APPENDIX L

EXCAVATED ROCK PLACEMENT ASSESSMENT

ANNEXURE F – LABORATORY ASSESSMENT
– SETTLEMENT CHARACTERISTICS OF THE FINE CRUSHED ROCK

Annexure F Laboratory Assessment – Settlement Characteristics of Fine Crushed Rock

REPORT

Snowy 2.0 Subaqueous Excavated Rock Placement

Settlement Characteristics of Fine Crushed Rock - Laboratory Assessment Factual Report

Client:	Snowy Hydro Limited
Reference:	PA1804 Laboratory Assessment
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Date:	12 September 2019

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Appendices

The laboratory investigations for the report herein were completed in 2018, and submitted to Snowy Hydro in January 2019. This document represents a modification of the January 2019 report. The modification is required as the option scenario for excavated rock placement (ERP) has changed in the intervening period. This report accompanies the 2019 Environmental Impact Statement (EIS) submission for Snowy 2.0 Main Works.

The methodology and location for ERP has evolved as outlined in the **Snowy 2.0 Main Works - Project development, options and alternatives (SHL et al, 2019)**.

At the time of revising the report herein, the preferred option for ERP in Talbingo Reservoir is Ravine Bay Placement, which involves placement of material from the shoreline of Talbingo Reservoir by conventional earth-moving plant such as dump trucks and excavators. As such, the settlement tests documented herein, which involve placement of material through a fall pipe, are less relevant to the current proposed methodology.

Executive Summary

Snowy Hydro Limited (Snowy Hydro) are exploring options for the management and disposal of excavated rock as part of the Environmental Impact Statement (EIS) for the “Snowy 2.0” Pumped Hydro-Electric Scheme (Snowy 2.0). Haskoning Australia Pty Ltd, a company of Royal HaskoningDHV (Haskoning), were engaged by Snowy Hydro to determine suitable location(s) for excavated rock placement (ERP) in Talbingo Reservoir and Tantangara Reservoir for the Snowy 2.0.

As part of the ERP studies, Haskoning have undertaken laboratory based investigations to assess the settling performance of crushed samples of the different rock zones that would be encountered during excavation of Snowy 2.0. In total, nine main geological formations are expected to be encountered within the tunnel alignment.

The scope of work for the laboratory investigations comprised four detailed tests which were undertaken for each geological formation, including:

1. Column test to establish TSS-turbidity relationship;
2. Settlement test to determine the settling behaviour of crushed rock;
3. Flocculation trial to assess whether a chemical flocculant would clarify the water; and
4. Critical particle size analysis to determine the maximum particle size remaining in suspension.

In addition, an initial settlement trial was undertaken in 1L columns in order to identify the prioritisation of the nine geological zones for detailed settlement testing.

It is apparent from the column tests and settlement tests that once fine crushed rock enters the water column, a portion of the finer particles remain in suspension for extended periods, in the order of several weeks (possibly longer). Crushed rock from the Tantangara Formation (Test 8), Ravine Beds (Test 1) and Boraig Group (Tests 2 and 3) geological zones generally resulted in extended periods of higher surface turbidity. In comparison, crushed rock from the Gooandra Volcanics (Test 5) geological zone settled out of suspension relatively quickly. Crushed rock from the Byron Range Group (Test 6) geological zone behaved differently to the other rock zones. While the material settled quickly in the settlement tests, elevated surface turbidity was recorded (higher than other tests) for an extended period when the water and crushed rock mixture was agitated for the column test.

With the exception of Byron Range Group, the TSS-turbidity correlations for the geological zones were similar. Turbidity equivalent to a TSS concentration of 50mg/L varied between 43 NTU (Nephelometric Turbidity Units) (Test 5 – Gooandra Volcanics) and 68 NTU (Test 8 – Tantangara Formation and Test 1 - Ravine Beds). The crushed rock was generally light grey to grey/blue in colour, with the exception of Byron Range Group, which was red-orange. The darker colour results in less light penetration and higher turbidity for an equivalent TSS concentration. Turbidity equivalent to a TSS concentration of 50 mg/L was 102 NTU for Test 6 - Byron Range Group.

The flocculation trial indicated alum, a readily available inorganic salt, is effective in clarifying the water and reducing surface turbidity. It should be noted that the particular chemical flocculant selected for the test was somewhat arbitrary and has not been approved for use during placement of rock in Snowy 2.0.

The critical particle size analysis aimed to determine the maximum particle size in suspension after a given period of time. After 15 minutes, the maximum particle size in suspension was 15 µm to 37 µm reducing to 2.5 µm to 6 µm after 24 hours, except for Test 6 - Byron Range Group. As expected, the

particle size distribution was coarser at depth within the columns. Settlement velocities determined from the critical particle size analysis are slower than those predicted by Stokes Law.

Quality Assurance tests were undertaken to ensure the results are repeatable and reliable. Overall, the accuracy of the laboratory investigation is considered to be fit for purpose and reliability of the settlement test results are considered reasonable as the general trends are repeatable. Reliability of the particle size analysis undertaken using laser techniques is considered excellent while noting that this technique can produce different results compared to conventional mechanical sieving and hydrometer methods.

Additional testing on the sensitivity of key parameters (Test 10) was conducted on crushed rock from a single geological zone, the Ravine Beds geological zone, which was also assessed during Test 1. Key findings from the sensitivity testing were that settlement performance is sensitive to:

1. The depth of placement, with deeper placement resulting in lower surface turbidity levels;
2. Temperature fluctuations, where a variation in water temperature was observed to result in an increase in surface turbidity. The increase in surface turbidity is hypothesized to be a result of convection currents.

Water temperature has a predictable influence on settlement behaviour as explained by Stokes Law. However, the effect of temperature was not significant to the outcome of the laboratory investigation.

Based on the laboratory investigation, it is inferred that:

- Placement of crushed rock near the bed of the reservoir reduces turbidity within the water column;
- Placement at depth within the reservoirs when a thermocline is apparent (i.e. during summer) is less likely to result in vertical mixing and advection of crushed rock towards the surface;
- Management measures that minimise or control the release of such fine fractions may improve the management of surface turbidity during rock placement activities; and,
- Minor disturbances to the water column during field rock placement activities in the reservoirs (e.g. due to fresh water flows, operational flows from the existing Snowy scheme (T2 and T3) wave action and propeller wash) are likely to disrupt the settlement process and/or re-suspend fine particles.

1 Introduction

Snowy Hydro Limited (Snowy Hydro) is exploring options for the management and disposal of excavated rock as part of the Environmental Impact Statement (EIS) for the Snowy 2.0 Pumped Hydro-Electric Scheme (Snowy 2.0).

To accomplish Snowy 2.0, Snowy Hydro will require ‘drill-out’ between two reservoirs; Talbingo Reservoir and Tantangara Reservoir. The preferred option to dispose of the excavated rock in the Feasibility Study (SHL, 2017) was subaqueous placement in both Reservoirs. Haskoning Australia Pty Ltd, a company of Royal HaskoningDHV (Haskoning), has been engaged by Snowy Hydro to determine suitable location(s) for subaqueous placement of excavated rock. It is intended that the design of the subaqueous placement locations would progress on the basis that this material is placed, preferentially, below the Minimum Operating Level (MOL) in the two reservoirs.

Under the scope of the Contract between Haskoning and Snowy Hydro, Haskoning provided a Submerged Excavated Rock Placement (SERP) – Draft Engineering Options Report to Snowy Hydro (RHDHV, 2018a). The report outlined all of the Haskoning findings and analysis with respect to the placement of excavated rock in Talbingo Reservoir and Tantangara Reservoir in connection with Snowy 2.0. The report also identified potential risks and issues associated with subaqueous excavated rock placement methodologies contained in the Civil Works Tenders.

Snowy Hydro will rely on the content of the Draft Engineering Options Report for the purpose of determining an engineered solution for the subaqueous placement of excavated rock. The report follows on from the Report for Final Investment Decision (FID Report) submitted by Haskoning to Snowy Hydro on 13 November 2018 (RHDHV, 2018b).

The ‘drill-out’ would produce approximately 10 million (M) m^3 of excavated rock (bulked volume) that may need to be placed within Talbingo and/or Tantangara Reservoirs, based on the Reference Design prepared by SMEC. The volume was updated in the Draft Engineering Options Report (RHDHV, 2018a) to be closer to 15M m^3. It is proposed to undertake the project in two stages, ‘Exploratory Works’ and ‘Main Works’. A subaqueous excavated rock placement trial is proposed during the Exploratory Works, with the bulk of subaqueous excavated rock placement to occur during the Main Works, subject to the successful completion of the trial and ongoing investigations.

As part of the ERP studies, Haskoning have undertaken laboratory based investigations to assess the settling performance of crushed samples of the different geological zones that would be encountered during excavation of Snowy 2.0. These laboratory investigations were required to better understand the risk of elevated turbidity during placement of excavated rock and to develop relationships between turbidity and total suspended solids (TSS) for monitoring purposes during placement in the field.

The method of excavation and ‘drill-out’ for Snowy 2.0 is expected to include tunnel boring machines (TBM) and drill & blast (D&B). Both methods are expected to generate a proportion of silt and clay sized particles, with a grain size diameter less than 63 µm (termed ‘fines’).

In total, nine main geological zones are expected to be encountered during 'drill-out' of the power waterway and associated infrastructure. The geological zones along the project alignment from Tantangara Reservoir to Talbingo Reservoir, and a brief description of the geology (SMEC, 2017), are provided below:

1. Kellys Plain Volcanics: dacite, ignimbrite, rhyodacite ignimbrite, tuff, agglomerate, rhyolite; porphyritic monzogranite. Terrestrial – volcaniclastic deposits.
2. Tantangara Formation: sedimentary turbidite sequence, sandstone, siltstone and shale; quartzite. Deep Marine – siliciclastic deposits.
3. Temperance Formation: Interbedded basaltic tuff, chert, and feldspathic arenite, minor agglomerate. Some monzonite, hornblendite, lamprophyre, quartz monzonite. Deep Marine – volcaniclastic deposits.
4. Boggy Plain Suite: I-type granitoids; even grained texture, mostly granodiorites and quartz monzogabbros, biotite monzogranite commonly containing hornblende. Shallow crustal - continental I-type deposits.
5. Gooandra Volcanics: metabasalt, basalt breccia (emplaced as pillow lavas), amphibolite, chloritic schists, feldspathic sandstone; aphyric and feldspar-phyric basalt, basaltic lava breccia, rhyolite, shale; fine-grained feldspathic siltstone and shale. Typically, deep marine - extrusive volcanic deposits.
6. Shaw Hill Gabbro: gabbro, diorite, metabasic intrusive rock, pyroxenite. Shallow crustal – continental deposits.
7. Byron Range Group: siltstone, quartzite, shale, sandstone, conglomerate & nodular limestone. Shallow Marine – siliciclastic deposits.
8. Boraig Group: rhyolite, rhyodacite, tuff, lapilli tuff, feldspathic sandstone, granophyre deposited in shield building volcanic complexes. Terrestrial - extrusive volcanic deposits.
9. Ravine Beds: shale, slate, siltstone, conglomerate. Shallow marine shelf deposits.

This report assumes the reader has an understanding of Snowy 2.0.

1.1 Structure of this Report

The report herein sets out the scope of work and methodology of the investigation in **Section 2** and **Section 3** respectively. The scope of work and methodology included an initial settlement trial followed by detailed settlement tests for each of the geological zones noted above, which included:

1. Column Test (Test D[1]) to establish TSS[2]-Turbidity[3] relationship;
2. Settlement Tests (Tests A, B and C[1]) to assess the settling behaviour of crushed rock;
3. Flocculation trial to assess effectiveness of a chemical flocculant. The trial was undertaken following completion of the column tests and settlement tests. Test A or Test B was used for the flocculation trial while the remaining columns were retained as 'control' columns; and,
4. Critical particle size analysis to determine the maximum particle size in suspension after a given time interval.

The settlement tests (Tests A, B and C) and column test (Test D) for each geological zone generally commenced on the same day. The flocculation trial was dependant on completion of the column test and settlement tests. The critical particle size analysis was independent of the other tests and required a shorter period of time to complete. However, it was generally undertaken around the same time as commencement of the column test and settlement tests.

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[1] *The column test and settlement tests are denoted by an alphabetic number. The reporting is not necessarily in alphabetical order.*
[2] *TSS (Total Suspended Solids) is a measurement of mass per unit volume, usually specified in mg/L.*
[3] *Turbidity is an optical property of water, measured in nephelometric turbidity units (NTU).*

Results from the initial settlement trial and a summary of results from the detailed settlement tests are provided in **Section 5**. Comprehensive results from the detailed settlement tests are attached in **Appendices A** to **I** with each appendix providing results for one geological zone as follows:

- Appendix A – Test 1 – Ravine Beds geological zone.
- Appendix B – Test 2 – Boraig Group geological zone, igneous rock.
- Appendix C – Test 3 – Boraig Group geological zone, sedimentary rock.
- Appendix D – Test 4 – Boggy Plain Suite geological zone.
- Appendix E – Test 5 – Gooandra Volcanics geological zone.
- Appendix F – Test 6 – Boggy Plain Suite geological zone.
- Appendix G – Test 7 – Kellys Plain Volcanics geological zone.
- Appendix H – Test 8 – Tantangara Formation geological zone.
- Appendix I – Test 9 – Temperance Formation geological zone.

A discussion regarding quality assurance of the laboratory investigation and further testing on sensitivity of key parameters is provided in **Section 6**. The additional testing on sensitivity of key parameters (Test 10) was conducted on crushed rock from a single geological zone, the Ravine Beds geological zone, which was also assessed during Test 1. A detailed description of the various quality assurance and sensitivity tests is presented in **Appendix J** along with observations, results and a discussion of each test.

Section 7 sets out the limitations identified with the laboratory investigation. An interpretation and discussion of results are provided in **Section 8**. Where applicable, the discussions in **Appendix J** and **Section 8** include inferences that could reasonably be drawn for placement of excavated rock into Talbingo and Tantangara Reservoirs for the construction of Snowy 2.0.

Conclusions from the laboratory investigations are provided in **Section 9**. This section includes a summary of results and findings from the investigations.

A memorandum outlining the results of the detailed testing for the Ravine Beds geological zone (Test 1) was provided to Snowy Hydro on the 27th September 2018. The report herein supersedes the previous memorandum.

2 Scope of Work

The scope of work for the laboratory investigations comprised four detailed tests which were undertaken for each geological zone, including:

1. Column test to establish TSS-turbidity relationship;
2. Settlement test to determine the settling behaviour of crushed rock;
3. Flocculation trial to assess whether a chemical flocculant would clarify the water; and
4. Critical particle size analysis to determine the maximum particle size remaining in suspension.

The scope of each test is outlined in the following **Sections 2.1** to **2.4** and the methodology for each test is presented in **Section 3**.

In addition, an initial settlement trial was undertaken in 1L columns in order to identify the prioritisation of the nine geological zones for detailed settlement testing. Prioritisation of testing also considered the quantity of each geological zone likely to be excavated during construction of Snowy 2.0 and the sequence of excavation as identified in the Snowy 2.0 Reference Design. With the exception of Test 1, the order of the tests for each geological zone in **Section 1.1** was selected following completion of the settlement trial.

The detailed settlement test for Test 1 (Ravine Beds) was completed prior to the initial settlement trial as it will be the predominant geological zone encountered during the Exploratory Works and comprises the material placed in Talbingo Reservoir during the subaqueous excavated rock trial. As such, detailed results were required in September 2018. A memorandum outlining the detailed settlement test results for Ravine Beds (Test 1) was provided to Snowy Hydro Limited on the 27th September 2018. The report herein supersedes the previous memorandum.

Between June and August 2018, rock cores from eight of the geological zones were supplied to Haskoning. The geotechnical investigations had not been completed at that time for the Shaw Hill Gabbro geological zone and, as such, a core was not available. The exact rock cores selected for sampling are presented below in **Table 1**. These cores were selected for a range of reasons including proximity to the proposed excavation areas and to ensure representivity of various geological zones and rock types.

Table 1: Rock cores supplied to Haskoning from the Snowy 2.0 geotechnical investigation.

Borehole ID	Sample Depth (m bgl) [1]	Geological Zone	Geology Description	Rock Type
BH1115	14 - 15	Kellys Plain Volcanics	Dacite	Igneous (extrusive)
BH2103	113 - 114	Tantangara Formation	Metasandstone	Metamorphic
BH3102	285 - 286	Temperance Formation	Interbedded metasiltstone and metasandstone	Metamorphic
BH3106	236 - 237	Boggy Plain Suite	Diorite	Igneous (intrusive)
BH3108	263 - 264	Gooandra Volcanics	Dolerite	Igneous (intrusive)
BH5105	6 - 7	Byron Range Group	Clayey gravel	Completely weathered rock
BH5105	94 - 95	Boraig Group - Igneous	Ignimbrite	Igneous (extrusive)
BH5105	461 - 362	Boraig Group - Sedimentary [2]	Interbedded siltstone and sandstone	Sedimentary
BH8106	631 - 632	Ravine Beds	Siltstone	Sedimentary

Notes:

1. *Metres below ground level (m bgl) is a measure of the distance from the top of the borehole (at the existing ground level) to the sample location. With the exception of BH3106, the angle of inclination of all boreholes was 90° (i.e. vertical) and the 'sample depth' is the vertical distance below the existing ground level. The angle of inclination of BH3106 was planned to be 75° to intercept the Boggy Plain Fault at depth (SHL, 2017). The 'sample depth' of BH3106 is relative to the inclination of the borehole and it is approximately 228 to 229 m vertically below the existing ground level at the borehole location.*
2. *The description of geology (SMEC, 2017) indicates that Boraig Group comprises terrestrial extrusive volcanic deposits (igneous rock). However, sedimentary rock in BH5105 was logged as part of the Boraig Group.*

The rock cores were crushed to produce fine-grained crushed rock, similar to the type of excavated rock that is likely to be produced by a TBM and D&B operations, albeit TBM operations are expected to produce a higher proportion of finer material compared to D&B operations. The crushed rock was sieved to 250 µm and the size fraction less than 250 µm was retained for inclusion in the laboratory testing. Crushed rock greater than 250 µm was not of primary interest for the laboratory investigation as it would readily settle and would not contribute to turbidity or TSS. Details on the method of crushing and sieving rock cores is provided in **Section 3.1**.

Water properties such as salinity and turbidity can influence the settling behaviour of sediment. As such, it is preferred that the water used in settlement tests is sourced from the site where project activities are proposed. Therefore, water used for the laboratory investigation was sourced from Talbingo and Tantangara Reservoirs. The selection of water for each test was based on the proposed location of subaqueous excavated rock placement in the Snowy 2.0 Reference Design.

2.1 Column Test

As part of the environmental management of major projects involving the placement of materials into the water column, water quality criteria relating to impacts on sensitive receptors are commonly specified in terms of TSS. In accordance with standard industry practice, compliance with these criteria is typically assessed through real time turbidity monitoring, as suspended solid concentrations are not as easily and quickly measured in the field.

A TSS-turbidity relationship is used to convert a TSS criterion into turbidity values that can be readily measured in the field during the proposed works and thus used for compliance monitoring and triggers for management actions.

The relationship between TSS and turbidity is highly site-specific, being dependant on the physical, optical and geochemical properties of suspended solids and the geochemical properties of the water. As such, testing is required to establish relationships between these properties for each of the various geological zones that would be encountered. Collection of field TSS-turbidity data during subaqueous excavated rock placement activities is recommended so that the relationship between turbidity and suspended solids can be continually validated and improved.

The test to establish TSS-turbidity relationships is based on recommendations outlined in the US Army Corps of Engineers guidelines “Improved Methods for Correlating Turbidity and Suspended Solids for Monitoring” (Thackston and Palermo, 2000).

2.2 Settlement Test

Settlement tests were undertaken to assess the settling behaviour of crushed rock. Two placement scenarios were tested, which were:

- Surface placement, simulating side dumping from a flat top barge (FTB) or split hopper barge (SHB); and,
- Placement through a fall pipe simulating placement of rock at (known) depth within the reservoirs.

Results and observations from the settlement tests were then used to help inform the selection of placement areas within the reservoir and to identify suitable placement methodologies. The tests also provided an indication of the potential change relating to turbidity generated from rock placement activities.

2.3 Flocculation Trial

Prior to completion of the settlement tests, a trial was undertaken to determine whether a chemical flocculant would accelerate settlement of fine particles and clarify the water. Flocculation is the process by which fine particulates or colloids are caused to aggregate together, forming a floc. Flocs may float to the top of a liquid, settle to the bottom of a liquid or be readily filtered from the liquid. Flocculants, or flocculating agents, are chemicals that promote flocculation. Flocculation is typically used in water purification and waste water treatment to remove suspended solids and clarify water.

The chemical flocculant selected for the test was alum (aluminium sulphate). It should be noted that the particular chemical flocculant selected for the test was arbitrary and has not been approved for use during placement of rock in Snowy 2.0.

2.4 Critical Particle Size Analysis

The critical particle size analysis test identifies the maximum particle size in suspension at a predefined time interval. This information is required to determine the size of particles that would contribute to turbidity and TSS. The maximum particle size was determined at various depths within the water column. The maximum particle size in suspension is used to estimate the settling velocity of fine crushed rock.

3 Methodology

3.1 Crushing of Rock

Two methods were utilised for crushing rock for the investigations:

1. Hammer drill; and,
2. Ring mill.

A hammer drill was used to crush rock for the first detailed settlement test, Test 1 (Ravine Beds). While this method was effective in producing fine-grained crushed rock, the procedure was not efficient. As such, a ring mill became the preferred method to crush rock for all remaining tests including the initial settlement trial and detailed settlement tests (Test 2 to Test 9). The ring mill was also used to crush rock for additional testing to determine sensitivity of test parameters (refer **Section 6**).

3.1.1 Hammer Drill

To simulate fine-grained crushed rock produced by a TBM or D&B operations, a section of core was placed in the top of a heavy-duty plastic bag and clamped in a bench vice. A hammer drill was used to drill numerous holes through the core. The drill dust and debris from the hammer drill was captured in the plastic bag beneath the core.

The crushed rock was passed through a 250 µm sieve screen to remove the coarse fraction. In total, approximately 220 g of crushed rock less than 250 µm was produced for Test 1 (Ravine Beds).

The sieved crushed rock was then evenly divided and randomly sampled by eye to obtain the required quantity for the various tests. The quantity of crushed rock for each test was weighed with a calibrated scale to the nearest 0.01g.

3.1.2 Ring Mill

Mechanical crushing, a jaw crusher and a ring mill were used to produce fine-grained crushed rock for Test 2 to Test 9 and for the repeat test on Ravine Beds to determine the sensitivity of test parameters (Test 10). The cores were first placed inside a heavy-duty plastic bag and mechanically broken, using a hammer, into cobble-sized fragments less than ~80 mm diameter. These fragments were then placed in a jaw crusher, which produces sand and gravel sized material between ~1-20 mm diameter. The material from the jaw crusher was then placed in a ring mill for around 40 seconds. Approximately 200 g of rock was placed in the ring mill each time. The milled rock was passed through a 250 µm sieve screen to remove the coarse fraction. Any crushed rock that did not pass through the 250 µm sieve screen (approximately 20%) was placed back in the ring mill for another 20 seconds. In total, approximately 500 g of crushed rock less than 250 µm was produced for settlement and column tests in the laboratory.

All equipment was blasted with air between crushing and milling different rock samples and crushed glass was placed in the ring mill to remove any residual ‘dust’. The 250 µm sieve screen was occasionally rinsed under water and air dried to remove particles clogging the screen, and to avoid cross contamination.

The sieved crushed rock was evenly divided using a riffle splitter box with 12 apertures. Each aperture has a spacing of ¼ inch (approximately 6.4 mm). The crushed rock was continuously divided until the required quantity was obtained for the various tests. The quantity of crushed rock for each test was weighed with a calibrated scale to the nearest 0.01 g.

3.1.3 Particle Size Distribution of Dry Crushed Rock

The particle size distribution of the crushed rock less than 250 µm was analysed using a Mastersizer 2000, which uses a laser to determine the size of particles in a dispersant (fluid). The method for analysis with the Mastersizer 2000 was as follows:

1. Add dispersant to the mixing basin of the Mastersizer 2000 and record the background refraction. Degassed Sydney tap water was typically used as the dispersant. Sydney tap water was degassed by pouring the water into a container and leaving it to settle for at least 24 hours.
2. Using a teaspoon, gently add a dry sub-sample of crushed rock (~2 g) to the mixing basin of the Mastersizer 2000 (with the dispersant) until obscuration of 5 to 10% is measured.
3. The Mastersizer 2000 establishes the particle size distribution based on the difference in refraction between the dispersant and the suspended sediment sample. The stirrer and pump of the Mastersizer 2000 ensures particles up to approximately 1 to 2 mm in diameter remain in suspension.

Additional details regarding the model adopted for analysis and properties of the dispersant and crushed rock are provided in **Section 3.3.4**.

3.2 Initial Settlement Trial

The initial settlement test aimed to provide a visual comparison of particle settling behaviour and to identify geological zones to be prioritised for detailed settlement testing. Approximately 5 g of sieved crushed rock and reservoir bed material from Talbingo Reservoir (note, this was the only test involving reservoir bed material) was added to separate 1L glass measuring cylinders (diameter approximately 62 mm and height to the 1 L measurement line approximately 330 mm) at 9:15 am on 14th September 2018. Water used for testing was collected from Talbingo Reservoir on 8th August 2018.

A video was recorded during placement of the material and photographs were taken at various time intervals thereafter.

Approximately 250 mL of water from near the surface of the 1L columns was extracted with a pipette for analysis of residual turbidity at ~3:00 pm on Wednesday 26th September 2018 (12 days and 5.75 hours after placement of material). The water was placed into a clean beaker. Turbidity in the beaker was measured using a Wetlab ECO-NTU sensor.

3.3 Detailed Settlement Tests

3.3.1 Column Test

The tests to establish TSS-turbidity relationships were based on recommendations outlined in the US Army Corps of Engineers guidelines “Improved Methods for Correlating Turbidity and Suspended Solids for Monitoring” (Thackston and Palermo, 2000). This guideline recommends specific procedures to develop TSS-turbidity relationships for three distinct areas related to field monitoring:

1. Monitoring re-suspension of solids in the immediate vicinity of sediment disturbance (e.g. adjacent to dredge cutter heads). This test procedure is commonly referred to as the ‘Dilution Test’.
2. Monitoring suspended solids in the effluent discharge from sedimentation ponds. This test procedure is commonly referred to as the ‘Column Test’.
3. Monitoring suspended solids during open-water dredged-material placement. The ‘Column Test’ procedure is also recommended for this type of monitoring.

Given that open-water placement of the excavated rock is proposed for Snowy 2.0, the ‘Column Test’ procedure is considered to be most appropriate (i.e. Item 3 above).

Column tests (Test D) were carried out in large settling columns (refer **Figure 1**) to minimise the ‘wall effects’ of the column sides on settling behaviour. The settling columns had a diameter of 200 mm and an overall height of 2000 mm.

Figure 1: Settling columns used for column test. Photographs were obtained ~5 to 35 minutes after commencement of Test 2D to 7D (from left to right).

The Column Test methodology involves the steps outlined below, based on the method outlined in Thackston and Palermo (2000).

1. Fill the column with 50 L of clean water from either Talbingo or Tantangara Reservoir, corresponding to the intended location of placement of the geological zone.
2. Place 47.5 g of crushed rock (<250 µm) from one of the geological zones into the column.
3. Agitate the crushed rock and water mixture until uniform mixing throughout the column is achieved (**Figure 1**). A surface turbidity of approximately 150 NTU was generally achieved.
4. Measure surface turbidity inside the column. Collect a sample of approximately 250 mL of water from the surface of the column using a clean glass beaker. Measure turbidity inside the beaker and decant a sub-sample into a plastic laboratory sample container for TSS and turbidity analysis. Excess water following the subsampling was not introduced back into the column. Generally, the full quantity of water from the beaker was transferred to a laboratory sample container.
5. Repeat Step 4 at desired time intervals for determination of turbidity and TSS. Obtain a photograph of the column test at each measurement time and record the height of all stratification layer(s) visibly present within the column in addition to any other observations. Frequent measurements are required initially when rapid change is occurring, with increasing time interval between measurements as the test progresses. Collect samples until the TSS and turbidity decreases to low (or lowest) levels.

Surface turbidity inside the column was measured using a Wetlab ECO-NTU sensor that was gently lowered to a depth of approximately 3.4 cm below the water surface. The depth of 3.4 cm was selected as this corresponded to a band on the turbidity probe, which ensured consistency in the depth of measurement. Turbidity was also measured inside the glass beaker using the Wetlab ECO-NTU sensor prior to sub-sampling.

Water samples were sent to a NATA-accredited laboratory for TSS and turbidity analysis. A minimum of 20 samples were collected during each column test.

TSS and turbidity data obtained from the testing was analysed to develop a relationship between these parameters.

3.3.2 Settlement Test

The settlement tests were carried out within large settling columns with a diameter of 200 mm and an overall height of 2000 mm (i.e. as per the column test). The following rock placement scenarios were investigated through separate settlement tests:

- Test A - Placement of dry crushed rock directly onto the water surface.
- Test B - Placement of dry crushed rock within a fall pipe with the opening submerged 500 mm below the water surface.

An additional test was undertaken for the Ravine Beds geological zone (Test 1C) to simulate placement of pre-wetted crushed rock within a fall pipe with the opening submerged 500 mm below the water surface. This test was not repeated for any of the other geological zones.

Settlement tests for the placement scenarios were undertaken concurrently for each geological zone. The settlement test procedure is based on the suggested method by Thackston and Palermo (2000) and is as follows:

1. Fill the column with 50 L of clean water from either Talbingo or Tantangara Reservoir, corresponding to the intended location of placement of the geological zone.
2. Place crushed rock from one of the geological zones into the column in the manner required for each test scenario (e.g. for Test B, dry crushed rock was placed within a fall pipe). A total of 40 g of sieved crushed rock was used for each test. The fall pipe for Test B and Test C was constructed using a clear 75 mm diameter polycarbonate tube that remained in the column for the duration of the test.
3. Measure the surface turbidity inside the column using a Wetlab ECO-NTU probe gently lowered to a depth of approximately 3.4 cm below the water surface. The turbidity probe was gently lowered into the settling column to minimise potential for re-agitation of the crushed rock/water mixture.
4. Repeat Step 4 at desired time intervals. Obtain a photograph of the settlement test at each measurement time and record the height of all stratification layer(s) visibly present within the column in addition to any other observations. Frequent measurements are required initially when rapid change is occurring, with increasing time interval between measurements as the test progresses.

Video footage was recorded at the start of each of the tests, as crushed rock was first introduced into the column. The videos were obtained to capture the initial settlement processes when crushed rock was descending and/or dispersing through the water column. The videos and subsequent photographs were compiled into a time-lapse sequence for each test.

In addition, a time series plot of surface turbidity was recorded for each settlement test.

Air temperature and water temperature was recorded every 15 minutes in Test 2B, 4B, 6B and 9B for the duration of the test using Solinist Leveloggers and a Barologger. Water temperature was monitored at two depths within the water column to assess whether fluctuations in water temperature influence the settlement process. As noted in **Section 1.1**, the settlement tests (Tests A, B and C) and the column test (Test D) were completed concurrently for each geological zone and typically commenced within a few hours of one another. In addition, Tests 2, 4, 6 and 9 were completed concurrently to Tests 3, 5, 7 and 8 respectively and they were undertaken in the same room and within approximately 2 m of each other. Water temperature was monitored in one column for each set of concurrent tests and water temperature in the remaining columns (in the same test and in concurrent tests) was assumed to be similar to the test where water temperature was monitored.

3.3.3 Flocculation Trial

Prior to completion of the settlement and column tests for each geological zone, a trial was undertaken to determine whether a chemical flocculant would accelerate settlement of fine particles and clarify the water.

The chemical flocculant selected for the test was alum (aluminium sulphate). Alum is a readily available inorganic salt used in water purification and waste water treatment. Alum neutralises the charge of colloids, which promotes suspended impurities to coagulate into larger particles and then settle. It should be noted that the particular chemical flocculant selected for the test was arbitrary and has not been approved for use during construction.

The supplier of the alum used during testing was Hy-Clor, a manufacturer of pool and spa cleaning products. Alum was dissolved in water and the solution was added to Test A at the manufacturer’s recommended dosage rate of 400 g per 10,000 L. The surface of the water in the column was lightly agitated with a glass stirring rod following the addition of the flocculant to encourage mixing and enhance the rate of the chemical reaction.

Surface turbidity inside the column was measured approximately 24 to 72 hours after addition of alum. Turbidity was measured using a Wetlab ECO-NTU sensor gently lowered to a depth of approximately 3.4 cm below the water surface. Photographs of the settlement tests were taken when the turbidity measurement was recorded.

3.3.4 Critical Particle Size Analysis

The procedure for the critical particle size analysis aimed to establish the particle size distribution of suspended crushed rock at various depths within the water column and at various time intervals. Particle size analysis was undertaken with a Mastersizer 2000. This instrument is sensitive to the reflective and refractive properties of particles (crushed rock) and concentration of suspended particles (TSS).

The test procedure for the critical particle size analysis was as follows:

1. Fill four 1 L glass measuring cylinders with approximately 1 L of water from either Talbingo or Tantangara Reservoir, corresponding to the intended location of placement of the geological zone. The four separate cylinders were prepared to obtain information regarding critical particle size in suspension at time intervals of 15 minutes, 2 hours, 6 hours and 24 hours.
2. Place approximately 5 g of crushed rock from one of the geological zones into each of the measuring cylinders.
3. Agitate the measuring cylinders by capping the end and inverting approximately 4 to 5 times. Start a timer.
4. Extract a sub-sample of approximately 100 to 150 mL of turbid water via a pipette from approximately 50 mm below the water surface (850 mL mark on the measuring cylinder) and 230 mm below the water surface (300 mL mark on the measuring cylinder) at the required time intervals of 15 minutes, 2 hours, 6 hours and 24 hours. Place the sub-sample in a clean beaker.
5. Analyse the particle size distribution of suspended crushed rock with the Mastersizer 2000. The method for analysis with the Mastersizer 2000 is as follows:
    a. Pour a dispersant into the mixing basin of the Mastersizer 2000 and record the background refraction of the dispersant. The dispersant is clean water obtained from the same source as that used to fill the 1 L columns in Step 1.
    b. Ensure the suspended crushed rock sub-sample in the beaker is fully agitated by mixing with a rotary mixer.
    c. Using a 5 mL syringe, add the suspended crushed rock subsample to the mixing basin of the Mastersizer 2000 (with the dispersant) until obscuration of 5 to 10% is measured. Alternatively, pour the content of the beaker into the mixing basin.
    d. The Mastersizer 2000 establishes the particle size distribution based on the difference in refraction between the dispersant and the suspended crushed rock sample.
    e. The Mastersizer 2000 was cleaned prior to each test with Sydney tap water.

To ensure repeatability and reliability of results from the Mastersizer 2000, a known standard of 150 to 180 µm was analysed at the start of each day of analysis. The results are presented in **Section 6** and **Appendix J**.

The General-Purpose model based on the Mie Theory (Malvern Instruments, 2007) was adopted for particle size analysis with the Mastersizer 2000. The particle properties adopted for the crushed rock were:

- Refractive index – 1.52 (default).
- Absorption – 2.

The Mastersizer 2000 reports the weighted residual for each analysis, which is a measure of the fit between the selected model (General-Purpose model) and the recorded data. The weighted residual should ideally be less than 1. A weighted residual greater than 1 indicates that the particle properties or the model are not suitable. The particle properties for crushed rock were adopted as they resulted in the lowest weighted residual (typically less than 1) for Test 1 (Ravine Beds). This indicates that the selection of the model and particle properties is suitable for the type of material.

The refractive index for water (Talbingo Reservoir, Tantangara Reservoir and Sydney tap water) was adopted as the default value of 1.33.

4 Selection of Mass of Excavated Rock for Laboratory Investigation

Ideally, the concentration of TSS in the laboratory investigations should be similar to the concentrations likely to be encountered during placement of excavated rock in the Reservoirs. However, at commencement of the laboratory investigation, there was uncertainty regarding the concentration of TSS likely to be encountered during placement of excavated rock in the reservoirs. This was in part due to limitations noted in **Sections 7.1** regarding the particle size distribution of excavated rock produced by TBM or D&B operations and limitations noted in **Section 7.2** regarding the preferred methodology for placement of excavated rock and the rate of placement.

The placement methodology and particle size distribution influences the potential for finer particles to be ‘trapped’ between larger particles during placement thereby reducing the percentage of finer particles that would be entrained in the water column. Entrainment of particles has a direct influence on the concentration of TSS with a reduction in entrainment resulting in a reduced concentration of TSS.

During scoping of the laboratory investigation, and determination of the required mass of crushed rock for each detailed settlement test, there were a number of uncertainties including:

- maximum size of particles that would remain in suspension;
- rate of settlement of crushed rock;
- potential for agglomeration of finer particles and the possibility that finer particles would form flocs that settle out of suspension relatively quickly. The formation of flocs is influenced by the geochemical properties of the water and crushed rock; and,
- extent of lateral dispersion, mixing and entrainment of crushed rock particles following placement. As noted above, the placement methodology and particle size distribution influence entrainment and mixing.

The above matters influence the resultant concentration of TSS after the addition of crushed rock, and influences the mass of crushed rock required to achieve a desired concentration of TSS in the laboratory investigation.

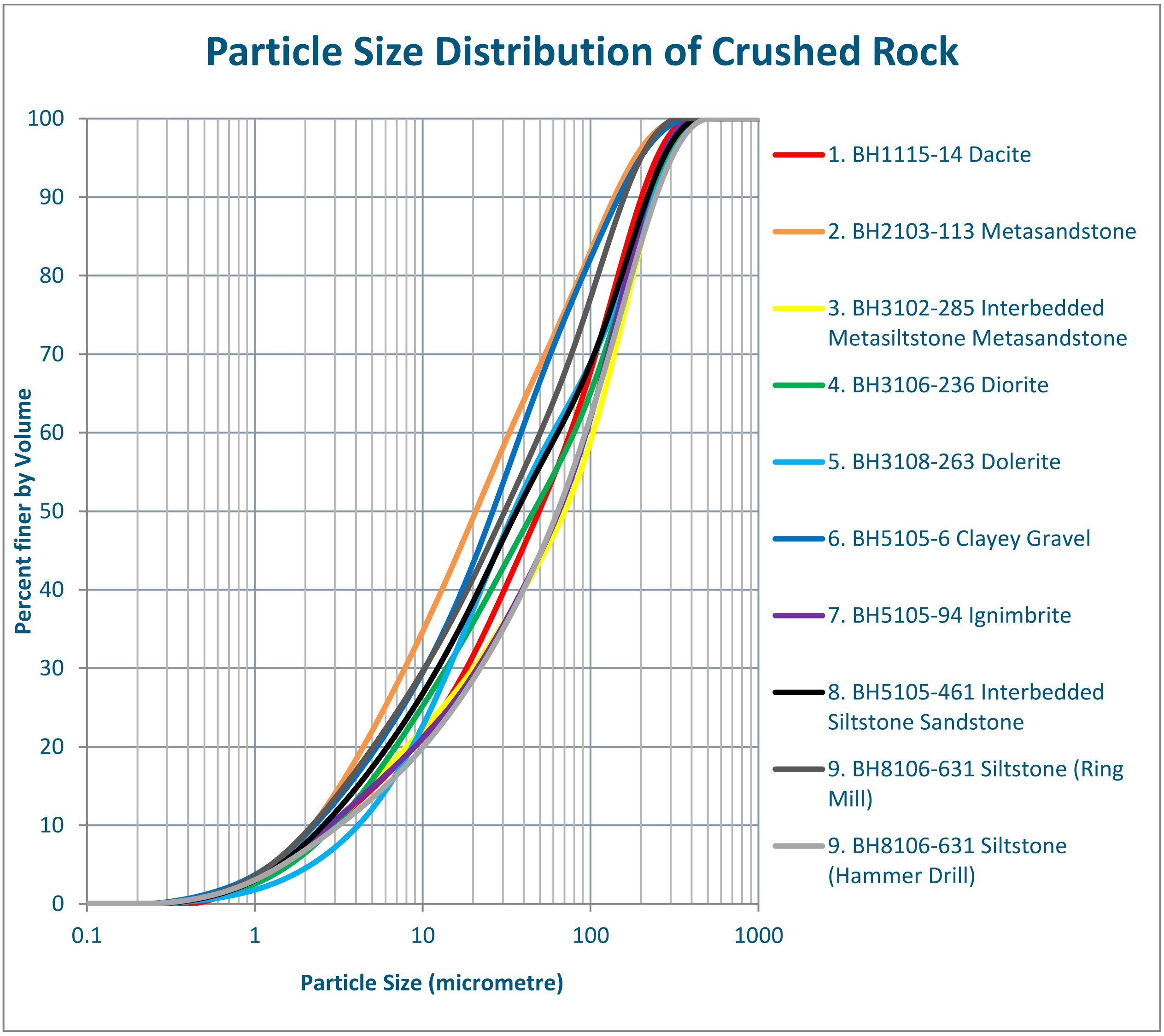
The mass of crushed rock selected for the laboratory investigation was somewhat arbitrary. However, it is anticipated that the concentration of TSS in the laboratory investigation is within the anticipated order of magnitude likely to be encountered during placement of excavated rock in the reservoirs, based on preliminary calculations and experience. Further, the mass of crushed rock in the detailed settlement tests was identical irrespective of the geological zone or particle size distribution.

