**In**	**Out**
K (m/day)	Calculated from the Level TROLL 700 logger data	16.0	18.4	14.7	14.4	15.6	15.2	15.3	15.6
	Test average	**17.2**		**14.5**		**15.4**		**15.4**	
	Total	**15.7**							



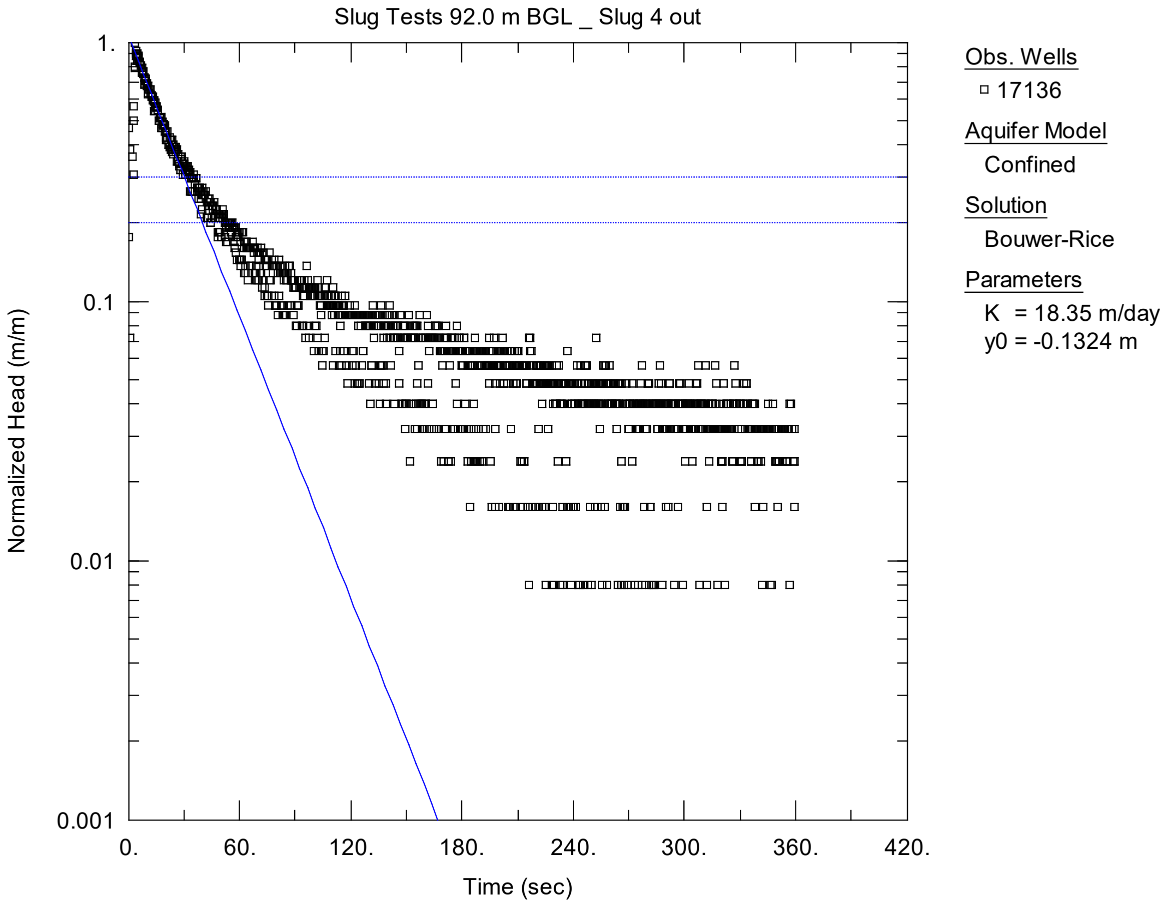
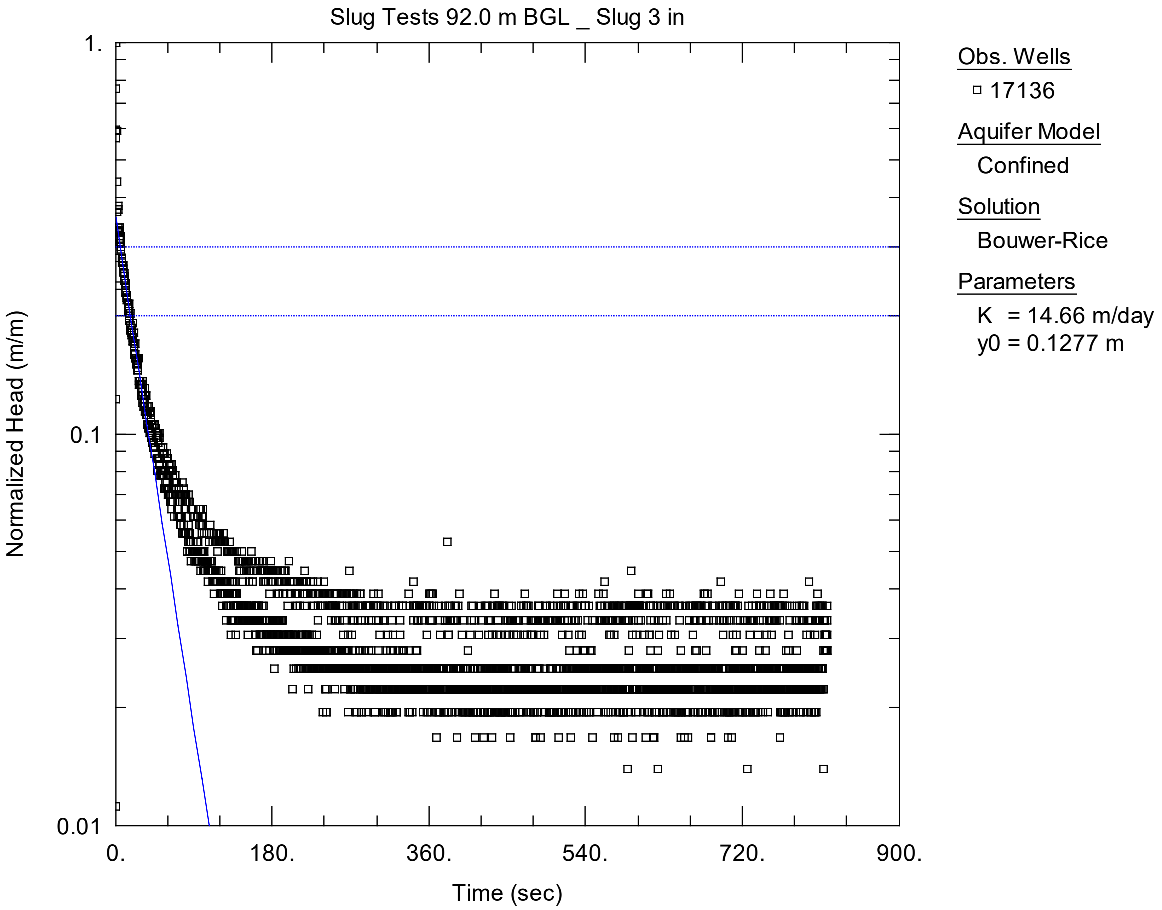


Figure A7.27 Results of the analysis for the slug-in and slug-out tests with slug 4, undertaken at 92.0 m BGL.



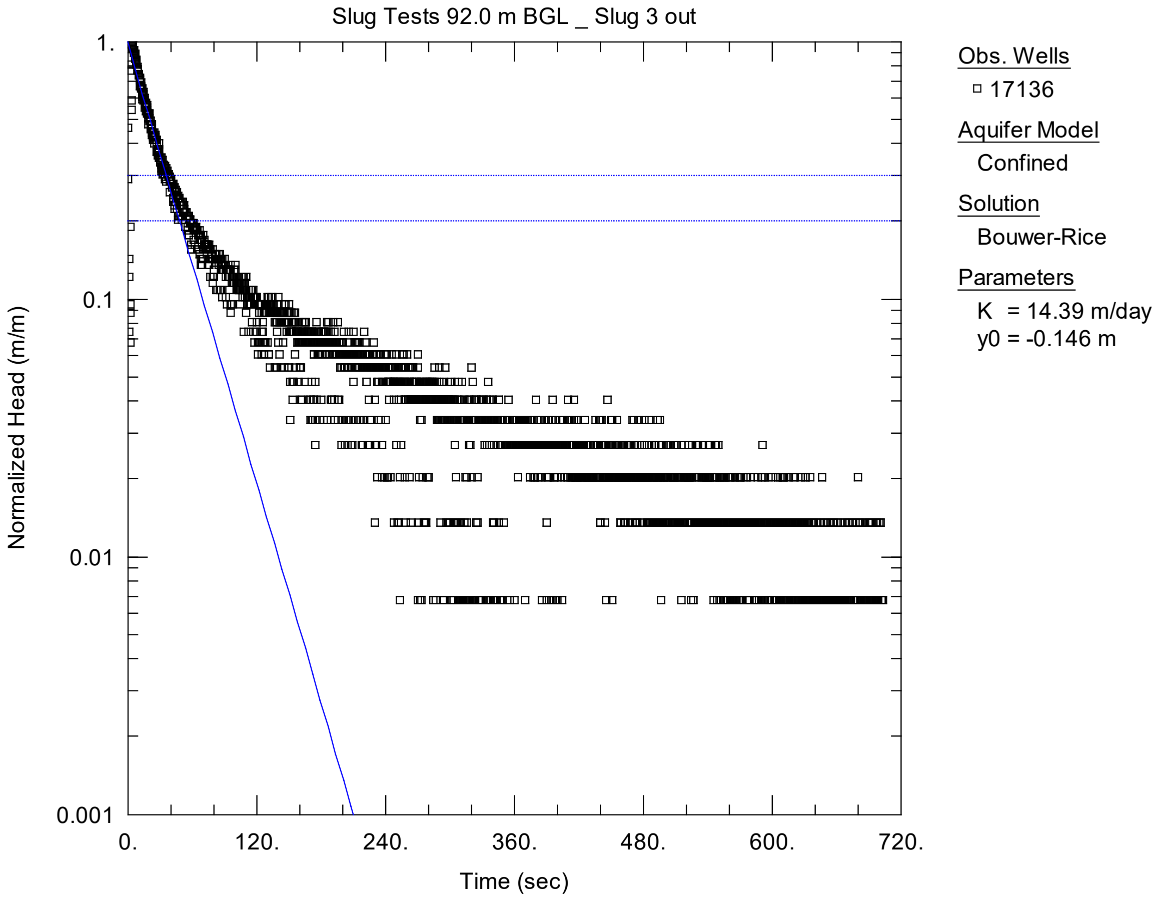
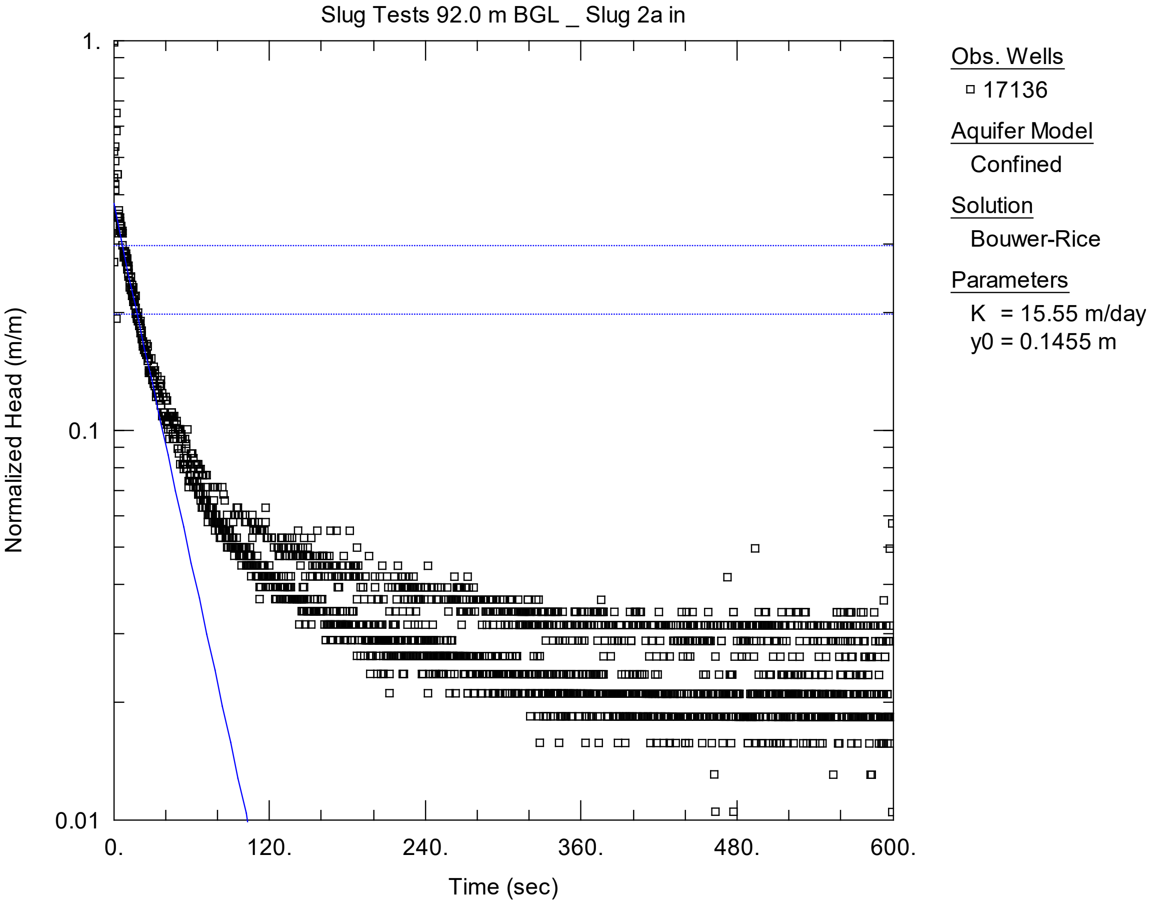


Figure A7.28 Results of the analysis for the slug-in and slug-out tests with slug 3, undertaken at 92.0 m BGL.



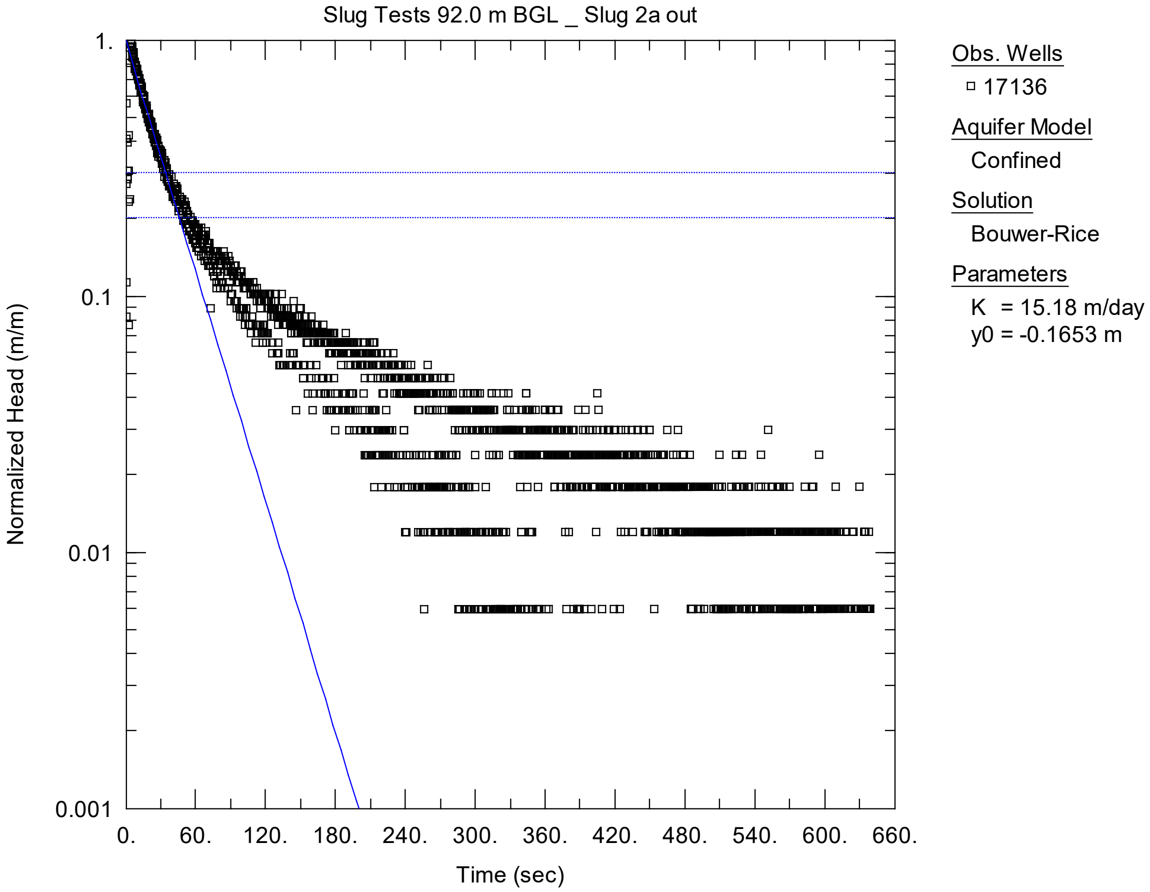
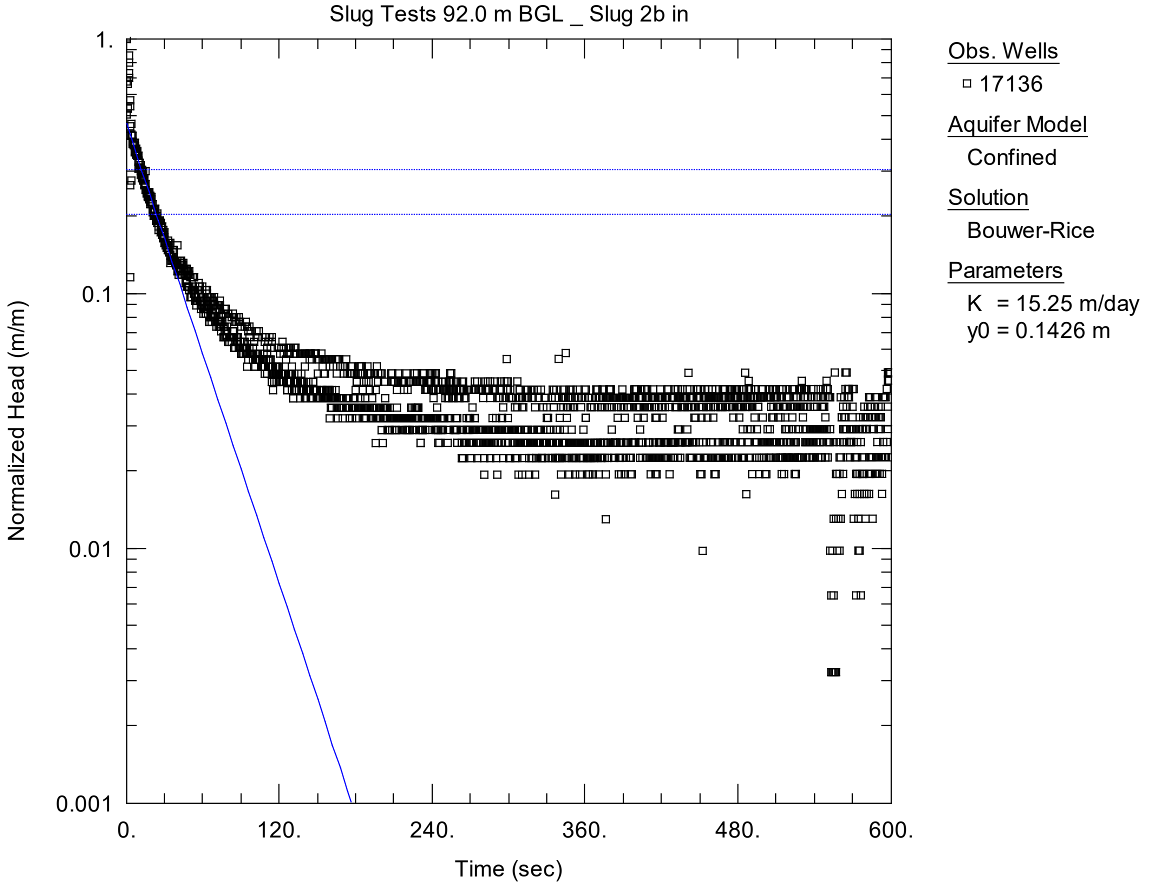