5 Results

The laboratory investigations commenced on 16th August 2018. The final test concluded on 12th December 2018. Results from the investigations are provided in **Sections 5.1** to **5.3**.

5.1 Crushing of Rock

The particle size distribution of crushed rock, sieved to finer than 250 µm, was analysed with a Mastersizer 2000. The particle size distributions for the 8 geological zones are presented in **Graph 1**. The Mastersizer 2000 reports volume of material in a size 'bin' (discrete size range) as a percentage of the total volume of particles in suspension. The crushed rock samples were generally reported to comprise particles between 0.28 and 478.63 µm. The size range of each 'bin' decreases as particle size decreases. For example, at the upper end of the recorded particle size, the 'bin' is from 416.87 to 478.63 µm (range 61.76 µm) while at the lower end of recorded particle size, the 'bin' is from 0.28 to 0.32 µm (range 0.04 µm). The volume in each size 'bin' can be reported as percent finer by volume as displayed in **Graph 1**.



Graph 1: Particle size distribution of crushed rock sieved to finer than 250 µm.

The particle size distributions indicate that the crushed rock samples are widely graded. Approximately 45 to 75% of the crushed rock samples were classified as fines (silt and clay sized particles less than 63 µm) and 10 to 20% of the crushed rock samples contain clay sized particles (less than 4 µm).

The Ravine Beds geological zone crushed with a hammer drill was coarser than the rock crushed with a ring mill.

The crushed rock samples were passed through a 250 µm sieve. However, the particle size distribution indicates the presence of coarser particles up to ~480 µm. The cause of this discrepancy is related to the shape of particles. A discussion is provided in **Section 7.4**.

5.2 Initial Settlement Trial

The initial settlement trial commenced at 9:15 am on Friday 14th September 2018. A photograph approximately 10 minutes following placement of material is provided in **Figure 2** and a photograph approximately 3 days after placement is shown in **Figure 3**.

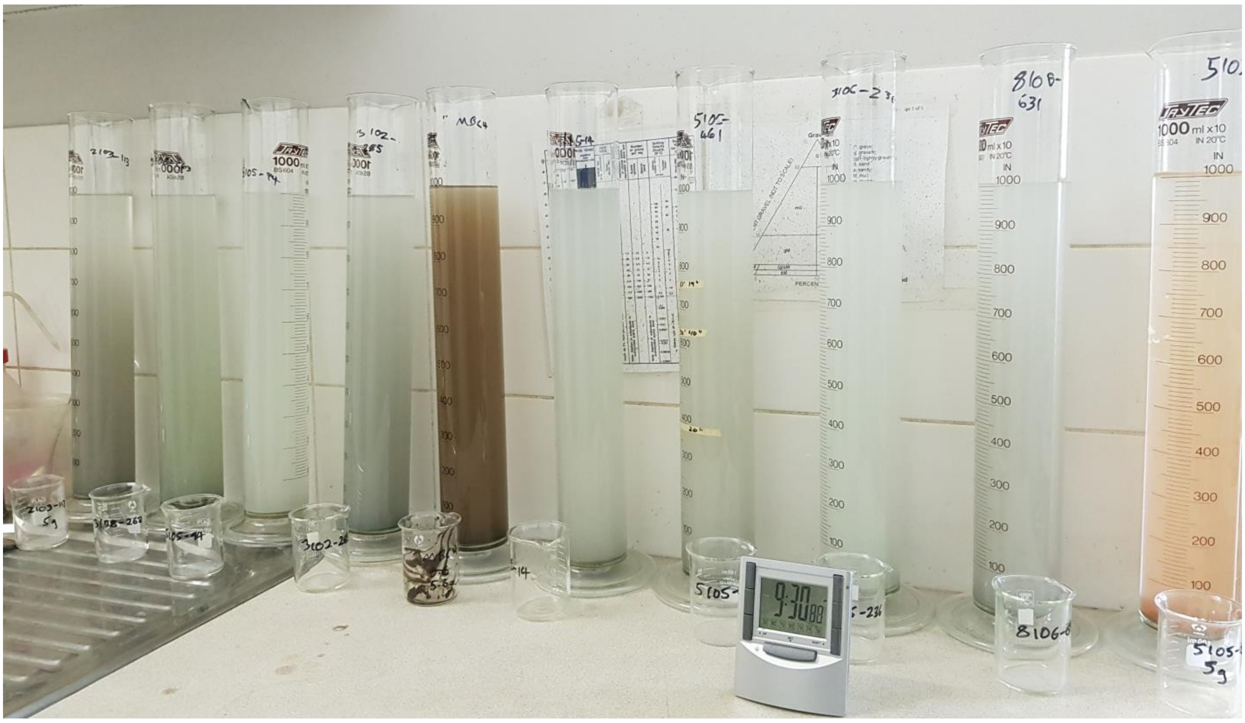


Figure 2: Photograph approximately 10 minutes after placement of crushed rock in 1 L columns.

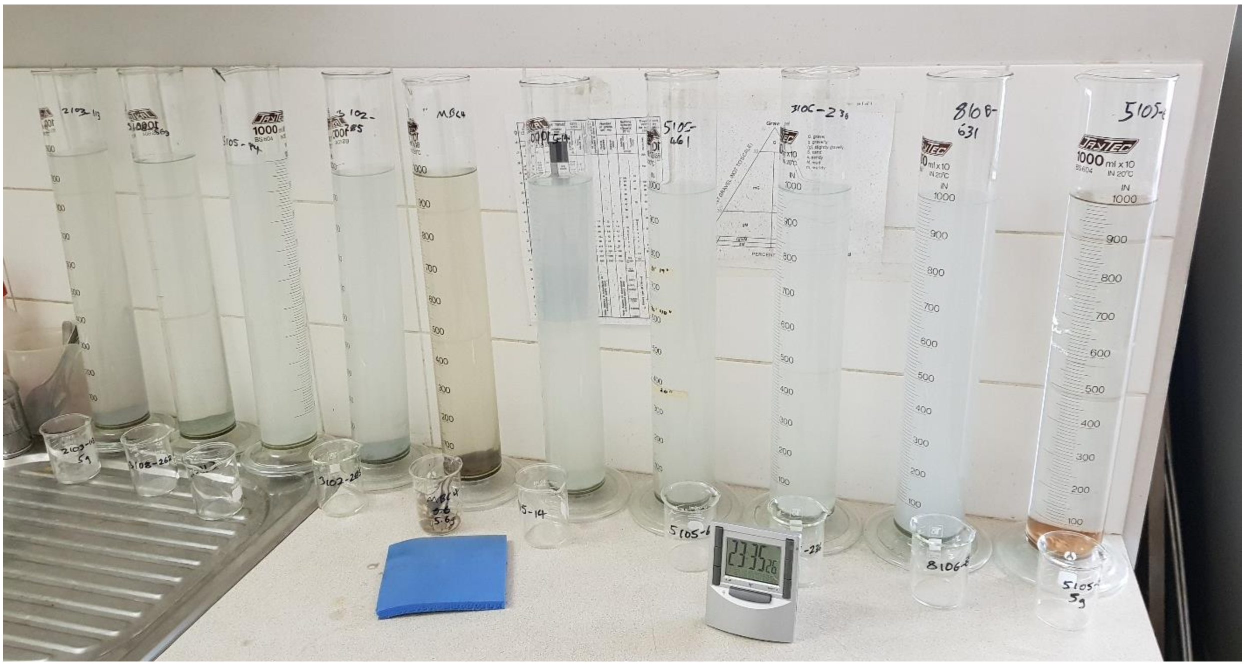


Figure 3: Photograph approximately 3 days following placement of crushed rock in 1L columns.

Approximately 250 mL of water from near the surface of the 1 L columns was extracted for analysis of residual turbidity at ~3:00 pm on Wednesday 26th September 2018 (12 days and 5.75 hours after placement of crushed rock). Results from the residual turbidity analysis are presented in **Table 2**. The results indicate that the sediment sample from Talbingo Reservoir and the crushed rock samples, except for Clayey Gravel from the Byron Range Group and Dolerite from the Gooandra Volcanics, contain colloids that remained in suspension in Talbingo Reservoir Water for the duration of the test. Sedimentary siltstones from the Ravine Beds and Boraig Group remained in suspension for a longer period compared to the other samples. These were the only two samples of sedimentary rock analysed.

The size of particles in the crushed rock samples (refer **Section 5.1**) does not explain the variation in turbidity and settlement rates observed in the initial settlement tests. It is more likely that other factors such as particle shape and chemical composition influence the settlement rate of fine crushed rock.

5.3 Detailed Settlement Test

Detailed settlement test results are presented in **Appendices A** to **I**. The order of testing and the appendices providing detailed results is outlined in **Table 3**. Prioritisation of testing was based on the initial settlement trial results (refer **Section 5.2**). The order of boreholes (and geological zones) listed in **Table 3** corresponds with the order along the power waterway tunnel moving from Tantangara Reservoir (east) to Talbingo Reservoir (west).

Table 2: Residual turbidity in 1L columns, 12 days and 5.75 hours after agitation.

Borehole ID.	Geological Zone	Geology Description	Rock Type	Residual Turbidity (NTU)
BH1115	Kellys Plain Volcanics	Dacite	Igneous (extrusive)	22.7
BH2103	Tantangara Formation	Metasandstone	Metamorphic	21.2
BH3102	Temperance Formation	Interbedded metasiltstone and metasandstone	Metamorphic	11.3
BH3106	Boggy Plain Suite	Diorite	Igneous (intrusive)	15.8
BH3108	Gooandra Volcanics	Dolerite	Igneous (intrusive)	4.1
BH5105	Byron Range Group	Clayey gravel	Completely weathered rock	1.6
BH5105	Boraig Group	Ignimbrite	Igneous (extrusive)	35.3
BH5105	Boraig Group	Interbedded siltstone and sandstone	Sedimentary	53
BH8106	Ravine Beds	Siltstone	Sedimentary	51
MBC4	NA	Silt	Sediment	9

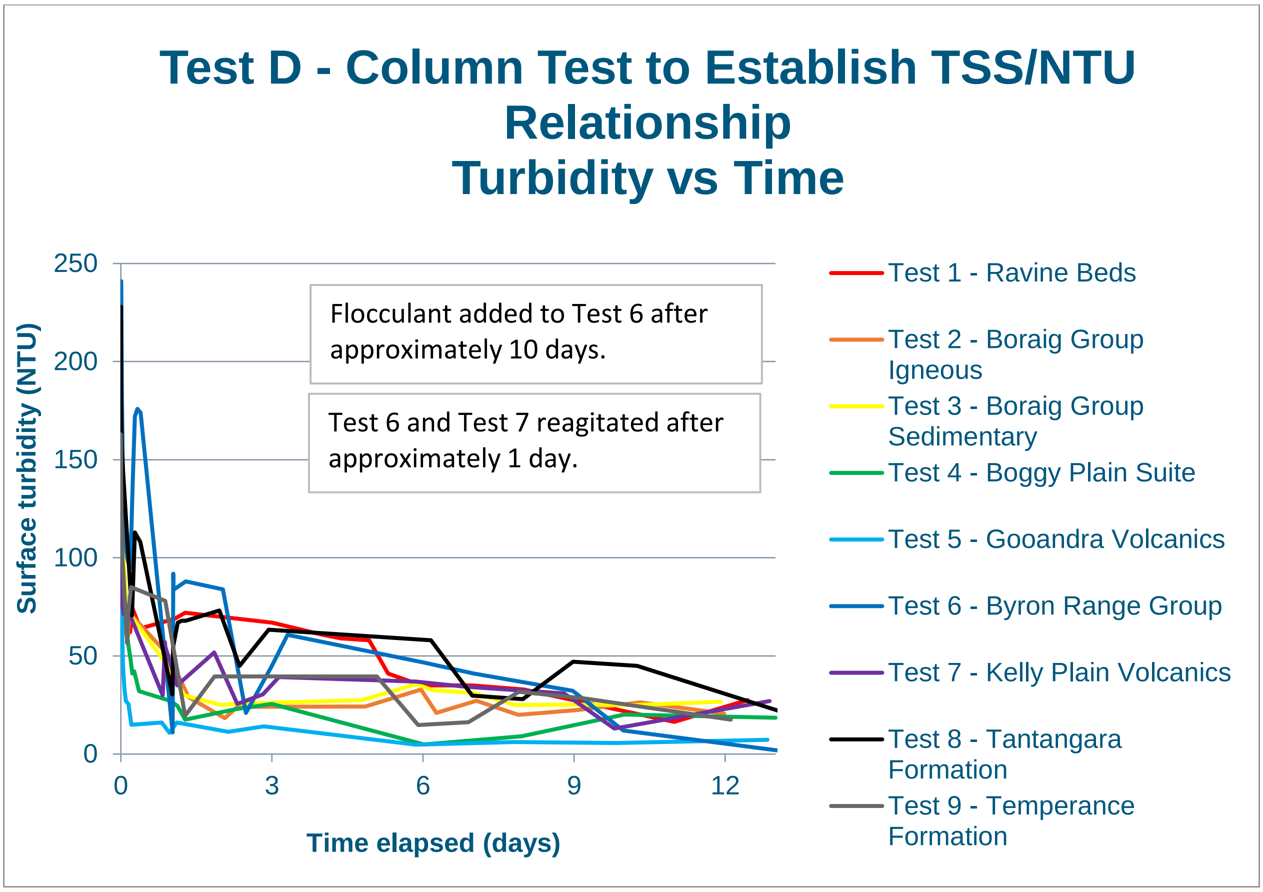
Table 3: Order of analysis of the geological zones and reference to Appendices containing results.

Borehole ID	Test No. / Appendix	Geological Zone	Rock Type	Assumed Disposal Location (water for test)	Date Commenced
BH1115	7 – Appendix G	Kellys Plain Volcanics	Igneous (extrusive)	Tantangara	23-10-18
BH2103	8 – Appendix H	Tantangara Formation	Metamorphic	Tantangara (TBC)	06-11-2018
BH3102	9 – Appendix I	Temperance Formation	Metamorphic	Talbingo (TBC)	07-11-2018
BH3106	4 – Appendix D	Boggy Plain Suite	Igneous (intrusive)	Talbingo	09-10-18
BH3108	5 – Appendix E	Gooandra Volcanics	Igneous (intrusive)	Talbingo	9/10/18 and 10/10/18
BH5105	6 – Appendix F	Byron Range Group	Completely weathered rock	Talbingo	23-10-18
BH5105	2 – Appendix B	Boraig Group	Igneous (extrusive)	Talbingo	26-09-18
BH5105	3 – Appendix C	Boraig Group	Sedimentary	Talbingo	26-09-18
BH8106	1 – Appendix A	Ravine Beds	Sedimentary	Talbingo	16-08-18

5.3.1 Column Test

Detailed results and analysis of the column tests are provided in **Appendices A** to **I**. A summary of the surface turbidity results measured during the column tests is provided in **Graph 2**. Immediately following agitation and mixing of the columns, surface turbidity varied between approximately 130 NTU (Test 7 - Kellys Plain Volcanics) and 250 NTU (Test 6 - Byron Range Group and Test 8 - Tantangara Formation). Surface turbidity decreased rapidly over the initial 24 hours and varied between 11 NTU (Test 5 -

Gooandra Volcanics and Test 6 - Byron Range Group) and 70 NTU (Test 1 - Ravine Beds). Two of the columns, Test 6 - Byron Range Group and Test 7 - Kellys Plain Volcanics, were reagitated after 24 hours to obtain samples with a higher turbidity[4]. Approximately 9 days after commencement, surface turbidity varied between 5.5 NTU (Test 5 - Gooandra Volcanics) and 45 NTU (Test 8 - Tantangara Formation).



Graph 2: Surface turbidity measured during the column tests (Test D).

Sub-samples were taken from the settling columns at varying time intervals throughout each column test for turbidity and TSS analysis. It should be noted that the surface turbidity results during the column tests (**Graph 2**) were likely influenced by the ongoing sub-sampling activity inside the settlement columns. For example, the progressive removal of surface water and suspended sediment for laboratory analysis would have artificially modified the settlement profile inside the column by reducing the depth of the upper clarifying layer. In comparison, the settlement test results (**Section 5.3.2**) would not have been influenced in this manner.

A summary of the TSS-turbidity relationships determined for each geological zone is provided in **Table 4**, including the turbidity values equivalent to a TSS concentration of 50 mg/L for each relationship. The selected TSS value of 50 mg/L is based on the water quality criterion commonly adopted for major marine construction projects. However, the water quality criterion for the project has not yet been defined and may vary. The trendlines corresponding to the line of best fit through the datasets are provided in **Graph 3**.

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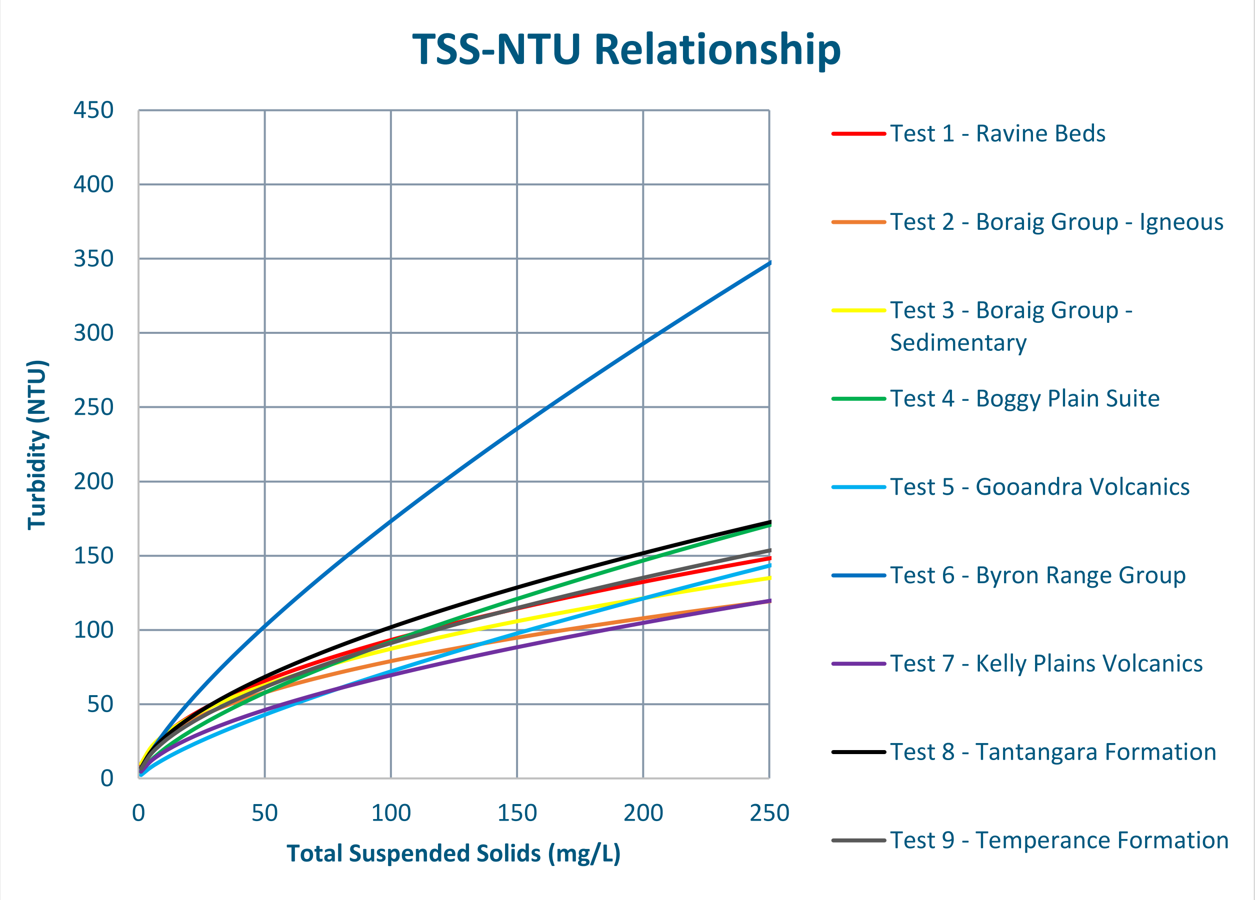
[4] It was necessary to collect water samples covering a wide range of TSS and turbidity values to ensure that a robust TSS-turbidity dataset could be established for the purposes of defining a meaningful relationship between turbidity and suspended solids.

Table 4: Summary of TSS-turbidity relationships for each material type.

Test ID	Material Type	Number of values	Trendline of Best Fit through Dataset – Power Function	R^2 value	Turbidity (NTU) equivalent to 50 mg/L TSS
1D	Ravine Beds	20	NTU = 9.0649 * $TSS^{0.506}$	0.96	66
2D	Boraig Group - Igneous	25	NTU = 9.9513 * $TSS^{0.4498}$	0.94	58
3D	Boraig Group - Sedimentary	21	NTU = 9.7845 * $TSS^{0.4752}$	0.94	63
4D	Boggy Plain Suite	25	NTU = 4.1376 * $TSS^{0.6735}$	0.80	58
5D	Gooandra Volcanics	22	NTU = 2.2757 * $TSS^{0.7502}$	0.89	43
6D	Byron Range Group	29	NTU = 5.2851 * $TSS^{0.7577}$	0.98	102
7D	Kellys Plains Volcanics	25	NTU = 4.5368 * $TSS^{0.5925}$	0.95	46
8D	Tantangara Formation	26	NTU = 7.1935 * $TSS^{0.5754}$	0.94	68
9D	Temperance Formation	22	NTU = 6.6365 * $TSS^{0.5688}$	0.89	61



Graph 3: Trendline of best fit through datasets - Power Function.

More than 20 samples were collected for each test, as recommended by Thackston and Palermo (2000). The power function was determined to provide the trendline of best fit for the datasets. Relatively high R^2 values were associated with the power function relationships (0.80 to 0.98), which indicates a good fit between each dataset and the respective trendlines. Turbidity is correlated to TSS and the trendline would provide a reasonable prediction of turbidity for a given TSS concentration or vice versa. Linear functions were also determined for the dataset (refer **Appendices A** to **I**). However, the R^2 values were lower indicating a weaker relationship between the dataset and the trendline.

The turbidity values, equivalent to 50 mg/L suspended solids, range from 43 NTU (Test 5 - Gooandra Volcanics) to 102 NTU (Test 6 - Byron Range Group). However, similar TSS-turbidity relationships were determined for most of the rock types tested, with six of the nine geological zones characterised by turbidity values equivalent to 50 mg/L suspended solids of 58 to 68 NTU.

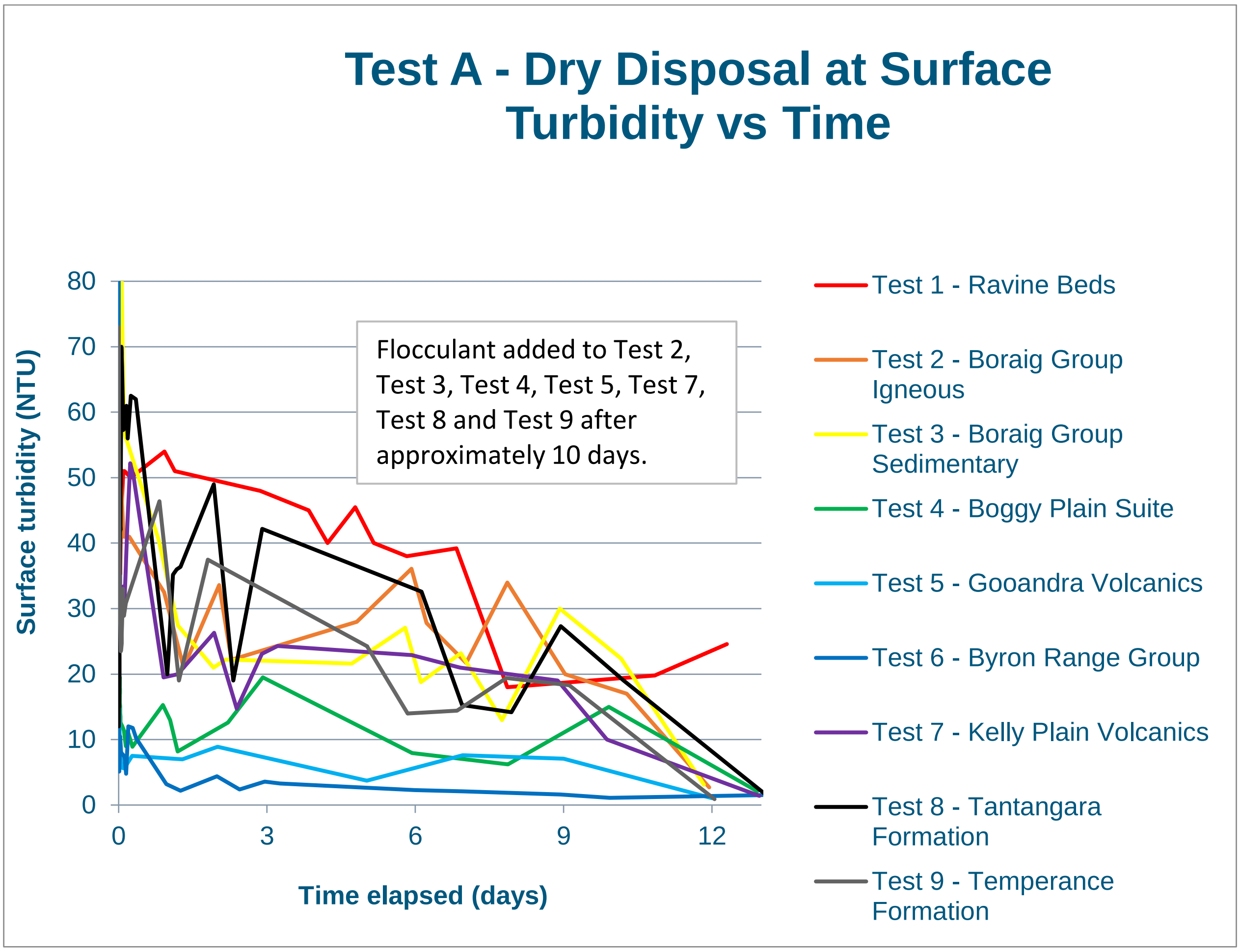
Most of the crushed rock appeared to be light grey to grey-blue in colour, except for crushed rock from the Byron Range Group which was red-orange in colour. It is inferred that the darker red-orange colour of the Byron Range Group results in higher turbidity for a given TSS concentration.

Overall, TSS-turbidity data collected during the column tests (Tests 1D to 9D) is considered to be reliable for the purpose of establishing a preliminary relationship between TSS and turbidity for each geological zone. However, as the properties and grading of the crushed rock placed during construction may vary to that used in the column tests, collection of field TSS-turbidity data during the subaqueous excavated rock placement trial, and subsequent placement activities, is recommended so that the relationships between turbidity and suspended solids can be continually validated and improved.

5.3.2 Settlement Test

Detailed results and analysis of the settlement tests are provided in **Appendices A** to **I**. A summary of the surface turbidity results measured during the settlement tests simulating surface placement of crushed rock (Test A) is provided in **Graph 4**. Surface turbidity was continuously monitored at 1 second intervals for the initial ~5 to 60 minutes following placement of crushed rock. The complete results from the continuous monitoring are not included in **Graph 4**. Random readings during the period of continuous monitoring are included to provide a general trend of turbidity over time. **Graph 4** does not include the instantaneous peak turbidity recorded during the continuous monitoring and placement of crushed rock into the columns, which typically lasted for less than 10 seconds. The instantaneous peak is recorded as crushed rock descends past the turbidity probe and it is somewhat dependant on the way in which material is placed, rather than the type of crushed rock.

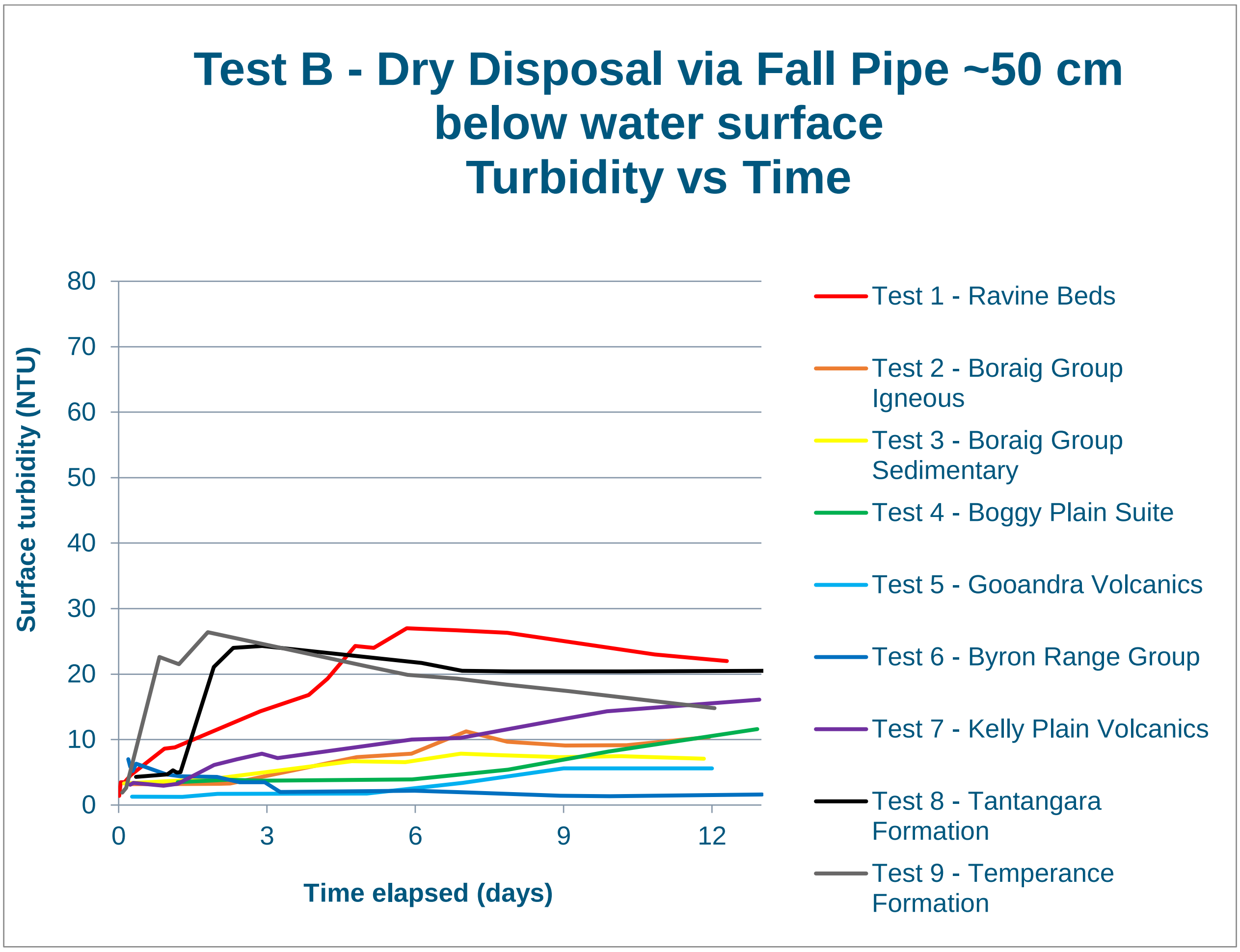
Surface turbidity approximately 20 minutes after placement of crushed rock varied between approximately 6 NTU (Test 6 – Byron Range Group) and 130 NTU (Test 3 – Boraig Group Sedimentary). Approximately 9 days after commencement, surface turbidity varied between 1.5 NTU (Test 6 – Byron Range Group) and 30 NTU (Test 3 – Boraig Group Sedimentary and Test 8 - Tantangara Formation).



Graph 4: Surface turbidity measured during the settlement tests simulating placement of dry crushed rock on the surface (Test A).

A summary of the surface turbidity measured during the settlement tests simulating placement of crushed rock through a short fall pipe (Test B) is provided in **Graph 5**. The base of the fall pipe was approximately 50 cm below the water surface. In all tests, the fall pipe initially appeared to be effective in reducing surface turbidity. However, over the subsequent days, advection of fine suspended particles towards the surface was noted with a corresponding increase in surface turbidity.

Surface turbidity varied between 1.6 (Test 6 – Byron Range Group) and 22 NTU (Test 1 – Ravine Beds and Test 8 - Tantangara Formation) approximately 12 days following commencement of the test. Except for Test 6 – Byron Range Group, surface turbidity exceeded 5 NTU, approximately 12 days following commencement of the test. Surface turbidity in two of the tests, Test 7 Kellys Plain Volcanics and Test 4 Boggy Plain Suite, was gradually increasing 12 days after commencement. Surface turbidity in the remaining tests was stable or decreasing.



Graph 5: Surface turbidity measured during the settlement tests simulating placement of dry crushed rock through a short fall pipe (Test B).

5.3.3 Flocculation Trial

In all tests, the selected flocculant was effective in clarifying the water and reducing surface turbidity. The selected flocculant was alum, a readily available inorganic salt used in water purification and waste water treatment. Alum was added to Test A (except for Test 6 – Byron Range Group where the alum was added to Test D) approximately 9 to 11 days after placement of crushed rock. Surface turbidity immediately prior to the addition of alum, and approximately 3 days after the addition of alum, is provided in **Table 5**. The remaining column tests and settlement tests were retained as a control. In all cases, the reduction in surface turbidity in the control columns was negligible, compared to the reduction in surface turbidity following addition of alum.

Table 5: Turbidity prior to and following addition of alum.

Test ID	Surface turbidity prior to addition of alum (NTU)	Surface turbidity following addition of alum (NTU)
Test 1 - Ravine Beds	18	2.7
Test 2 - Boraig Group - Igneous	17	2.7
Test 3 - Boraig Group - Sedimentary	22.4	3.1
Test 4 - Boggy Plain Suite	15	2.1
Test 5 - Gooandra Volcanics	7.1	1.05
Test 6 - Byron Range Group	12	1.8
Test 7 - Kellys Plain Volcanics	10	1.4
Test 8 - Tantangara Formation	19	1.2
Test 9 - Temperance Formation	18.3	0.9

Alum neutralises the charge of colloids, which promotes suspended impurities to coagulate into larger particles and then settle. Photographs from two columns, Test 4A – Boggy Plain Suite and Test 8A – Tantangara Formation, are provided in **Figure 4**. In both columns, deposition layers of crushed rock and flocculated crushed rock is visible. The photographs also show how flocculated material adhered to the wall of the columns. The flocculated material forms visibly larger, coagulated particles that appear to be 'light' and 'fluffy'. Conversely, depositional layers prior to addition of flocculant comprised visually smaller particles. Flocculated crushed rock was easily disturbed when a syphon was placed into the column for emptying the column (refer Test 4A – Boggy Plain Suite in **Figure 4**). The coagulants in the flocculated material did not appear to break apart. However, they were readily resuspended.

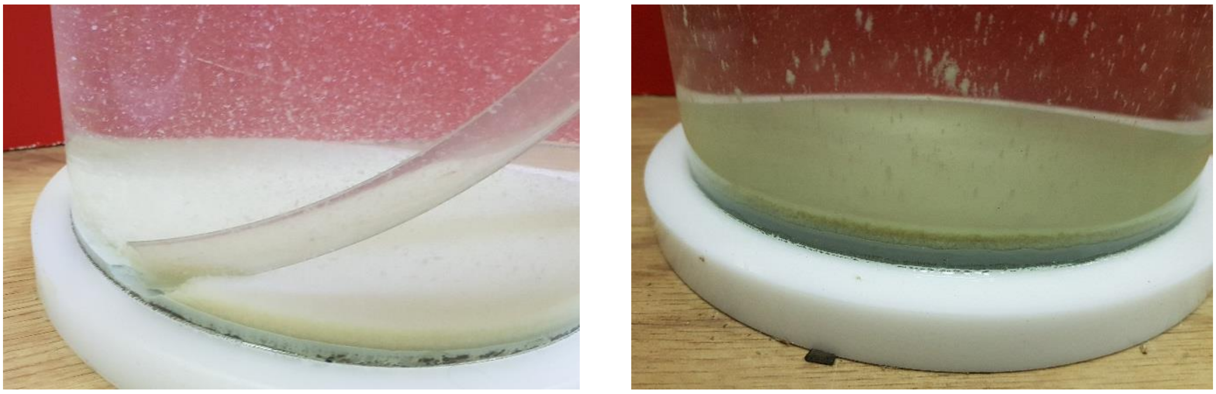


Figure 4: Settlement columns following addition of flocculant. Left, Test 4A – Boggy Plain Suite and right, Test 8A – Tantangara Formation.

5.3.4 Critical Particle Size Analysis

Results from the critical particle size analysis, indicating the maximum particle size in suspension at various time intervals, are provided in **Table 6**.

After 15 minutes (0.25 hours), the maximum particle size in suspension varied between 15 and 23.5 µm, 50 mm below the water surface, and 26.5 to 36 µm, 230 mm below the water surface for all tests. The maximum particle size in suspension progressively decreased over time.

After 24 hours, the maximum particle size in suspension was typically 2.5 to 4 µm, 50 mm below the water surface. The only exception was Test 6 – Byron Range Group where the maximum particle size, 50 mm below the water surface, was 11.5 µm. Similarly, after 24 hours and at 230 mm below the water surface, the maximum particle size in suspension was typically 4 to 6 µm, except for Test 6 – Byron Range Group where the maximum particle size was 13 µm.

In all tests, the maximum particle size, and particle size distribution was coarser at greater depths within the water column. This is to be expected based on theoretical settlement rates defined by Stokes Law where larger particles settle out of suspension faster than smaller particles.

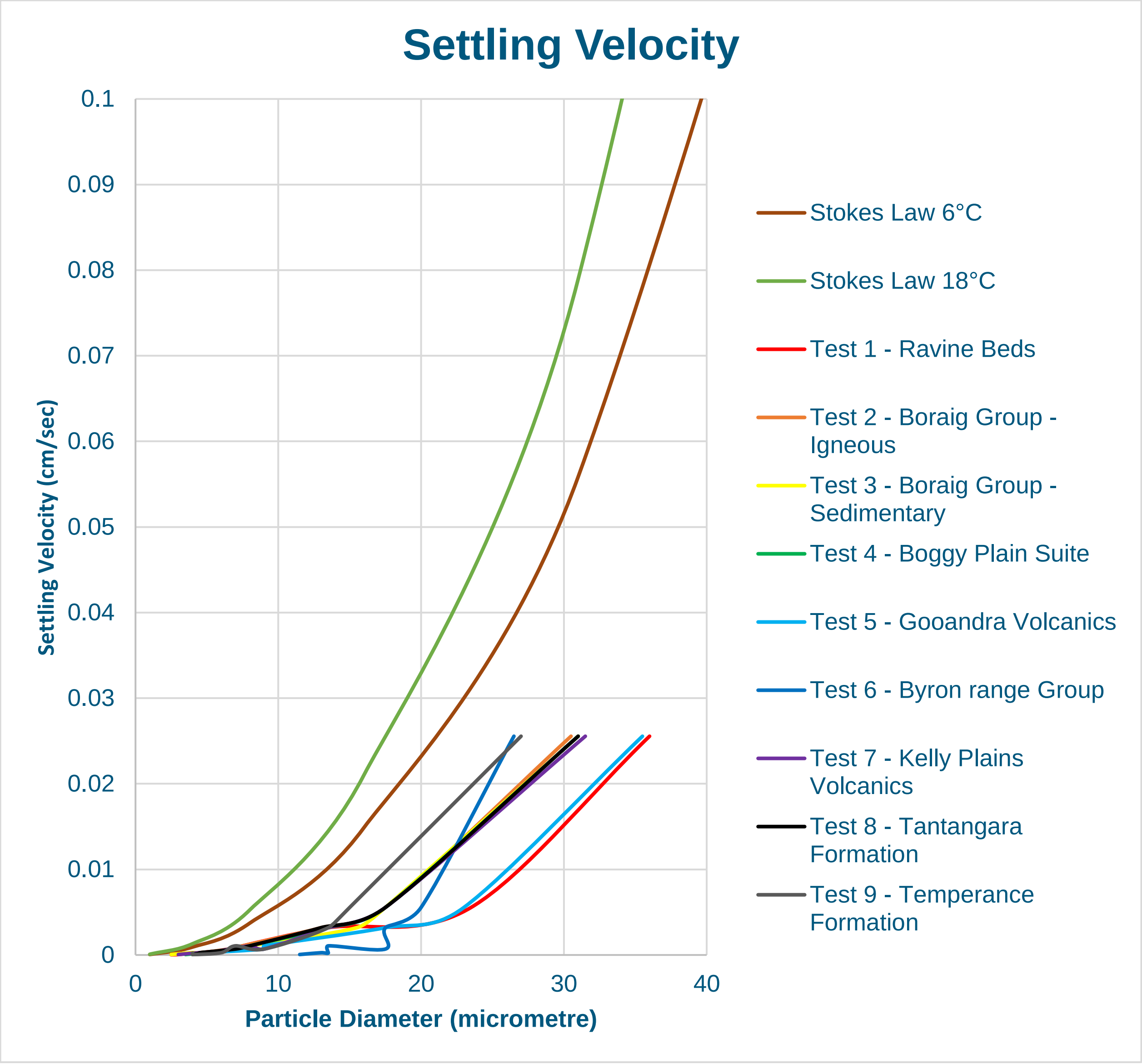
Table 6: Summary of results from critical particle size analysis.