Figure A7.29 Results of the analysis for the first slug-in and slug-out tests with slug 2, undertaken at 92.0 m BGL.



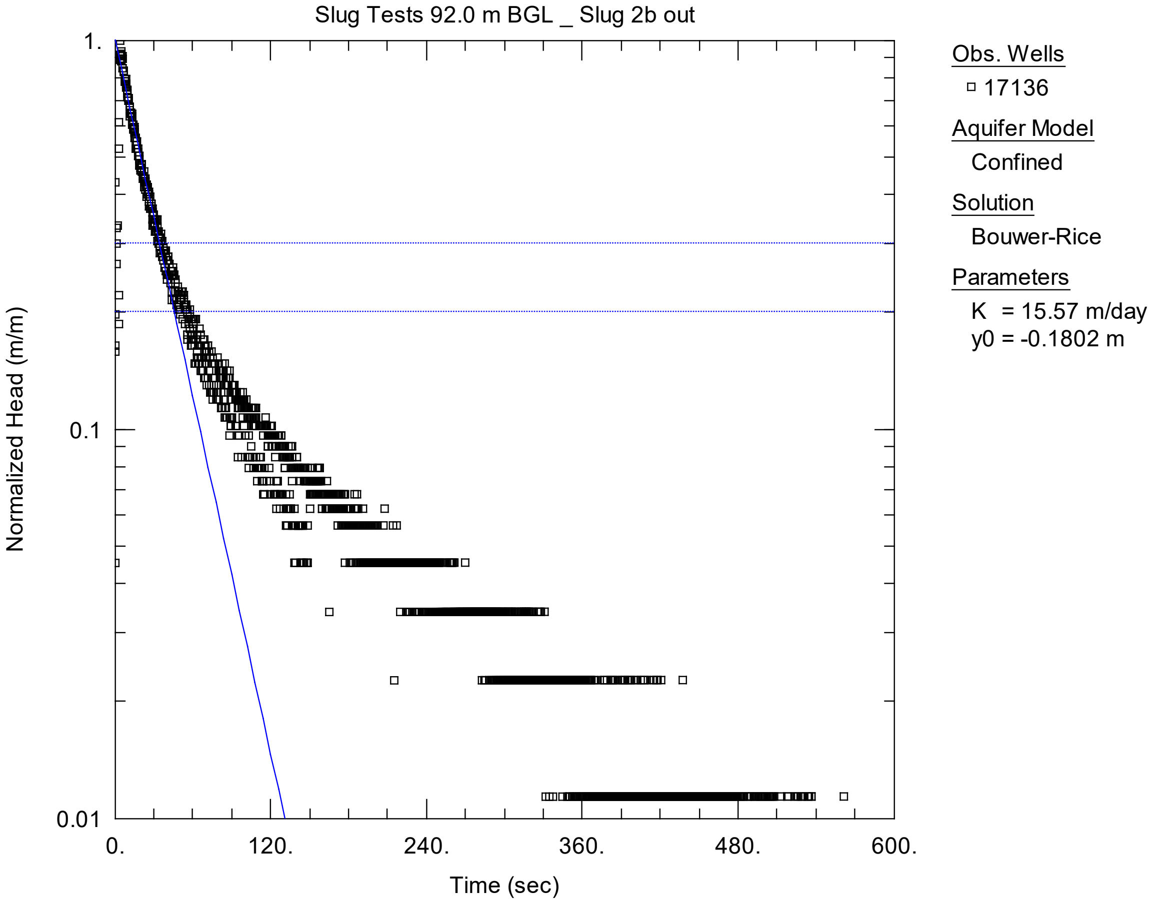


Figure A7.30 Results of the analysis for the second slug-in and slug-out tests with slug 2, undertaken at 92.0 m BGL.

A7.9 Slug Tests at 97.0 m BGL

A7.9.1 Settings Details

A series of slug tests were performed on 28 May 2021 at a depth between 92.8 and 97.0 m BGL. The casing screen sat between 93.0 and 94.0 m BGL in a poorly sorted sub-angular gravel layer above a 3 m open hole between 94.0 and 97.0 m BGL in a poorly sorted sub-angular gravel layer between 94.0 and 96.3 m BGL and 96.8 and 97.0 m BGL and in a well-sorted very fine clayey sand layer between 96.3 and 96.8 m BGL (Figure A7.31). Two different sizes of slugs (slugs 1 and 2) were used to undertake slug-in and slug-out tests. Slug tests were repeated for quality assurance (Figure A7.32). Slug 1 was slightly smaller than the casing inner diameter, therefore it could not be dropped in or pulled out of the casing instantly.

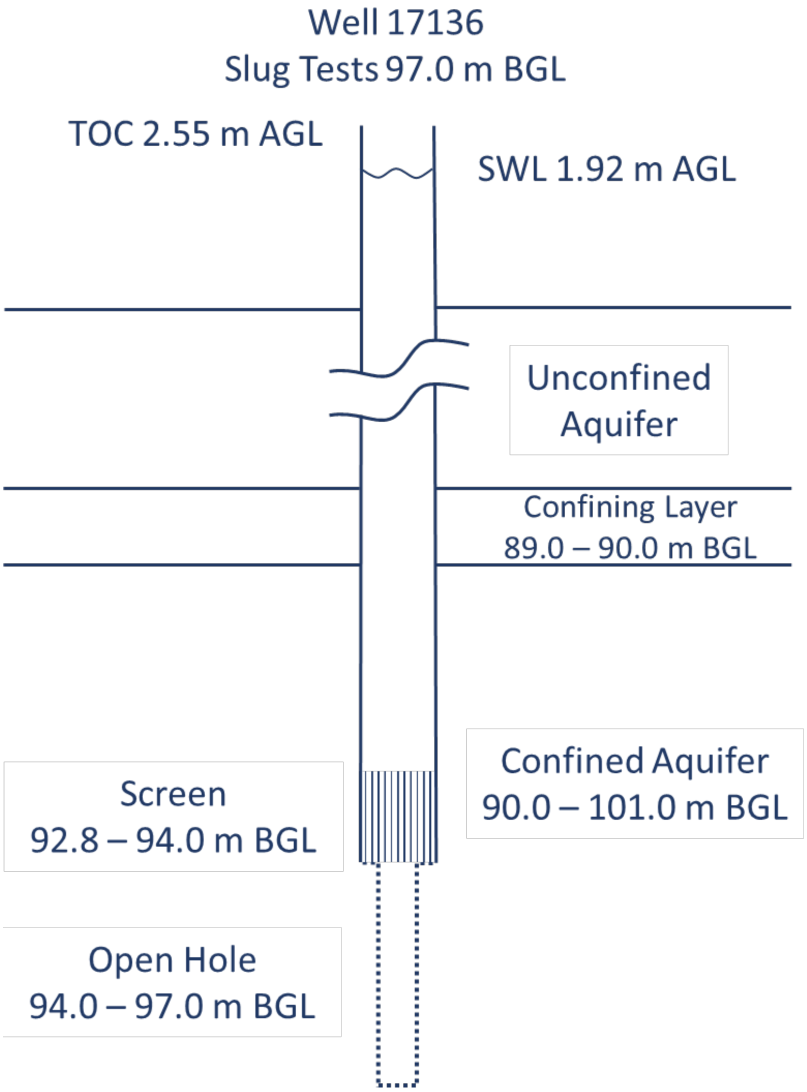


Figure A7.31 Schematic showing the well during the slug tests at 97.0 m BGL. The well was drilled to a depth of 97.0 m BGL, with a 3 m open hole between 94.0 and 97.0 m BGL. The bottom of the casing sits at 94.0 m BGL with the screen between 92.8 and 94.0 m BGL. TOC: Top Of Casing; SWL: Static Water Level.

Water levels were recorded at 250 millisecond intervals using an In-Situ Level TROLL 700 data logger. The weather was overcast, with no rainfall recorded over the duration of the test. A barometric pressure coefficient correction of 0.5372 was applied to the data prior to its analysis.

The water level seemed static prior to the start of the tests; however, a slow increase of the water level became noticeable during the first few tests with an overall 6 cm increase over 1 hour and 15 minutes. As the increase seemed to be sufficiently slow, it was decided to repeat the tests with slug 2 (Figure A7.32).

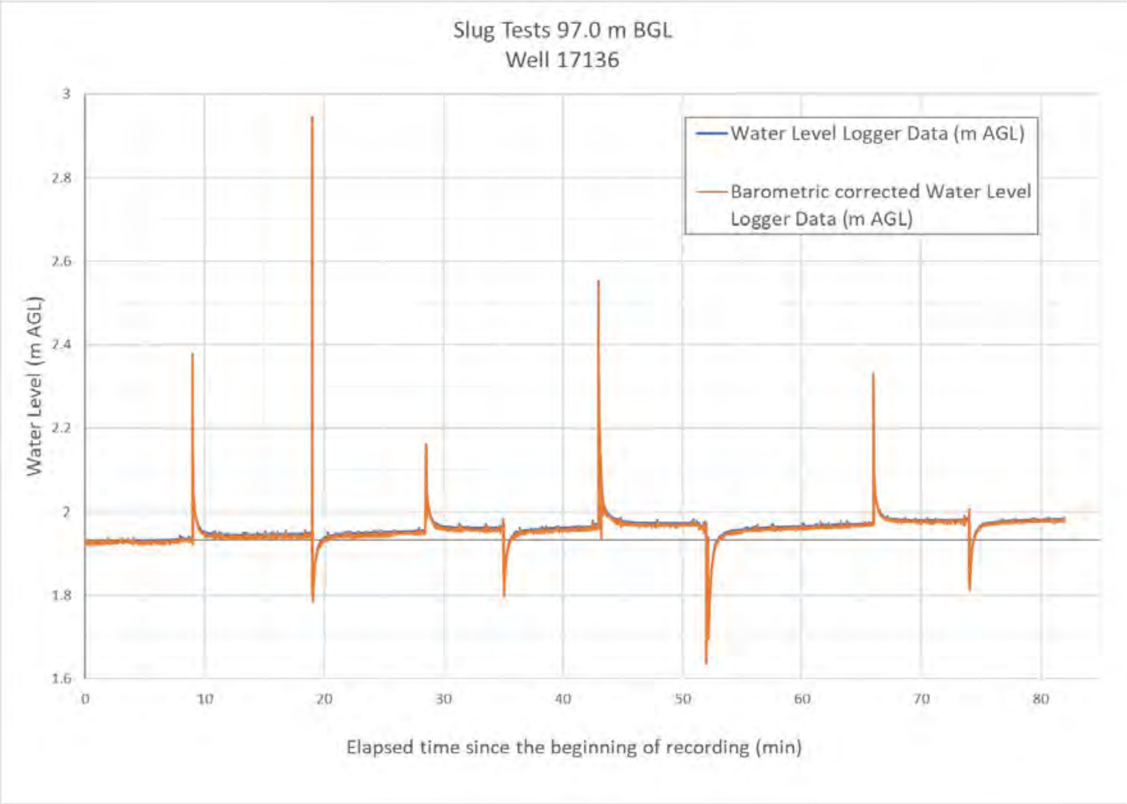


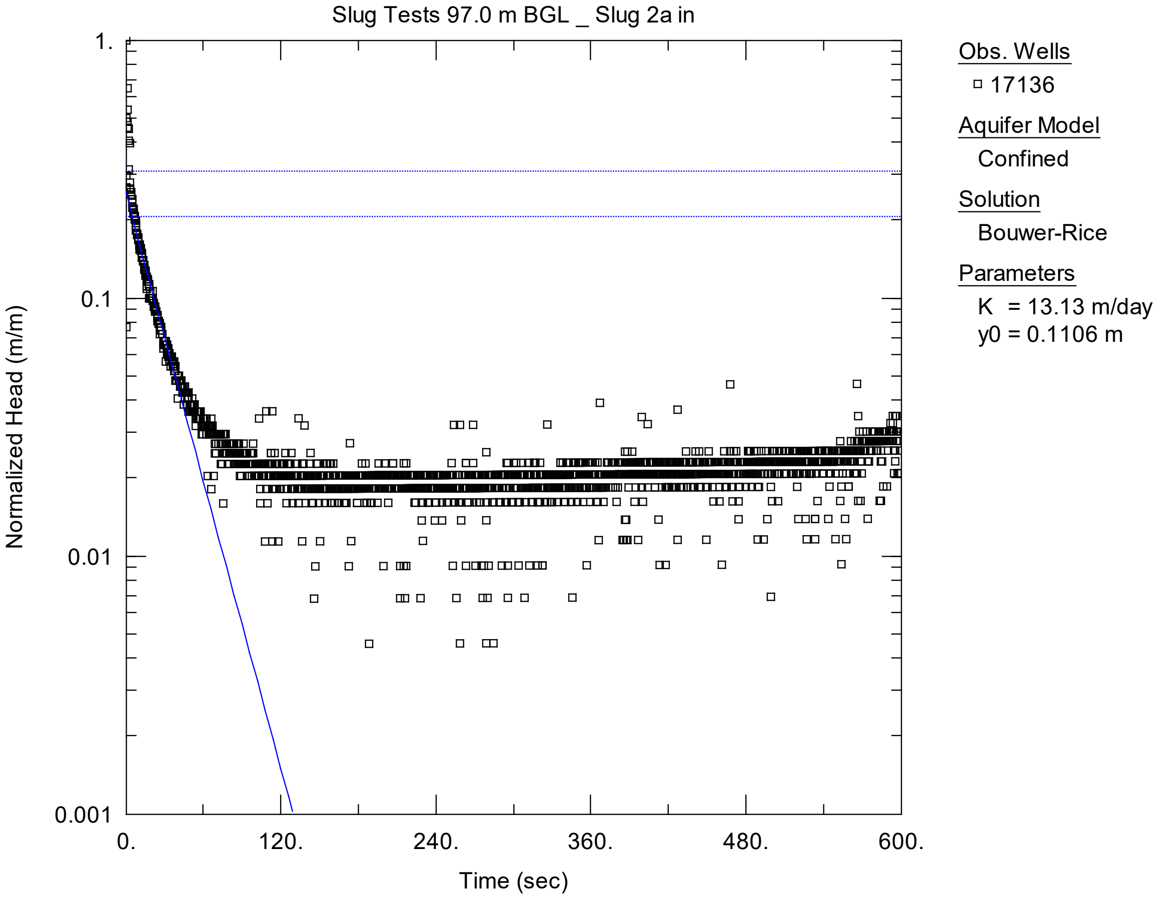
Figure A7.32 Fluctuation of the water level during the slug tests at 97.0 m BGL. Four slug tests were undertaken with the following slugs in order: slug 2, slug 2, slug 1 and slug 2.

A7.9.2 Results and Analysis

The slug-test data was analysed using AQTESOLV Pro software. Each slug-in and slug-out were analysed on their own, and a Bouwer-Rice solution was fitted on the curves (Figures A7.33–A7.36). From this solution, a hydraulic conductivity (K) was calculated and summarised in Table A7.9. A hydraulic conductivity average of 16.7 m/day was estimated for this layer. Assumptions made on the different parameters for this analysis (e.g. saturated thickness of the aquifer) might impact the results as they may be over- or under-estimated.

Table A7.9 Summary of the hydraulic conductivity calculated for each slug-in and slug-out test.