Test Number	Depth below water surface	Time (hours)			
		0.25	2	6	24
		Maximum Particle Size in Suspension (µm)			
Test 1 - Ravine Beds	50 mm below water surface	23.5	7	4	3
	230 mm below water surface	36	13.5	7.5	4.5
Test 2 - Boraig Igneous	50 mm below water surface	17.5	6.5	4.5	2.5
	230 mm below water surface	30.5	13	7.5	4
Test 3 - Boraig Sedimentary	50 mm below water surface	17.5	7	4.5	2.5
	230 mm below water surface	31	15.5	8	4
Test 4 - Boggy Plain Suite	50 mm below water surface	17.5	8	4.5	3.5
	230 mm below water surface	31	13.5	8	4.5
Test 5 - Gooandra Volcanics	50 mm below water surface	23	9	5	-
	230 mm below water surface	35.5	17.5	9	5
Test 6 - Byron range Group	50 mm below water surface	20	17.5	13.5	11.5
	230 mm below water surface	26.5	17.5	13.5	13
Test 7 - Kellys Plain Volcanics	50 mm below water surface	17.5	9	5	3
	230 mm below water surface	31.5	13.5	8	4.5
Test 8 - Tantangara Formation	50 mm below water surface	17.5	7	4.5	4
	230 mm below water surface	31	13	8	4.5
Test 9 - Temperance Formation	50 mm below water surface	15	9	4	4
	230 mm below water surface	27	13.5	7	6

Based on the maximum particle size in suspension, at a given depth and after a predefined time interval, the settling velocity can be calculated. The settling velocities calculated from the critical particle size analysis are provided in **Graph 6** along with theoretical settling velocities determined by Stokes Law for a water temperature of 6 °C and 18 °C. Water temperature was not monitored as part of the critical particle size analysis. However, the temperature would have been similar to that used in the settlement columns (refer **Section 3.7** in **Appendix J**), which was between 15 °C and 25 °C (average 17.4 °C to 21.5 °C) for all tests.

From **Graph 6**, it is evident that the settling velocities determined from the critical particle size analysis results are slower than the theoretical settling velocity determined by Stokes Law. A discussion regarding Stokes Law and settling velocities is provided in **Section 8.3**. The settling velocity for Test 6 – Byron

Range Group and Test 9 – Temperance Formation are plotted as uneven curves whereas the remaining settling velocities form smooth curves. This is a result of an identical maximum particle size reported for Test 6 – Byron Range Group at the various depths, 2 hours and 6 hours after commencement and an identical maximum particle size reported for Test 9 – Temperance Formation at 50 mm below the water surface, 6 and 24 hours after commencement.



Graph 6: Settling velocity calculated from the critical particle size analysis.

6 Quality Assurance and Sensitivity of Test Parameters

During completion of the various tests, duplicates and aliquots were analysed to ensure the results from the settlement tests and critical particle size analysis are accurate and reliable. Additional tests were also undertaken on crushed rock from the Ravine Beds geological zone in an attempt to assess sensitivity of various test parameters (Test 10).

6.1 Quality Assurance of Critical Particle Size Analysis

To ensure that the results from the critical particle size analysis, obtained using the Mastersizer 2000, are repeatable and reliable, the following quality assurance was undertaken:

- The Mastersizer 2000 was validated prior to each day of analysis by determining the particle size distribution of a known standard;
- The procedure of sub-sampling dry crushed rock for analysis with the Mastersizer 2000 was validated by assessing the particle size distribution of aliquots of crushed rock;
- The procedure of sub-sampling suspended crushed rock for analysis with the Mastersizer 2000 was validated by assessing the particle size distribution of aliquots of samples extracted from the 1 L columns;
- Repeatability of the critical particle size analysis was validated by duplicating the test on Ravine Beds crushed rock. It should be noted that the original test was conducted on rock crushed using a hammer drill (refer **Section 3.1.1**) while the duplicate test was conducted on rock crushed with a ring mill (refer **Section 3.1.2**).

Test results for the quality assurance of the critical particle size analysis are presented in **Appendix J**. The quality assurance indicates the results are reliable and accurate. It is noted that the particle size analysis was undertaken using laser techniques, which can produce different results compared to conventional mechanical sieving and hydrometer methods.

6.2 Sensitivity of Test Parameters

Several test parameters were not assessed in detail, due to practical constraints. However, sensitivity of several key test parameters was evaluated by conducting various additional tests on crushed rock from the Ravine Beds geological zone (Test 10).

The objectives of the sensitivity tests and the respective test procedures are outlined in **Table 7**.

Table 7: Objective and procedure of various tests to determine sensitivity of test parameters.

Objective No.	Objective Description	Test Procedure
1	To determine whether water temperature influences settlement velocity and the size of particles in suspension after a given period.	The critical particle size analysis was duplicated for Ravine Beds crushed rock. One set of columns (3 in total) was maintained at approximately 3.5 °C while a second set of columns were maintained at approximately 21.2 °C.
2	To determine whether the depth of the fall pipe influences surface turbidity.	Settlement Test B (dry placement through a fall pipe) was duplicated in two columns simultaneously with varying length fall pipes.
3	To determine whether the lid of the settlement columns has an influence on settlement velocity and surface turbidity.	Settlement Test A (dry placement on the surface) was duplicated in two columns simultaneously, with and without a lid on the columns.
4	To determine whether placing small quantities of crushed rock progressively over a number of days influences surface turbidity compared to a bulk one-off placement.	Settlement Test A (dry placement on the surface) was duplicated in two columns simultaneously. A total of 40 g of sieved crushed rock was placed in the first column at the start of the tests, while 5 g of sieved crushed rock was placed in the second column each day for 8 days (40 g in total).
5	To determine whether temperature fluctuations influence settlement of crushed rock in the Settlement Tests.	The following settlement tests were duplicated: • Test A (dry placement on the surface); and, • Test B (dry placement through a fall pipe, approximately 50 cm below the surface). The original tests were undertaken in the absence of block-out curtains across the laboratory windows (block-out curtains were installed for all other testing in an attempt to regulate room temperature). The air conditioning was set at 23 °C for the duplicate test in an attempt to further regulate air temperature. It is noted that temperature was not measured during the original tests but would be expected to have varied in comparison to the duplicate tests.

The results from the sensitivity tests are presented in **Appendix J**.

The results indicate that the settlement tests are sensitive to:

1. The depth of placement, with deeper placement resulting in lower surface turbidity levels;
2. The presence of lids placed on the column, with evaporation and condensation appearing to have a significant influence on surface turbidity; and,
3. Temperature fluctuations, where a variation in water temperature was observed to result in an increase in surface turbidity. The increase in surface turbidity is hypothesized to be a result of convection currents.

Water temperature has a predictable influence on settlement behaviour. This is explained by Stokes Law and is due to an increase in density and dynamic viscosity of cooler water (and vice versa for warmer water). The effect of water temperature is measurable but not significant to the outcome of the laboratory investigation.

Surface turbidity in the laboratory investigation appears to be sensitive to the way that crushed rock is placed as it influences fall velocity through the upper portion of the water column and clumping of crushed rock. Surface turbidity in the laboratory investigation does not appear to be sensitive to the rate of placement of crushed rock. Following placement of the same mass of crushed rock, surface turbidity appeared to be similar.

It is considered that there are numerous variables that can influence the settlement of crushed rock in the columns. Overall, the accuracy of the laboratory investigation is considered to be fit for purpose and reliability of the settlement test results are considered reasonable at a high level as the general trends in the settlement tests are repeatable. However, due to the uncontrolled variables resulting in fluctuations in surface turbidity, the tests are not completely repeatable. Notwithstanding, the tests conclusively indicate that the fine crushed rock is colloidal and once the particles are entrained in the water column, they remain in suspension for extended periods in the order of several weeks (at least).

7 Limitations

Limitations in the laboratory investigation arise due to assumptions adopted for the investigation and scale effects. The limitations of the laboratory investigation include:

1. Representivity of particle size distribution;
2. Representivity of the starting TSS;
3. Scale effects;
4. Measurement of particle diameter; and,
5. Hydrodynamic stability of placed excavated rock.

The limitations are discussed in **Sections 7.1** to **7.5**.

7.1 Representivity of Particle Size Distribution

The particle size distribution produced by either TBM or D&B operations was not confirmed prior to the laboratory investigation. It is likely that the particle size distribution will vary depending on the method of excavation and the strength and type of rock encountered.

The available literature (Bellopede et al, 2011; Peila et al, 2013; and Petitat et al, 2014) indicates that a TBM produces approximately 10% fines and the maximum particle size is approximately 70 to 100 mm. However, the maximum particle size and particle size distribution is dependent on the size of the cutters and spacing between the cutters. The exact distribution of the particle sizes will not be known until excavation operations commence.

The size of rock from D&B operations can be somewhat controlled by altering the spacing and depth of drill holes and the type and quantity of explosive. It is understood that to improve handling of excavated rock, and to avoid the requirement for post-processing and crushing of excavated rock, a maximum rock diameter of approximately 300 to 400 mm would be targeted in the D&B operations. A proportion of fines would be produced during D&B operations and during handling and transport of excavated rock. However, the portion of fines produced by D&B operations would be less than TBM operations resulting in a coarser distribution of particles. Again, the actual distribution of the particle sizes will not be known until excavation commences.

The laboratory investigation did not consider particle sizes coarser than 250 µm (determined with a sieve). The sieved crushed rock sample used for the laboratory investigation is well graded and has a good representation of particle sizes from approximately 1 µm (determined with the Mastersizer 2000) to 250 µm (determined with a sieve screen). Therefore, the maximum particle size of the sieved crushed rock in the laboratory investigation (250 µm) is significantly smaller than the maximum particle size produced by D&B and/or TBM operations (100 to 400 mm). However, this would not be expected to influence the overall findings of the investigation, given that large crushed rock (greater than 250 µm) would be expected to readily settle following placement and not contribute to surface turbidity or elevated concentrations of TSS.

It should also be noted that the size distribution of the particle fraction smaller than 250 µm in the sieved rock sample in the laboratory investigation may be different to that produced by D&B and/or TBM operations.

The particle size distribution produced by either TBM or D&B operations would need to be considered when assessing potential impacts of ERP by considering the proportion of the total volume of material that may be entrained and remain suspended in the water column.

7.2 Representivity of the Starting Total Suspended Solids

Given uncertainties (at the time of scoping the investigations) around a number of construction matters including particle size distribution, subaqueous rock placement rates, placement locations, placement methodology, and location of turbidity control measures, the laboratory analysis did not attempt to scale placement rates or total placement quantity of crushed rock.

Furthermore, the laboratory investigation did not consider the effect of the concentration of TSS on settlement rates or the distribution of particle sizes in suspension. However, it should be noted that one of the sensitivity tests (refer **Table 7**, **Section 6.2**) assessed whether placing small quantities of crushed rock progressively over a number of days influences surface turbidity compared to a bulk one-off placement. The results from this test suggested that placement of crushed rock into a water body containing suspended crushed rock particles has minimal influence on the settlement of particles already in suspension.

Nevertheless, a higher concentration of TSS may lead to increased collision between particles and possibly agglomeration of smaller particles corresponding to increased settlement rates. Conversely, Brownian motion (the erratic random movement of microscopic particles in a fluid, as a result of continuous bombardment from molecules of the surrounding medium) may lead to decreased settlement rates if TSS concentrations increase (‘hindered’ settlement).

7.3 Scale Effects

As with all laboratory testing and small scale physical modelling, it is necessary to consider scale effects. Scale effects are errors that can be introduced when the model input parameters and results are scaled up to prototype values when there is not complete similarity between the model and prototype. The laboratory testing herein adopted a scaled water column only. The fluid type and properties (reservoir water) and physical properties of the crushed rock (particle size) were not scaled.

The water columns used for the laboratory testing are inert and as large as practical. The interaction between suspended solids and the wall of the column, referred to as the ‘wall effect’, can lead to inaccuracies in laboratory testing. Large diameter columns, used for the column tests and settlement tests described herein, minimise the potential for wall effects. However, they are not completely eliminated. As a result of the ‘wall effect’, higher settlement rates may be encountered in the prototype excavated rock placement in the reservoir/s, in comparison to the settlement rates observed during the laboratory investigations.

Conversely, a higher settlement velocity was observed in the settlement test simulating crushed rock placement through a long fall pipe compared to the settlement tests simulating crushed rock placement through a short fall pipe. Crushed rock was observed to diffuse through the entire width of the settlement column, below the base of the fall pipe. It is inferred that a loss in fall velocity was encountered below the base of the short fall pipe, due to entrainment of the surrounding ambient (stationery) fluid. The same observation may occur when comparing settlement in the laboratory columns to settlement in a reservoir, i.e. settlement in the reservoir may be slower than observed during the laboratory investigations, because lateral dispersion would not be confined in the prototype scenario.

7.4 Measurement of particle diameter

Particle size analysis was undertaken using the Mastersizer 2000, which is a laser diffraction particle analyser. It is noted that the Mastersizer 2000 reports volume of material in each size ‘bin’ (discrete size range) whereas conventional sieve analysis (Australian Standard 1289.3.6.1-2009) and hydrometer particle size methods (Australian Standard 1289.3.6.3-2003) report ‘mass of material’ in each ‘bin’.

Conventional sieve methods and laser particle sizing may report different gradings for the same material depending on the shape of the particles. Elongated particles, such as those shown in **Figure 5**, may pass through a sieve screen lengthwise and would be reported as a lesser particle size. However, depending on the orientation of the particles in the viewing window of the Mastersizer 2000, a larger particle size corresponding to the length of the particle could be estimated. The shape of particles explains why the maximum particle size of the crushed rock, sieved to 250 µm, is up to approximately 480 µm when analysed with the Mastersizer 2000 (refer **Section 5.1**).

Figure 5: Elongated particles may be reported as a different size, depending on the method of particle sizing.

Conventional hydrometer methods and laser particle sizing may report different gradings for the same material depending on a range of factors, including shape and charge of particles and salinity of the dispersant. Conventional hydrometer methods measure the ‘hydrodynamic diameter’ based on the fall velocity and Stokes Law. As discussed in **Section 8.3**, there are a number of assumptions underpinning Stokes Law that do not necessarily apply to fines (<63 µm). In addition, the settlement rate of fine particles is dependent on the salinity of the dispersant, with saline water resulting in increased settlement rates (this in part explains the effect of inorganic salts such as alum used in the flocculation test). Laser particle size analysis measures the ‘optical diameter’ based on diffraction of a laser beam. Laser particle size analysis is independent of the charge of particles or salinity of the dispersant. However, it is dependent on the optical properties of the particle and it is somewhat dependant on the shape of particles, as discussed above.

Future testing, and comparison of test results, should consider the method of analysing the particle size distribution. It is noted that all particle size analysis conducted by CSIRO also utilises laser techniques (Mastersizer 3000). There is not expected to be a difference between the Mastersizer 2000 and Mastersizer 3000 for the type of particles analysed.

7.5 Hydrodynamic Stability of Placed Excavated Rock

The laboratory investigation included an assessment of the maximum particle size that remains in suspension after a given period and simulated various placement methodologies. Therefore, the laboratory investigation assists in defining particle sizes that could theoretically be placed in a reservoir and settle in a manageable period and provides some insight on viable placement methodologies.

The laboratory investigation was not designed to assess whether smaller particles, once settled, remain in place or whether they are remobilised by currents from either natural events and/or operation of the Snowy scheme. Hydrodynamic and sediment transport modelling, or a laboratory investigation in a flume, would be required to assess the risk of remobilisation of the excavated rock following subaqueous placement within the reservoirs. It is noted than RHDHV were also engaged to undertake hydrodynamic and sediment transport modelling (RHDHV, 2018c) as part of the ERP studies.

8 Interpretation and Discussion

The results of the critical particle size analysis indicate that a portion of particles finer than approximately 6 µm remain in suspension for the duration of the tests (i.e. more than 24 hours). The settlement tests indicate that a portion of this crushed rock is colloidal clay and behaves like a neutrally buoyant substance even though the specific gravity of the clay is well in excess of water (2.6 and higher). With the exception of Test 6 – Byron Range Group, the settlement tests conclusively indicate that the fine crushed rock that becomes entrained in the water column remains in suspension for longer than the duration of the test (~12 days). It is concluded that the crushed rock would remain in suspension for extended periods in the order of several weeks (or possibly longer).

A few unexpected observations were recorded in most of the detailed settlement tests and in the sensitivity tests. These include:

- Fluctuations in surface turbidity and collapse of stratified layers;
- Advection of fine crushed rock following placement through a fall pipe; and
- Settlement velocities that are slower than the theoretical velocities predicted by Stokes Law.

Our interpretation of the observations, and potential impacts for placement of excavated rock in the reservoirs are discussed in **Sections 8.1** to **8.3**.

8.1 Fluctuations in Surface Turbidity and Collapse of Stratified Layers

In all column tests and settlement tests, surface turbidity was noted to fluctuate throughout the test and stratified layers were observed to collapse. It was initially hypothesised that this was due to:

a. Weak thermal convection currents within the column resulting in the mixing of stratified layers and rising warm water transporting suspended particles to the surface thereby increasing surface turbidity; or,
b. Disturbance of the water column and settlement process when the turbidity probe is gently lowered into the upper layer of the column (~3.4 cm below the water surface).

However, following completion of Test 10 to analyse sensitivity of test parameters, it was hypothesised that the observations were likely a result of evaporation and condensation inside the columns that were capped with a lid. The lids were placed on the columns to prevent foreign material from entering the column. However, when lids were placed on the columns, surface turbidity levels fluctuated and condensation was noted at the top of the column. The results from Test 10 are provided in **Appendix J**.

Regardless of the cause of surface turbidity fluctuations in the laboratory tests, which were not confirmed with certainty, it is apparent that minor disturbances to the water column in the laboratory investigation were sufficient to disrupt the settlement process and redistribute fine suspended particles within the column, despite the laboratory investigation being conducted in a controlled environment.

This is a key observation from the investigations that indicates surface turbidity fluctuations could be expected to occur in the reservoirs, during and following rock placement activities, due to disturbances to the water body. It is considered that there is a greater potential for disturbances and currents in the reservoirs due to wind waves and undertow, streamflow and runoff, propeller wash, temperature variability, operation of the existing Snowy scheme (T2 and T3) etc. compared to the columns used in the laboratory investigation.

8.2 Advection of Fine Crushed Rock

An increase in surface turbidity following placement through a short fall pipe was unexpected, with ongoing settlement following initial mixing considered more likely to occur. It was hypothesised that this observation was influenced by one or more of the following factors:

1. Weak thermal convection currents within the column resulting in rising warm water transporting suspended particles towards the surface. Air temperature and water temperature were monitored for the duration of Tests 2 to 9. It is apparent (and expected) that the water temperature warms and cools in response to the air temperature. Furthermore, the difference in water temperature between the top and bottom of the column increases during a warming phase and decreases during a cooling phase (refer **Appendices A** to **I**).

   It was inferred that thermal energy from the air in a warming phase is conducted to the settlement columns and water near the wall of the columns. Convection currents would be established as the warmer water near the wall of the columns, with a lower density, rises to cooler areas in the column and cooler water, with a higher density, sinks to take the place of the warmer water. The velocity of convection currents are difficult to determine due to a range of factors.

   This hypothesis was supported by the observation that the water temperature at an upper monitoring location in the column was warmer than the water temperature at a lower monitoring location in the column. However, a test was undertaken to identify whether there was a difference in water temperature across the column at approximately the mid-point of the column. This test was undertaken with Solinist Leveloggers, which are accurate to ±0.05 °C. The precision of the equipment was insufficient to identify a difference in water temperature across the column.

2. The sieved crushed rock may contain clay particles that are anionic. The repelling force between charged particles in suspension may result in suspended solids diffusing and distributing evenly throughout the water column. However, following placement through a long fall pipe in Test 10, diffusion of suspended crushed rock was not observed.

3. The action of gently lowering a turbidity probe into the upper layer of the column (~3.4 cm below the water surface) may have been sufficient to disturb the water column resulting in advection of very fine suspended particles.

Following completion of Test 10, when an automatic air conditioner was run to regulate air temperature, it was observed that the increase in surface turbidity corresponded to a period of decreasing water temperature and minimal temperature variation between the upper and lower temperature monitoring locations in the column. Following completion of Test 10, it was inferred that warmer water near the top of the column would have a lower density and would therefore be slightly buoyant compared to the cooler water lower in the column. This is referred to as a thermocline and reduces the potential for vertical mixing within a body of water. However, during a period of cooling, the temperature variation between the upper and lower monitoring locations reduced and the water density throughout the column would be similar. The similarity in water temperature and density would be less likely to suppress mixing and/or the formation of convection currents. Therefore, minor variations in water temperature, such as cooling of surface water, would be sufficient to form weak convection currents in the column that could result in advection of suspended solids (refer **Appendix J**).

A longer fall pipe was simulated in Test 10 and resulted in a reduction in surface turbidity compared to a short fall pipe. It is hypothesised that weak convection currents in the test with a short fall pipe resulted in the advection of crushed rock towards the surface. In contrast, end effects (boundary effect) at the base of the column with the long fall pipe may have reduced the velocity of vertical (and horizontal) currents below the base of the fall pipe (refer **Appendix J**).

In addition, a higher fall velocity was observed in the settlement test simulating placement through a long fall pipe, compared to the settlement test simulating placement through a short fall pipe. The fall pipe would physically prevent lateral dispersion of crushed rock. Crushed rock was observed to diffuse through the entire width of the laboratory settlement column, below the base of the short fall pipe. It is inferred that a loss in fall velocity is encountered below the base of the short fall pipe, due to entrainment of the surrounding ambient (stationery) fluid.

These observations have practical implications on the placement of crushed rock in the reservoirs. Thermoclines have been recorded in Talbingo Reservoir during summer with warmer water near the surface and cooler water at depth. However, the water temperature throughout the reservoir depth is similar during winter. Based on the observations from the laboratory investigation, when the water temperature throughout the reservoir is similar (during the winter months), there is increased potential for vertical mixing to occur. Therefore, surface placement or deep placement of excavated rock during winter could potentially generate additional surface turbidity. Conversely, a thermocline, typically observed in the reservoirs during summer, may supress vertical mixing and placement of excavated rock at depth within the reservoir is less likely to contribute to surface turbidity.

The boundary effect and boundary layer for open channel flow regimes is portrayed in **Figure 6** for various shaped channels. Boundary effects are expected to occur in the reservoirs, particularly since the bed roughness due to submerged vegetation would be high. However, currents and boundary effects in the reservoir would be complicated due to:

- Operational flow from the Snowy scheme (T2 and T3);
- Temperature of inflow from the Snowy scheme and catchment runoff where cool, dense inflows may result in higher bed flows; and,
- Undertow in the opposite direction to surface wind shear and wind waves.

These factors may result in bidirectional currents directed ‘upstream’ or ‘downstream’ whereas open channel flow in **Figure 6** is typically unidirectional. Deep within the side bays of Talbingo Reservoir (i.e. off the main reservoir alignment impacted by operation of the Snowy scheme (T2 and T3)), boundary effects are expected to be more pronounced. Placing rock within a boundary layer, where horizontal and vertical currents are reduced, is less likely to result in advection of suspended crushed rock.

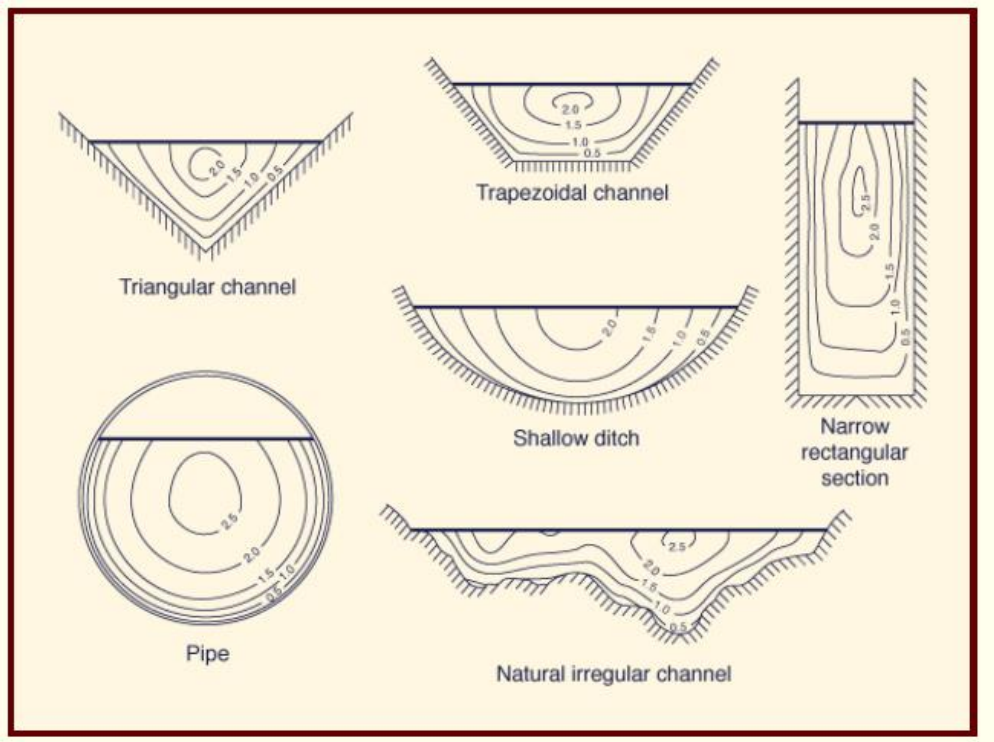


Figure 6: Diagrammatic representation of boundary effect and boundary layer for various open channel sections. The cross sections include isovels that joins regions of equal horizontal water velocity through the channel (San Diego State University, 2018).

8.3 Settling Velocity and Stokes Law

Results for the critical particle size analysis in **Section 5.3.4** suggests that the settling velocity measured in the laboratory is slower than theoretical settling velocities determined by Stokes Law.

Stokes Law only applies with the following assumptions:

1. There is no other particle nearby that would affect flow pattern;
2. The motion of the particle is constant;
3. The particle is spherical and rigid;
4. The water velocity right at the particle surface is zero; and,
5. The fluid is incompressible.

Several of the assumptions underpinning Stokes Law do not hold true for the settlement of particles in the laboratory investigation, nor are they likely to hold true for placement in the reservoir (for the same reasons). The crushed rock particles would not be spherical, rather there would be a range of particle shapes including elongated and flat particles, which would not settle in the same way as a spherical particle. In addition, the assumption that no other particles nearby would affect flow pattern is unlikely to be true and collision between particles is likely to occur.

Stokes Law is generally not suitable for determining the settlement velocity of ionic colloids where the charge of the particles affects settlement behaviour. The sieved crushed rock may contain clay particles that are anionic and the repelling force between the particles in suspension may result in slower than expected settlement velocities.

Stokes Law is the basis for the conventional hydrometer analysis for determining the distribution of fines based on the ‘hydrodynamic particle diameter’ as discussed in **Section 8.4**. Hydrometer analysis was not used in the laboratory investigation herein. Rather determining the ‘optical diameter’ of fines with the Mastersizer 2000 was the preferred method for analysing the distribution of particles. As mentioned previously, future testing, and comparison of test results, should consider the method of analysing the particle size distribution.

Given that not all assumptions behind Stokes Law hold true for settlement of particles in the laboratory investigation, the settlement velocities calculated from the critical particle size analysis herein are considered to be reasonable. Given the low settlement velocities, minor disturbances in the water column from fresh water flows, operational flows from the existing Snowy scheme (T2 and T3) wave action and propeller wash are likely to disrupt the settlement process resulting in the advection of fine crushed rock.

It is inferred that management measures that minimise or control the release of problematic fine fractions (i.e. less than 6 µm) may provide a contribution to the management of surface turbidity during subaqueous excavated rock placement activities.

9 Conclusions

It is apparent from the column tests and settlement tests that once fine crushed rock enters the water column, the finest particles (<6 µm) remain in suspension for extended periods, in the order of several weeks (possibly longer). Whilst surface turbidity levels generally appear to reduce over time, it may take an extremely long time to reach the background levels of 1 to 5 NTU, as reported in water quality monitoring by Cardno. Furthermore, the settlement behaviour of the fine crushed rock during the laboratory investigations was highly sensitive to a range of factors such as minor temperature variations. This suggests that any minor disturbances to the water column during field rock placement activities in the reservoirs (e.g. due to fresh water flows, operational flows from the existing Snowy scheme (T2 and T3) wave action and propeller wash) are likely to disrupt the settlement process.

The simulated placement of crushed rock through a short fall pipe appears to result in a reduction in surface turbidity, compared to the settlement tests simulating surface placement of crushed rock. However, in all tests except Test 6 – Bryon Range Group, surface turbidity following placement through a short fall pipe exceeded background turbidity levels in the reservoir at the end of the 12-day test period and in two of the tests with a short fall pipe, surface turbidity exceeded 20 NTU. Placement of crushed rock through a longer fall pipe in Test 10 resulted in a negligible increase in surface turbidity up to 22 days following placement.

The critical particle size in suspension that would contribute to prolonged surface turbidity in the water column (more than 24 hours, the maximum duration of the critical particle size analysis) would be less than approximately 6 µm. This observation suggests that any management measures that can successfully minimise or control the release of such fine fractions may reduce surface turbidity during rock placement activities.

The results of the chemical flocculation tests indicate that alum accelerates settlement rates of fine particles and clarifies the water.

TSS-turbidity data collected during the column tests is considered to be reliable for the purpose of establishing preliminary relationships between TSS and turbidity for the various geological zones. As the properties and grading of the crushed rock placed during construction may vary to that used in the column test, collection of field TSS-turbidity data during subaqueous excavated rock placement activities is recommended so that the relationship between turbidity and suspended solids can be continually validated and improved.

10 References

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Appendix A

TSS – Turbidity and Settling Test Results Ravine Beds Geological Zone

Table of Contents

1 Introduction

The Ravine Beds geological zone comprises shallow marine shelf deposits including shale, slate, siltstone and conglomerate. A 1-m long section of core from this geological zone was supplied to Royal HaskoningDHV (Haskoning) from BH8106 taken between 631 m and 632 m below the ground surface. The core was logged as siltstone, a fine grained sedimentary rock.

Water for testing was obtained from Talbingo Reservoir on the 8th August 2018. The turbidity of the reservoir water sample was between 1.5 and 2 NTU. This was within the turbidity range of field monitoring, undertaken by Cardno in 2018, which indicated typical 'background' turbidity of 1 to 5 NTU in Talbingo Reservoir.

2 Results

2.1 Test 1D – TSS-Turbidity

2.1.1 Overview

The TSS-Turbidity Test for the Ravine Beds crushed rock ('Test 1D') commenced on the 16th August 2018 and was concluded on the 28th August 2018, 12 days following commencement.

The Certificate of Analysis provided by ALS Environmental for the TSS and turbidity analyses undertaken for samples collected during testing is provided in **Attachment 1**. Laboratory log records completed during the TSS-turbidity test are provided in **Attachment 2**, which includes surface turbidity measurements undertaken during testing for each sample.

Photographs taken during the column test are provided in **Figure 1**. These photographs were taken:

- prior to commencement;
- immediately following agitation of the sieved crushed rock in the column;
- approximately 4 days after commencement; and
- approximately 11 days after commencement.

TEST ID	1D
GEOLOGICAL UNIT	RAVINE BEDS
START TIME	16/8/18 9:20
CURRENT TIME	16/8/18 9:20

TEST ID	1D
GEOLOGICAL UNIT	RAVINE BEDS
START TIME	16/8/18 9:20
CURRENT TIME	20/8/18 9:00

TEST ID	1D
GEOLOGICAL UNIT	RAVINE BEDS
START TIME	16/8/18 9:20
CURRENT TIME	27/8/18 9:00

Figure 1: Column test –

1. *Talbingo Reservoir water without addition of the sieved crushed rock*
2. *Column test immediately following agitation*
3. *Column test 4 days after commencement*
4. *Column test 11 days after commencement*

2.1.2 Surface Turbidity vs Time Results

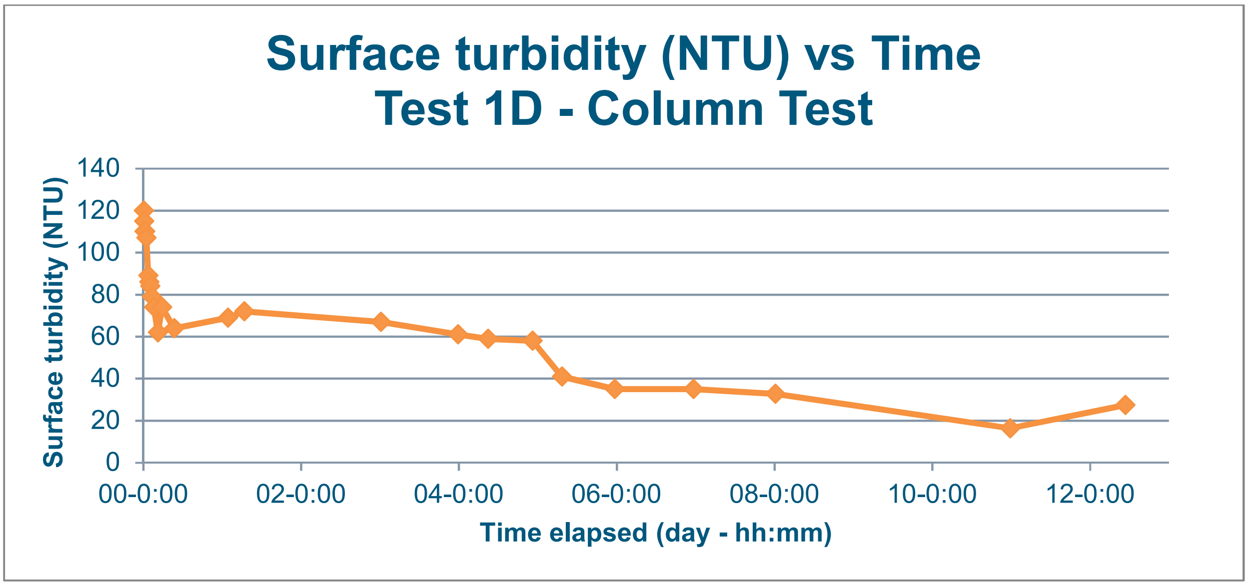
The variation in surface turbidity during Test 1D is plotted in **Graph 1**. The graph shows that surface turbidity decreased relatively rapidly from 145 NTU to 74 NTU during the first three hours of testing. Surface turbidity levels subsequently remained relatively constant at approximately 60 to 70 NTU for approximately five days, before decreasing to around 35 NTU after six days.

Approximately eight days following commencement, the upper portion of the column was beginning to stratify with the following observations noted:

- 8 days after commencement – upper 2 cm began to clarify. Layer easily disturbed.
- 11 days after commencement – notably clearer to 9.5 cm below the water surface in the column.

These observations coincided with a decrease in surface turbidity to levels of around 15 to 30 NTU.

At the end of testing (12 days and 11 hours following commencement), stratification was not observed corresponding with an increase in surface turbidity to 27.5 NTU compared to the previous measurement of 16.4 NTU after 11 days. A discussion regarding the observed mixing between stratified layers is provided in **Section 3**.



Graph 1: Surface turbidity measured during the column test – Ravine Beds crushed rock (Test 1D).

2.1.3 TSS – Turbidity Results

A total of 20 samples were collected during testing for laboratory TSS and turbidity analysis. TSS values for the collected samples ranged between <5 mg/L[1] and around 220 mg/L, while turbidity values of up to 135 NTU were recorded.

A plot of TSS versus turbidity for all data collected during testing is provided in **Graph 2**. Turbidity values used in this dataset are the measurements taken during testing (inside the glass beaker prior to sub-sampling) rather than the laboratory results[2]. This dataset is plotted with trendlines corresponding to both

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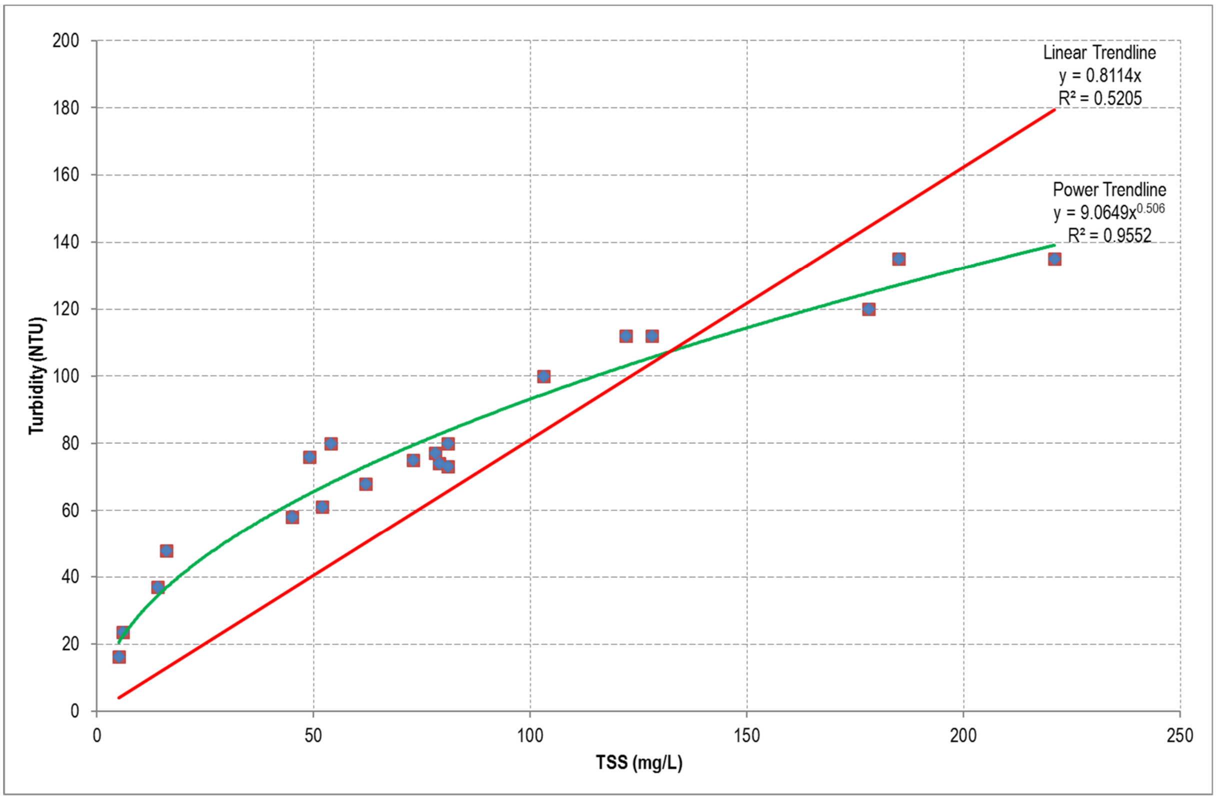
[1] The Limit of Reporting (LOR) value for TSS analysis is 5 mg/L, refer **Attachment 1**. Results for samples with TSS concentrations below the LOR value are reported as <5 mg/L.

[2] Turbidity results reported by the laboratory were compared with turbidity results obtained during testing using the Wetlab-ECO-NTU sensor. No significant differences between the turbidity datasets were evident (i.e. selection of the turbidity dataset does not significantly influence the TSS-turbidity relationship for the Ravine Beds crushed rock).

linear and power functions. It is evident that the power function provides a much closer fit of the data, characterised by an R^2 value of 0.96[3] whereas the linear line of best fit has a lower R^2 value of 0.52.