		Slug Test 2a		Slug Test 2b		Slug Test 1		Slug Test 2c	
		In	Out	In	Out	In	Out	In	Out
K (m/day)	Calculated from the Level TROLL 700 logger data	13.1	17.8	16.6	15.5	23.5	14.0	14.9	15.8
	Test average	**15.4**		**16.0**		**18.8**		**15.4**	
	Total	**16.7**							



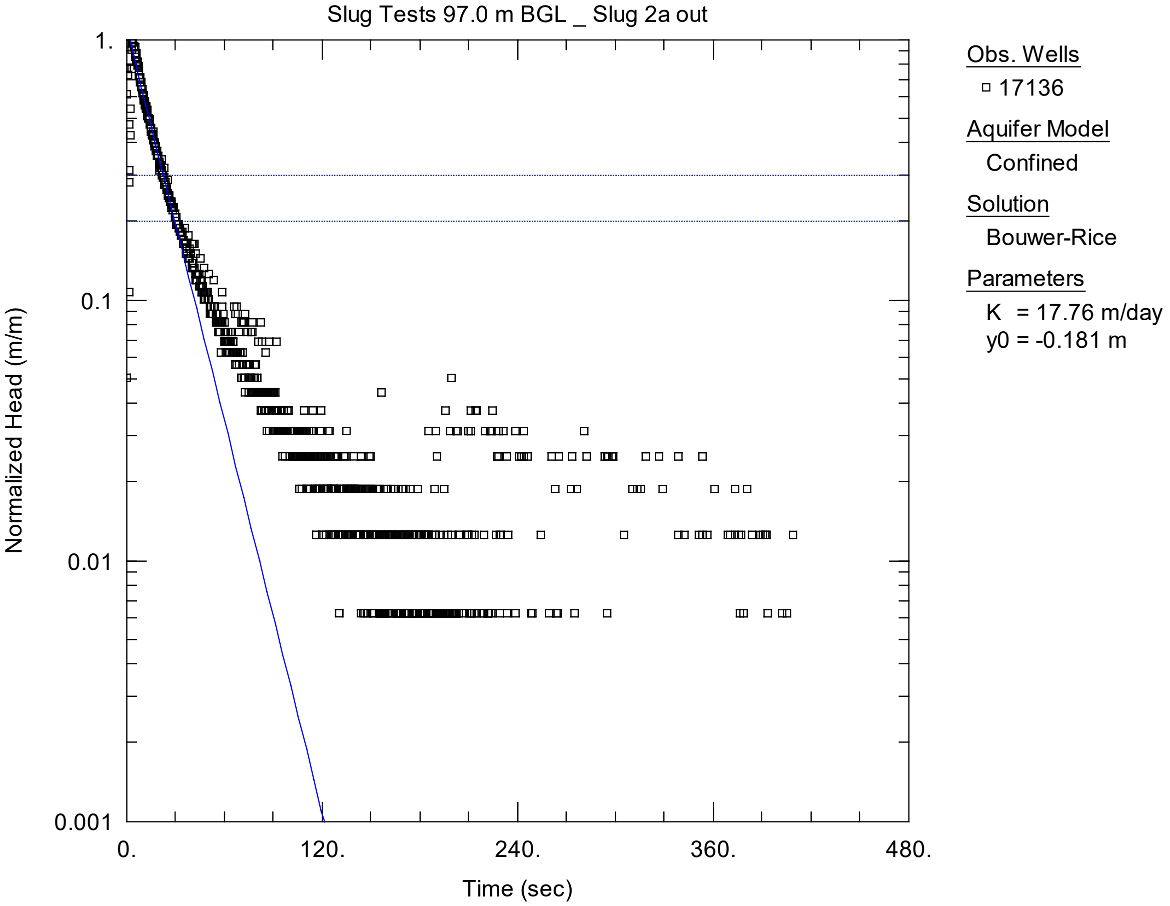
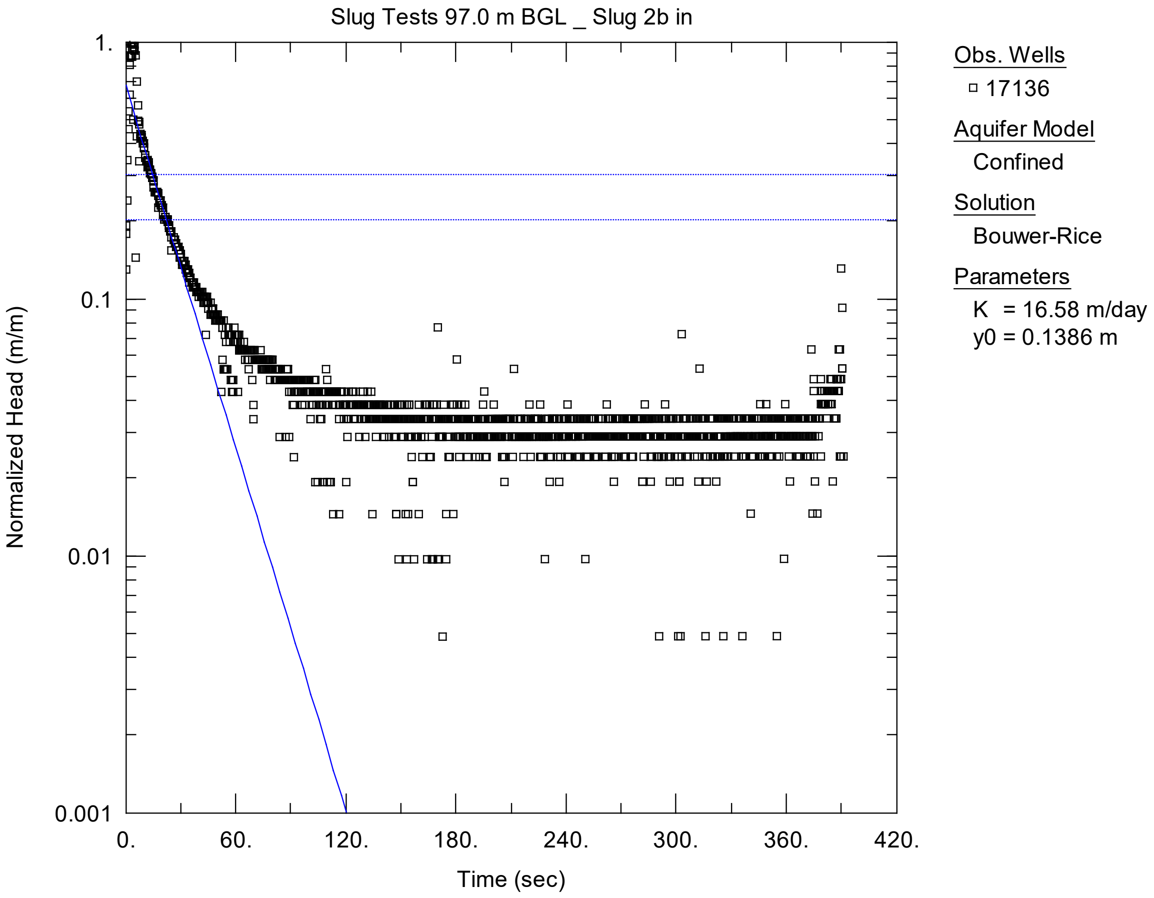


Figure A7.33 Results of the analysis for the first slug-in and slug-out tests with slug 2, undertaken at 97.0 m BGL.



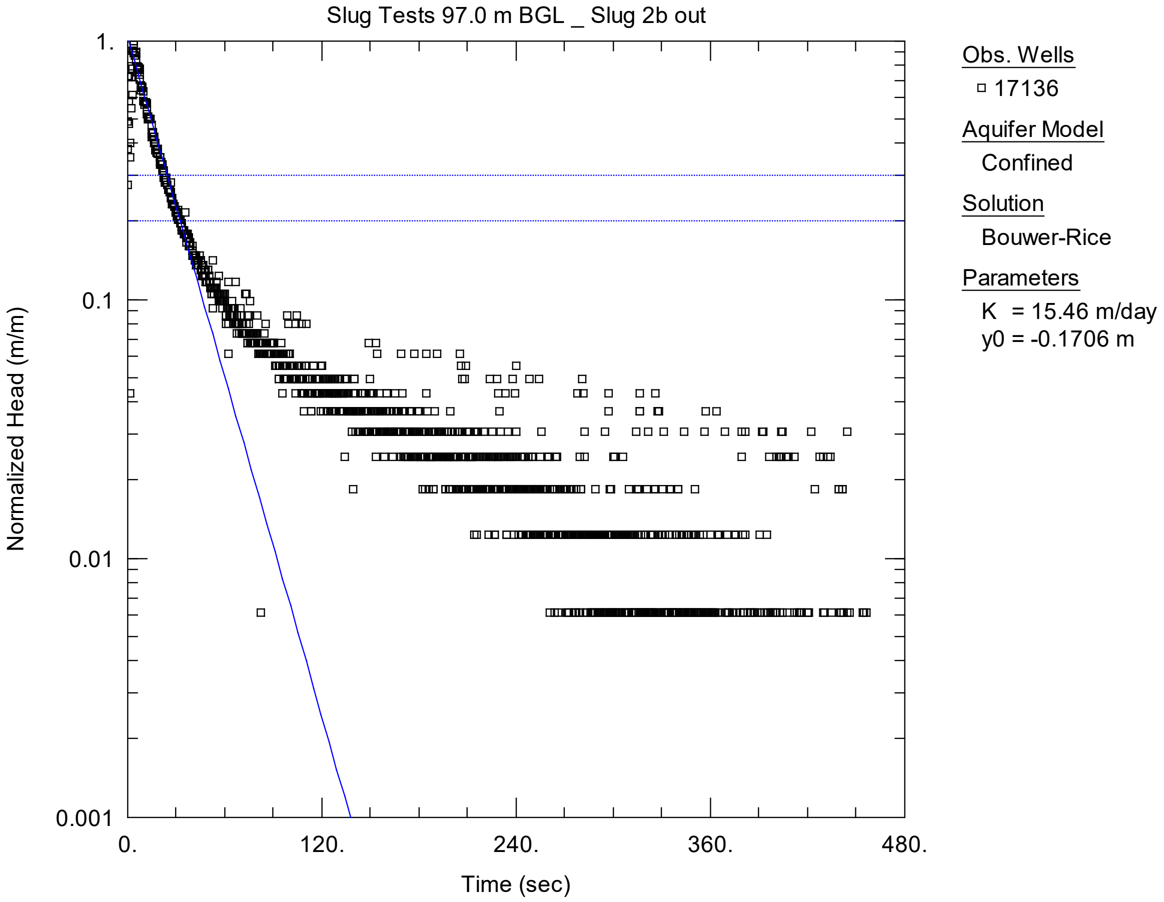
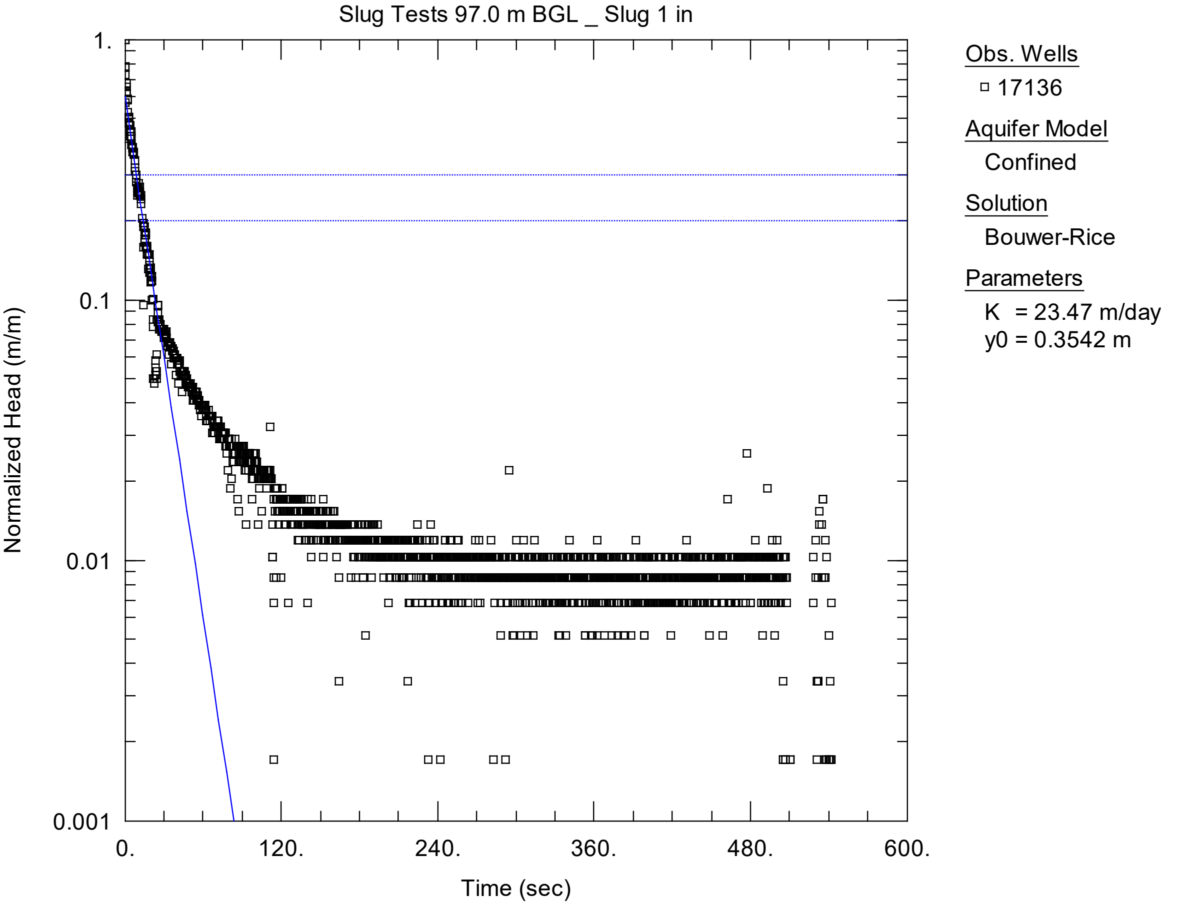


Figure A7.34 Results of the analysis for the second slug-in and slug-out tests with slug 2, undertaken at 97.0 m BGL.



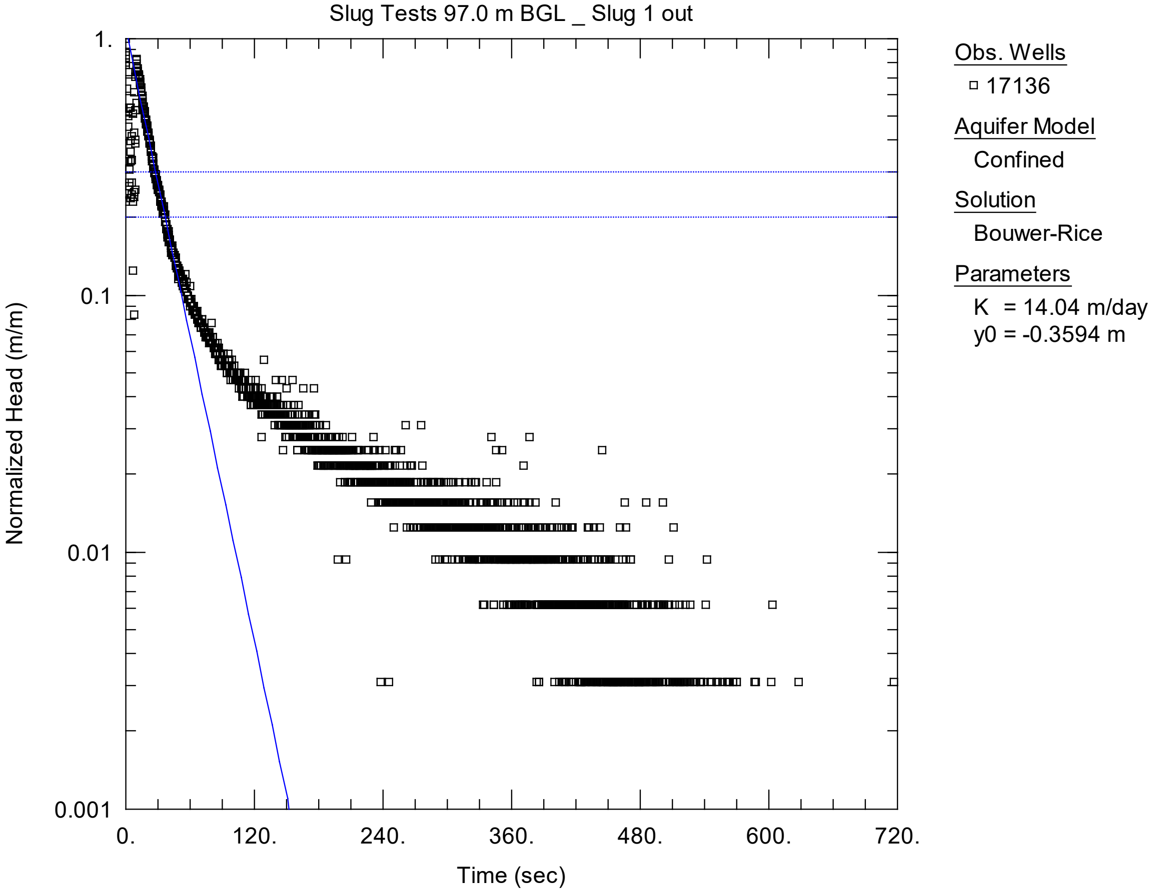
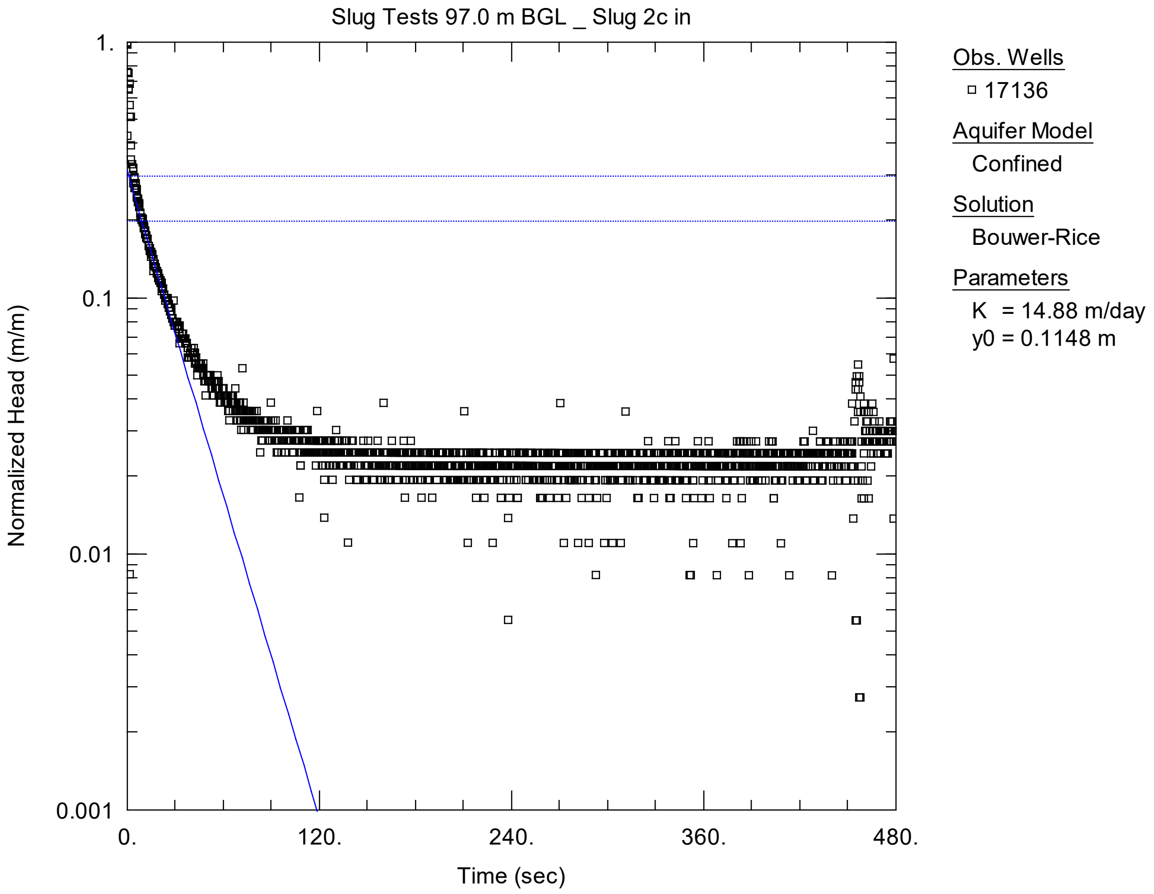