Graph 2: TSS-turbidity results – Ravine Beds crushed rock (Test 1D)

2.1.4 TSS – Turbidity Relationship

A summary of the TSS-turbidity relationships determined for the Test 1D dataset is provided in **Table 1**, including the turbidity values equivalent to a TSS concentration of 50 mg/L for each of the linear and power function trendlines. The selected TSS value of 50 mg/L is somewhat arbitrary and the water quality limit for the project may vary.

Table 1: Summary of TSS-turbidity relationships for Ravine Beds crushed rock

Trendline Function	Number of values	R^2 value	Turbidity (NTU) equivalent to 50 mg/L TSS
Linear	20	0.52	41
Power	20	0.96	66

As noted above, the power function trendline provides a much better fit of the dataset compared to the linear trendline. Furthermore, the high R^2 value associated with the power function trendline (0.96) indicates a strong correlation between TSS and turbidity for the dataset, and is considered to be valid for the data collected during testing. The turbidity value equivalent to 50 mg/L suspended solids is 66 NTU for this dataset.

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[3] The R^2 value, also known as the coefficient of determination, is a measure of how close the plotted data are to the fitted regression line (i.e. the line of best fit). An R^2 value of 1 indicates that the regression line perfectly fits the data.

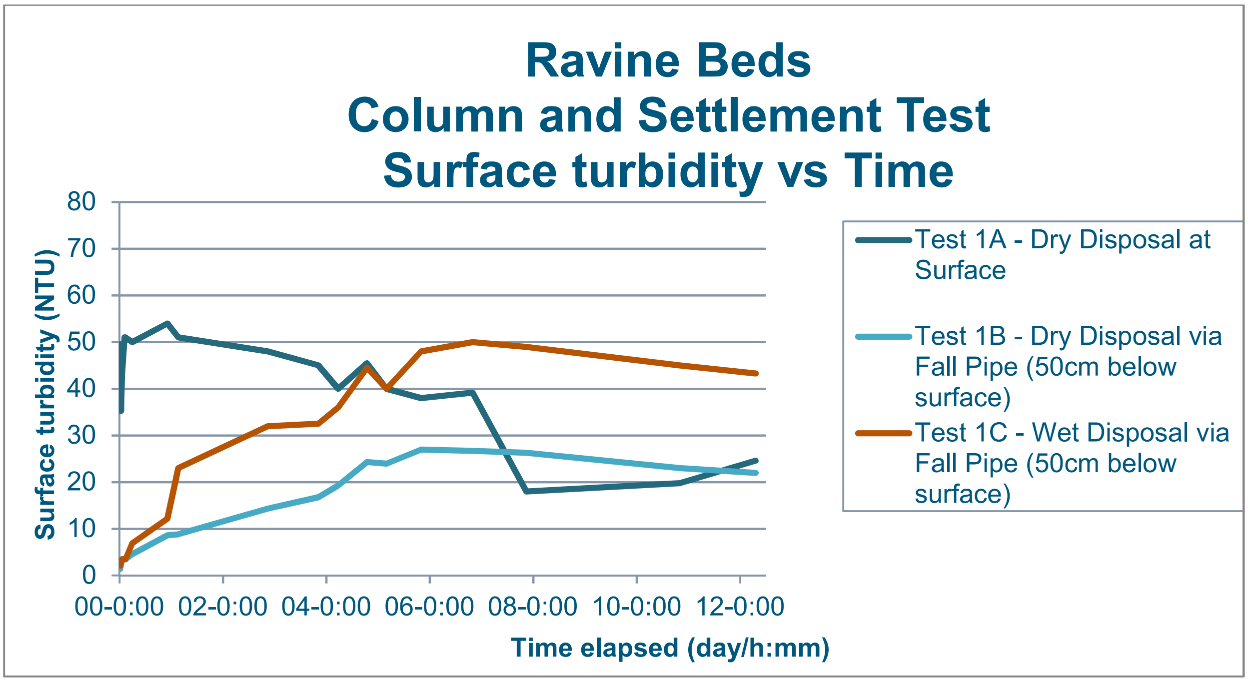
2.2 Settlement Tests

2.2.1 Overview

The three settlement tests for the Ravine Beds crushed rock (Tests 1A, 1B and 1C) commenced simultaneously on the 16th August 2018 at 12:45pm. Different disposal methods were simulated in the respective columns as described in **Sections 2.2.2** to **2.2.4**. The tests were concluded on the 28th August 2018, 12 days following commencement.

Surface turbidity in the three columns was measured 15 minutes prior to addition of the crushed rock and it was 1.88 NTU, 1.64 NTU and 1.94 NTU for Test 1A, 1B and 1C respectively.

Surface turbidity measured at varying time intervals during the 12-day test duration is plotted in **Graph 3** for the three settlement tests. These results are discussed in the following sections, along with a summary of the key observations for each settlement test. Test sheets completed during the settlement tests are provided in **Attachment 2**.



Graph 3: Surface turbidity measured during the settlement tests – Ravine Beds crushed rock (Tests 1A, 1B and 1C).

Photographs taken during the settlement tests are provided in **Figures 2** to **5**. These photographs were taken prior to commencement (**Figure 2**), 10 minutes after commencement (**Figure 3**), approximately 3 days and 20 hours after commencement (**Figure 4**), and 10 days 20 hours after commencement (**Figure 5**).

Figure 2: Settlement test prior to placement of sieved crushed rock -
Left: Test 1A - Placement of dry sieved crushed rock directly onto the water surface
Middle: Test 1B - Placement of dry sieved crushed rock within a fall pipe with opening submerged 50 cm below the water surface,
Right: Test 1C - Placement of pre-wetted sieved crushed rock within a fall pipe with opening submerged 50 cm below the water surface.

Figure 3: Settlement test 10 minutes following placement of sieved crushed rock-
Left: Test 1A - Placement of dry sieved crushed rock directly onto the water surface,
Middle: Test 1B - Placement of dry sieved crushed rock within a fall pipe with opening submerged 50 cm below the water surface,
Right: Test 1C - Placement of pre-wetted sieved crushed rock within a fall pipe with opening submerged 50 cm below the water surface.

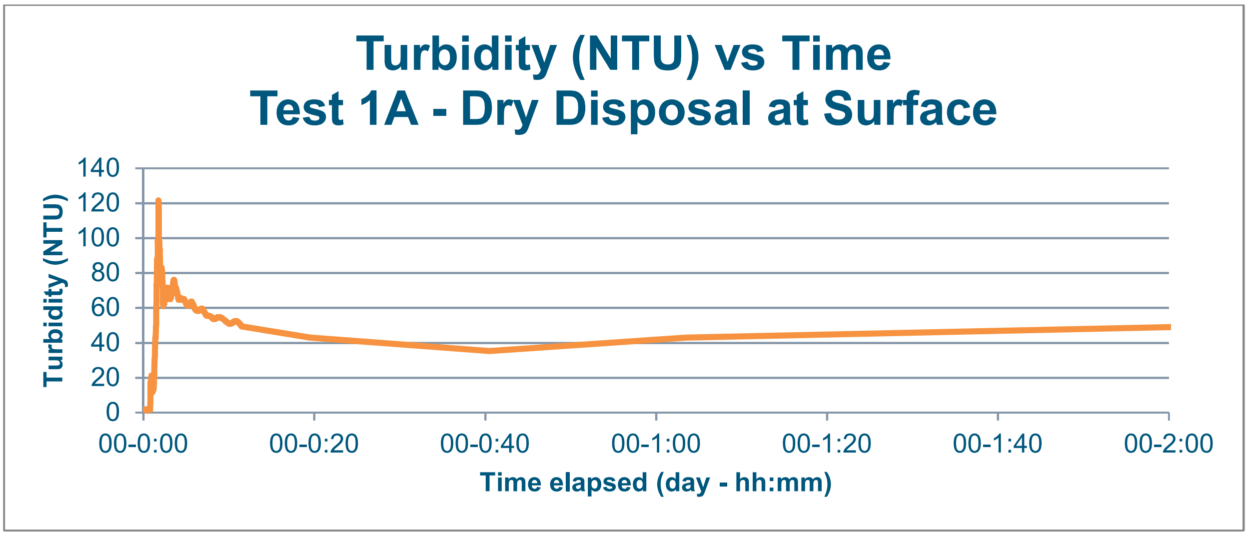
Figure 4: Settlement test approximately 3 days and 20 hours following placement of sieved crushed rock -
Left: Test 1A - Placement of dry sieved crushed rock directly onto the water surface,
Middle: Test 1B - Placement of dry sieved crushed rock within a fall pipe with opening submerged 50 cm below the water surface,
Right: Test 1C - Placement of pre-wetted sieved crushed rock within a fall pipe with opening submerged 50 cm below the water surface.

Figure 5: Settlement test approximately 10 days and 20 hours following placement of sieved crushed rock -
Left: Test 1A - Placement of dry sieved crushed rock directly onto the water surface,
Middle: Test 1B - Placement of dry sieved crushed rock within a fall pipe with opening submerged 50 cm below the water surface,
Right: Test 1C - Placement of pre-wetted sieved crushed rock within a fall pipe with opening submerged 50 cm below the water surface.

2.2.2 Test 1A - Placement of dry sieved crushed rock directly onto the water surface

For Test 1A, the sieved crushed rock was gently sprinkled onto the water surface from a height of approximately 25 cm above the water surface. Clumps of sieved crushed rock were observed to fall quickly to the bottom of the column without significantly affecting visible turbidity in the surrounding water, whereas the remainder of the sieved crushed rock diffused slowly through the column and generated surrounding turbidity. After several minutes, mixing inside the column was relatively uniform and turbid throughout.

Surface turbidity levels were measured continuously (at one second time intervals) during the first 10 minutes of Test 1A and the Wetlab ECO-NTU sensor remained in the water column for this period. Surface turbidity levels were measured at varying time intervals thereafter. The Wetlab ECO-NTU sensor was placed in the water column for each measurement and removed after a stable reading was recorded. Surface turbidity during crushed rock placement and at various time intervals during the first two hours is plotted in **Graph 4** for Test 1A**.**



Graph 4: Surface turbidity measured during the first two hours following placement of Ravine Beds crushed rock, Test 1A.

Surface turbidity levels increased rapidly from background levels of around 2 NTU to a maximum of around 120 NTU during placement of the sieved crushed rock (i.e. within the first two minutes of testing). Surface turbidity levels subsequently decreased to around 50 NTU approximately 10 minutes after commencement and 35 NTU approximately 40 minutes after commencement. However, surface turbidity levels subsequently increased to around 50 NTU approximately two hours after commencement.

Surface turbidity measured at varying time intervals over the 12-day test duration is plotted in **Graph 3** (refer **Section 2.2.1**) for Test 1A alongside the results for Tests 1B and 1C. Surface turbidity levels gradually decreased from around 50 NTU (two hours after commencement) to around 40 NTU (six days after commencement). After approximately 6 days and 20 hours, the upper portion of the column was beginning to stratify with the following observations noted:

- 6 days and 20 hours – upper 2 cm of the column notably clearer than underlying column;
- 7 days 21 hours – upper 5 cm of the column visibly clearer than underlying column; and,
- 10 days and 20 hours – upper 1cm very clear. Stratification also evident 31 cm below the surface.

These observations corresponded with a reduction in surface turbidity to approximately 20 NTU.

The above stratification was not observed after 12 days and 7 hours and an increase in surface turbidity to 24.6 NTU was reported compared to the previous measurement of 19.8 NTU after 10 days and 20 hours. A discussion regarding the observed mixing between stratified layers is provided in **Section 3**.

2.2.3 Test 1B - Placement of dry sieved crushed rock within a fall pipe with opening submerged 50 cm below the water surface

For Test 1B, the sieved crushed rock was gently sprinkled into the fall pipe with an internal diameter of approximately 50 mm. The top of the fall pipe was approximately 75 cm above the water surface. The inside of the fall pipe was rinsed with water from Talbingo Reservoir to ensure that all of the sieved crushed rock entered the column.

Similarly to Test 1A, clumps of sieved crushed rock were observed to fall quickly to the bottom of the column without significantly affecting visible turbidity in the surrounding water, whereas the remainder of the sieved crushed rock diffused slowly through column, below the bottom of the fall pipe, and generated surrounding turbidity.

During the initial stages of Test 1B, turbidity was generated below the base of the fall pipe only. Mixing in the column below the fall pipe was uniform and turbid. A denser layer of turbid water appeared to form around base of the fall pipe. There was no immediate discernible change in turbidity above the base of the fall pipe, with the upper 50 cm of water in the column (i.e. above the base of the fall pipe) remaining relatively clear for several hours following commencement.

During the first few hours of Test 1B, the fall pipe appeared to significantly reduce surface turbidity, with turbidity at the surface remaining at background levels (refer **Graph 3**, **Section 2.2.1**). However, surface turbidity levels then began to gradually increase over the following days, reaching a maximum of 27 NTU six days after commencement. Surface turbidity levels subsequently decreased to around 22 NTU at the conclusion of Test 1B (12 days and 7 hours after commencement).

A discussion regarding the observed increase in surface turbidity over time during Test 1B is provided in **Section 3**.

After approximately 7 days and 20 hours, it was observed that the upper portion of the column was beginning to stratify, however this stratification was not observed several days later at the conclusion of Test 1B. A discussion regarding the observed mixing between stratified layers is provided in **Section 3**.

2.2.4 Test 1C - Placement of pre-wetted sieved crushed rock within a fall pipe with opening submerged 50 cm below the water surface

For Test 1C, approximately 19.5 mL of water from Talbingo Reservoir was mixed with the sieved crushed rock in a small beaker to create a slurry. The slurry was placed into the fall pipe with an internal diameter of approximately 50 mm. The top of the fall pipe was approximately 75 cm above the water surface. The inside of the fall pipe was rinsed with water from Talbingo Reservoir to ensure that all of the sieved crushed rock entered the column.

The slurry fell quickly to the bottom of the column and mixed fairly uniformly throughout column, below the base of fall pipe. There was a noticeably different mixing process to the dry disposal fall pipe method

(Test 1B). Wetting the sieved crushed rock appeared to increase the depth profile within which initial mixing occurred, resulting in a slightly less dense layer around the base of the fall pipe. Similar to Test 1B, there was no immediate discernible change in turbidity above the base of the fall pipe, with the upper 50 cm of water in the column (i.e. above the base of the fall pipe) remaining relatively clear for several hours following commencement.

Initially, the fall pipe and pre-wetting of sieved crushed rock appeared to significantly reduce surface turbidity levels, with turbidity at the surface remaining at background levels for the first few hours (refer **Graph 3**, **Section 2.2.1**). However, surface turbidity levels then began to gradually increase over the following days, reaching a maximum of 50 NTU seven days after commencement. Surface turbidity levels subsequently decreased to around 43 NTU at the conclusion of Test 1C (12 days and 7 hours after commencement).

It is noted that higher surface turbidity levels were recorded during Test 1C in comparison to Test 1B. This may be due to the more uniform initial mixing process observed during Test 1C.

A discussion regarding the observed increase in surface turbidity over time during Test 1C is provided in **Section 3**.

2.3 Flocculation Test

Prior to completion of the settlement tests, a trial was undertaken to determine whether a chemical flocculant would accelerate settlement of fine particles and clarify the water. The chemical flocculant selected for the test was alum (aluminium sulphate). It should be noted that the particular chemical flocculant selected for the test was arbitrary and has not been approved for use during construction.

Flocculant was added to Test 1A (renamed 1E) on the 14th September 2018 at 11:00am, approximately 29 days following commencement of the settlement test. Test 1B (renamed 1F) was retained as a control column for comparison.

Surface turbidity in Test 1E and 1F on the 14th September 2018 (prior to addition of flocculant) and the 17th September 2018 (following addition of flocculant) is reported in **Table 2**. Surface turbidity in Test 1E decreased from 18 to 2.7 NTU while the surface turbidity in the control column, Test 1F, remained relatively constant at elevated levels. This indicates that the chemical flocculant was effective in clarifying the water.

Table 2: Surface turbidity before and after the addition of flocculant to Test 2A.

Date/Time	Test 1E (NTU)	Test 1F (NTU)
14th September 2018, 11:00am	18	18
17th September 2018,9:00am	2.7	17.6

A photograph of the two Test columns taken on the 17th September 2018 is provided in **Figure 6**. It should be noted that some of the flocculated crushed rock in Test 1E adhered to the walls of the column thereby making the column appear slightly 'cloudy' when viewed side on. However, when viewed from above, the water was clear as indicated by the surface turbidity reading.

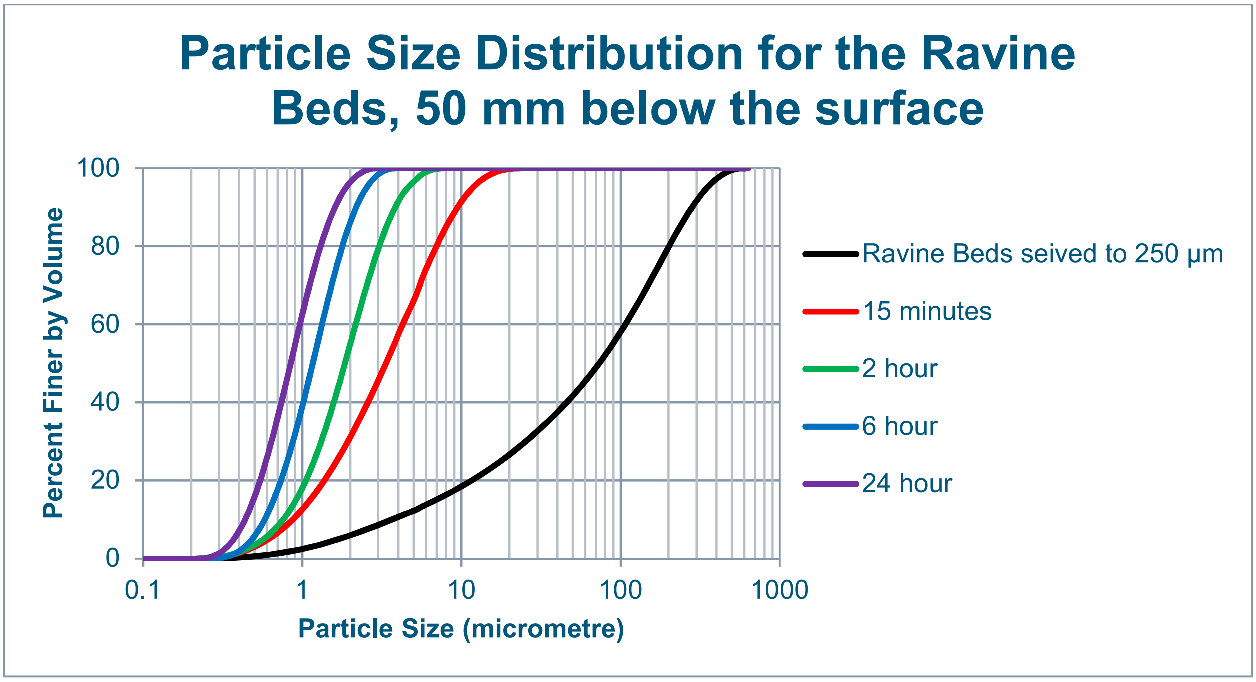
Figure 6: Flocculation test on 17th September 2018.

- *Left – Test 1E, Flocculant (alum) added (turbidity 2.7 NTU).*
- *Right – Test 1F, No flocculant (turbidity 17.6 NTU).*

2.4 Critical Particle Size

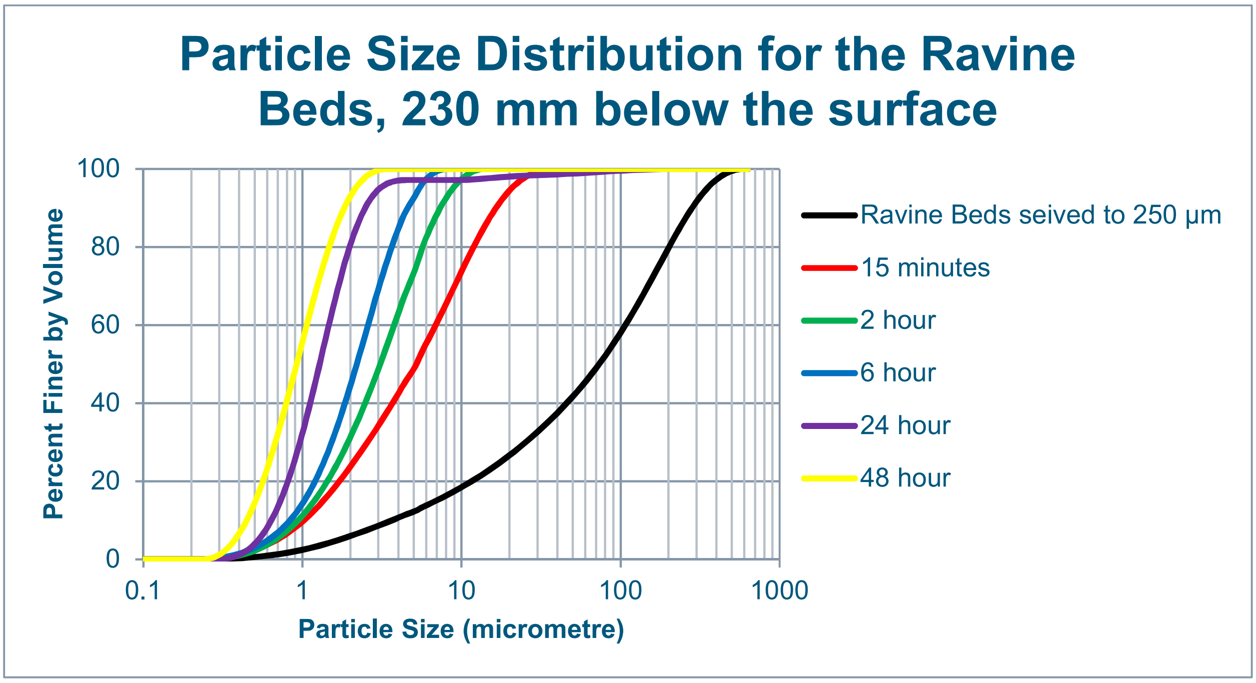
The tests to determine the critical particle size in suspension commenced on the 15th August 2018. Particle size analysis using the Mastersizer 2000 was completed on the 16th August.

Graph 5 plots the particle size distribution of the sieved crushed rock (used for all tests) and the particle size that remains in suspension after each time interval (15 minutes, 2 hours, 6 hours, and 24 hours) at 50 mm below the water surface (850 mL mark on cylinder). The maximum particle size in suspension at various time intervals is outlined in **Table 3**. The maximum particle size in suspension decreases over time from around 20 µm (15 minutes) to 2.5 µm (24 hours).



Graph 5: Particle size distribution at varying time intervals, 50 mm below the water surface.

Graph 6 plots the particle size distribution of the sieved crushed rock (used for all tests) and the particle size that remains in suspension after a given time interval (15 minutes, 2 hours, 6 hours, 24 hours and 48 hours) at 230 mm below the water surface (300 mL mark on cylinder). The maximum particle size in suspension at various time intervals is outlined in **Table 3**. The maximum particle size in suspension decreases over time from around 32 µm (15 minutes) to 3.3 µm (48 hours).



Graph 6: Particle size distribution at varying time intervals 230 mm the water surface.

Table 3: Maximum particle size in suspension at varying time intervals, 50 mm and 230 mm below the water surface.

Time	Maximum particle size in suspension (µm)	
	50 mm below the water surface	230 mm below the water surface
15 minutes	20	32
2 hours	7	11
6 hours	3.5	8
24 hours	2.5	4
48 hours		3.3

Based on the results presented above, it is evident that, for the same given time intervals, the maximum particle size in suspension is larger at greater depths within the water column, as would be expected.

3 Discussion

3.1 Dispersion of fines in Test 1B and 1C

As described in **Section 2**, during the first few hours following crushed rock placement via a fall pipe (Tests 1B and 1C), there was no immediate discernible increase in turbidity above the base of the fall pipe. However, surface turbidity levels then began to gradually increase over the following days, reaching maximum values of 27 NTU (Test 1B) and 50 NTU (Test 1C), respectively.

These observations were somewhat unexpected, with ongoing settlement following initial mixing considered more likely to occur. It is possible that the observations were influenced by one or more of the following factors:

1. The settling columns were exposed to the afternoon sun, shining through the laboratory window, between approximately 3:30pm and 4:30pm each day. Thermal heating from the sun may have been sufficient to establish a weak thermal convection current within the column, which could have resulted in rising warm water transporting suspended particles to the surface. However, surface turbidity was noted to increase overnight as well, when heating would not have occurred.
2. The sieved crushed rock may contain clay particles that are anionic and repel each other when in suspension. This could result in suspended solids diffusing and distributing evenly throughout the water column.
3. The action of gently lowering a turbidity probe into the upper layer of the column (~3.4 cm below the water surface) may be sufficient to disturb the water column resulting in advection of very fine suspended particles with the potential to generate surface turbidity.

Regardless of the reason for increased surface turbidity observed during Tests 1B and 1C, it is clear that minor disturbances to the water column are sufficient to redistribute fine suspended particles within the water column.

3.2 Stratification and Dispersion - Tests 1A and 1D

As described in **Section 2**, stratification was first observed in the columns used for Tests 1A and 1D after 6 days and 20 hours and after 8 days respectively. When monitoring was undertaken at 10 days and 20 hours following commencement in Test 1A and 11 days after commencement in Test 1D, stratification was again noted in both columns with the following observations made:

- Test 1A – upper 1 cm very clear. Stratification also evident 31 cm below the surface.
- Test 1D – notably clearer to 9.5 cm below the water surface in the column.

Stratification in both columns was absent when the subsequent and final surface turbidity readings were recorded on 28th August 2018, 12 days and 7 hours after commencement of Test 1A and 12 days 11 hours after commencement of Test 1D. Further, the collapse of the stratification was noted to coincide with in an increase in surface turbidity in both columns.

It is our interpretation that the turbid water below the stratified boundary mixed with the clearer water above the stratified boundary leading to an increase in surface turbidity. The reason for the stratification collapsing and the suspended particles below the stratified boundary mixing with the clearer water above is not clear. It may be linked to the formation of thermal convection currents or other factors discussed in **Section 3.1**.

Regardless of the reason for increased surface turbidity associated with the collapse of the stratified layer observed during Tests 1A and 1B, it is clear that minor disturbances to the water column are sufficient to disrupt the settlement process and cause stratification in the water column to collapse.

4 Conclusions

It is apparent from the column test and settlement tests that once fine crushed rock from the Ravine Beds geological zone enters the water column, the fine particles remain in suspension for extended periods in the order of several days to weeks. Elevated surface turbidity levels of around 20 NTU to 40 NTU were recorded at the conclusion of the tests, around 12 days following commencement.

While surface turbidity levels generally appear to reduce over time, it may take an extremely long time to reach background levels of 1 NTU to 5 NTU, as reported by Cardno. Furthermore, minor disturbances to the water column are likely to disrupt the settlement process and/or re-suspend fine particles.

The critical particle size in suspension that would be contributing to prolonged surface turbidity in the water column (more than 24 hours) would be less than approximately 3 µm.

TSS-turbidity data collected during the Column Test (Test 1D) is considered to be reliable for the purpose of establishing a preliminary relationship between TSS and turbidity for the Ravine Beds geological zone. The turbidity value equivalent to 50 mg/L suspended solids is 66 NTU for this dataset. Furthermore, as the properties and grading of the crushed rock placed during construction may vary to that used in the column test, collection of field TSS-turbidity data during subaqueous excavated rock placement activities is recommended so that the relationship between turbidity and suspended solids can be continually validated and improved.

Test 1 was repeated in Test 10 to examine sensitivity of test parameters. The results for Test 10 are provided in **Appendix J**. The repeat tests indicated that the settlement test and critical particle size analysis are reliable.

Attachment 1 – Laboratory Certificates

ALS Environmental

CERTIFICATE OF ANALYSIS

Work Order : **ES1825228**
Client : **HASKONING AUSTRALIA- ROYAL HASKONING**
Contact : MR PATRICK LAWLESS
Address : LEVEL 14 56 Berry Street
NORTH SYDNEY 2060
Telephone : ----
Project : ----
Order number :
C-O-C number : ----
Sampler : Patrick Lawless
Site : ----
Quote number : EN/222
No. of samples received : 20
No. of samples analysed : 20

Page : 1 of 6
Laboratory : Environmental Division Sydney
Contact : Customer Services ES
Address : 277-289 Woodpark Road Smithfield NSW Australia 2164
Telephone : +61-2-8784 8555
Date Samples Received : 27-Aug-2018 17:10
Date Analysis Commenced : 28-Aug-2018
Issue Date : 30-Aug-2018 16:56

Accreditation No. 825
Accredited for compliance with
ISO/IEC 17025 - Testing

This report supersedes any previous report(s) with this reference. Results apply to the sample(s) as submitted. This document shall not be reproduced, except in full.

This Certificate of Analysis contains the following information:

- General Comments
- Analytical Results

Additional information pertinent to this report will be found in the following separate attachments: Quality Control Report, QA/QC Compliance Assessment to assist with Quality Review and Sample Receipt Notification.

Signatories

This document has been electronically signed by the authorized signatories below. Electronic signing is carried out in compliance with procedures specified in 21 CFR Part 11.

Signatories	*Position*	*Accreditation Category*
Ankit Joshi	Inorganic Chemist	Sydney Inorganics, Smithfield, NSW

General Comments

The analytical procedures used by the Environmental Division have been developed from established internationally recognized procedures such as those published by the USEPA, APHA, AS and NEPM. In house developed procedures are employed in the absence of documented standards or by client request.

Where moisture determination has been performed, results are reported on a dry weight basis.

Where a reported less than (<) result is higher than the LOR, this may be due to primary sample extract/digestate dilution and/or insufficient sample for analysis.

Where the LOR of a reported result differs from standard LOR, this may be due to high moisture content, insufficient sample (reduced weight employed) or matrix interference.

When sampling time information is not provided by the client, sampling dates are shown without a time component. In these instances, the time component has been assumed by the laboratory for processing purposes.

Where a result is required to meet compliance limits the associated uncertainty must be considered. Refer to the ALS Contact for details.

Key : CAS Number = CAS registry number from database maintained by Chemical Abstracts Services. The Chemical Abstracts Service is a division of the American Chemical Society.
LOR = Limit of reporting
^ = This result is computed from individual analyte detections at or above the level of reporting
ø = ALS is not NATA accredited for these tests.
~ = Indicates an estimated value.

Analytical Results

Sub-Matrix: **WATER** (Matrix: **WATER**)			Client sample ID	**1D-1**	**1D-2**	**1D-3**	**1D-4A**	**1D-4B**
			Client sampling date / time	16-Aug-2018 00:00	16-Aug-2018 00:00	16-Aug-2018 00:00	16-Aug-2018 00:00	16-Aug-2018 00:00
Compound	*CAS Number*	*LOR*	*Unit*	**ES1825228-001**	**ES1825228-002**	**ES1825228-003**	**ES1825228-004**	**ES1825228-005**
				Result	Result	Result	Result	Result
EA025: Total Suspended Solids dried at 104 ± 2°C								
Suspended Solids (SS)	----	5	mg/L	**221**	**185**	**178**	**122**	**128**
EA045: Turbidity								
Turbidity	----	0.1	NTU	**141**	**118**	**136**	**92.0**	**90.2**

Analytical Results

Sub-Matrix: **WATER** (Matrix: **WATER**)			*Client sample ID*	**1D-5**	**1D-6**	**1D-7**	**1D-8**	**1D-9**
			Client sampling date / time	16-Aug-2018 00:00	16-Aug-2018 00:00	16-Aug-2018 00:00	16-Aug-2018 00:00	16-Aug-2018 00:00
Compound	*CAS Number*	*LOR*	*Unit*	**ES1825228-006**	**ES1825228-007**	**ES1825228-008**	**ES1825228-009**	**ES1825228-010**
				Result	Result	Result	Result	Result
EA025: Total Suspended Solids dried at 104 ± 2°C								
Suspended Solids (SS)	----	5	mg/L	**103**	**73**	**81**	**79**	**81**
EA045: Turbidity								
Turbidity	----	0.1	NTU	**88.0**	**75.4**	**79.5**	**67.0**	**70.7**

Analytical Results

Sub-Matrix: **WATER**
(Matrix: **WATER)**

			Client sample ID	**1D-10**	**1D-11**	**1D-12**	**1D-13**	**1D-14**
			Client sampling date / time	16-Aug-2018 00:00	17-Aug-2018 00:00	17-Aug-2018 00:00	19-Aug-2018 00:00	20-Aug-2018 00:00
Compound	*CAS Number*	*LOR*	*Unit*	**ES1825228-011**	**ES1825228-012**	**ES1825228-013**	**ES1825228-014**	**ES1825228-015**
				Result	Result	Result	Result	Result
EA025: Total Suspended Solids dried at 104 ± 2°C								
Suspended Solids (SS)	----	5	mg/L	**62**	**78**	**49**	**54**	**52**
EA045: Turbidity								
Turbidity	----	0.1	NTU	**73.6**	**66.0**	**56.5**	**71.9**	**71.4**

Analytical Results

Sub-Matrix: **WATER** (Matrix: **WATER**)			Client sample ID	**1D-15**	**1D-16**	**1D-17**	**1D-18**	**1D-19**
			Client sampling date / time	21-Aug-2018 00:00	22-Aug-2018 00:00	23-Aug-2018 00:00	24-Aug-2018 00:00	27-Aug-2018 00:00
Compound	CAS Number	LOR	Unit	**ES1825228-016**	**ES1825228-017**	**ES1825228-018**	**ES1825228-019**	**ES1825228-020**
				Result	Result	Result	Result	Result
EA025: Total Suspended Solids dried at 104 ± 2°C								
Suspended Solids (SS)	----	5	mg/L	**45**	**16**	**14**	**6**	<5
EA045: Turbidity								
Turbidity	----	0.1	NTU	**68.2**	**38.2**	**40.4**	**24.0**	**16.6**

Attachment 2 – Ravine Bed Laboratory Log Records

Test ID	1A	
Geological Unit	Ravine Beds	
Description	Test 1A - Dry Disposal at Surface	
Start Date/Time	16-08-18 12:45	
Water volume	50 L	
Water surface level in column	176.2	cm
Mass sediment added	40 g	(sieved to <250 um)
Test Location	Geochemical Assessments Workshop, Roseville NSW	
Test Officers	Pat Lawless, Rick Plain, Stuart Taylor	

Observations

Date/Time	Time since start	Turbidity (NTU)	Measurement Location (cm)	Measurement Depth (cm)	Comments
16-08-18 10:45	Two hours prior	1.88	172.8	3.4	Background turbidity measured 2 hours before test start
16-08-18 12:57	00-0:11	49.5	172.8	3.4	Fully mixed column
16-08-18 13:05	00-0:19	43	172.8	3.4	
16-08-18 13:26	00-0:40	35.3	172.8	3.4	
16-08-18 13:49	00-1:03	43	172.8	3.4	
16-08-18 15:05	00-2:19	51	172.8	3.4	Probe entering/exiting column may be re-entraining sediment
16-08-18 15:34	00-2:48	51	172.8	3.4	No NTU measurement, assume same value as previous
16-08-18 18:40	00-5:54	50	172.8	3.4	
17-08-18 11:00	00-22:14	54	172.8	3.4	
17-08-18 16:00	01-3:14	51	172.8	3.4	
19-08-18 9:30	02-20:44	48	172.8	3.4	
20-08-18 9:00	03-20:14	45	172.8	3.4	
20-08-18 18:10	04-5:24	40	172.8	3.4	
21-08-18 7:40	04-18:54	45.5	172.8	3.4	
21-08-18 16:40	05-3:54	40	172.8	3.4	
22-08-18 8:40	05-19:54	38	172.8	3.4	
23-08-18 8:40	06-19:54	39.2	172.8	3.4	Top say 2 cm visibly clearer. Layer easily disturbed.
24-08-18 9:30	07-20:44	18	172.8	3.4	Top 5 cm visibly clearer.
27-08-18 9:00	10-20:14	19.8	172.8	3.4	Top 1 cm very clear. Boundary at 31 cm below surface.
28-08-18 20:00	12-7:14	24.6	172.8	3.4	No visible boundaries near the top of the column

Test ID	1B	
Geological Unit	Ravine Beds	
Description	Test 1B - Dry Disposal via Fall Pipe (50cm below surface)	
Start Date/Time	16-08-18 12:45	
Water volume	50 L	
Water surface level in column	176.2	cm
Mass sediment added	40 g	(sieved to <250 um)
Test Location	Geochemical Assessments Workshop, Roseville NSW	
Test Officers	Pat Lawless, Rick Plain, Stuart Taylor	

Observations

Date/Time	Time since start	Turbidity (NTU)	Measurement Location (cm)	Measurement Depth (cm)	Comments
16-08-18 10:45	15 minutes prior	1.65	172.8	3.4	Background turbidity measured 15 minutes before test start.
16-08-18 13:00	00-0:14	1.4	172.8	3.4	Turbid layer at 127 cm.
16-08-18 13:50	00-1:04	3.5	172.8	3.4	
16-08-18 15:34	00-2:48	3.5	172.8	3.4	Turbid layer at 126 cm (just above base of pipe, clearing up a bit).
16-08-18 18:40	00-5:54	4.6	172.8	3.4	Slightly turbid near surface.
17-08-18 11:00	00-22:14	8.6	172.8	3.4	Turbid layer at 122.5 cm (below base of fall pipe). Minor turbidity visible above layer. Minimal visible turbidity in fall pipe.
17-08-18 16:00	01-3:14	8.8	172.8	3.4	Turbidity +/-0.1. Turbid layer at 114 cm. Boundary becoming less distinct. Visibly more turbid on the side of the column exposed to the afternoon sun (direct sun through window from say 3:15-4:15 p.m). Turbidity measurement taken on opposite side of column (i.e. side of column not in sun).
19-08-18 9:30	02-20:44	14.3	172.8	3.4	Turbidity +/-0.1. Turbid layer at 107 cm. Boundary becoming less distinct.
20-08-18 9:00	03-20:14	16.8	172.8	3.4	Turbidity +/-0.1. Turbid layer at 107 cm. Boundary indistinct.
20-08-18 18:10	04-5:24	19.3	172.8	3.4	
21-08-18 7:40	04-18:54	24.3	172.8	3.4	
21-08-18 16:40	05-3:54	24	172.8	3.4	
22-08-18 8:40	05-19:54	27	172.8	3.4	
23-08-18 8:40	06-19:54	26.7	172.8	3.4	
24-08-18 9:30	07-20:44	26.3	172.8	3.4	Starting to clear near surface.
27-08-18 9:00	10-20:14	23	172.8	3.4	
28-08-18 20:00	12-7:14	22	172.8	3.4	No visible boundaries near the top of the column.