Figure A7.35 Results of the analysis for the slug-in and slug-out tests with slug 1, undertaken at 97.0 m BGL.



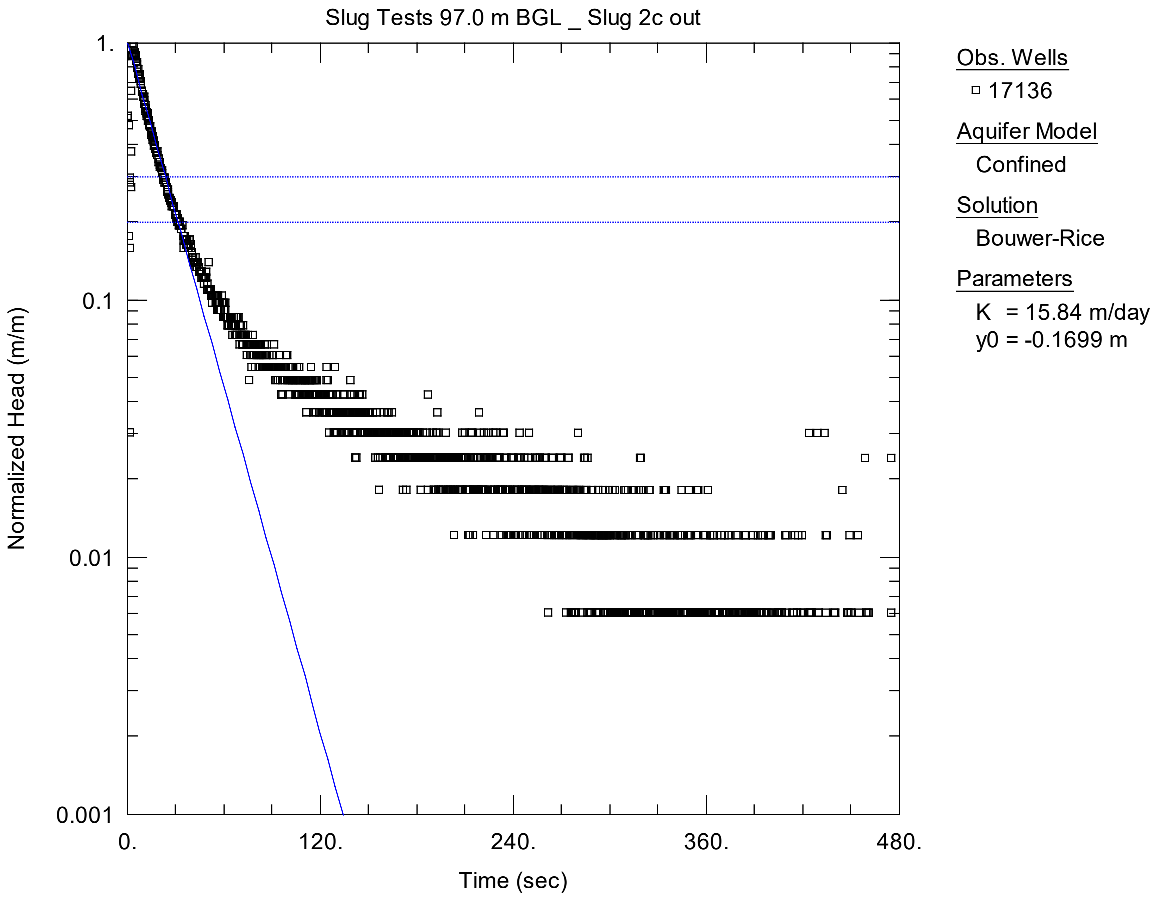


Figure A7.36 Results of the analysis for the third slug-in and slug-out tests with slug 2, undertaken at 97.0 m BGL.

A7.10 Slug Tests at 110.5 m BGL

A7.10.1 Settings Details

A slug test was performed on 18 June 2021 at a depth of 110.5 m BGL in a moderately well to well-sorted rounded medium sand (blue running sands) layer. The bottom of the casing screen was at 112.0 m BGL, with most of the screen in the sand layer. Two different sizes of slugs (slugs 3 and 6) were used to attempt slug-in and slug-out tests.

Before the slug tests, the water level had recovered above the top of casing (0.587 m above ground level) overnight with water overflowing in the morning. Conclusive slug tests could not be properly undertaken with those conditions, and no reliable data was recorded (Figure A7.37).

Water levels were recorded at 250 millisecond intervals using an In-Situ Level TROLL 700 data logger. The weather was constant, with no rainfall recorded over the length of the test.

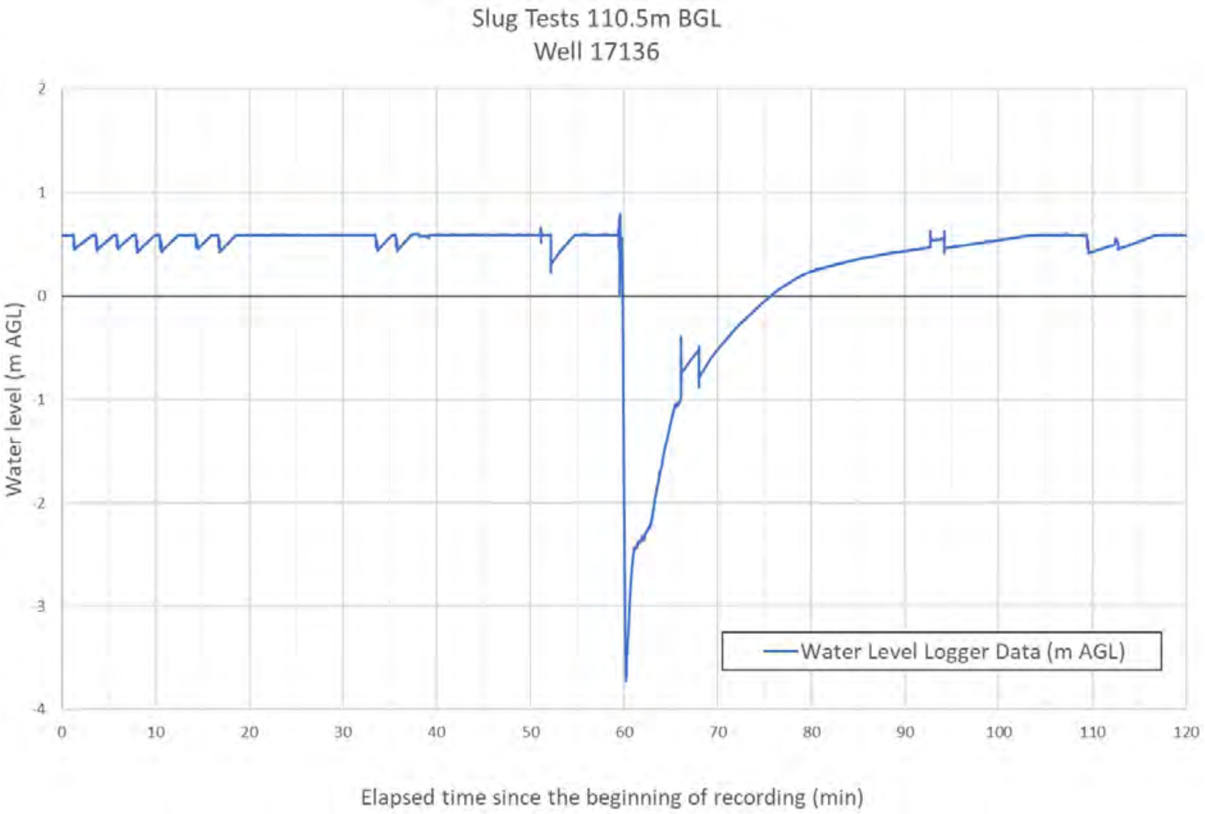


Figure A7.37 Fluctuation of the water level during the slug test attempts at 110.5 m BGL. The water was overflowing at the top of the casing when arriving on-site, and a few tests were undertaken to estimate the flow rate by removing a constant amount of water and recording how long it took to recover back to the top of casing. One hour after starting to record the water level, a large volume of water was removed from the well, and two slug tests were attempted with slugs 3 and 6. As expected, no reliable results were obtained.