Test ID	1C	
Geological Unit	Ravine Beds	
Description	Test 1C - Wet Disposal via Fall Pipe (50cm below surface)	
Start Date/Time	16-08-18 12:45	
Water volume	50 L	
Water surface level in column	176.2	cm
Mass sediment added	47.5 g	(sieved to <250 um)
Test Location	Geochemical Assessments Workshop, Roseville NSW	
Test Officers	Pat Lawless, Rick Plain, Stuart Taylor	

Observations

Date/Time	Time since start	Turbidity (NTU)	Measurement Location (cm)	Measurement Depth (cm)	Comments
16-08-18 10:45	15 minutes prior	1.94	172.8	3.4	Background turbidity measured 15 minutes before test start.
16-08-18 13:02	00-0:16	2.1	172.8	3.4	Turbid layer at 128 cm (just above base of pipe).
16-08-18 13:50	00-1:04	3.5	172.8	3.4	
16-08-18 15:34	00-2:48	3.5	172.8	3.4	Turbid layer at 127 cm (just above base of pipe, clearing up a bit).
16-08-18 18:40	00-5:54	6.9	172.8	3.4	
17-08-18 11:00	00-22:14	12.2	172.8	3.4	Turbid layer at 123.5 cm (below base of fall pipe). Minor turbidity visible above layer. Minimal visible turbidity in fall pipe.
17-08-18 16:00	01-3:14	23	172.8	3.4	Turbidity +/-2. Turbid layer at ~107 cm. Boundary becoming less distinct. Visibly more turbid on the side of the column exposed to the afternoon sun (direct sun through window from say 3:15-4:15 pm). Turbidity measurement taken on opposite side of column (i.e. side of column not in sun). Distinct mixing in upper section of the column at ~4:24 pm.
19-08-18 9:30	02-20:44	32	172.8	3.4	Turbidity +/-0.5. Turbid layer at ~102 cm. Boundary becoming less distinct.
20-08-18 9:00	03-20:14	32.5	172.8	3.4	Turbidity +/-0.1. Turbid layer at ~97.5 cm. Boundary becoming less distinct.
20-08-18 18:10	04-5:24	36	172.8	3.4	
21-08-18 7:40	04-18:54	44.5	172.8	3.4	
21-08-18 16:40	05-3:54	40	172.8	3.4	
22-08-18 8:40	05-19:54	48	172.8	3.4	
23-08-18 8:40	06-19:54	50	172.8	3.4	
24-08-18 9:30	07-20:44	49	172.8	3.4	
27-08-18 9:00	10-20:14	45	172.8	3.4	
28-08-18 20:00	12-7:14	43.3	172.8	3.4	

Test ID	1D	
Geological Unit	Ravine Beds	
Description	Test 1D - Column Test to develop TSS/NTU relationship	
Start Date/Time	16-08-18 9:20	
Water volume	50 L	
Water surface level in column	176.2	cm
Mass sediment added	47.5 g	(sieved to <250 um)
Test Location	Geochemical Assessments Workshop, Roseville NSW	
Test Officers	Pat Lawless, Rick Plain, Stuart Taylor	

Observations

Date/Time	Time since start	Turbidity (NTU)		TSS Sample Taken?	TSS Sample ID	Column Measurements			Comments
		Inside Column	Inside Beaker			Water Surface	Measurement Location	Sensor Depth	
16-08-18 9:21	00-0:01	145	135	Yes	1D-1	175.8	172.4	3.4	Start of test
16-08-18 9:25	00-0:05	120	135	Yes	1D-2	175	171.6	3.4	Variable turbidity in beaker and column (+/- 10NTU)
16-08-18 9:31	00-0:11	115	120	Yes	1D-3	173.9	170.5	3.4	200mL in sample
16-08-18 9:40	00-0:20	110		No		173.2	169.8	3.4	Variability +/- 2 NTU
16-08-18 9:50	00-0:30	110	112	Yes	1D-4A and 1D-4B	173.2	169.8	3.4	Duplicate sample taken
16-08-18 10:10	00-0:50	107	100	Yes	1D-5	171.8	168.4	3.4	
16-08-18 10:50	00-1:30	89	75	Yes	1D-6	170.8	167.4	3.4	Turbidity in column noticeably higher than sub-sample
16-08-18 11:02	00-1:42	86		No		170.1	166.7	3.4	
16-08-18 11:20	00-2:00	84	80	Yes	1D-7	170.1	166.7	3.4	
16-08-18 11:52	00-2:32	79		No		169.4	166	3.4	
16-08-18 12:32	00-3:12	74	74	Yes	1D-8	169.4	166	3.4	
16-08-18 13:40	00-4:20	62	73	Yes	1D-9	168.6	165.2	3.4	Measuring 75-85 NTU a few minutes after sample removed.
16-08-18 15:00	00-5:40	74		No		167.7	164.3	3.4	
16-08-18 18:40	00-9:20	64	68	Yes	1D-10	167.7	164.3	3.4	
17-08-18 11:00	01-1:40	69	77	Yes	1D-11	166.7	163.3	3.4	Measuring 75 NTU a few minutes after sample removed.
17-08-18 16:00	01-6:40	72	76	Yes	1D-12	165.5	162.1	3.4	Turbidity +/- 0.5. Measuring 69.5 NTU a few minutes after sample removed.
19-08-18 9:30	03-0:10	67	80	Yes	1D-13	164.2	160.8	3.4	Turbidity +/- 1. Measuring 64 NTU a few minutes after sample removed.
20-08-18 9:00	03-23:40	61	61	Yes	1D-14	163.3	159.9	3.4	
20-08-18 18:10	04-8:50	59		No		162.3	158.9	3.4	
21-08-18 7:40	04-22:20	58	58	Yes	1D-15	162.3	158.9	3.4	
21-08-18 16:40	05-7:20	41		No		158.9	155.5	3.4	Water extracted for particle size analysis.
22-08-18 8:40	05-23:20	35	47.8	Yes	1D-16	158.9	155.5	3.4	
23-08-18 8:40	06-23:20	35	37	Yes	1D-17	157.7	154.3	3.4	
24-08-18 9:30	08-0:10	32.8	23.5	Yes	1D-18	156.9	153.5	3.4	Top say 2cm starting to clear. Easily disturbed.
27-08-18 9:00	10-23:40	16.4	16.3	Yes	1D-19	156	152.6	3.4	Clearer to ~146.5 cm.
28-08-18 20:00	12-10:40	27.5	32	Yes	1D-20	154.9	151.5	3.4	No visible boundaries near top of column

Appendix B

TSS – Turbidity and Settling Test Results
Boraig Group Geological Zone – Igneous

Table of Contents

1 Introduction

The Boraig Group geological zone is highly variable and comprises sedimentary and extrusive igneous rock types. A 1-m long section of core from this geological zone was supplied to Haskoning from BH5105 taken between 94 m and 95 m below the ground surface. The rock core was logged as ignimbrite, an extrusive igneous rock.

Water for settlement and column testing was obtained from Talbingo Reservoir on the 18th September 2018. The water was collected in 1000 L Intermediate Bulk Containers (IBC) and delivered to Haskoning on the 21st September 2018. The water was visibly turbid upon delivery and it was left to settle for approximately 5 days. Supernatant was decanted from the top of the IBCs. The turbidity of the reservoir water sample used for the testing was between 1.9 and 2.8 NTU. This is within the turbidity range of field monitoring, as undertaken by Cardno in 2018, which indicated typical 'background' turbidity of 1 to 5 NTU in Talbingo Reservoir.

Water for the critical particle size analysis was obtained from Talbingo Reservoir on the 2nd October 2018. The water was similarly collected in 1000 L IBC and delivered to Haskoning on the 5th October 2018. The turbidity of the water sample used for the testing was between 1.7 and 2.7 NTU.

2 Results

2.1 Test 2D – TSS-Turbidity

2.1.1 Overview

The TSS-Turbidity Test for the Boraig Group igneous rock ('Test 2D') commenced on the 26th September 2018. The test concluded on the 8th October 2018, approximately 12 days following commencement.

The Certificate of Analysis provided by ALS Environmental for the TSS and turbidity analyses undertaken for samples collected during testing is provided in **Attachment 1**. Laboratory log records completed during the TSS-turbidity test are provided in **Attachment 2**, which includes turbidity measurements undertaken during testing for each sample.

Photographs taken during the column test are provided in **Figure 1**. These photographs were taken:

- prior to commencement;
- 3 hours and 40 minutes after commencement;
- 1 day and 8 hours after commencement;
- 4 days and 20.5 hours after commencement; and
- 11 days and 23.5 hours after commencement.

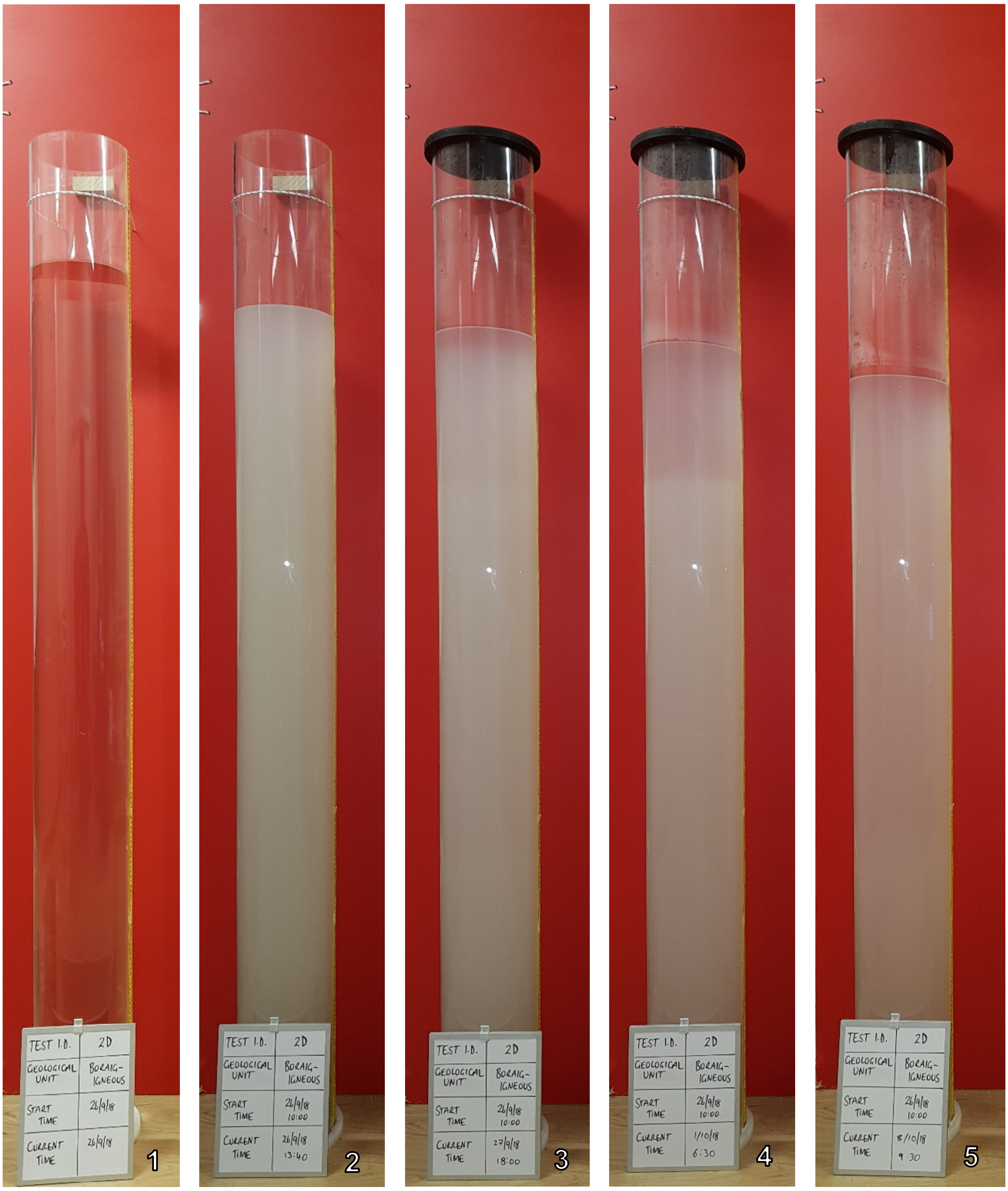


Figure 1: Column test –

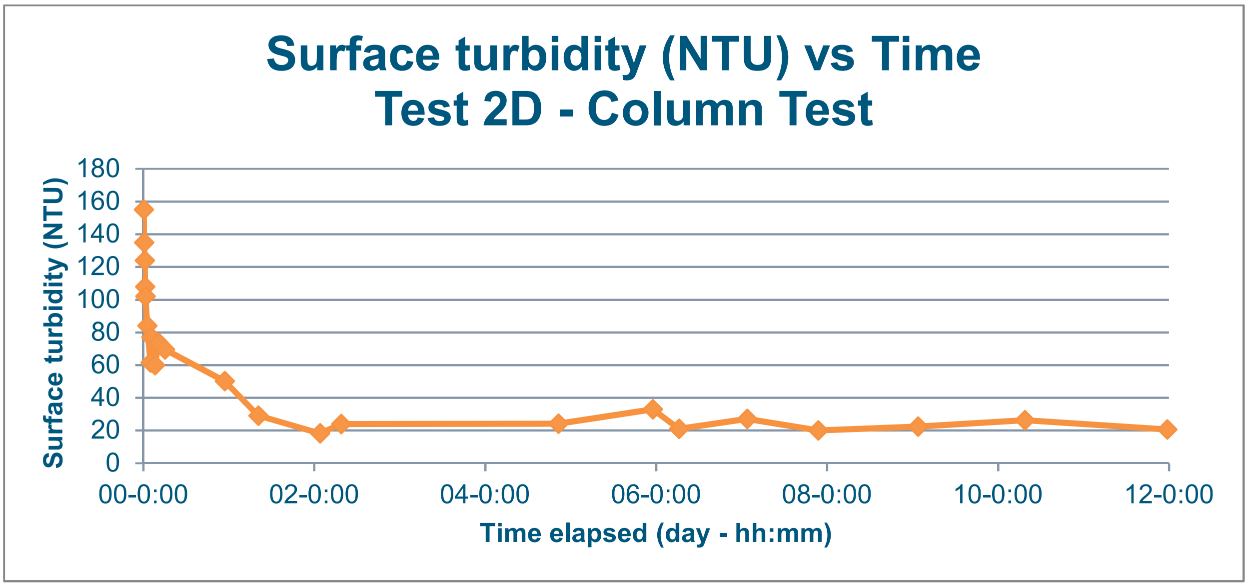
1. *Talbingo Reservoir water without addition of the sieved crushed rock,*
2. *Column test 3 hours and 40 minutes after commencement,*
3. *Column test 1 day and 8 hours after commencement,*
4. *Column test 4 days and 20.5 hours after commencement,*
5. *Column test 11 days and 23.5 hours after commencement.*

2.1.2 Surface Turbidity vs Time Results

The variation in surface turbidity during Test 2D is plotted in **Graph 1**. The graph shows that surface turbidity decreased relatively rapidly from 155 NTU to 80 NTU during the first 2 hours of testing. Between 2 hours and 6 hours after commencement, surface turbidity fluctuated between 60 and 80 NTU.

Surface turbidity levels continued to decrease, at a slower rate, to approximately 25 NTU after 2 days. Between approximately 2 and 12 days after commencement, surface turbidity fluctuated between 18.3 NTU (2 days and 2 hours after commencement) to 36.9 NTU (5 days and 23 hours after commencement). The average surface turbidity during this period was 25 NTU. By day 8 after commencement, surface turbidity had decreased to approximately 25 NTU and remained relatively constant for the remainder of the test.

A discussion regarding the observed increase and fluctuations in surface turbidity is provided in **Section 3**.



Graph 1: Surface turbidity measured during the column test – Boraig Group igneous crushed rock (Test 2D).

2.1.3 TSS – Turbidity Results

A total of 25 samples were collected during testing for laboratory TSS and turbidity analysis. TSS values for the collected samples ranged between <5 mg/L[1] and 263 mg/L, while turbidity values of up to 137 NTU were recorded.

A plot of TSS versus turbidity for all data collected during testing is provided in **Graph 2**. Turbidity values used in this dataset are the measurements taken during testing (inside the glass beaker prior to sub-sampling) rather than the laboratory results[2]. This dataset is plotted with trendlines corresponding to both linear and power functions. It is evident that the power function provides a much closer fit of the data, characterised by an R^2 value of 0.94[3] whereas the linear line of best fit has a lower R^2 value of 0.79.

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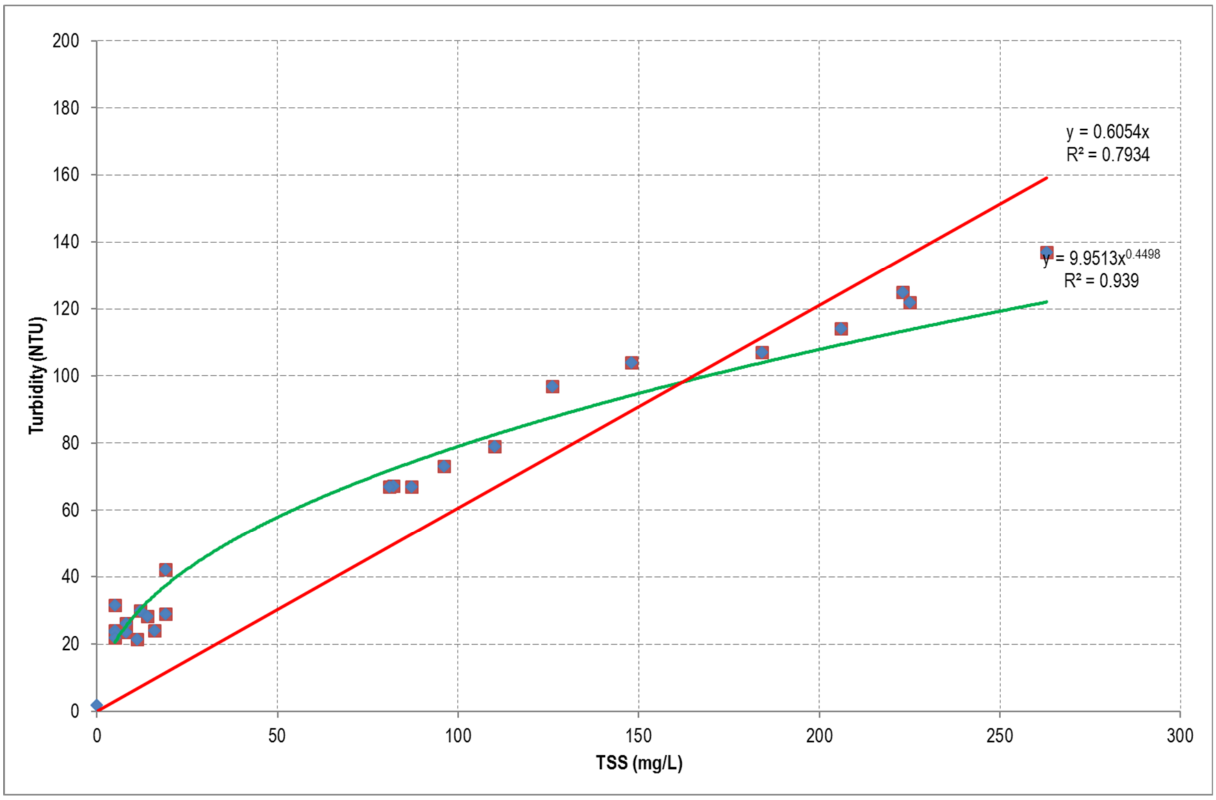
[1] The Limit of Reporting (LOR) value for TSS analysis is 5 mg/L, refer **Attachment 1**. Results for samples with TSS concentrations below the LOR value are reported as <5 mg/L.

[2] Turbidity results reported by the laboratory were compared with turbidity results obtained during testing using the Wetlab-ECO-NTU sensor. No significant differences between the turbidity datasets were evident (i.e. selection of the turbidity dataset does not significantly influence the TSS-turbidity relationship reported herein).

[3] The R^2 value, also known as the coefficient of determination, is a measure of how close the plotted data are to the fitted regression line (i.e. the line of best fit). An R^2 value of 1 indicates that the regression line perfectly fits the data.



Graph 2: TSS-turbidity results – Boraig Group igneous crushed rock (Test 2D)

2.1.4 TSS – Turbidity Relationship

A summary of the TSS-turbidity relationships determined for the Test 2D dataset is provided in **Table 1**, including the turbidity values equivalent to a TSS concentration of 50 mg/L for each the linear and power function trendline. The selected TSS value of 50 mg/L is somewhat arbitrary and the water quality limit for the project may vary.

Table 1: Summary of TSS-turbidity relationships for Boraig Group igneous crushed rock

Trendline Function	Number of values	R^2 value	Turbidity (NTU) equivalent to 50 mg/L TSS
Linear	25	0.79	30
Power	25	0.94	58

As noted above, the power function trendline provides a much better fit of the dataset compared to the linear trendline. Furthermore, the high R^2 value associated with the power function trendline (0.94) indicates a strong correlation between TSS and turbidity for the dataset, and is considered to be valid for the data collected during testing. The turbidity value equivalent to 50 mg/L suspended solids is 58 NTU for this dataset.

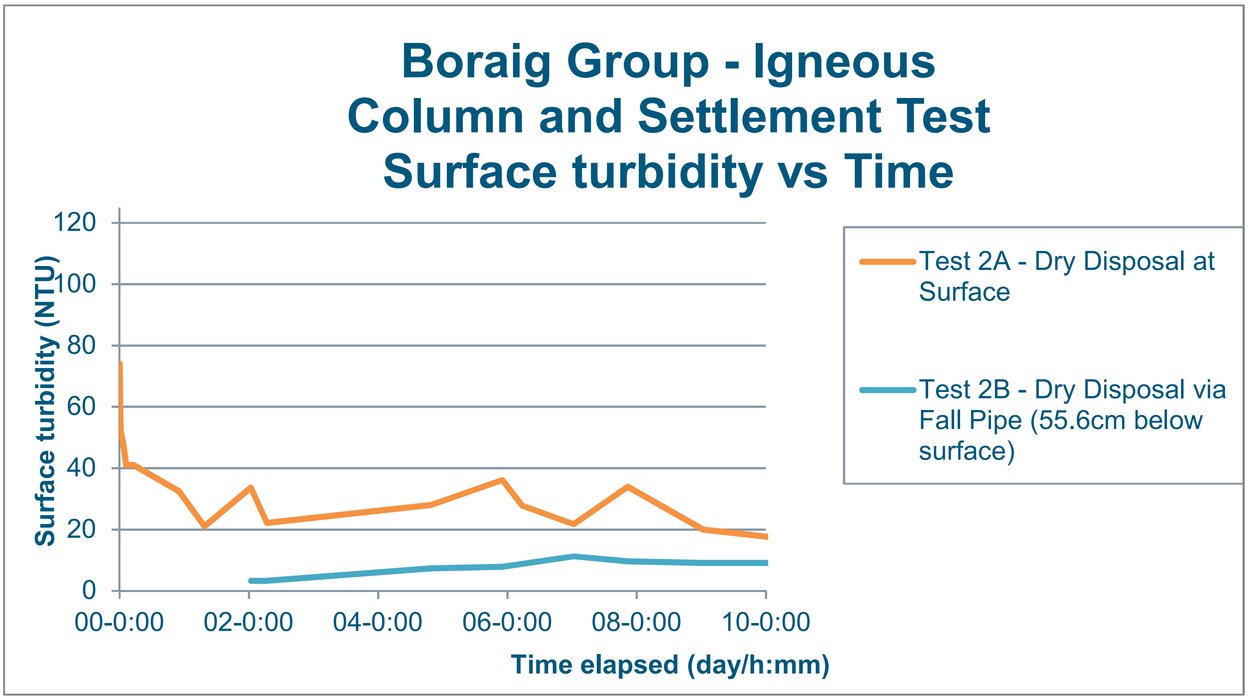
2.2 Settlement Tests

2.2.1 Overview

The two settlement tests for the Boraig Group igneous rock (Tests 2A and 2B) commenced simultaneously on the 26th September 2018 at 10:50am. Different disposal methods were simulated in the respective columns as described in **Sections 2.2.2** to **2.2.4**. The tests concluded on 6th October 2018, approximately 10 days following commencement.

Surface turbidity in the two columns was measured 10 minutes prior to addition of the crushed rock at 2.3 NTU and 2.2 NTU for Test 2A and 2B respectively.

Surface turbidity measured at varying time intervals during the 10-day test duration is plotted in **Graph 3** for the two settlement tests. These results are discussed in the following sections, along with a summary of the key observations for each settlement test. Laboratory log records completed during the settlement tests are provided in **Attachment 2**.



Graph 3: Surface turbidity measured during the settlement tests – Boraig Group igneous crushed rock type (Tests 2A and 2B).

Photographs taken during the settlement tests are provided in **Figures 2** to **6**. These photographs were taken prior to commencement (**Figure 2**), 3 hours and 40 minutes after commencement (**Figure 3**), 1 day and 8 hours after commencement (**Figure 4**), 4 days and 20.5 hours after commencement (**Figure 5**), and 11 days and 23.5 hours after commencement (**Figure 6**).

Figure 2: Settlement test prior to placement of sieved crushed rock -
Left: Test 2A - Placement of dry sieved crushed rock directly onto the water surface,
Right: Test 2B - Placement of dry sieved crushed rock within a fall pipe with opening submerged 55.6 cm below the water surface.

TEST I.D.	2A
GEOLOGICAL UNIT	BORAIG-IGNEOUS
START TIME	26/9/18 10:50
CURRENT TIME	26/9/18 13:40

TEST I.D.	2B
GEOLOGICAL UNIT	BORAIG-IGNEOUS
START TIME	26/9/18 10:50
CURRENT TIME	26/9/18 13:40

Figure 3: Settlement test 2 hours and 50 minutes following placement of sieved crushed rock -
Left: Test 2A - Placement of dry sieved crushed rock directly onto the water surface,
Right: Test 2B - Placement of dry sieved crushed rock within a fall pipe with opening submerged 55.6 cm below the water surface.

TEST I.D.	2A
GEOLOGICAL UNIT	BORAIG-IGNEOUS
START TIME	26/9/18 10:50
CURRENT TIME	27/9/18 8:30

TEST I.D.	2B
GEOLOGICAL UNIT	BORAIG-IGNEOUS
START TIME	26/9/18 10:50
CURRENT TIME	27/9/18 8:30

Figure 4: Settlement test 21 hours and 40 minutes following placement of sieved crushed rock -
Left: Test 2A - Placement of dry sieved crushed rock directly onto the water surface,
Right: Test 2B - Placement of dry sieved crushed rock within a fall pipe with opening submerged 55.6 cm below the water surface.

TEST I.D.	2A
GEOLOGICAL UNIT	BORAIG-IGNEOUS
START TIME	26/9/18 10:50
CURRENT TIME	1/10/18 6:30

TEST I.D.	2B
GEOLOGICAL UNIT	BORAIG-IGNEOUS
START TIME	26/9/18 10:50
CURRENT TIME	1/10/18 6:30

Figure 5: Settlement test 4 days and 20.7 hours following placement of sieved crushed rock -
Left: Test 2A - Placement of dry sieved crushed rock directly onto the water surface,
Right: Test 2B - Placement of dry sieved crushed rock within a fall pipe with opening submerged 55.6 cm below the water surface.

TEST I.D.	2A
GEOLOGICAL UNIT	BORAIG-IGNEOUS
START TIME	26/9/18 10:50
CURRENT TIME	4/10/18 7:30

TEST I.D.	2B
GEOLOGICAL UNIT	BORAIG-IGNEOUS
START TIME	26/9/18 10:50
CURRENT TIME	4/10/18 7:30

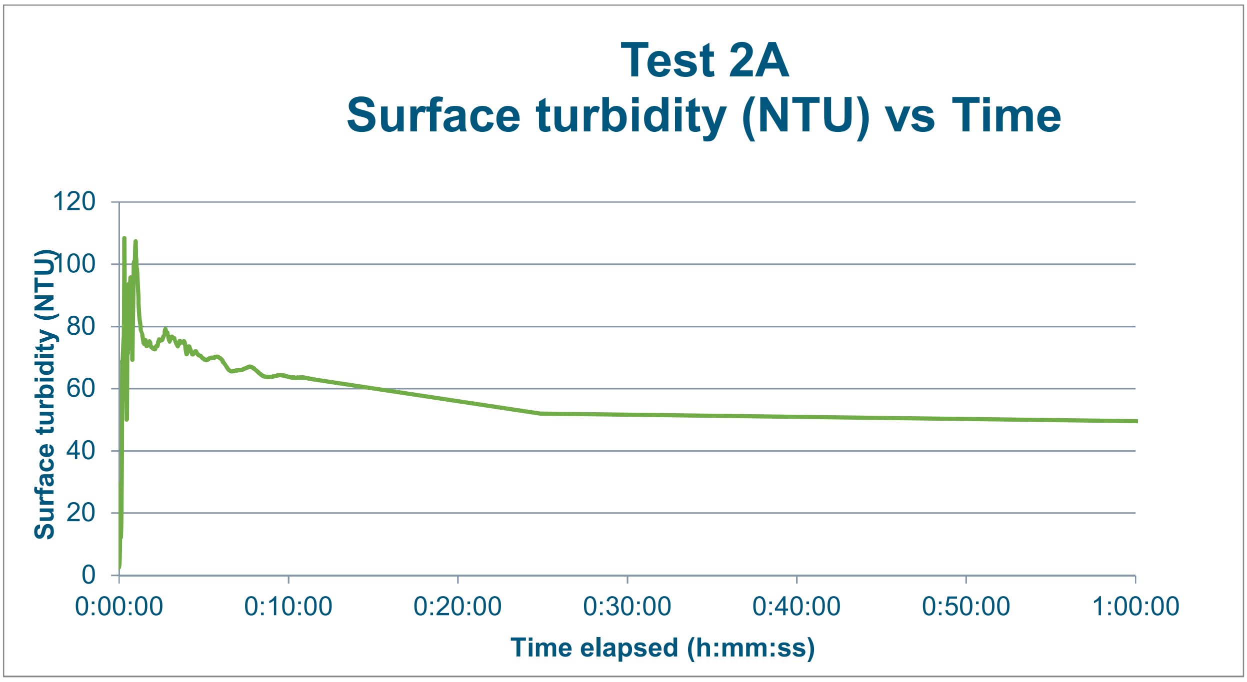
Figure 6: Settlement test 7 days and 21 hours following placement of sieved crushed rock -
Left: Test 2A - Placement of dry sieved crushed rock directly onto the water surface,
Right: Test 2B - Placement of dry sieved crushed rock within a fall pipe with opening submerged 55.6 cm below the water surface.

2.2.2 Test 2A - Placement of dry sieved crushed rock directly onto the water surface

For Test 2A, the sieved crushed rock was gently sprinkled onto the water surface from a height of approximately 25 cm above the water surface. Clumps of crushed rock fell through the upper portion of the column. However, fine material parted from the clumps during descent and a turbid trail formed through the water column in the wake of the clumps. The clumps generally dissipated before descending to the bottom of the column.

Significant diffusion and mixing of the crushed rock was observed in the upper third to half of the water column immediately following placement. The top half of the column appeared to be turbid while the bottom of the column remained relatively clear, with the exception of turbid trails in the wake of the clumps. After approximately 1 minute and 40 seconds, turbidity throughout the entire water column appeared to be relatively uniform.

Surface turbidity levels were measured continuously (at one second time intervals) during the first 12 minutes of Test 2A and the Wetlab ECO-NTU sensor remained in the water column for this period. Surface turbidity levels were measured at varying time intervals thereafter. The Wetlab ECO-NTU sensor was placed in the water column for each measurement and removed after a stable reading was recorded. Surface turbidity during crushed rock placement and at various time intervals during the first hour is plotted in **Graph 4** for Test 2A**.**



Graph 4: Surface turbidity measured during the first two hours following placement of Ravine Beds crushed rock, Test 3A.

Surface turbidity levels increased rapidly from background levels of around 2 NTU to a maximum of around 110 NTU during placement of the crushed rock (i.e. within the first minute of testing). Surface turbidity during this initial one-minute period fluctuated numerous times between approximately 60 NTU and 110 NTU. Surface turbidity levels subsequently decreased to around 63 NTU approximately 12 minutes after commencement and 48 NTU approximately 1 hour and 22 minutes after commencement.

Surface turbidity measured at varying time intervals over the 10-day test duration is plotted in **Graph 3** (refer **Section 2.2.1**) for Test 2A alongside the results for Tests 2B. Surface turbidity levels gradually decreased from around 48 NTU (1 hour and 22 minutes after commencement) to around 21 NTU (1 day and 7 hours after commencement). After 1 day and 7 hours, stratification was observed within the water column. Between 1 day and 10 days after commencement, surface turbidity fluctuated between 17 NTU (10 days and 6 hours after commencement) and 36.1 NTU (5 days and 22 hours after commencement). The average surface turbidity during this period was 26 NTU.

Stratification in the water columns was observed at 7 days and 9 days following commencement. However, at the remaining monitoring intervals, stratification was not observed within the column.

A discussion regarding the observed increase and fluctuation in surface turbidity and the mixing between stratified layers is provided in **Section 3**.

After approximately 10 days and 6 hours, surface turbidity reduced to approximately 17 NTU. At this point in time, flocculant was added to the column. Refer **Section 2.3**.

2.2.3 Test 2B - Placement of dry sieved crushed rock within a fall pipe with opening submerged 55.6 cm below the water surface

For Test 2B, the sieved crushed rock was gently sprinkled into the fall pipe with an internal diameter of approximately 50 mm. The top of the fall pipe was approximately 75 cm above the water surface. The inside of the fall pipe was rinsed with water from the Talbingo Reservoir to ensure that all of the sieved crushed rock entered the column.

Significant mixing and diffusion of crushed rock was observed within the fall pipe. Clumps of crushed rock fell through the upper portion of the column. However, fine material parted from the clumps during descent and a turbid trail formed through the water column in the wake of the clumps. The clumps generally dissipated before descending to the bottom of the column.

The dense turbid plume in the fall pipe gradually descended and diffused throughout the water column, primarily below the base of the fall pipe. After approximately 1 minute and 30 seconds, a turbid layer formed near the base of the fall pipe, in the middle third of the column. After approximately 3 minutes, relatively even mixing and uniform turbidity was observed in the lower two thirds of the water column, below the base of the fall pipe. The top of the turbid plume was recorded 2.5 cm above the base of the fall pipe.

There was no immediate discernible change in turbidity above the turbid plume, with the upper 52 cm of water in the column (i.e. above the base of the fall pipe) remaining relatively clear with surface turbidity at background levels (refer **Graph 3**, **Section 2.2.1**). However, over the subsequent 7 days, surface turbidity increased to approximately 11.25 NTU and remained above 9 NTU for the remained of the test.

The top of the turbid plume was observable for the duration of the test and gradually descended over time. After 25 minutes, the top of the plume was at53.1 cm below the water surface, 2.5 cm above the base of the fall pipe. The top of the plume descended to 91.1 cm below the water surface after 10 days and 6 hours, at a rate of 3.7 cm/day.

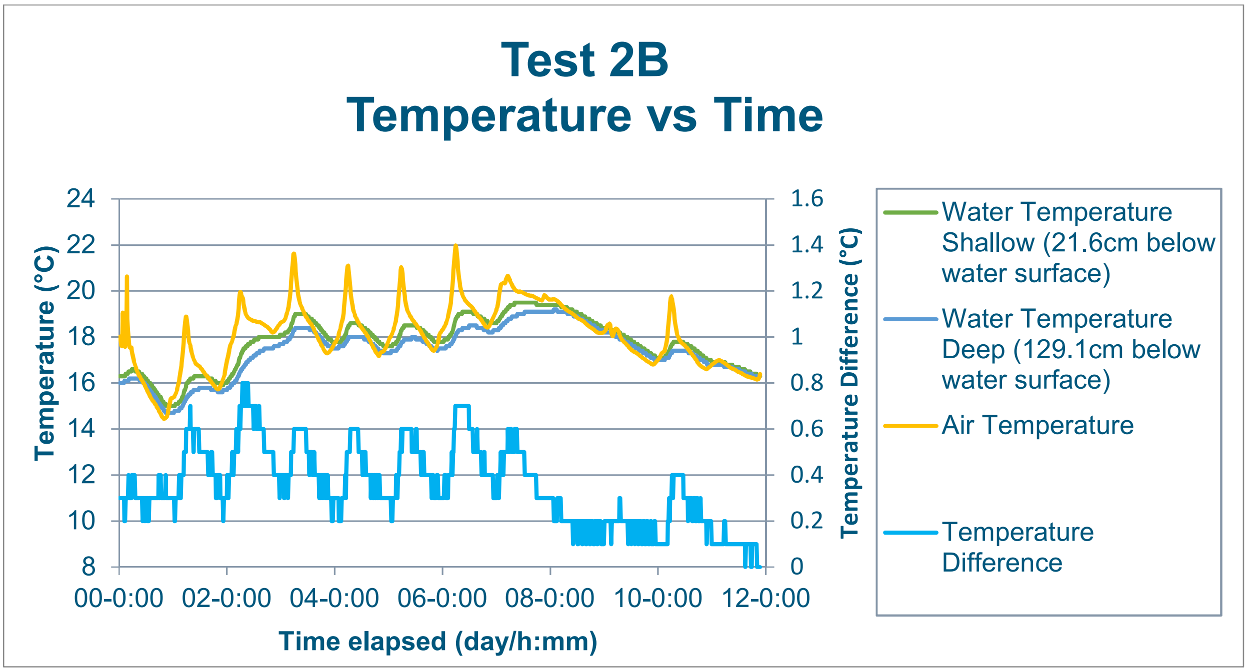
The settlement test simulating placement through a fall pipe resulted in a significant reduction in surface turbidity, compared to surface placement in Test 2A. However, after approximately 4 days and 20 hours, surface turbidity exceeded the original background turbidity levels and remained elevated for the remainder of the test.

A discussion regarding the observed increase in surface turbidity over time during Test 2B is provided in **Section 3**.

2.2.4 Air and Water Temperature

Air temperature and water temperature was recorded every 15 minutes in Test 2B for the duration of the test using Solinist Leveloggers and a Barologger. Water temperature was monitored at two depths, 21.6 cm and 129.1 cm below the water surface.

Graph 5 provides air and water temperature variation over time for Test 2B.



Graph 5: Air and water temperature in Test 2B. Elapsed time relative to commencement of Test 2A and 2B.

Air temperature in Test 2B fluctuated between approximately 14.5 °C and 22 °C. Block out curtains were placed across all windows for the duration of the test in an attempt to regulate air temperature within the laboratory.

Water temperature varied between 14.5 °C and 19.5 °C. Water temperature was consistently 0 °C to 0.7°C warmer at the upper monitoring location and the average temperature differential between the monitoring depths was 0.35 °C. The warmer water near the top of the column would have a lower density and would, therefore, be buoyant compared to cooler water lower in the column.

2.3 Flocculation Test

Prior to completion of the settlement tests, a trial was undertaken to determine whether a chemical flocculant would accelerate settlement of fine particles and clarify the water. The chemical flocculant selected for the test was alum (aluminium sulphate). It should be noted that the particular chemical flocculant selected for the test was somewhat arbitrary and has not been approved for use during construction.

Flocculant was added to Test 2A on the 6th October 2018 at 5:30pm, approximately 10 days and 7 hours following commencement of the settlement test. Test 2B and 2D were retained as control columns for comparison.

Surface turbidity in Test 2A, 2B and 2D on the 6th October 2018 (prior to addition of flocculant) and the 8th October 2018 (following addition of flocculant) is reported in **Table 2**. Surface turbidity in Test 2A decreased from 17 to 2.7 NTU while the surface turbidity in the control columns, Test 2B and 2D, remained relatively constant at elevated levels. This indicates that the chemical flocculant was effective in clarifying the water.

Table 2: Surface turbidity before and after the addition of flocculant to Test 2A.

Date/Time	Test 2A (NTU)	Test 2B (NTU)	Test 2D (NTU)
6th October 2018, 5:15 pm,	17	9.12	26.4
8th October 2018, 9:30 am,	2.7	10.37	20.7

A photograph of the three Test columns taken on the 6th and 8th October 2018 is provided in **Figure 7**. It should be noted that some of the flocculated crushed rock in Test 2A adhered to the walls of the column thereby making the column appear slightly ‘cloudy’ when viewed side on. However, when viewed from above, the water was clear as indicated by the surface turbidity reading.

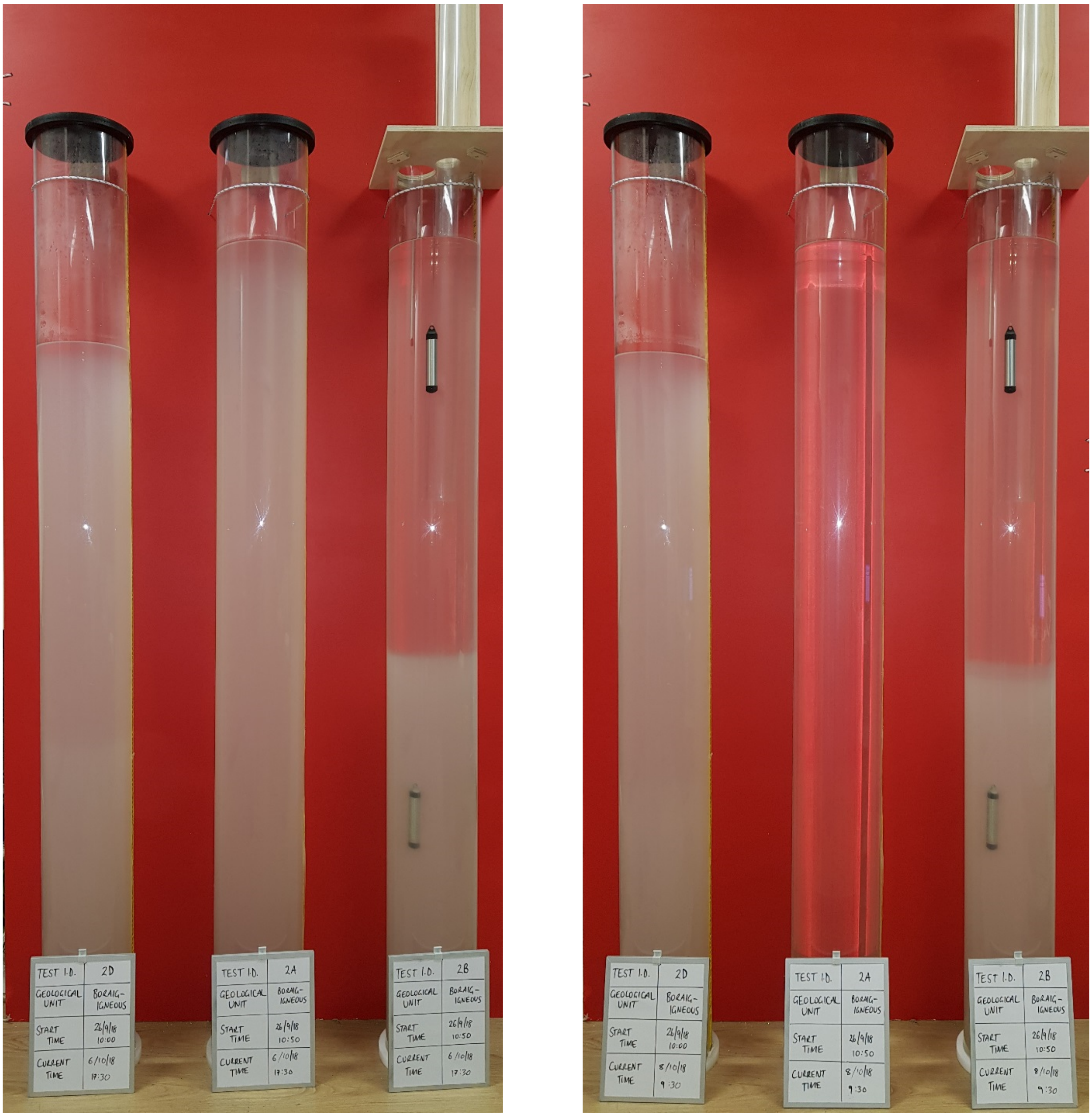


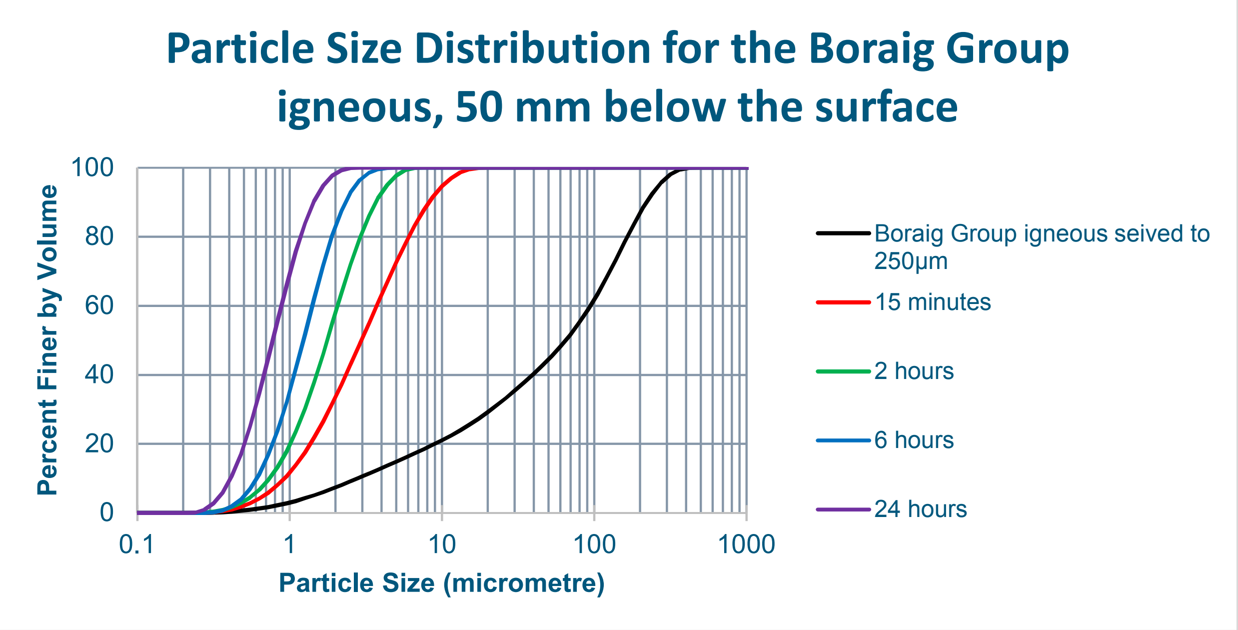
Figure 7: Column and Settlement tests prior to and following addition of chemical flocculant to Test 2A-
Left: Test 2D, 2A and 2B (from left to right) prior to the addition of flocculant to Test 2A. Photographed on the 6th October at 5:30pm, approximately 10 days and 6.7 hours following commencement of the settlement tests.
Right: Test 2D, 2A and 2B (from left to right), following the addition of flocculant to Test 2A. Photographed on the 8th October at 9:30am, approximately 11 days and 22.8 hours following commencement of the settlement tests.

2.4 Critical Particle Size

The tests to determine the critical particle size in suspension commenced on the 9th October 2018. Particle size analysis using the Mastersizer 2000 was completed on the 9th and 10th October 2018.

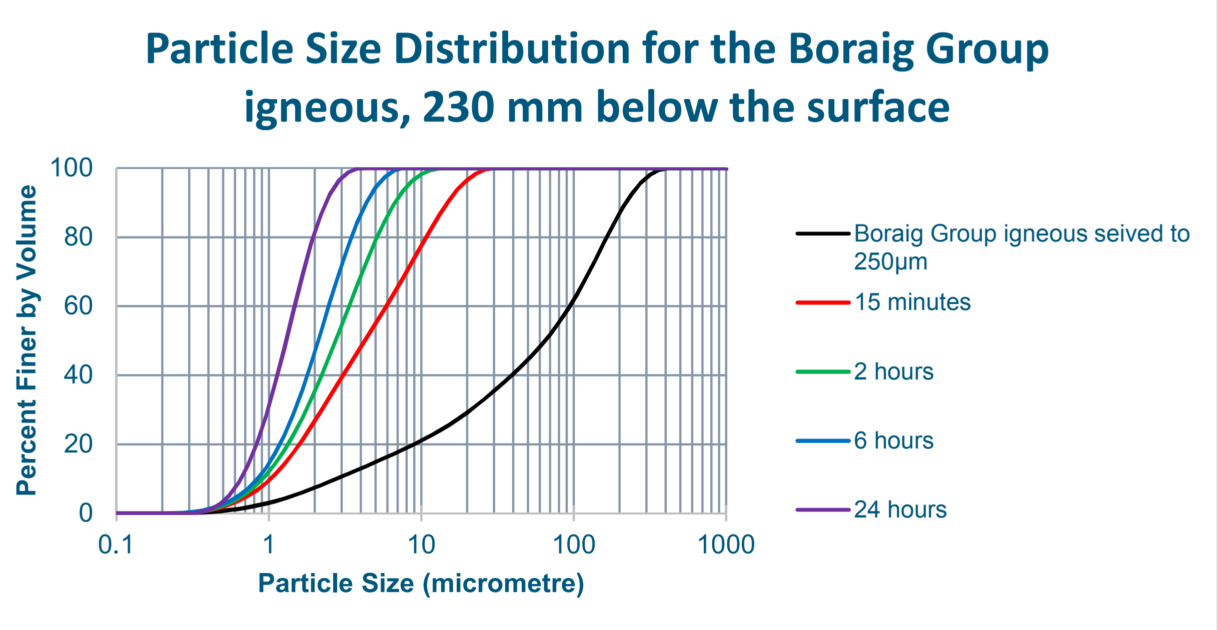
Graph 6 plots the particle size distribution of the sieved crushed rock (used for all tests) and the particle size that remains in suspension after each time interval (15 minutes, 2 hours, 6 hours, and 24 hours) at 50 mm below the water surface (850 mL mark on cylinder). The maximum particle size in suspension at

various time intervals is outlined in **Table 3**. The maximum particle size in suspension decreases over time from around 17.5 µm (15 minutes) to 2.5 µm (24 hours).



Graph 6: Particle size distribution at varying time intervals, 50 mm below the water surface.

Graph 7 plots the particle size distribution of the sieved crushed rock (used for all tests) and the particle size that remains in suspension after a given time interval (15 minutes, 2 hours, 6 hours, 24 hours and 48 hours) at 230 mm below the water surface (300 mL mark on cylinder). The maximum particle size in suspension at various time intervals is outlined in **Table 3**. The maximum particle size in suspension decreases over time from around 30.5 µm (15 minutes) to 4 µm (24 hours).



Graph 7: Particle size distribution at varying time intervals 230 mm the water surface.

Table 3: Maximum particle size in suspension at varying time intervals, 50 mm and 230 mm below the water surface.

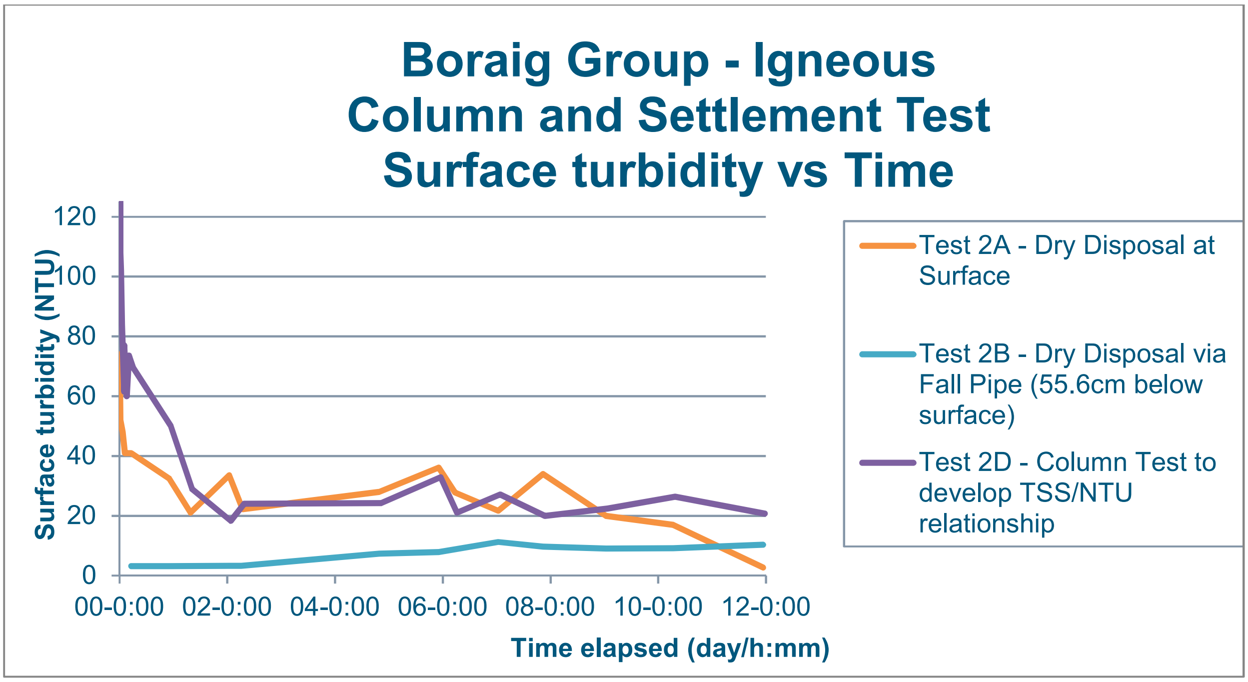
Time	Maximum particle size in suspension (µm)	
	50 mm below the water surface	230 mm below the water surface
15 minutes	17.5	30.5
2 hours	6.5	13
6 hours	4.5	7.5
24 hours	2.5	4

Based on the results presented above, it is evident that, for the same given time intervals, the maximum particle size in suspension is larger at greater depths within the water column, as would be expected.

3 Discussion

3.1 Fluctuating Turbidity and Increase in Surface Turbidity

As described in **Section 2**, surface turbidity in Test 2A and 2D fluctuated, particularly between 2 and 12 days following commencement and surface turbidity in Test 2B increased, particularly up to 7 days following commencement. The surface turbidity for the three tests is shown in **Graph 8**. The graph includes the addition of flocculant to Test 3A, 10 days and 6 hours following commencement.



Graph 8: Surface turbidity measured during the settlement and column tests – Boraig Group igneous crushed rock (Tests 2A, 2B and 2D).

An increase in surface turbidity was unexpected, with ongoing settlement and decreasing turbidity following initial mixing considered more likely to occur. It is possible that the observations were influenced by one or more of the following factors:

1. Weak thermal convection currents within the column may result in mixing of stratified layers and rising warm water transporting suspended particles to the surface. Air temperature and water temperature was monitored for the duration of the test. The results are reported in **Section 2.2.4** and presented in **Graph 5**.

   It is apparent from **Graph 5** that the water temperature warms and cools in response to the air temperature. Furthermore, the difference in water temperature between the top and bottom of the column increases during a warming phase and decreases during a cooling phase.

   It is inferred that heat is transferred from the air to the column and from the column to the adjacent water near the wall of the column through the process of conduction, which is the transfer of heat between objects in contact with each other, or through a substance due to the collision of molecules. Heating of water near the wall of the column would result in differential water temperature across the column with cooler water near the centre of the column. The differential water temperature would lead to two processes, conduction and convection where convection is the process of warmer water, with a lower density, rising to cooler areas in the column and cooler water, with a higher density, sinking to take the place of the warmer water. The velocity of convection currents are difficult to determine and due to a range of factors.

2. The sieved crushed rock may contain clay particles that are anionic. The repelling force between charged particles in suspension may result in suspended solids diffusing and distributing evenly throughout the water column.

3. The action of gently lowering a turbidity probe into the upper layer of the column (~3.4 cm below the water surface) may be sufficient to disturb the water column resulting in advection of very fine suspended particles.

Regardless of the reason for fluctuating and increasing surface turbidity in Test 2A, 2B and 2D, it is clear that minor disturbances to the water column dare sufficient to disrupt the settlement process and redistribute fine suspended particles within the water column.

4 Conclusions

It is apparent from the column test and settlement tests that once fine crushed rock from the igneous rock in the Boraig Group geological zone enters the water column, the fine particles remain in suspension for extended periods in the order of several days to weeks. Elevated surface turbidity levels of around 20 NTU were recorded in Test 2A and 2D at the conclusion of the tests, around 10 to 12 days following commencement.

While surface turbidity levels generally appear to reduce over time, it may take an extremely long time to reach background levels of 1 NTU to 5 NTU as reported by Cardno. Furthermore, minor disturbances to the water column are likely to disrupt the settlement process and/or re-suspend fine particles.

The critical particle size in suspension that would be contributing to prolonged surface turbidity in the water column (more than 24 hours) would be less than approximately 4 µm.

The results of a chemical flocculation test for the Boraig Group igneous crushed rock indicate that the addition of flocculant may accelerate settlement of fine particles and clarify the water.

TSS-turbidity data collected during the Column Test (Test 2D) is considered to be reliable for the purpose of establishing a preliminary relationship between TSS and turbidity for the igneous rock in the Boraig Group geological zone. The turbidity value equivalent to 50 mg/L suspended solids is 58 NTU for this dataset. Furthermore, as the properties and grading of the crushed rock placed during construction may vary to that used in the column test, collection of field TSS-turbidity data during subaqueous excavated rock placement activities is recommended so that the relationship between turbidity and suspended solids can be continually validated and improved.

Attachment 1 – Laboratory Certificates

ES1828636			Compound Group	EA025: Total Suspended Solids dried at 104 ± 2°C	EA045: Turbidity
			Method	EA025H	EA045
			Accredited	Y	Y
Sub-Matrix	Sample Name			Suspended Solids (SS)	Turbidity
			Units	mg/L	NTU
			Rep. LOR	5	0.1
WATER	2D-1	Original	1	<5	0.4
		Duplicate	1	0	0.339
WATER	2D-2	Original	2	268	45.4
		Duplicate	2	263	202
WATER	2D-3	Original	3	197	46
		Duplicate	3	223	183
WATER	2D-4	Original	4	200	43.9
		Duplicate	4	225	171
WATER	2D-5	Original	5	164	46.6
		Duplicate	5	206	165
WATER	2D-6	Original	6	123	45.3
		Duplicate	6	148	146
WATER	2D-7	Original	7	107	41.4
		Duplicate	7	126	112
WATER	2D-8	Original	8	68	43.6
		Duplicate	8	96	90.4
WATER	2D-9	Original	9	100	43.2
		Duplicate	9	110	114
WATER	2D-10	Original	10	44	41.6
		Duplicate	10	87	75.1
WATER	2D-11	Original	11	68	42
		Duplicate	11	82	87
WATER	2D-12	Original	12	62	44
		Duplicate	12	81	87.4
WATER	2D-13	Original	13	6	41.8
		Duplicate	13	19	51.8
WATER	2D-6A	Original	14	130	45
		Duplicate	14	184	154
WATER	3D-1	Original	15	<5	1.1
		Duplicate	15	1	0.82
WATER	3D-2	Original	16	294	43.7
		Duplicate	16	300	232
WATER	3D-3	Original	17	189	41.6
		Duplicate	17	194	189
WATER	3D-4	Original	18	172	44.9
		Duplicate	18	186	165
WATER	3D-5	Original	19	108	44.3
		Duplicate	19	122	136
WATER	3D-6	Original	20	119	43.2
		Duplicate	20	126	147
WATER	3D-7	Original	21	85	48.4
		Duplicate	21	87	119
WATER	3D-8	Original	22	90	45.4
		Duplicate	22	87	88.9
WATER	3D-9	Original	23	62	43.3
		Duplicate	23	70	99
WATER	3D-10	Original	24	20	39.8
		Duplicate	24	22	54

Note: Original and Duplicate testing undertaken by ALS Environmental. The Duplicate results were used to establish TSS-Turbidity relationship. Laboratory Certificates were not provided for the Duplicate tests.

ALS Environmental

CERTIFICATE OF ANALYSIS

Work Order : **ES1829038**
Client : **HASKONING AUSTRALIA- ROYAL HASKONING**
Contact : MR PATRICK LAWLESS
Address : LEVEL 14 56 Berry Street
NORTH SYDNEY 2060
Telephone : ----
Project : Snowy 2.0 TSS-NTU (Test 2/3)
Order number :
C-O-C number : ----
Sampler : Patrick Lawless
Site : ----
Quote number : EN/222
No. of samples received : 12
No. of samples analysed : 12

Page : 1 of 5
Laboratory : Environmental Division Sydney
Contact : Customer Services ES
Address : 277-289 Woodpark Road Smithfield NSW Australia 2164
Telephone : +61-2-8784 8555
Date Samples Received : 02-Oct-2018 17:00
Date Analysis Commenced : 03-Oct-2018
Issue Date : 08-Oct-2018 12:42

NATA
Accreditation No. 825
Accredited for compliance with
ISO/IEC 17025 - Testing

This report supersedes any previous report(s) with this reference. Results apply to the sample(s) as submitted. This document shall not be reproduced, except in full.

This Certificate of Analysis contains the following information:

- General Comments
- Analytical Results

Additional information pertinent to this report will be found in the following separate attachments: Quality Control Report, QA/QC Compliance Assessment to assist with Quality Review and Sample Receipt Notification.

Signatories

This document has been electronically signed by the authorized signatories below. Electronic signing is carried out in compliance with procedures specified in 21 CFR Part 11.

Signatories	*Position*	*Accreditation Category*
Ankit Joshi	Inorganic Chemist	Sydney Inorganics, Smithfield, NSW

General Comments

The analytical procedures used by the Environmental Division have been developed from established internationally recognized procedures such as those published by the USEPA, APHA, AS and NEPM. In house developed procedures are employed in the absence of documented standards or by client request.

Where moisture determination has been performed, results are reported on a dry weight basis.

Where a reported less than (<) result is higher than the LOR, this may be due to primary sample extract/digestate dilution and/or insufficient sample for analysis.

Where the LOR of a reported result differs from standard LOR, this may be due to high moisture content, insufficient sample (reduced weight employed) or matrix interference.

When sampling time information is not provided by the client, sampling dates are shown without a time component. In these instances, the time component has been assumed by the laboratory for processing purposes.

Where a result is required to meet compliance limits the associated uncertainty must be considered. Refer to the ALS Contact for details.

Key : CAS Number = CAS registry number from database maintained by Chemical Abstracts Services. The Chemical Abstracts Service is a division of the American Chemical Society.
LOR = Limit of reporting
^ = This result is computed from individual analyte detections at or above the level of reporting
ø = ALS is not NATA accredited for these tests.
~ = Indicates an estimated value.

Analytical Results

Sub-Matrix: **WATER** (Matrix: **WATER**)			*Client sample ID*	**2D-14**	**2D-15**	**2D-16**	**2D-17**	**2D-18**
			Client sampling date / time	27-Sep-2018 00:00	28-Sep-2018 00:00	28-Sep-2018 00:00	01-Oct-2018 00:00	02-Oct-2018 00:00
Compound	*CAS Number*	*LOR*	*Unit*	**ES1829038-001**	**ES1829038-002**	**ES1829038-003**	**ES1829038-004**	**ES1829038-005**
				Result	Result	Result	Result	Result
EA025: Total Suspended Solids dried at 104 ± 2°C								
Suspended Solids (SS)	----	5	mg/L	**19**	**8**	<5	<5	<5
EA045: Turbidity								
Turbidity	----	0.1	NTU	**32.0**	**26.3**	**31.3**	**31.8**	**20.5**

Analytical Results

Sub-Matrix: **WATER**
(Matrix: **WATER**)

			Client sample ID	**2D-19**	**3D-11**	**3D-12**	**3D-13**	**3D-14**
			Client sampling date / time	02-Oct-2018 00:00	27-Sep-2018 00:00	28-Sep-2018 00:00	28-Sep-2018 00:00	01-Oct-2018 00:00
Compound	CAS Number	LOR	Unit	**ES1829038-006**	**ES1829038-007**	**ES1829038-008**	**ES1829038-009**	**ES1829038-010**
				Result	Result	Result	Result	Result
EA025: Total Suspended Solids dried at 104 ± 2°C								
Suspended Solids (SS)	----	5	mg/L	**14**	**15**	<5	**7**	**21**
EA045: Turbidity								
Turbidity	----	0.1	NTU	**26.1**	**25.4**	**34.2**	**31.9**	**36.2**

Analytical Results

Sub-Matrix: **WATER**
(Matrix: **WATER)**

			Client sample ID	**3D-15**	**3D-16**	**----**	**----**	**----**
			Client sampling date / time	02-Oct-2018 00:00	02-Oct-2018 00:00	----	----	----
Compound	*CAS Number*	*LOR*	*Unit*	**ES1829038-011**	**ES1829038-012**	**--------**	**--------**	**--------**
				Result	Result	----	----	----
EA025: Total Suspended Solids dried at 104 ± 2°C								
Suspended Solids (SS)	----	5	mg/L	**14**	**13**	**----**	**----**	**----**
EA045: Turbidity								
Turbidity	----	0.1	NTU	**26.8**	**26.6**	**----**	**----**	**----**

CERTIFICATE OF ANALYSIS

Work Order : **ES1830022**
Client : **HASKONING AUSTRALIA- ROYAL HASKONING**
Contact : MR PATRICK LAWLESS
Address : LEVEL 14 56 Berry Street
NORTH SYDNEY 2060
Telephone : ----
Project : Snowy 2.0 TSS-NTU (Test 2/3)
Order number :
C-O-C number : ----
Sampler : PATRICK LAWLESS
Site : ----
Quote number : EN/222
No. of samples received : 50
No. of samples analysed : 50

Page : 1 of 12
Laboratory : Environmental Division Sydney
Contact : Customer Services ES
Address : 277-289 Woodpark Road Smithfield NSW Australia 2164
Telephone : +61-2-8784 8555
Date Samples Received : 10-Oct-2018 16:30
Date Analysis Commenced : 11-Oct-2018
Issue Date : 17-Oct-2018 17:40

Accreditation No. 825
Accredited for compliance with
ISO/IEC 17025 - Testing

This report supersedes any previous report(s) with this reference. Results apply to the sample(s) as submitted. This document shall not be reproduced, except in full.

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Signatories

This document has been electronically signed by the authorized signatories below. Electronic signing is carried out in compliance with procedures specified in 21 CFR Part 11.

Signatories	*Position*	*Accreditation Category*
Ankit Joshi	Inorganic Chemist	Sydney Inorganics, Smithfield, NSW

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LOR = Limit of reporting
^ = This result is computed from individual analyte detections at or above the level of reporting
ø = ALS is not NATA accredited for these tests.
~ = Indicates an estimated value.

Analytical Results

Sub-Matrix: **WATER**
(Matrix: **WATER)**

			Client sample ID	**2D-20**	**2D-21**	**2D-22**	**2D-23**	**2D-24**
			Client sampling date / time	03-Oct-2018 00:00	04-Oct-2018 00:00	05-Oct-2018 00:00	06-Oct-2018 00:00	08-Oct-2018 00:00
Compound	*CAS Number*	*LOR*	*Unit*	**ES1830022-001**	**ES1830022-002**	**ES1830022-003**	**ES1830022-004**	**ES1830022-005**
				Result	Result	Result	Result	Result
EA025: Total Suspended Solids dried at 104 ± 2°C								
Suspended Solids (SS)	----	5	mg/L	**----**	<5	**16**	**----**	**----**
Suspended Solids (SS)	----	5	mg/L	**8**	**----**	**----**	**12**	**11**
EA045: Turbidity								
Turbidity	----	0.1	NTU	**32.9**	**21.2**	**30.4**	**35.5**	**23.7**

Analytical Results

Sub-Matrix: **WATER**
(Matrix: **WATER)**

			Client sample ID	**3D-17**	**3D-18**	**3D-19**	**3D-20**	**3D-21**
			Client sampling date / time	03-Oct-2018 00:00	04-Oct-2018 00:00	05-Oct-2018 00:00	06-Oct-2018 00:00	08-Oct-2018 00:00
Compound	*CAS Number*	*LOR*	*Unit*	**ES1830022-006**	**ES1830022-007**	**ES1830022-008**	**ES1830022-009**	**ES1830022-010**
				Result	Result	Result	Result	Result
EA025: Total Suspended Solids dried at 104 ± 2°C								
Suspended Solids (SS)	----	5	mg/L	**----**	**8**	**13**	**----**	**----**
Suspended Solids (SS)	----	5	mg/L	**8**	**----**	**----**	**8**	<5
EA045: Turbidity								
Turbidity	----	0.1	NTU	**30.1**	**28.7**	**28.2**	**26.8**	**22.6**

Analytical Results

Sub-Matrix: **WATER** (Matrix: **WATER**)			*Client sample ID*	**4D-1**	**4D-2**	**4D-3**	**4D-4**	**4D-5**
			Client sampling date / time	09-Oct-2018 00:00	09-Oct-2018 00:00	09-Oct-2018 00:00	09-Oct-2018 00:00	09-Oct-2018 00:00
Compound	*CAS Number*	*LOR*	*Unit*	**ES1830022-011**	**ES1830022-012**	**ES1830022-013**	**ES1830022-014**	**ES1830022-015**
				Result	Result	Result	Result	Result
EA025: Total Suspended Solids dried at 104 ± 2°C								
Suspended Solids (SS)	----	5	mg/L	<5	**206**	**204**	**121**	**166**
EA045: Turbidity								
Turbidity	----	0.1	NTU	**0.4**	**240**	**148**	**150**	**109**

Analytical Results

Sub-Matrix: **WATER** (Matrix: **WATER**)			*Client sample ID*	**4D-6**	**4D-7**	**4D-8**	**4D-9**	**4D-10**
			Client sampling date / time	09-Oct-2018 00:00	09-Oct-2018 00:00	09-Oct-2018 00:00	09-Oct-2018 00:00	09-Oct-2018 00:00
Compound	*CAS Number*	*LOR*	*Unit*	**ES1830022-016**	**ES1830022-017**	**ES1830022-018**	**ES1830022-019**	**ES1830022-020**
				Result	Result	Result	Result	Result
EA025: Total Suspended Solids dried at 104 ± 2°C								
Suspended Solids (SS)	----	5	mg/L	**116**	**142**	**45**	**42**	**97**
EA045: Turbidity								
Turbidity	----	0.1	NTU	**169**	**119**	**130**	**125**	**94.2**

Analytical Results

Sub-Matrix: **WATER** (Matrix: **WATER**)			*Client sample ID*	**4D-11**	**4D-12**	**4D-13**	**4D-14**	**4D-15**
			Client sampling date / time	09-Oct-2018 00:00	09-Oct-2018 00:00	09-Oct-2018 00:00	09-Oct-2018 00:00	09-Oct-2018 00:00
Compound	*CAS Number*	*LOR*	*Unit*	**ES1830022-021**	**ES1830022-022**	**ES1830022-023**	**ES1830022-024**	**ES1830022-025**
				Result	Result	Result	Result	Result
EA025: Total Suspended Solids dried at 104 ± 2°C								
Suspended Solids (SS)	----	5	mg/L	**84**	**80**	**31**	**40**	**22**
EA045: Turbidity								
Turbidity	----	0.1	NTU	**92.7**	**96.0**	**113**	**110**	**100**

Analytical Results

Sub-Matrix: **WATER** (Matrix: **WATER**)			Client sample ID	**4D-16**	**4D-17**	**4D-18**	**4D-19**	**5D-1**
			Client sampling date / time	09-Oct-2018 00:00	09-Oct-2018 00:00	09-Oct-2018 00:00	09-Oct-2018 00:00	09-Oct-2018 00:00
Compound	CAS Number	LOR	Unit	**ES1830022-026**	**ES1830022-027**	**ES1830022-028**	**ES1830022-029**	**ES1830022-030**
				Result	Result	Result	Result	Result
EA025: Total Suspended Solids dried at 104 ± 2°C								
Suspended Solids (SS)	----	5	mg/L	**24**	**54**	**51**	**25**	<5
EA045: Turbidity								
Turbidity	----	0.1	NTU	**22.8**	**25.8**	**33.1**	**29.3**	**0.5**

Analytical Results

Sub-Matrix: **WATER** (Matrix: **WATER**)			*Client sample ID*	**5D-2**	**5D-3**	**5D-4**	**5D-5**	**5D-6**
			Client sampling date / time	09-Oct-2018 00:00	09-Oct-2018 00:00	09-Oct-2018 00:00	09-Oct-2018 00:00	09-Oct-2018 00:00
Compound	*CAS Number*	*LOR*	*Unit*	**ES1830022-031**	**ES1830022-032**	**ES1830022-033**	**ES1830022-034**	**ES1830022-035**
				Result	Result	Result	Result	Result
EA025: Total Suspended Solids dried at 104 ± 2°C								
Suspended Solids (SS)	----	5	mg/L	**130**	**124**	**142**	**118**	**180**
EA045: Turbidity								
Turbidity	----	0.1	NTU	**184**	**177**	**182**	**168**	**167**

Analytical Results

Sub-Matrix: **WATER** (Matrix: **WATER**)			*Client sample ID*	**5D-7**	**5D-8**	**5D-9**	**5D-10**	**5D-11**
			Client sampling date / time	09-Oct-2018 00:00	09-Oct-2018 00:00	09-Oct-2018 00:00	09-Oct-2018 00:00	09-Oct-2018 00:00
Compound	*CAS Number*	*LOR*	*Unit*	**ES1830022-036**	**ES1830022-037**	**ES1830022-038**	**ES1830022-039**	**ES1830022-040**
				Result	Result	Result	Result	Result
EA025: Total Suspended Solids dried at 104 ± 2°C								
Suspended Solids (SS)	----	5	mg/L	**132**	**95**	**110**	**70**	**62**
EA045: Turbidity								
Turbidity	----	0.1	NTU	**130**	**107**	**101**	**60.2**	**20.8**

Analytical Results

Sub-Matrix: **WATER** (Matrix: **WATER**)			Client sample ID	**5D-12**	**5D-13**	**5D-14**	**5D-15**	**4D-20**
			Client sampling date / time	09-Oct-2018 00:00	09-Oct-2018 00:00	09-Oct-2018 00:00	09-Oct-2018 00:00	10-Oct-2018 00:00
Compound	CAS Number	LOR	Unit	**ES1830022-041**	**ES1830022-042**	**ES1830022-043**	**ES1830022-044**	**ES1830022-045**
				Result	Result	Result	Result	Result
EA025: Total Suspended Solids dried at 104 ± 2°C								
Suspended Solids (SS)	----	5	mg/L	**24**	**26**	**11**	**10**	**26**
EA045: Turbidity								
Turbidity	----	0.1	NTU	**31.2**	**19.2**	**16.3**	**16.0**	**20.9**

Analytical Results

Sub-Matrix: **WATER** (Matrix: **WATER**)			*Client sample ID*	**4D-21**	**5D-16**	**5D-17a**	**5D-17b**	**5D-18**
			Client sampling date / time	10-Oct-2018 00:00	10-Oct-2018 00:00	10-Oct-2018 00:00	10-Oct-2018 00:00	10-Oct-2018 00:00
Compound	*CAS Number*	*LOR*	*Unit*	**ES1830022-046**	**ES1830022-047**	**ES1830022-048**	**ES1830022-049**	**ES1830022-050**
				Result	Result	Result	Result	Result
EA025: Total Suspended Solids dried at 104 ± 2°C								
Suspended Solids (SS)	----	5	mg/L	**12**	**16**	**7**	**14**	**17**
EA045: Turbidity								
Turbidity	----	0.1	NTU	**17.0**	**9.2**	**7.3**	**7.8**	**9.8**

Attachment 2 – Boraig Group - Igneous Laboratory Log Records

Test ID	2A	
Geological Unit	Boraig Group - Igneous	
Description	Test 2A - Dry Disposal at Surface	
Start Date/Time	26-09-18 10:50	
Water volume	50 L	
Water surface level in column	176.2	cm
Mass sediment added	40 g	(sieved to <250 um)
Test Location	Geochemical Assessments Workshop, Roseville NSW	
Test Officers	Pat Lawless, Rick Plain	

Observations

Date/Time	Time since start	Turbidity (NTU)	Measurement Location (cm)	Measurement Depth (cm)	Comments
26-09-18 10:40	10 Minutes Prior	2.3	172.8	3.4	Background turbidity measured 10 minutes before test start.
26-09-18 10:54	00-0:04	74	172.8	3.4	
26-09-18 10:59	00-0:09	66	172.8	3.4	
26-09-18 11:00	00-0:10	64	172.8	3.4	
26-09-18 11:02	00-0:12	63	172.8	3.4	
26-09-18 11:15	00-0:25	52	172.8	3.4	Probe stopped and started. 60 NTU after restarting.
26-09-18 12:13	00-1:23	48	172.8	3.4	
26-09-18 13:15	00-2:25	41	172.8	3.4	
26-09-18 14:19	00-3:29	41	172.8	3.4	
26-09-18 16:00	00-5:10	41	172.8	3.4	Measuring 41 NTU three times in a row.
27-09-18 8:53	00-22:03	32.5	172.8	3.4	
27-09-18 18:20	01-7:30	21	172.8	3.4	Stratification at 142.5 cm and 175 cm.
28-09-18 11:37	02-0:47	33.6	172.8	3.4	Stratification at 134 cm.
28-09-18 17:35	02-6:45	22.2	172.8	3.4	Gradual change down to ~130 cm.
01-10-18 6:30	04-19:40	28	172.8	3.4	Gradual change down to ~120 cm (minimal).
02-10-18 9:00	05-22:10	36.1	172.8	3.4	
02-10-18 16:20	06-5:30	27.8	172.8	3.4	
03-10-18 11:30	07-0:40	21.7	172.8	3.4	Stratification at 169 cm.
04-10-18 7:30	07-20:40	34	172.8	3.4	
05-10-18 11:30	09-0:40	20	172.8	3.4	Stratification at 171 cm. Fluctuating 18-22 NTU.
06-10-18 17:30	10-6:40	17	172.8	3.4	Fluctuating 17-20 NTU. **Flocculant added to the Column.**
08-10-18 9:30	11-22:40	2.7	172.8	3.4	

Test ID	2B		
Geological Unit	Boraig Group - Igneous		
Description	Test 2B - Dry Disposal via Fall Pipe (55.6cm below surface)		
Start Date/Time	26-09-18 10:50		
Water volume	50 L		
Water surface level in column	177.1	cm	
Mass sediment added	40 g	(sieved to <250 um)	
Test Location	Geochemical Assessments Workshop, Roseville NSW		
Test Officers	Pat Lawless, Rick Plain		
Depth of Temperature Probes	145.5 cm	48 cm	New Probe at Top

Observations

Date/Time	Time since start	Turbidity (NTU)	Measurement Location (cm)	Measurement Depth (cm)	Comments
26-09-18 10:40	10 minutes prior	2.2	173.7	3.4	Background turbidity measured 10 minutes before test start
26-09-18 10:54	00-0:04				Turbid plume at 124 cm.
26-09-18 11:15	00-0:25				Turbid plume at 124 cm.
27-09-18 13:47	01-2:57				Turbid plume at 124 cm.
27-09-18 14:22	01-3:32				Turbid plume at 123.5 cm.
26-09-18 16:00	00-5:10	3.2	173.7	3.4	Turbid plume at 123.2 cm.
27-09-18 9:00	00-22:10	3.2	173.7	3.4	Turbid plume at 121 cm.
27-09-18 18:00	01-7:10		173.7	3.4	Turbid plume at 121.5 cm.
28-09-18 11:40	02-0:50	3.26	173.7	3.4	Turbid plume at 121.5 cm.
28-09-18 17:00	02-6:10	3.3	173.7	3.4	Turbid plume at 120 cm.
01-10-18 6:30	04-19:40	7.3	173.7	3.4	Turbid plume at 109.5 cm. Slight haze above. Probe reading 0 when placed in water.
02-10-18 9:00	05-22:10	7.86	173.7	3.4	Turbid plume at 106.5 cm. Slight haze above.
02-10-18 16:20	06-5:30		173.7	3.4	Turbid plume at 103 cm. Slight haze above. Wafting/rising plume on side of column closest to window, above turbid layer. Video recorded.
03-10-18 11:30	07-0:40	11.25	173.7	3.4	Turbid plume at 100 cm. Slight haze above.
04-10-18 7:30	07-20:40	9.67	173.7	3.4	Turbid plume at 97.5 cm. Slight haze above.
05-10-18 11:30	09-0:40	9.1	173.7	3.4	Turbid plume at 95.5 cm. Slight haze above.
06-10-18 17:30	10-6:40	9.12	173.7	3.4	Turbid plume at 88 cm. Slight haze above.
08-10-18 9:30	11-22:40	10.37	173.7	3.4	Turbid plume at 86 cm. Slight haze above.

Test ID	2D	
Geological Unit	Boraig Group - Igneous	
Description	Test 2D - Column Test to develop TSS/NTU relationship	
Start Date/Time	26-09-18 10:00	
Water volume	50 L	
Water surface level in column	176.2	cm
Mass sediment added	47.5 g	(sieved to <250 um)
Test Location	Geochemical Assessments Workshop, Roseville NSW	
Test Officers	Pat Lawless, Rick Plain	

Observations

Date/Time	Time since start	Turbidity (NTU)		TSS Sample Taken?	TSS Sample ID	Column Measurements			Comments
		Inside Column	Inside Beaker			Water Surface	Measurement Location	Sensor Depth	
26-09-18 9:38	20 minutes prior to start	2		Yes	2D-1	176.2	172.8	3.4	Before commencement
26-09-18 10:05	00-0:05	155	137	Yes	2D-2	176.2	172.8	3.4	Instrument initially reading over 250 NTU. Potential Error. Possibly sediment residu on lens.
26-09-18 10:12	00-0:12	135	125	Yes	2D-3	175.1	171.7	3.4	Turbidity increases with depth.
26-09-18 10:20	00-0:20	124	122	Yes	2D-4	173.5	170.1	3.4	
26-09-18 10:25	00-0:25	108	114	Yes	2D-5	172.8	169.4	3.4	
26-09-18 10:34	00-0:34	102	104	Yes	2D-6	172.1	168.7	3.4	Duplicate 2D-6A.
26-09-18 10:34	00-0:34	102	107	Yes	2D-6A	171.3	167.9	3.4	
26-09-18 10:34	00-0:34	102	107	Yes	2D-6A	170.4	167	3.4	
26-09-18 11:07	00-1:07	84	97	Yes	2D-7	170.1	166.7	3.4	Issue with battery. Delay in reading. Photo at 11:00. 93 NTU in column afte sampling.
26-09-18 12:00	00-2:00	61.5	73	Yes	2D-8	169.4	166	3.4	
26-09-18 12:07	00-2:07	77	79	Yes	2D-9	168.8	165.4	3.4	Turbidity increase since 12:00 pm reading likely due to minor agitation by probe slightly more turbid underlying material.
26-09-18 13:15	00-3:15	60	67	Yes	2D-10	167.5	164.1	3.4	
26-09-18 14:15	00-4:15	73.6	67.2	Yes	2D-11	167	163.6	3.4	
26-09-18 16:00	00-6:00	69.5	67	Yes	2D-12	165.6	162.2	3.4	
27-09-18 8:47	00-22:47	50.2	42.3	Yes	2D-13	164.4	161	3.4	Stratification at 162.6 cm. Probe in turbid water. Sample mostly layer above.
27-09-18 18:15	01-8:15	29	29	Yes	2D-14	163.3	159.9	3.4	Stratification at 135 cm and 160 cm. Probe in turbid water. Sample mostly layer above.
28-09-18 11:35	02-1:35	18.3	23.6	Yes	2D-15	162.5	159.1	3.4	Stratification at 158 cm. Gradual change below to ~132 cm.
28-09-18 17:30	02-7:30	24	24.1	Yes	2D-16	161.3	157.9	3.4	Stratification at 156.5 cm. Gradual change below to ~125 cm.
01-10-18 6:30	04-20:30	24.25	23.5	Yes	2D-17	160.3	156.9	3.4	Stratification at 134 cm.
02-10-18 9:00	05-23:00	32.9	31.6	Yes	2D-18	159	155.6	3.4	Stratification at 120 cm.
02-10-18 16:20	06-6:20	21	28.2	Yes	2D-19	158.3	154.9	3.4	Stratification at 108 cm. Turbidity in column 34 NTU after sample taken.
03-10-18 11:30	07-1:30	27.2	26.2	Yes	2D-20	157.3	153.9	3.4	Stratification at 98 cm (minor).
04-10-18 7:30	07-21:30	20	22	Yes	2D-21	156.3	152.9	3.4	Top of column relatively clear. Gradual increase in density in column. Fluctuating i column 19-23 NTU.
05-10-18 11:30	09-1:30	22.4	24	Yes	2D-22	155.5	152.1	3.4	Stratification at ~150.6 cm.
06-10-18 17:30	10-7:30	26.4	30	Yes	2D-23	154.5	151.1	3.4	Stratification at ~153 cm.
08-10-18 9:30	11-23:30	20.7	21.5	Yes	2D-24	153.5	150.1	3.4	Stratification at ~150.5 cm.