A7.10.2 Results and Analysis

No reliable results of the two attempted slug tests were recorded, hence no analysis was undertaken at this layer.

APPENDIX 8 WATER CHEMISTRY

A8.1 Water Sampling at 92.0 m BGL

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Private Bag 2000, Taupo
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Fax: (07) 374 8199
Email: w.labmanager@gns.cri.nz

CERTIFICATE OF ANALYSIS
SkyTEM Site 17136
Report No: 2021052605
Customer Ref:900W4173-06

Zara Rawlinson
GNS Science
Private Bag 2000
Taupo

GNS Lot No: **2021052605**

GNS Sample No. 2021003013
Collection Date 24/05/2021
Site ID 17136
Field ID

Total Alkalinity	mg/l	213	-	-	-
Alk Analysis Temperature	ºC	20	-	-	-
pH		7.87	-	-	-
Ammonia (preserved)	mg/l	3.1	-	-	-
Bromide	mg/l	0.04	-	-	-
Calcium	mg/l	23	-	-	-
Chloride	mg/l	10.2	-	-	-
Collection Temperature[4]†	ºC	14.4	-	-	-
Conductivity	µS/cm	394	-	-	-
Diss. Reactive Phosphorus	mg/l	0.17	-	-	-
Field Conductivity[4]†	µS/cm	401	-	-	-
Field pH[4]†		6.91	-	-	-
Fluoride	mg/l	0.13	-	-	-
Iron	mg/l	0.04	-	-	-
Magnesium	mg/l	5.3	-	-	-
Manganese	mg/l	0.07	-	-	-
Nitrate as N	mg/l	0.02	-	-	-
Potassium	mg/l	9.0	-	-	-
Silica (as SiO_2)	mg/l	55	-	-	-
Sodium	mg/l	41	-	-	-
Sulphate	mg/l	11.2	-	-	-
Temperature on arrival†	ºC	6.2	-	-	-

Tests marked with a † are not accredited and are outside the scope of the laboratory's accreditation

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Report Date: 4/06/2021
Report No: 2021052605

SUMMARY OF METHODS AND DETECTION LIMITS

The following table gives a brief description of the methods used to conduct the analyses on this report.
The detection limits given below are those attainable in a relatively clean matrix.

Parameter	**Method**	***Detection Limit**	
Ammonia (total as NH_3)	FIA - APHA 4500 NH3-H 23rd Edition 2017	0.003	mg/l
Bromide	Ion Chromatography - APHA 4110-B 23rd Edition 2017	0.02	mg/l
Calcium (GW)	ICP-OES - APHA 3120-B 23rd Edition 2017	0.01	mg/l
Chloride (IC)	Ion Chromatograhpy - APHA 4110-B 23rd Edition 2017	0.05	mg/l
Conductivity	Conductivity Meter - APHA 2510-B 23rd Edition 2017	1.0	µS/cm
Fluoride (IC)	Ion Chromatography - APHA 4110-B 23rd Edition 2017	0.02	mg/l
Iron (GW)	ICP-OES - APHA 3120-B 23rd Edition 2017	0.005	mg/l
Magnesium (GW)	ICP-OES - APHA 3120-B 23rd Edition 2017	0.005	mg/l
Manganese (GW)	ICP-OES - APHA 3120-B 23rd Edition 2017	0.001	mg/l
Nitrate Nitrogen (as N)	Ion Chromatography - APHA 4110-B 23rd Edition 2017	0.01	mg/l
Phosphorus(Dis.reactive)	FIA, APHA 4500-PG (Modified) 23rd Edition 2017	0.004	mg/l
Potassium (GW)	ICP-OES - APHA 3120-B 23rd Edition 2017	0.10	mg/l
Silica (GW)	ICP-OES - APHA 3120-B 23rd Edition 2017	0.10	mg/l
Sodium (GW)	ICP-OES - APHA 3120-B 23rd Edition 2017	0.02	mg/l
Sulphate	Ion Chromatography - APHA 4110-B 23rd Edition 2017	0.03	mg/l
Total Alkalinity(as HCO_3)	Auto Titration Method APHA 2320 - B 23rd Edition 2017	5.0	mg/l

*Detection limits may be higher for individual samples should insufficient sample be available, or if the matrix requires that dilutions be performed during analysis.

[4] These tests have been conducted by Field Technicians not associated with the laboratory.

Page 2 of 3
Report Date: 4/06/2021
Report No: 2021052605

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M.K. Appleby.

Moya Appleby
Principal Technician

A8.2 Water Sampling at 168.0 m BGL

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CERTIFICATE OF ANALYSIS
SkyTEM Site 17136-168m
Report No: 2021072103
Customer Ref:900W4172-06

Zara Rawlinson
GNS Science
Private Bag 2000
Taupo

GNS Lot No: **2021072103**

GNS Sample No.	2021004180
Collection Date	20/07/2021
Site ID	17136-168
Field ID	

Total Alkalinity	mg/l	399	-	-	-
Alk Analysis Temperature	°C	20	-	-	-
pH		8.80	-	-	-
Ammonia (preserved)	mg/l	7.0	-	-	-
Bromide	mg/l	0.05	-	-	-
Calcium	mg/l	6.1	-	-	-
Chloride	mg/l	10.5	-	-	-
Collection Temperature^4†	°C	13.5	-	-	-
Conductivity	µS/cm	720	-	-	-
CO_3 Alkalinity	mg/l	22	-	-	-
Diss. Reactive Phosphorus	mg/l	0.05	-	-	-
Field Conductivity^4†	µS/cm	745	-	-	-
Field pH^4†		8.64	-	-	-
Fluoride	mg/l	1.3	-	-	-
Iron	mg/l	0.47	-	-	-
Magnesium	mg/l	4.3	-	-	-
Manganese	mg/l	0.10	-	-	-
Nitrate as N	mg/l	<0.01	-	-	-
Potassium	mg/l	11.2	-	-	-
Silica (as SiO_2)	mg/l	8.1	-	-	-
Sodium	mg/l	151	-	-	-
Sulphate	mg/l	27	-	-	-
Temperature on arrival†	°C	6.1	-	-	-

ACCREDITED TESTING LABORATORY
Nº 768

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Page 1 of 3
Report Date: 29/07/2021
Report No: 2021072103

SUMMARY OF METHODS AND DETECTION LIMITS

The following table gives a brief description of the methods used to conduct the analyses on this report.
The detection limits given below are those attainable in a relatively clean matrix.

Parameter	Method	*Detection Limit	
Alkalinity CO_3	Auto titration method APHA 2320-B 23rd Edition 2017	5	mg/l
Ammonia (total as NH_3)	FIA - APHA 4500 NH3-H 23rd Edition 2017	0.003	mg/l
Bromide	Ion Chromatography - APHA 4110-B 23rd Edition 2017	0.02	mg/l
Calcium (GW)	ICP-OES - APHA 3120-B 23rd Edition 2017	0.01	mg/l
Chloride (IC)	Ion Chromatograhpy - APHA 4110-B 23rd Edition 2017	0.05	mg/l
Conductivity	Conductivity Meter - APHA 2510-B 23rd Edition 2017	1.0	µS/cm
Fluoride (IC)	Ion Chromatography - APHA 4110-B 23rd Edition 2017	0.02	mg/l
Iron (GW)	ICP-OES - APHA 3120-B 23rd Edition 2017	0.005	mg/l
Magnesium (GW)	ICP-OES - APHA 3120-B 23rd Edition 2017	0.005	mg/l
Manganese (GW)	ICP-OES - APHA 3120-B 23rd Edition 2017	0.001	mg/l
Nitrate Nitrogen (as N)	Ion Chromatography - APHA 4110-B 23rd Edition 2017	0.01	mg/l
Phosphorus(Dis.reactive)	FIA, APHA 4500-PG (Modified) 23rd Edition 2017	0.004	mg/l
Potassium (GW)	ICP-OES - APHA 3120-B 23rd Edition 2017	0.10	mg/l
Silica (GW)	ICP-OES - APHA 3120-B 23rd Edition 2017	0.10	mg/l
Sodium (GW)	ICP-OES - APHA 3120-B 23rd Edition 2017	0.02	mg/l
Sulphate	Ion Chromatography - APHA 4110-B 23rd Edition 2017	0.03	mg/l
Total Alkalinity(as HCO_3)	Auto Titration Method APHA 2320 - B 23rd Edition 2017	5.0	mg/l

*Detection limits may be higher for individual samples should insufficient sample be available, or if the matrix requires that dilutions be performed during analysis.

[4] These tests have been conducted by Field Technicians not associated with the laboratory.

report must not be reproduced, except in full, without the written consent of the signatory. Samples are held at the laboratory after reporting for a period of 2 to 6 months, dependent on sample type.

Analyst Comment: Sodium and Chloride have been checked and the original results confirmed.

M.K. Appleby.

Moya Appleby
Principal Technician

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