Appendix C

TSS – Turbidity and Settling Test Results
Boraig Group Geological Zone – Sedimentary

Royal
HaskoningDHV
Enhancing Society Together

Table of Contents

1 Introduction

The Boraig Group geological zone is highly variable and comprises sedimentary and extrusive igneous rock types. A 1-m long section of core from this geological zone was supplied to Royal HaskoningDHV (Haskoning) from BH5105 taken between 431 m and 432 m below the ground surface. The rock core was logged as interbedded siltstone and sandstone.

Water for settlement and column testing was obtained from Talbingo Reservoir on the 18th September 2018. The water was collected in 1000 L Intermediate Bulk Containers (IBC) and delivered to Haskoning on the 21st September 2018. The water was visibly turbid upon delivery and it was left to settle for approximately 5 days. Supernatant was decanted from the top of the IBCs. The turbidity of the reservoir water sample used for the testing was between 1.9 and 2.8 NTU. This was within the turbidity range of field monitoring, as undertaken by Cardno in 2018, which indicated typical 'background' turbidity of 1 to 5 NTU in Talbingo Reservoir.

Water for the critical particle size analysis was obtained from Talbingo Reservoir on the 2nd October 2018. The water was collected in 1000 L IBC and delivered to Haskoning on the 5th October 2018. The turbidity of the water sample used for the testing was between 1.7 and 2.7 NTU.

2 Results

2.1 Test 3D – TSS-Turbidity

2.1.1 Overview

The TSS-Turbidity Test for the Boraig Group sedimentary rock ('Test 3D') commenced on the 26th September 2018 and concluded on the 8th October 2018, approximately 12 days following commencement.

The Certificate of Analysis provided by ALS Environmental for the TSS and turbidity analyses undertaken for samples collected during testing is provided in **Attachment 1**. Laboratory log records completed during the TSS-turbidity test are provided in **Attachment 2**, which includes turbidity measurements undertaken during testing for each sample.

Photographs taken during the column test are provided in **Figure 1**. These photographs were taken:

- prior to commencement;
- 2 hours after commencement;
- 1 day and 22.3 hours after commencement;
- 4 days and 18.8 hours after commencement; and
- 11 days and 21.8 hours after commencement.

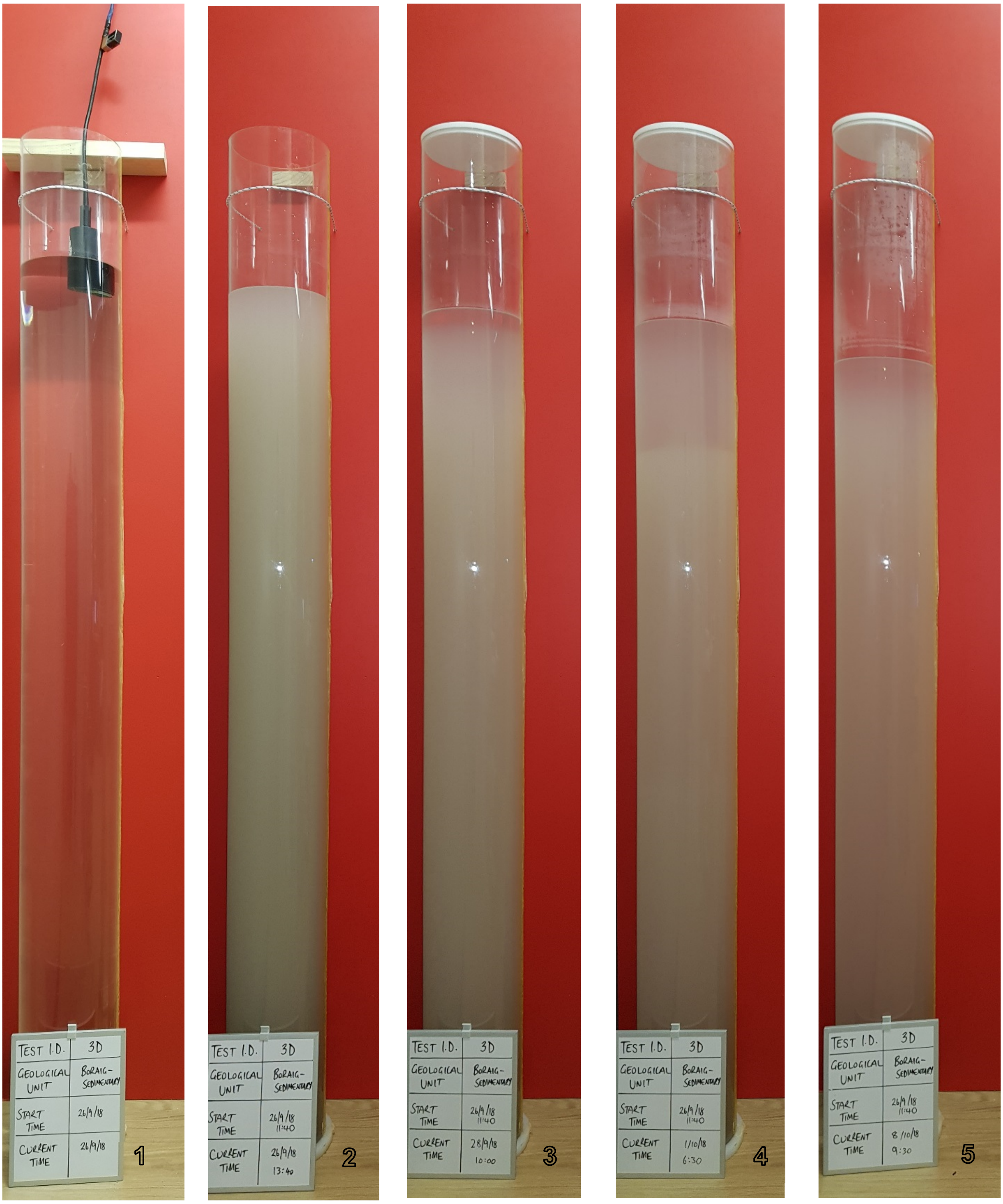


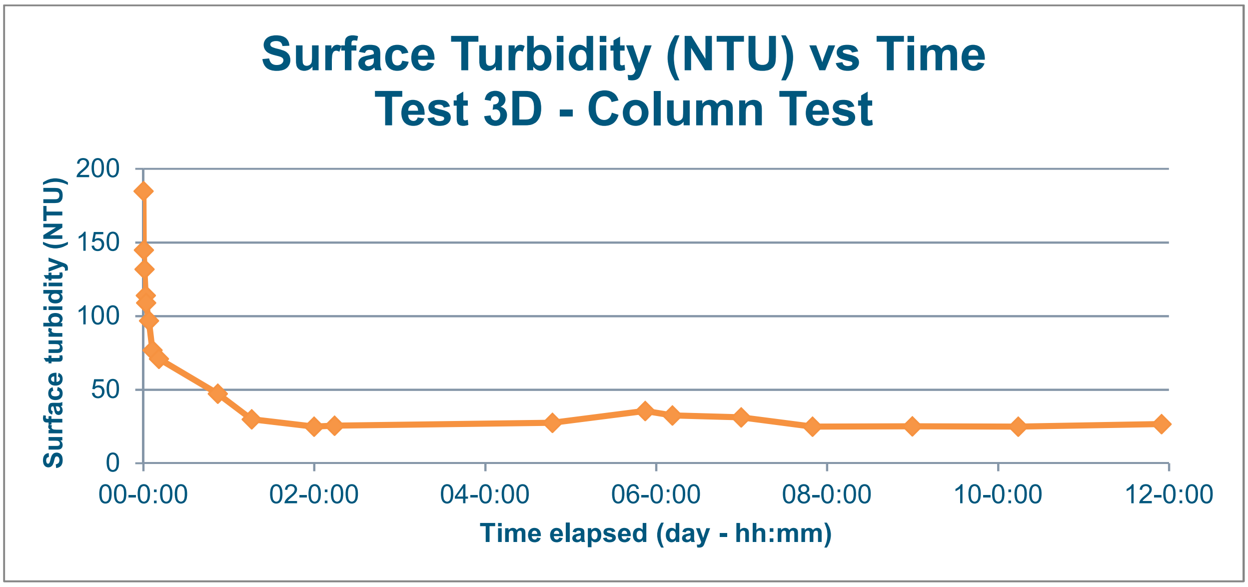
Figure 1: Column test –

1. *Talbingo Reservoir water without addition of the sieved crushed rock,*
2. *Column test 2 hours after commencement,*
3. *Column test 1 day and 22.3 hours after commencement,*
4. *Column test 4 days and 18.8 hours after commencement, and*
5. *Column test 11 days and 21.8 hours after commencement.*

2.1.2 Surface Turbidity vs Time Results

The variation in surface turbidity during Test D is plotted in **Graph 1**. The graph shows that surface turbidity decreased relatively rapidly from 185 NTU to 77 NTU during the first 2.5 hours of testing. Surface turbidity levels continued to decrease, at a slower rate, to approximately 25 NTU after 2 days.

Between approximately 2 and 6 days after commencement, surface turbidity increased from 25 NTU to 36 NTU. By day 8 after commencement, surface turbidity had decreased to approximately 25 NTU and remained relatively constant for the remainder of the test.



Graph 1: Turbidity measured during the column test – Boraig Group Sedimentary crushed rock (Test 3D).

2.1.3 TSS – Turbidity Results

A total of 21 samples were collected during testing for laboratory TSS and turbidity analysis. TSS values for the collected samples ranged between <5 mg/L[1] and 300 mg/L, while turbidity values of up to 165 NTU were recorded.

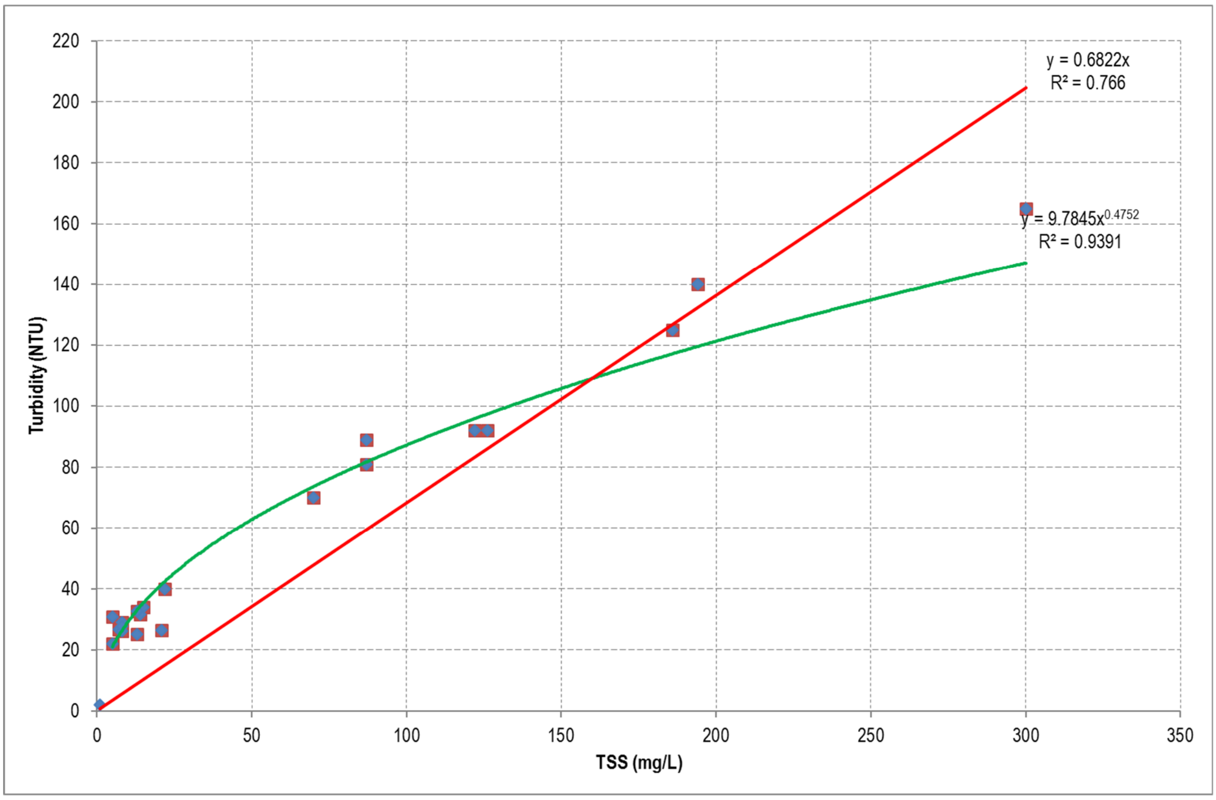
A plot of TSS versus turbidity for all data collected during testing is provided in **Graph 2**. Turbidity values used in this dataset are the measurements taken during testing (inside the glass beaker prior to sub-sampling) rather than the laboratory results[2]. This dataset is plotted with trendlines corresponding to both linear and power functions. It is evident that the power function provides a much closer fit of the data, characterised by an R^2 value of 0.94[3] whereas the linear line of best fit has a lower R^2 value of 0.77.

---

[1] The Limit of Reporting (LOR) value for TSS analysis is 5 mg/L, refer **Attachment 1**. Results for samples with TSS concentrations below the LOR value are reported as <5 mg/L.

[2] Turbidity results reported by the laboratory were compared with turbidity results obtained during testing using the Wetlab-ECO-NTU sensor. No significant differences between the turbidity datasets were evident (i.e. selection of the turbidity dataset does not significantly influence the TSS-turbidity relationship reported herein).

[3] The R^2 value, also known as the coefficient of determination, is a measure of how close the plotted data are to the fitted regression line (i.e. the line of best fit). An R^2 value of 1 indicates that the regression line perfectly fits the data.



Graph 2: TSS-turbidity results – Boraig Group Sedimentary crushed rock (Test 3D).

2.1.4 TSS – Turbidity Relationship

A summary of the TSS-turbidity relationships determined for the Test 3D dataset is provided in **Table 1**, including the turbidity values equivalent to a TSS concentration of 50 mg/L for each the linear and power function trendline. The selected TSS value of 50mg/L is somewhat arbitrary and the water quality limit for the project may vary.

Table 1: Summary of TSS-turbidity relationships for Boraig Group Sedimentary crushed rock

Trendline Function	Number of values	R^2 value	Turbidity (NTU) equivalent to 50 mg/L TSS
Linear	21	0.77	34
Power	21	0.94	63

As noted above, the power function trendline provides a much better fit of the dataset compared to the linear trendline. Furthermore, the high R^2 value associated with the power function trendline (0.94) indicates a strong correlation between TSS and turbidity for the dataset, and is considered to be valid for the data collected during testing. The turbidity value equivalent to 50 mg/L suspended solids is 63 NTU for this dataset.

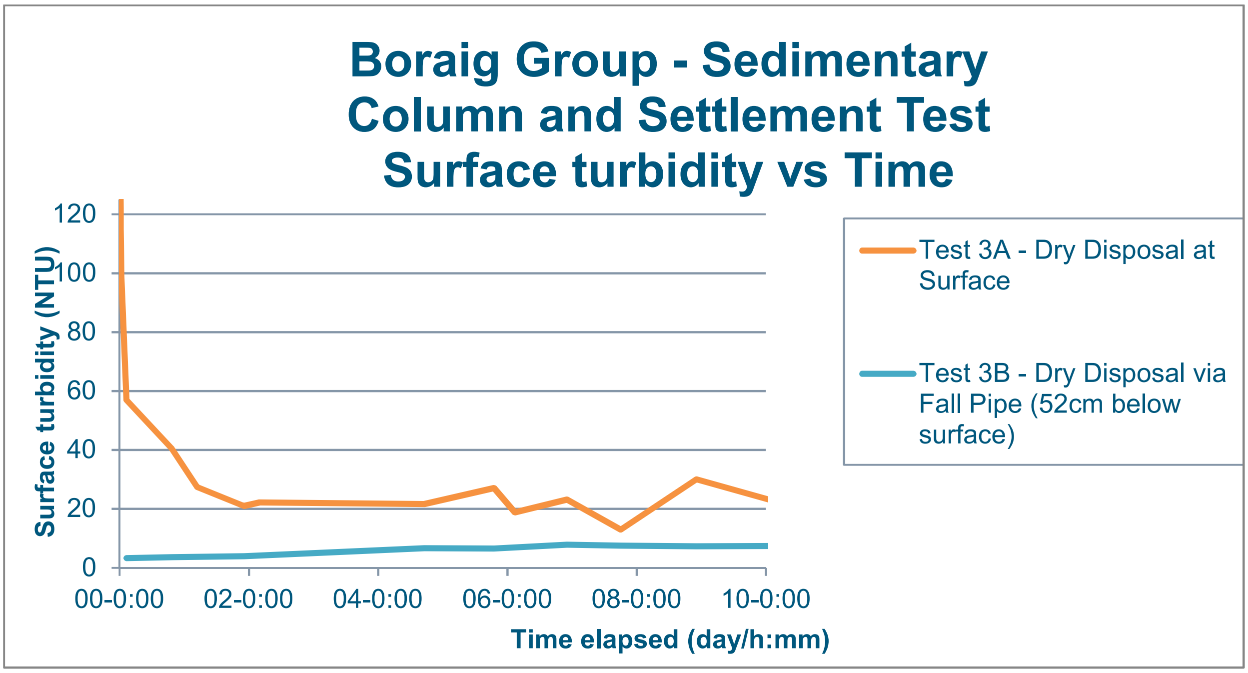
2.2 Settlement Tests

2.2.1 Overview

The two settlement tests for the Boraig Group sedimentary rock (Tests 3A and 3B) commenced simultaneously on the 26th September 2018 at 1:25pm. Different disposal methods were simulated in the respective columns as described in **Section 2.2.2** to **2.2.4**. The tests concluded on the 6th October 2018, approximately 10 days following commencement.

Surface turbidity in the two columns was measured 2 hours prior to addition of the sieved crushed rock and it was 2.8 NTU and 2.6 NTU for Test 3A and 3B respectively.

Surface turbidity measured at varying time intervals during the 10-day test duration is plotted in **Graph 3** for the two settlement tests. These results are discussed in the following sections, along with a summary of the key observations for each settlement test. Laboratory log records completed during the settlement tests are provided in **Attachment 2**.



Graph 3: Surface turbidity measured during the settlement tests – Boraig Group sedimentary crushed rock (Tests 3A and 3B).

Photographs taken during the settlement tests are provided in **Figures 2** to **6**. These photographs were taken prior to commencement (**Figure 2**), 15 minutes after commencement (**Figure 3**), 1 day and 4.6 hours after commencement (**Figure 4**), 4 days and 17.1 hours after commencement (**Figure 5**), and 8 days and 22.1 hours after commencement (**Figure 6**).

TEST I.D.	3A
GEOLOGICAL UNIT	BORAIG - SEDIMENTARY
START TIME	26/9/18
CURRENT TIME	26/9/18

TEST I.D.	3B
GEOLOGICAL UNIT	BORAIG - SEDIMENTARY
START TIME	26/9/18
CURRENT TIME	26/9/18

Figure 2: Settlement test prior to placement of sieved crushed rock-
Left: Test 3A - Placement of dry sieved crushed rock directly onto the water surface,
Right: Test 3B - Placement of dry sieved crushed rock within a fall pipe with opening submerged 52 cm below the water surface.

TEST I.D.	3A
GEOLOGICAL UNIT	BORAIG-SEDIMENTARY
START TIME	26/9/18 13:25
CURRENT TIME	26/9/18 13:40

TEST I.D.	3B
GEOLOGICAL UNIT	BORAIG-SEDIMENTARY
START TIME	26/9/18 13:25
CURRENT TIME	26/9/18 13:40

Figure 3: Settlement test 15 minutes following placement of sieved crushed rock-
Left: Test 3A - Placement of dry sieved crushed rock directly onto the water surface,
Right: Test 3B - Placement of dry sieved crushed rock within a fall pipe with opening submerged 52 cm below the water surface.

TEST I.D.	3A
GEOLOGICAL UNIT	BORAIG-SEDIMENTARY
START TIME	26/9/18 13:25
CURRENT TIME	27/9/18 18:00

TEST I.D.	3B
GEOLOGICAL UNIT	BORAIG-SEDIMENTARY
START TIME	26/9/18 13:25
CURRENT TIME	27/9/18 18:00

Figure 4: Settlement test 1 day and 4.6 hours following placement of sieved crushed rock-
Left: Test 3A - Placement of dry sieved crushed rock directly onto the water surface,
Right: Test 3B - Placement of dry sieved crushed rock within a fall pipe with opening submerged 52 cm below the water surface.

Figure 5: Settlement test 4 days and 17.1 hours following placement of sieved crushed rock-
Left: Test 3A - Placement of dry sieved crushed rock directly onto the water surface,
Right: Test 3B - Placement of dry sieved crushed rock within a fall pipe with opening submerged 52 cm below the water surface.

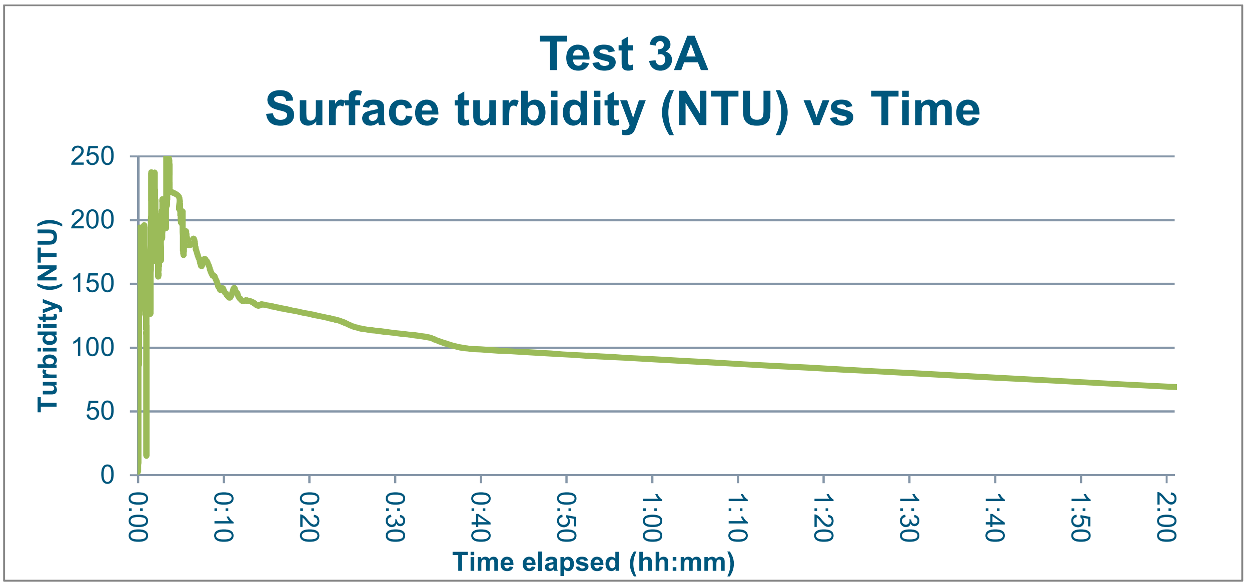
Figure 6: Settlement test 8 days and 22 hours following placement of sieved crushed rock-
Left: Test 3A - Placement of dry sieved crushed rock directly onto the water surface,
Right: Test 3B - Placement of dry sieved crushed rock within a fall pipe with opening submerged 52 cm below the water surface.

2.2.2 Test 3A - Placement of dry sieved crushed rock directly onto the water surface

For Test 3A, the sieved crushed rock was gently sprinkled onto the water surface from a height of approximately 25 cm above the water surface. Clumps of crushed rock fell through the upper portion of the column. However, fine material parted from the clumps during descent and a turbid trail formed through the water column in the wake of the clumps. The clumps generally dissipated before descending to the bottom of the column.

Significant diffusion and mixing of the crushed rock was observed in the upper half of the water column after approximately 1 minute. The top half of the column appeared to be turbid while the bottom of the column remained relatively clear, with the exception of the turbid trails in the wake of the clumps. After approximately 2 minutes and 30 seconds, surface turbidity throughout the entire water column appeared to be relatively uniform.

Surface turbidity levels were measured continuously (at one second time intervals) during the first 40 minutes of Test 3A and the Wetlab ECO-NTU sensor remained in the water column for this period. Surface turbidity levels were measured at varying time intervals thereafter. The Wetlab ECO-NTU sensor was placed in the water column for each measurement and removed after a stable reading was recorded. Surface turbidity during crushed rock placement and at various time intervals during the first two hours is plotted in **Graph 4** for Test 3A**.** It should be noted that the Wetlab ECO-NTU sensor measures NTU between 0 and 250 NTU. Surface turbidity higher than 250 NTU is recorded at the maximum value of 250 NTU.



Graph 4: Surface turbidity measured during the first two hours following placement of Ravine Beds crushed rock, Test 3A.

Surface turbidity levels increased rapidly from background levels of around 2 NTU to a maximum of around 250 NTU during placement of the sieved crushed rock (i.e. within the first three minutes of testing). Surface turbidity during this initial three-minute period fluctuated numerous times between approximately 90 NTU and 250 NTU. Surface turbidity levels subsequently decreased to around 100 NTU approximately 40 minutes after commencement and 57 NTU approximately 2.5 hours after commencement.

Surface turbidity measured at varying time intervals over the 10-day test duration is plotted in **Graph 3** (refer **Section 2.2.1**) for Test 3A alongside the results for Tests 3B. Surface turbidity levels gradually decreased from around 57 NTU (2.5 hours after commencement) to around 20 NTU (two days after commencement). Surface turbidity generally remained relatively constant between 18 and 27 NTU between 2 and 7 days after commencement.

After approximately 7 days and 18 hours, surface turbidity in the column was recorded as 13 NTU. Stratification was observed approximately 3 cm below the water surface in the column with the upper portion of the column relatively clear. After 8 days and 22 hours (approximately 1 day later), stratification was not observed and the surface turbidity was reported to be 30 NTU. A discussion regarding the observed mixing between stratified layers is provided in **Section 3**.

After approximately 10 days and 4 hours, surface turbidity reduced to approximately 22.4 NTU. At this point in time, flocculant was added to the column (**Section 2.3**).

2.2.3 Test 3B - Placement of dry sieved crushed rock within a fall pipe with opening submerged 52 cm below the water surface

For Test 3B, the sieved crushed rock was gently sprinkled into a fall pipe with an internal diameter of approximately 50 mm. The top of the fall pipe was approximately 75 cm above the water surface. The inside of the fall pipe was rinsed with water from Talbingo Reservoir to ensure that all of the sieved crushed rock entered the column.

Significant mixing and diffusion of crushed rock was observed within the fall pipe. Clumps of crushed rock fell through the upper portion of the column. However, fine material parted from the clumps during descent and a turbid trail formed through the water column in the wake of the clumps. The clumps generally dissipated before descending to the bottom of the column.

The dense turbid plume in the fall pipe gradually descended and diffused throughout the water column, primarily below the base of the fall pipe. After approximately 3 minutes and 40 seconds, relatively even mixing and turbidity was observed in the lower two thirds of the water column, below the base of the fall pipe. The top of the turbid plume was recorded 8 cm above the base of the fall pipe.

There was no immediate discernible change in turbidity above the turbid plume, with the upper 44 cm of water in the column (i.e. above the base of the fall pipe) remaining relatively clear with turbidity at background levels (refer **Graph 3**, **Section 2.2.1**). However, over the subsequent 6 days and 22 hours, surface turbidity increased to approximately 7.8 NTU and remained above 7 NTU for the remainder of the test.

The top of the turbid plume was observable for the duration of the test and gradually descended over time. After 7 minutes the top of the plume was at 44.2 cm below the water surface, 8 cm above the base of the fall pipe. The top of the plume descended relatively quickly to 48.2 cm below the water surface after 21 minutes at a rate of 410 cm/day. Approximately 10 days and 4 hours after commencement, the top of the plume had descended to 75.7 cm below the water surface at a rate of 2.7 cm/day.

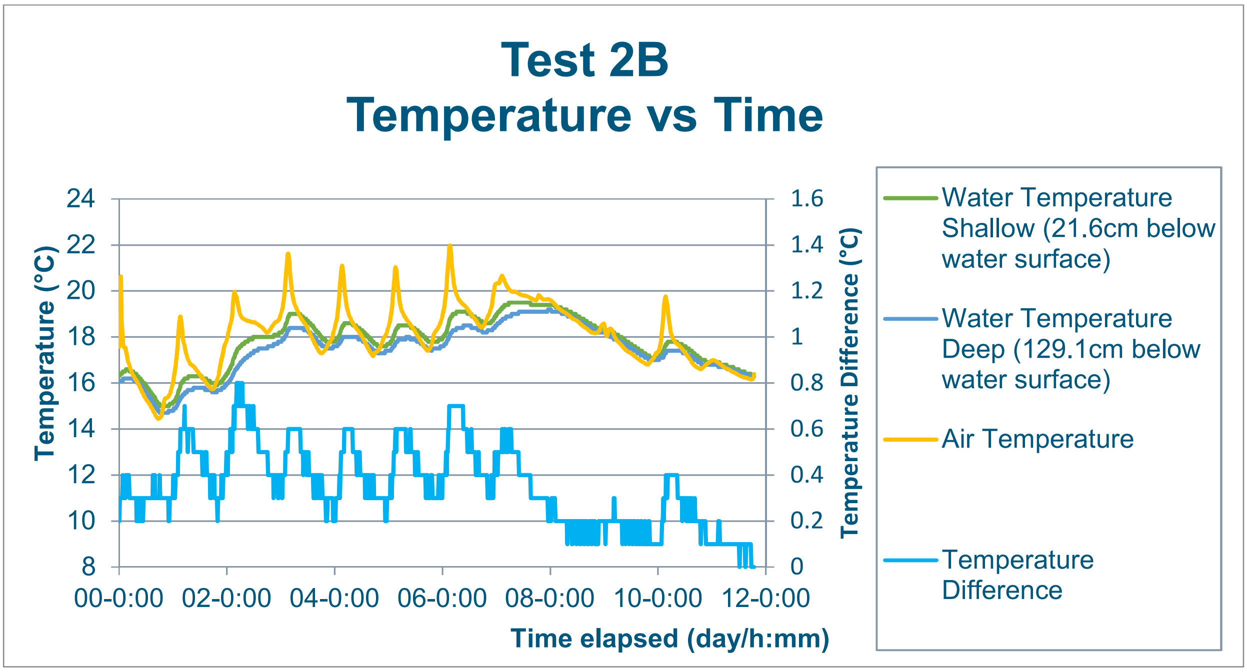
The settlement test simulating placement through a fall pipe resulted in a significant reduction in surface turbidity, compared to surface placement in Test 3A. However, after approximately 4 days and 17 hours, surface turbidity exceeded the original background turbidity levels and remained elevated for the remainder of the test.

A discussion regarding the observed increase in surface turbidity over time during Test 3B is provided in **Section 3**.

2.2.4 Air and Water Temperature

Air temperature and water temperature was recorded every 15 minutes in Test 2B for the duration of the test using Solinist Leveloggers and a Barologger. Water temperature was monitored at two depths, 21.6 cm and 129.1 cm below the water surface. Test 2B commenced approximately 50 minutes before Test 3D and approximately 2 hours and 35 minutes before Test 3A and 3B. Test 2B was undertaken in the same room and within approximately 2 m of Test 3A, 3B and 3D.

Graph 5 provides air and water temperature variation over time for Test 2B. The elapsed time is reported relative to commencement of Test 3A and 3B.



Graph 5: Air and water temperature in Test 2B. Elapsed time relative to commencement of Test 3A and 3B.

Air temperature in Test 2B fluctuated between approximately 14.5 °C and 22 °C. Block out curtains were placed across all windows for the duration of the test in an attempt to regulate air temperature within the laboratory.

Water temperature varied between 14.7 °C and 19.5 °C. Water temperature was consistently 0 °C to 0.7 °C warmer at the upper monitoring location and the average temperature differential between the monitoring depths was 0.35 °C. The warmer water near the top of the column would have a lower density and would, therefore, be buoyant compared to cooler water lower in the column.

2.3 Flocculation Test

Prior to completion of the settlement tests, a trial was undertaken to determine whether a chemical flocculant would accelerate settlement of fine particles and clarify the water. The chemical flocculant selected for the test was alum (aluminium sulphate). It should be noted that the particular chemical flocculant selected for the test was somewhat arbitrary and has not been approved for use during construction.

Flocculant was added to Test 3A on the 6th October 2018 at 5:15pm, approximately 10 days and 4 hours following commencement of the settlement test. Test 3B and 3D were retained as control columns for comparison.

Surface turbidity in Test 3A, 3B and 3D on the 6th October 2018 (prior to addition of flocculant) and 8th October 2018 (following addition of flocculant) is reported in **Table 2**. Surface turbidity in Test 3A decreased from 22.4 to 3.1 NTU while the surface turbidity in the control columns, Test 3B and 3D, remained relatively constant. This indicates that the chemical flocculant was effective in clarifying the water.

Table 2: Surface turbidity before and after the addition of flocculant to Test 3A.

Date/Time	Test 3A (NTU)	Test 3B (NTU)	Test 3D (NTU)
6th October 2018, 5:15 pm,	22.4	7.45	25
8th October 2018, 9:30 am,	3.1	7.1	26.7

A photograph of the three Test columns taken on the 6th and 8th October 2018 is provided in **Figure 7**. It should be noted that some of the flocculated crushed rock in Test 3A adhered to the walls of the column, thereby, making the column appear slightly ‘cloudy’ when viewed side on. However, when viewed from above, the water was clear as indicated by the surface turbidity reading.

TEST I.D.	3D
GEOLOGICAL UNIT	BORAIG-SEDIMENTARY
START TIME	26/9/18 11:40
CURRENT TIME	6/10/18 17:30

TEST I.D.	3A
GEOLOGICAL UNIT	BORAIG-SEDIMENTARY
START TIME	26/9/18 13:25
CURRENT TIME	6/10/18 17:30

TEST I.D.	3B
GEOLOGICAL UNIT	BORAIG-SEDIMENTARY
START TIME	26/9/18 13:25
CURRENT TIME	6/10/18 17:30

TEST I.D.	3D
GEOLOGICAL UNIT	BORAIG-SEDIMENTARY
START TIME	26/9/18 11:40
CURRENT TIME	8/10/18 9:30

TEST I.D.	3A
GEOLOGICAL UNIT	BORAIG-SEDIMENTARY
START TIME	26/9/18 13:25
CURRENT TIME	8/10/18 9:30

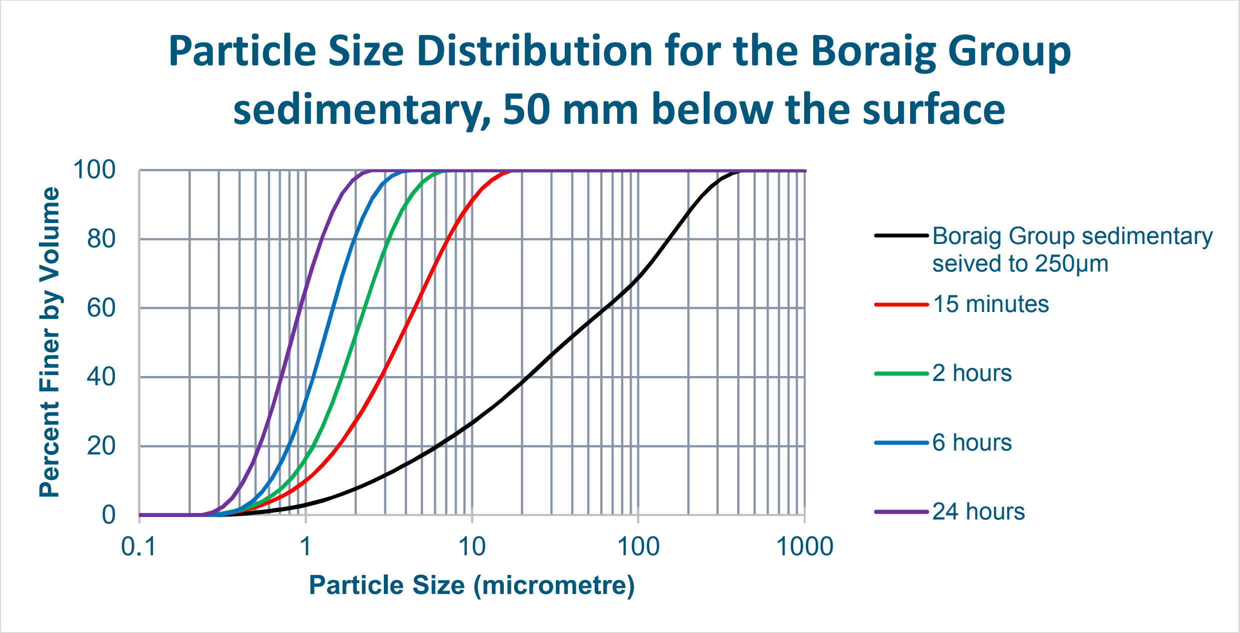
TEST I.D.	3B
GEOLOGICAL UNIT	BORAIG-SEDIMENTARY
START TIME	26/9/18 13:25
CURRENT TIME	8/10/18 9:30

Figure 7: Column and Settlement tests prior to and following addition of chemical flocculant to Test 3A-
Left: Test 3D, 3A and 3B (from left to right) prior to the addition of flocculant to Test 3A. Photographed on the 6th October at 5:30pm, approximately 10 days and 4.1 hours following commencement of the settlement tests.
Right: Test 3D, 3A and 3B (from left to right), following the addition of flocculant to Test 3A. Photographed on the 8th October at 9:30am, approximately 11 days and 20.1 hours following commencement of the settlement tests.

2.4 Critical Particle Size

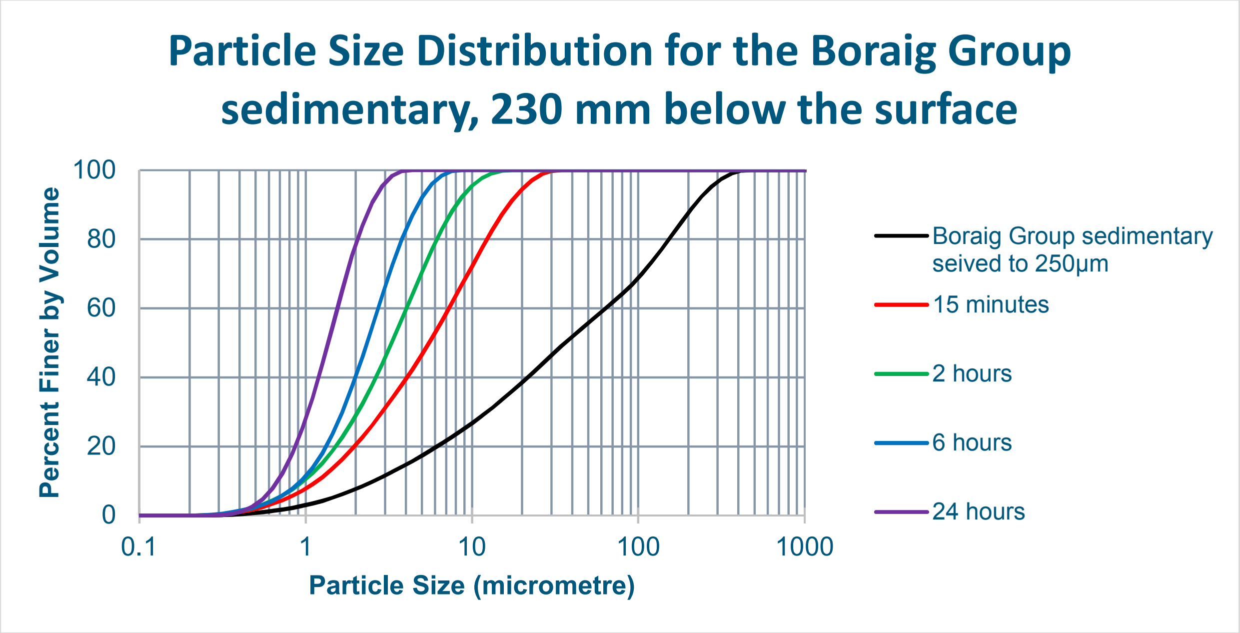
The tests to determine the critical particle size in suspension commenced on the 9th October 2018. Particle size analysis using the Mastersizer 2000 was completed on the 9th and 10th October 2018.

Graph 6 plots the particle size distribution of the sieved crushed rock (used for all tests) and the particle size that remains in suspension after each time interval (15 minutes, 2 hours, 6 hours, and 24 hours) at 50 mm below the water surface (850 mL mark on cylinder). The maximum particle size in suspension at various time intervals is outlined in **Table 3**. The maximum particle size in suspension decreases over time from around 17.5 µm (15 minutes) to 2.5 µm (24 hours).



Graph 6: Particle size distribution at varying time intervals, 50 mm below the water surface.

Graph 7 plots the particle size distribution of the sieved crushed rock (used for all tests) and the particle size that remains in suspension after a given time interval (15 minutes, 2 hours, 6 hours, 24 hours and 48 hours) at 230 mm below the water surface (300 mL mark on cylinder). The maximum particle size in suspension at various time intervals is outlined in **Table 3**. The maximum particle size in suspension decreases over time from around 31 µm (15 minutes) to 4 µm (24 hours).



Graph 7: Particle size distribution at varying time intervals 230 mm the water surface.

Table 3: Maximum particle size in suspension at varying time intervals, 50 mm and 230 mm below the water surface.

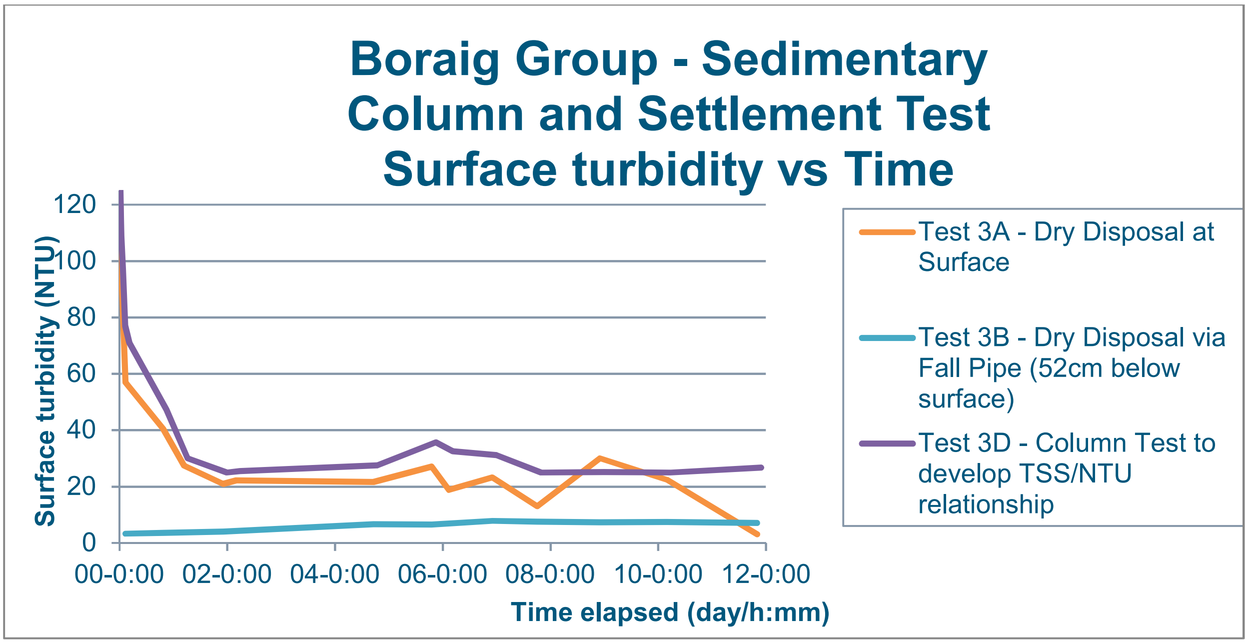
Time	Maximum particle size in suspension (µm)	
	50 mm below the water surface	230 mm below the water surface
15 minutes	17.5	31
2 hours	7	15.5
6 hours	4.5	8
24 hours	2.5	4

Based on the results presented above, it is evident that, for the same given time intervals, the maximum particle size in suspension is larger at greater depths within the water column, as would be expected.

3 Discussion

3.1 Fluctuating Turbidity and Increase in Surface Turbidity

As described in **Section 2**, surface turbidity in Test 3A and 3D fluctuated, particularly between 4 and 10 days following commencement and surface turbidity in Test 3B increased, particularly up to 4 days following commencement. Surface turbidity for the three tests is shown in **Graph 8**. The graph includes the addition of flocculant to Test 3A, 10 days and 4 hours following commencement.



Graph 8: Surface turbidity measured during the settlement and column tests – Boraig Group sedimentary crushed rock (Tests 3A, 3B and 3D).

An increase in surface turbidity was unexpected, with ongoing settlement and decreasing turbidity following initial mixing considered more likely to occur. It is possible that the observations may be influenced by one or more of the following factors:

1. Weak thermal convection currents within the column may result in mixing of stratified layers and rising warm water transporting suspended particles to the surface. Air temperature and water temperature was monitored for the duration of the test. The results are reported in **Section 2.2.4** and presented in **Graph 5**.

   It is apparent from **Graph 5** that the water temperature warms and cools in response to the air temperature. Further, the difference in water temperature between the top and bottom of the column increases during a warming phase and decreases during a cooling phase.

   It is inferred that heat is transferred from the air to the column and from the column to the adjacent water near the wall of the column through the process of conduction, which is the transfer of heat between objects in contact with each other, or through a substance due to the collision of molecules. Heating of water near the wall of the column would result in differential water temperature across the column with cooler water near the centre of the column. The differential water temperature would lead to two processes, conduction and convection where

convection is the process of warmer water, with a lower density, rising to cooler areas in the column and cooler water, with a higher density, sinking to take the place of the warmer water. The velocity of convection currents are difficult to determine and due to a range of factors.

2. The sieved crushed rock may contain clay particles that are anionic. The repelling force between charged particles in suspension may result in suspended solids diffusing and distributing evenly throughout the water column.

3. The action of gently lowering a turbidity probe into the upper layer of the column (~3.4 cm below the water surface) may be sufficient to disturb the water column resulting in advection of very fine suspended particles.

Regardless of the reason for fluctuating and increasing surface turbidity in Test 3A, 3B and 3D, it is clear that minor disturbances to the water column during construction (e.g. fresh water flows, wave action, propeller wash, etc.) would be sufficient to disrupt the settlement process and redistribute fine suspended particles within the water column.

4 Conclusions

It is apparent from the column test and settlement tests that once fine crushed rock from the sedimentary rock in the Boraig Group geological zone enters the water column, the fine particles remain in suspension for extended periods in the order of several days to weeks.Elevated surface turbidity levels of around 20 NTU to 30 NTU were recorded at the conclusion of the tests, around 10 to 12 days following commencement.

While surface turbidity levels generally appear to reduce over time, it may take an extremely long time to reach background levels of 1 NTU to 5 NTU, as reported by Cardno. Furthermore, minor disturbances to the water column are likely to disrupt the settlement process and/or re-suspend fine particles.

The critical particle size in suspension that would be contributing to prolonged surface turbidity in the water column (more than 24 hours) would be less than approximately 4 µm.

The results of a chemical flocculation test for the Boraig Group sedimentary crushed rock indicate that the addition of flocculant may accelerate settlement of fine particles and clarify the water.

TSS-turbidity data collected during the Column Test (Test 3D) is considered to be reliable for the purpose of establishing a preliminary relationship between TSS and turbidity for the sedimentary rock in the Boraig Group geological zone. The turbidity value equivalent to 50 mg/L suspended solids is 63 NTU for this dataset. Furthermore, as the properties and grading of the crushed rock placed during construction may vary to that used in the column test, collection of field TSS-turbidity data during subaqueous excavated rock placement activities is recommended so that the relationship between turbidity and suspended solids can be continually validated and improved.

Attachment 1 – Laboratory Certificates

ES1828636			Compound Group	EA025: Total Suspended Solids dried at 104 ± 2°C	EA045: Turbidity
			Method	EA025H	EA045
			Accredited	Y	Y
Sub-Matrix	Sample Name			Suspended Solids (SS)	Turbidity
			Units	mg/L	NTU
			Rep. LOR	5	0.1
WATER	2D-1	Original	1	<5	0.4
		Duplicate	1	0	0.339
WATER	2D-2	Original	2	268	45.4
		Duplicate	2	263	202
WATER	2D-3	Original	3	197	46
		Duplicate	3	223	183
WATER	2D-4	Original	4	200	43.9
		Duplicate	4	225	171
WATER	2D-5	Original	5	164	46.6
		Duplicate	5	206	165
WATER	2D-6	Original	6	123	45.3
		Duplicate	6	148	146
WATER	2D-7	Original	7	107	41.4
		Duplicate	7	126	112
WATER	2D-8	Original	8	68	43.6
		Duplicate	8	96	90.4
WATER	2D-9	Original	9	100	43.2
		Duplicate	9	110	114
WATER	2D-10	Original	10	44	41.6
		Duplicate	10	87	75.1
WATER	2D-11	Original	11	68	42
		Duplicate	11	82	87
WATER	2D-12	Original	12	62	44
		Duplicate	12	81	87.4
WATER	2D-13	Original	13	6	41.8
		Duplicate	13	19	51.8
WATER	2D-6A	Original	14	130	45
		Duplicate	14	184	154
WATER	3D-1	Original	15	<5	1.1
		Duplicate	15	1	0.82
WATER	3D-2	Original	16	294	43.7
		Duplicate	16	300	232
WATER	3D-3	Original	17	189	41.6
		Duplicate	17	194	189
WATER	3D-4	Original	18	172	44.9
		Duplicate	18	186	165
WATER	3D-5	Original	19	108	44.3
		Duplicate	19	122	136
WATER	3D-6	Original	20	119	43.2
		Duplicate	20	126	147
WATER	3D-7	Original	21	85	48.4
		Duplicate	21	87	119
WATER	3D-8	Original	22	90	45.4
		Duplicate	22	87	88.9
WATER	3D-9	Original	23	62	43.3
		Duplicate	23	70	99
WATER	3D-10	Original	24	20	39.8
		Duplicate	24	22	54

Note: Original and Duplicate testing undertaken by ALS Environmental. The Duplicate results were used to establish TSS-Turbidity relationship. Laboratory Certificates were not provided for the Duplicate tests.

CERTIFICATE OF ANALYSIS

Work Order : **ES1829038**
Client : **HASKONING AUSTRALIA- ROYAL HASKONING**
Contact : MR PATRICK LAWLESS
Address : LEVEL 14 56 Berry Street
NORTH SYDNEY 2060
Telephone : ----
Project : Snowy 2.0 TSS-NTU (Test 2/3)
Order number :
C-O-C number : ----
Sampler : Patrick Lawless
Site : ----
Quote number : EN/222
No. of samples received : 12
No. of samples analysed : 12

Page : 1 of 5
Laboratory : Environmental Division Sydney
Contact : Customer Services ES
Address : 277-289 Woodpark Road Smithfield NSW Australia 2164
Telephone : +61-2-8784 8555
Date Samples Received : 02-Oct-2018 17:00
Date Analysis Commenced : 03-Oct-2018
Issue Date : 08-Oct-2018 12:42

Accreditation No. 825
Accredited for compliance with
ISO/IEC 17025 - Testing

This report supersedes any previous report(s) with this reference. Results apply to the sample(s) as submitted. This document shall not be reproduced, except in full.

This Certificate of Analysis contains the following information:

- General Comments
- Analytical Results

Additional information pertinent to this report will be found in the following separate attachments: Quality Control Report, QA/QC Compliance Assessment to assist with Quality Review and Sample Receipt Notification.

Signatories

This document has been electronically signed by the authorized signatories below. Electronic signing is carried out in compliance with procedures specified in 21 CFR Part 11.

Signatories	*Position*	*Accreditation Category*
Ankit Joshi	Inorganic Chemist	Sydney Inorganics, Smithfield, NSW

General Comments

The analytical procedures used by the Environmental Division have been developed from established internationally recognized procedures such as those published by the USEPA, APHA, AS and NEPM. In house developed procedures are employed in the absence of documented standards or by client request.

Where moisture determination has been performed, results are reported on a dry weight basis.

Where a reported less than (<) result is higher than the LOR, this may be due to primary sample extract/digestate dilution and/or insufficient sample for analysis.

Where the LOR of a reported result differs from standard LOR, this may be due to high moisture content, insufficient sample (reduced weight employed) or matrix interference.

When sampling time information is not provided by the client, sampling dates are shown without a time component. In these instances, the time component has been assumed by the laboratory for processing purposes.

Where a result is required to meet compliance limits the associated uncertainty must be considered. Refer to the ALS Contact for details.

Key : CAS Number = CAS registry number from database maintained by Chemical Abstracts Services. The Chemical Abstracts Service is a division of the American Chemical Society.
LOR = Limit of reporting
^ = This result is computed from individual analyte detections at or above the level of reporting
ø = ALS is not NATA accredited for these tests.
~ = Indicates an estimated value.

Analytical Results

Sub-Matrix: **WATER** (Matrix: **WATER**)			*Client sample ID*	**2D-14**	**2D-15**	**2D-16**	**2D-17**	**2D-18**
			Client sampling date / time	27-Sep-2018 00:00	28-Sep-2018 00:00	28-Sep-2018 00:00	01-Oct-2018 00:00	02-Oct-2018 00:00
Compound	*CAS Number*	*LOR*	*Unit*	**ES1829038-001**	**ES1829038-002**	**ES1829038-003**	**ES1829038-004**	**ES1829038-005**
				Result	Result	Result	Result	Result
EA025: Total Suspended Solids dried at 104 ± 2°C								
Suspended Solids (SS)	----	5	mg/L	**19**	**8**	<5	<5	<5
EA045: Turbidity								
Turbidity	----	0.1	NTU	**32.0**	**26.3**	**31.3**	**31.8**	**20.5**

Analytical Results

Sub-Matrix: **WATER** (Matrix: **WATER**)			*Client sample ID*	**2D-19**	**3D-11**	**3D-12**	**3D-13**	**3D-14**
			Client sampling date / time	02-Oct-2018 00:00	27-Sep-2018 00:00	28-Sep-2018 00:00	28-Sep-2018 00:00	01-Oct-2018 00:00
Compound	*CAS Number*	*LOR*	*Unit*	**ES1829038-006**	**ES1829038-007**	**ES1829038-008**	**ES1829038-009**	**ES1829038-010**
				Result	Result	Result	Result	Result
EA025: Total Suspended Solids dried at 104 ± 2°C								
Suspended Solids (SS)	----	5	mg/L	**14**	**15**	<5	**7**	**21**
EA045: Turbidity								
Turbidity	----	0.1	NTU	**26.1**	**25.4**	**34.2**	**31.9**	**36.2**

Analytical Results

Sub-Matrix: **WATER** (Matrix: **WATER**)			*Client sample ID*	**3D-15**	**3D-16**	**----**	**----**	**----**
			Client sampling date / time	02-Oct-2018 00:00	02-Oct-2018 00:00	----	----	----
Compound	*CAS Number*	*LOR*	*Unit*	**ES1829038-011**	**ES1829038-012**	**--------**	**--------**	**--------**
				Result	Result	----	----	----
EA025: Total Suspended Solids dried at 104 ± 2°C								
Suspended Solids (SS)	----	5	mg/L	**14**	**13**	**----**	**----**	**----**
EA045: Turbidity								
Turbidity	----	0.1	NTU	**26.8**	**26.6**	**----**	**----**	**----**

ALS Environmental

CERTIFICATE OF ANALYSIS

Work Order : **ES1830022**
Client : **HASKONING AUSTRALIA- ROYAL HASKONING**
Contact : MR PATRICK LAWLESS
Address : LEVEL 14 56 Berry Street
NORTH SYDNEY 2060
Telephone : ----
Project : Snowy 2.0 TSS-NTU (Test 2/3)
Order number :
C-O-C number : ----
Sampler : PATRICK LAWLESS
Site : ----
Quote number : EN/222
No. of samples received : 50
No. of samples analysed : 50

Page : 1 of 12
Laboratory : Environmental Division Sydney
Contact : Customer Services ES
Address : 277-289 Woodpark Road Smithfield NSW Australia 2164
Telephone : +61-2-8784 8555
Date Samples Received : 10-Oct-2018 16:30
Date Analysis Commenced : 11-Oct-2018
Issue Date : 17-Oct-2018 17:40

ilac-MRA NATA
Accreditation No. 825
Accredited for compliance with
ISO/IEC 17025 - Testing

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Signatories

This document has been electronically signed by the authorized signatories below. Electronic signing is carried out in compliance with procedures specified in 21 CFR Part 11.

Signatories	*Position*	*Accreditation Category*
Ankit Joshi	Inorganic Chemist	Sydney Inorganics, Smithfield, NSW

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Key :
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LOR = Limit of reporting
^ = This result is computed from individual analyte detections at or above the level of reporting
ø = ALS is not NATA accredited for these tests.
~ = Indicates an estimated value.

Analytical Results

Sub-Matrix: **WATER**
(Matrix: **WATER)**

			Client sample ID	**2D-20**	**2D-21**	**2D-22**	**2D-23**	**2D-24**
			Client sampling date / time	03-Oct-2018 00:00	04-Oct-2018 00:00	05-Oct-2018 00:00	06-Oct-2018 00:00	08-Oct-2018 00:00
Compound	CAS Number	LOR	Unit	**ES1830022-001**	**ES1830022-002**	**ES1830022-003**	**ES1830022-004**	**ES1830022-005**
				Result	Result	Result	Result	Result
EA025: Total Suspended Solids dried at 104 ± 2°C								
Suspended Solids (SS)	----	5	mg/L	**----**	<5	**16**	**----**	**----**
Suspended Solids (SS)	----	5	mg/L	**8**	**----**	**----**	**12**	**11**
EA045: Turbidity								
Turbidity	----	0.1	NTU	**32.9**	**21.2**	**30.4**	**35.5**	**23.7**

Analytical Results

Sub-Matrix: **WATER**
(Matrix: **WATER)**

			Client sample ID	**3D-17**	**3D-18**	**3D-19**	**3D-20**	**3D-21**
			Client sampling date / time	03-Oct-2018 00:00	04-Oct-2018 00:00	05-Oct-2018 00:00	06-Oct-2018 00:00	08-Oct-2018 00:00
Compound	*CAS Number*	*LOR*	*Unit*	**ES1830022-006**	**ES1830022-007**	**ES1830022-008**	**ES1830022-009**	**ES1830022-010**
				Result	Result	Result	Result	Result
EA025: Total Suspended Solids dried at 104 ± 2°C								
Suspended Solids (SS)	----	5	mg/L	**----**	**8**	**13**	**----**	**----**
Suspended Solids (SS)	----	5	mg/L	**8**	**----**	**----**	**8**	<5
EA045: Turbidity								
Turbidity	----	0.1	NTU	**30.1**	**28.7**	**28.2**	**26.8**	**22.6**

Analytical Results

Sub-Matrix: **WATER**
(Matrix: **WATER)**

			Client sample ID	**4D-1**	**4D-2**	**4D-3**	**4D-4**	**4D-5**
			Client sampling date / time	09-Oct-2018 00:00	09-Oct-2018 00:00	09-Oct-2018 00:00	09-Oct-2018 00:00	09-Oct-2018 00:00
Compound	*CAS Number*	*LOR*	*Unit*	**ES1830022-011**	**ES1830022-012**	**ES1830022-013**	**ES1830022-014**	**ES1830022-015**
				Result	Result	Result	Result	Result
EA025: Total Suspended Solids dried at 104 ± 2°C								
Suspended Solids (SS)	----	5	mg/L	<5	**206**	**204**	**121**	**166**
EA045: Turbidity								
Turbidity	----	0.1	NTU	**0.4**	**240**	**148**	**150**	**109**

Analytical Results

Sub-Matrix: **WATER** (Matrix: **WATER**)			*Client sample ID*	**4D-6**	**4D-7**	**4D-8**	**4D-9**	**4D-10**
			Client sampling date / time	09-Oct-2018 00:00	09-Oct-2018 00:00	09-Oct-2018 00:00	09-Oct-2018 00:00	09-Oct-2018 00:00
Compound	*CAS Number*	*LOR*	*Unit*	**ES1830022-016**	**ES1830022-017**	**ES1830022-018**	**ES1830022-019**	**ES1830022-020**
				Result	Result	Result	Result	Result
EA025: Total Suspended Solids dried at 104 ± 2°C								
Suspended Solids (SS)	----	5	mg/L	**116**	**142**	**45**	**42**	**97**
EA045: Turbidity								
Turbidity	----	0.1	NTU	**169**	**119**	**130**	**125**	**94.2**

Analytical Results

Sub-Matrix: **WATER** (Matrix: **WATER**)			*Client sample ID*	**4D-11**	**4D-12**	**4D-13**	**4D-14**	**4D-15**
			Client sampling date / time	09-Oct-2018 00:00	09-Oct-2018 00:00	09-Oct-2018 00:00	09-Oct-2018 00:00	09-Oct-2018 00:00
Compound	*CAS Number*	*LOR*	*Unit*	**ES1830022-021**	**ES1830022-022**	**ES1830022-023**	**ES1830022-024**	**ES1830022-025**
				Result	Result	Result	Result	Result
EA025: Total Suspended Solids dried at 104 ± 2°C								
Suspended Solids (SS)	----	5	mg/L	**84**	**80**	**31**	**40**	**22**
EA045: Turbidity								
Turbidity	----	0.1	NTU	**92.7**	**96.0**	**113**	**110**	**100**

Analytical Results

Sub-Matrix: **WATER** (Matrix: **WATER**)			*Client sample ID*	**4D-16**	**4D-17**	**4D-18**	**4D-19**	**5D-1**
			Client sampling date / time	09-Oct-2018 00:00	09-Oct-2018 00:00	09-Oct-2018 00:00	09-Oct-2018 00:00	09-Oct-2018 00:00
Compound	*CAS Number*	*LOR*	*Unit*	**ES1830022-026**	**ES1830022-027**	**ES1830022-028**	**ES1830022-029**	**ES1830022-030**
				Result	Result	Result	Result	Result
EA025: Total Suspended Solids dried at 104 ± 2°C								
Suspended Solids (SS)	----	5	mg/L	**24**	**54**	**51**	**25**	<5
EA045: Turbidity								
Turbidity	----	0.1	NTU	**22.8**	**25.8**	**33.1**	**29.3**	**0.5**

Analytical Results

Sub-Matrix: **WATER** (Matrix: **WATER**)			Client sample ID	**5D-2**	**5D-3**	**5D-4**	**5D-5**	**5D-6**
			Client sampling date / time	09-Oct-2018 00:00	09-Oct-2018 00:00	09-Oct-2018 00:00	09-Oct-2018 00:00	09-Oct-2018 00:00
Compound	CAS Number	LOR	Unit	**ES1830022-031**	**ES1830022-032**	**ES1830022-033**	**ES1830022-034**	**ES1830022-035**
				Result	Result	Result	Result	Result
EA025: Total Suspended Solids dried at 104 ± 2°C								
Suspended Solids (SS)	----	5	mg/L	**130**	**124**	**142**	**118**	**180**
EA045: Turbidity								
Turbidity	----	0.1	NTU	**184**	**177**	**182**	**168**	**167**

Analytical Results

Sub-Matrix: **WATER** (Matrix: **WATER**)			Client sample ID	**5D-7**	**5D-8**	**5D-9**	**5D-10**	**5D-11**
			Client sampling date / time	09-Oct-2018 00:00	09-Oct-2018 00:00	09-Oct-2018 00:00	09-Oct-2018 00:00	09-Oct-2018 00:00
Compound	CAS Number	LOR	Unit	**ES1830022-036**	**ES1830022-037**	**ES1830022-038**	**ES1830022-039**	**ES1830022-040**
				Result	Result	Result	Result	Result
EA025: Total Suspended Solids dried at 104 ± 2°C								
Suspended Solids (SS)	----	5	mg/L	**132**	**95**	**110**	**70**	**62**
EA045: Turbidity								
Turbidity	----	0.1	NTU	**130**	**107**	**101**	**60.2**	**20.8**

Analytical Results

Sub-Matrix: **WATER** (Matrix: **WATER**)			*Client sample ID*	**5D-12**	**5D-13**	**5D-14**	**5D-15**	**4D-20**
			Client sampling date / time	09-Oct-2018 00:00	09-Oct-2018 00:00	09-Oct-2018 00:00	09-Oct-2018 00:00	10-Oct-2018 00:00
Compound	*CAS Number*	*LOR*	*Unit*	**ES1830022-041**	**ES1830022-042**	**ES1830022-043**	**ES1830022-044**	**ES1830022-045**
				Result	Result	Result	Result	Result
EA025: Total Suspended Solids dried at 104 ± 2°C								
Suspended Solids (SS)	----	5	mg/L	**24**	**26**	**11**	**10**	**26**
EA045: Turbidity								
Turbidity	----	0.1	NTU	**31.2**	**19.2**	**16.3**	**16.0**	**20.9**

Analytical Results

Sub-Matrix: **WATER** (Matrix: **WATER**)			*Client sample ID*	**4D-21**	**5D-16**	**5D-17a**	**5D-17b**	**5D-18**
			Client sampling date / time	10-Oct-2018 00:00	10-Oct-2018 00:00	10-Oct-2018 00:00	10-Oct-2018 00:00	10-Oct-2018 00:00
Compound	*CAS Number*	*LOR*	*Unit*	**ES1830022-046**	**ES1830022-047**	**ES1830022-048**	**ES1830022-049**	**ES1830022-050**
				Result	Result	Result	Result	Result
EA025: Total Suspended Solids dried at 104 ± 2°C								
Suspended Solids (SS)	----	5	mg/L	**12**	**16**	**7**	**14**	**17**
EA045: Turbidity								
Turbidity	----	0.1	NTU	**17.0**	**9.2**	**7.3**	**7.8**	**9.8**

Attachment 2 – Boraig Group - Sedimentary Laboratory Log Records

Test ID	3A	
Geological Unit	Boraig Group - Sedimentary	
Description	Test 3A - Dry Disposal at Surface	
Start Date/Time	26-09-18 13:25	
Water volume	50 L	
Water surface level in column	175.5	cm
Mass sediment added	40 g	(sieved to <250 um)
Test Location	Geochemical Assessments Workshop, Roseville NSW	
Test Officers	Pat Lawless, Rick Plain	

Observations

Date/Time	Time since start	Turbidity (NTU)	Measurement Location (cm)	Measurement Depth (cm)	Comments
26-09-18 11:30	2 hours prior	2.8	172.1	3.4	Background turbidity measured 2 hours before test start.
26-09-18 13:32	00-0:07	168	172.1	3.4	
26-09-18 13:35	00-0:10	142	172.1	3.4	
26-09-18 13:39	00-0:14	134	172.1	3.4	
26-09-18 13:44	00-0:19	134	172.1	3.4	Continuous monitoring stopped and probe cleaned before reading.
26-09-18 13:48	00-0:23	122	172.1	3.4	
26-09-18 13:51	00-0:26	115	172.1	3.4	
26-09-18 13:59	00-0:34	108	172.1	3.4	
26-09-18 14:04	00-0:39	99	172.1	3.4	
26-09-18 16:00	00-2:35	57	172.1	3.4	
27-09-18 8:45	00-19:20	40.6	172.1	3.4	Stratification at 159 cm.
27-09-18 18:10	01-4:45	27.4	172.1	3.4	Stratification at 149 cm and 172 cm.
28-09-18 11:30	01-22:05	21	172.1	3.4	Stratification at 169 cm. Gradual change below to ~137 cm.
28-09-18 17:25	02-4:00	22.25	172.1	3.4	Stratification at 164 cm. Gradual change below to ~137 cm.
01-10-18 6:30	04-17:05	21.63	172.1	3.4	Stratification at 129 cm.
02-10-18 8:30	05-19:05	27.1	172.1	3.4	Stratification at 114 cm.
02-10-18 16:10	06-2:45	18.8	172.1	3.4	Stratification at 101 cm.
03-10-18 11:30	06-22:05	23.2	172.1	3.4	Stratification at ~97 cm.Minor change. Gradual change above.
04-10-18 7:30	07-18:05	13	172.1	3.4	Stratification at ~173 cm. Fluctuating between 11 and 24 NTU.
05-10-18 11:30	08-22:05	30	172.1	3.4	Seems high compared to previous reading. Double checked reading and is correct.
06-10-18 17:15	10-3:50	22.4	172.1	3.4	**Flocculant added.**
08-10-18 9:30	11-20:05	3.1	172.1	3.4	

Test ID	3B	
Geological Unit	Boraig Group - Sedimentary	
Description	Test 3B - Dry Disposal via Fall Pipe (52cm below surface)	
Start Date/Time	26-09-18 13:25	
Water volume	50 L	
Water surface level in column	178.2	cm
Mass sediment added	40 g	(sieved to <250 um)
Test Location	Geochemical Assessments Workshop, Roseville NSW	
Test Officers	Pat Lawless, Rick Plain	

Observations

Date/Time	Time since start	Turbidity (NTU)	Measurement Location (cm)	Measurement Depth (cm)	Comments
26-09-18 11:30	2 hours prior	2.6	174.8	3.4	Background turbidity measured 2 hours before test start.
26-09-18 13:32	00-0:07				Turbid plume at 134 cm.
26-09-18 13:46	00-0:21				Turbid plume at 130 cm.
26-09-18 16:00	00-2:35	3.3	174.8	3.4	Turbid plume at 130 cm.
27-09-18 9:00	00-19:35	3.6	174.8	3.4	Turbid plume at 127 cm.
27-09-18 18:00	01-4:35		174.8	3.4	Turbid plume at 126.5cm.
28-09-18 11:40	01-22:15	4	174.8	3.4	Turbid plume at 126.2cm.
28-09-18 17:00	02-3:35		174.8	3.4	Turbid plume at 123.6 cm.
01-10-18 6:30	04-17:05	6.7	174.8	3.4	Turbid plume at 115 cm. Slight haze above. Probe reading 0 when placed in water.
02-10-18 8:30	05-19:05	6.53	174.8	3.4	Turbid plume at 113.7 cm. Slight Haze above.
02-10-18 16:10	06-2:45		174.8	3.4	Turbid plume at 112 cm. Slight Haze above and minor wafting/rising TSS above turbid layer.
03-10-18 11:30	06-22:05	7.85	174.8	3.4	Turbid plume at 109 cm. Slight Haze above.
04-10-18 7:30	07-18:05	7.6	174.8	3.4	Turbid plume at 106.5 cm. Slight Haze above.
05-10-18 11:30	08-22:05	7.3	174.8	3.4	Turbid plume at 104.5 cm. Slight Haze above.
06-10-18 17:15	10-3:50	7.45	174.8	3.4	Turbid plume at 102.5 cm. Slight Haze above.
08-10-18 9:30	11-20:05	7.1	174.8	3.4	Turbid plume at 99.5 cm. Slight Haze above.

Test ID	3D	
Geological Unit	Boraig Group - Sedimentary	
Description	Test 3D - Column Test to develop TSS/NTU relationship	
Start Date/Time	26-09-18 11:40	
Water volume	50 L	
Water surface level in column	176.2	cm
Mass sediment added	47.5 g	(sieved to <250 um)
Test Location	Geochemical Assessments Workshop, Roseville NSW	
Test Officers	Pat Lawless, Rick Plain	

Observations

Date/Time	Time since start	Turbidity (NTU)		TSS Sample Taken?	TSS Sample ID	Column Measurements			Comments
		Inside Column	Inside Beaker			Water Surface	Measurement Location	Sensor Depth	
26-09-18 11:35	5 mins Prior to start	1.9	2.1	Yes	3D-1	175.8	172.4	3.4	Start of test
26-09-18 11:42	00-0:02	185	165	Yes	3D-2	174.7	171.3	3.4	
26-09-18 11:46	00-0:06	145	140	Yes	3D-3	174	170.6	3.4	Variable readings inside beaker, 120-145 NTU.
26-09-18 11:55	00-0:15	132	125	Yes	3D-4	173.3	169.9	3.4	Variable readings inside beaker, 120-130 NTU.
26-09-18 12:15	00-0:35	114	92	Yes	3D-5	172.7	169.3	3.4	
26-09-18 12:25	00-0:45	109	92	Yes	3D-6	172.1	168.7	3.4	
26-09-18 13:10	00-1:30	97	81	Yes	3D-7	171	167.6	3.4	
26-09-18 14:10	00-2:30	77	89	Yes	3D-8	170.3	166.9	3.4	
26-09-18 16:00	00-4:20	71	70	Yes	3D-9	169.1	165.7	3.4	
27-09-18 8:30	00-20:50	47.3	40	Yes	3D-10	168.1	164.7	3.4	Stratification boundary at ~158 cm.
27-09-18 18:00	01-6:20	30	34	Yes	3D-11	167.4	164	3.4	Stratification boundary at ~153.5 cm and 165.5 cm.
28-09-18 11:30	01-23:50	25	30.9	Yes	3D-12	166.4	163	3.4	Stratification boundary at ~152 cm (minimal, gradual change) and 163.5 cm.
28-09-18 17:20	02-5:40	25.5	26.7	Yes	3D-13	165.2	161.8	3.4	Stratification boundary at ~150 cm (minimal, gradual change) and 160.5 cm.
01-10-18 6:30	04-18:50	27.5	26.4	Yes	3D-14	164.3	160.9	3.4	Stratification boundary at ~140 cm.
02-10-18 8:30	05-20:50	35.7	31.7	Yes	3D-15	163.1	159.7	3.4	Stratification boundary at ~132 cm.
02-10-18 16:10	06-4:30	32.6	32.8	Yes	3D-16	162.2	158.8	3.4	Stratification boundary at ~116.5 cm.
03-10-18 11:30	06-23:50	31.2	29	Yes	3D-17	161	157.6	3.4	Stratification boundary at ~160 cm. Top ~1 cm very clear. Gradual change to ~100 cm.
04-10-18 7:30	07-19:50	25	26.2	Yes	3D-18	159.9	156.5	3.4	Turbidity reading fluctuating. 20-25 NTU before sampling and 25-26 NTU in colum after sampling.
05-10-18 11:30	08-23:50	25.2	25.1	Yes	3D-19	158.6	155.2	3.4	Stratification boundary at 144 cm.
06-10-18 17:15	10-5:35	25	27.7	Yes	3D-20	157.4	154	3.4	Undulating 23-27 NTU in column.
08-10-18 9:30	11-21:50	26.7	22	Yes	3D-21	156.4	153	3.4	Stratification 149.5 cm. Fluctuating 24-27 NTU.

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Appendix D

TSS – Turbidity and Settling Test Results
Boggy Plain Suite Geological Zone

Table of Contents

1 Introduction

The Boggy Plain Suite geological zone comprises intrusive igneous rock (plutonic rock). The Boggy Plain Suite forms part of the Kosciusko Batholith. A 1-m long section of core from this geological zone was supplied to Royal HaskoningDHV (Haskoning) from BH3106, taken between 236 m and 237 m below the ground surface. The rock core was logged as diorite, an intrusive igneous rock.

Water for laboratory testing was obtained from the Talbingo Reservoir on the 2nd October 2018. The water was collected in 1000 L Intermediate Bulk Containers (IBC) and delivered to Haskoning on the 5th October 2018. The turbidity of the reservoir water sample used for the testing was between 1.7 and 2.5 NTU. This is within the turbidity range of field monitoring, as undertaken by Cardno in 2018, which indicated typical 'background' turbidity of 1 to 5 NTU in Talbingo Reservoir.

2 Results

2.1 Test 4D – TSS-Turbidity

2.1.1 Overview

The TSS-Turbidity Test for the Boggy Plain Suite ('Test 4D') commenced on the 9th October 2018 at 9:00am and concluded on the 22nd October 2018, approximately 13 days following commencement.

The Certificate of Analysis provided by ALS Environmental for the TSS and turbidity analyses undertaken for samples collected during testing is provided in **Attachment 1**. Laboratory log records completed during the TSS-turbidity test are provided in **Attachment 2**, which includes turbidity measurements undertaken during testing for each sample.

Photographs taken during the column test are provided in **Figure 1**. These photographs were taken:

- prior to commencement;
- 1 hours and 55 minutes after commencement;
- 1 day and 6.5 hours after commencement;
- 6 days and 0.5 hours after commencement; and
- 13 days after commencement.

Figure 1: Column test –

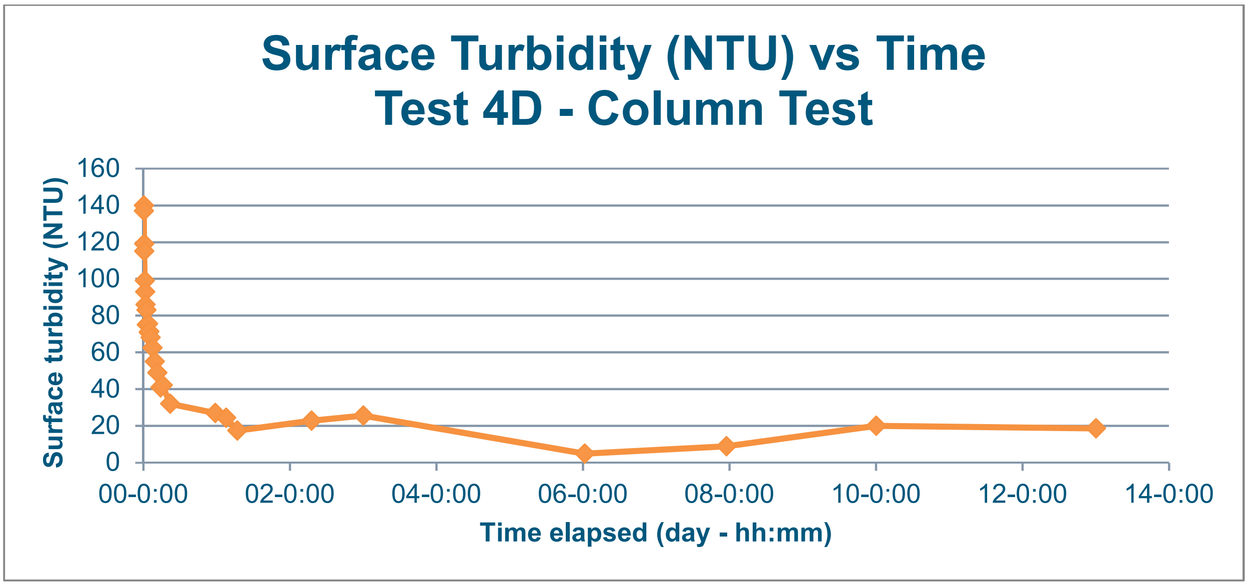
1. *Talbingo Reservoir water 20 minutes prior to addition of the sieved crushed rock,*
2. *Column test 1 hours and 55 minutes after commencement,*
3. *Column test 1 day and 6.5 hours after commencement,*
4. *Column test 6 days and 0.5 hours after commencement, and*
5. *Column test 13 days after commencement.*

2.1.2 Surface Turbidity vs Time Results

The variation in surface turbidity during Test 4D is plotted in **Graph 1**. The graph shows that surface turbidity decreased relatively rapidly from 140 NTU to 80 NTU during the first hour of testing. Approximately 8 hours after commencement, surface turbidity decreased to 32 NTU.

Surface turbidity levels continued to decrease, at a slower rate, to approximately 17.5 NTU after 1 day and 6 hours. Between approximately 1 day and 6 hours after commencement and 13 days after commencement, surface turbidity fluctuated between 4.9 NTU (6 days after commencement) to 25.6 NTU (3 days after commencement). The average surface turbidity during this period was 16.8 NTU. After 13 days, surface turbidity was recorded at 18.6 NTU.

A discussion regarding the observed increase and fluctuations in surface turbidity is provided in **Section 3**.



Graph 1: Surface turbidity measured during the column test – Boggy Plain Suite crushed rock (Test 4D).

2.1.3 TSS – Turbidity Results

A total of 25 samples were collected during testing for laboratory TSS and turbidity analysis. TSS values for the collected samples ranged between <5 mg/L[1] and 206 mg/L, while turbidity values of up to 150 NTU were recorded.

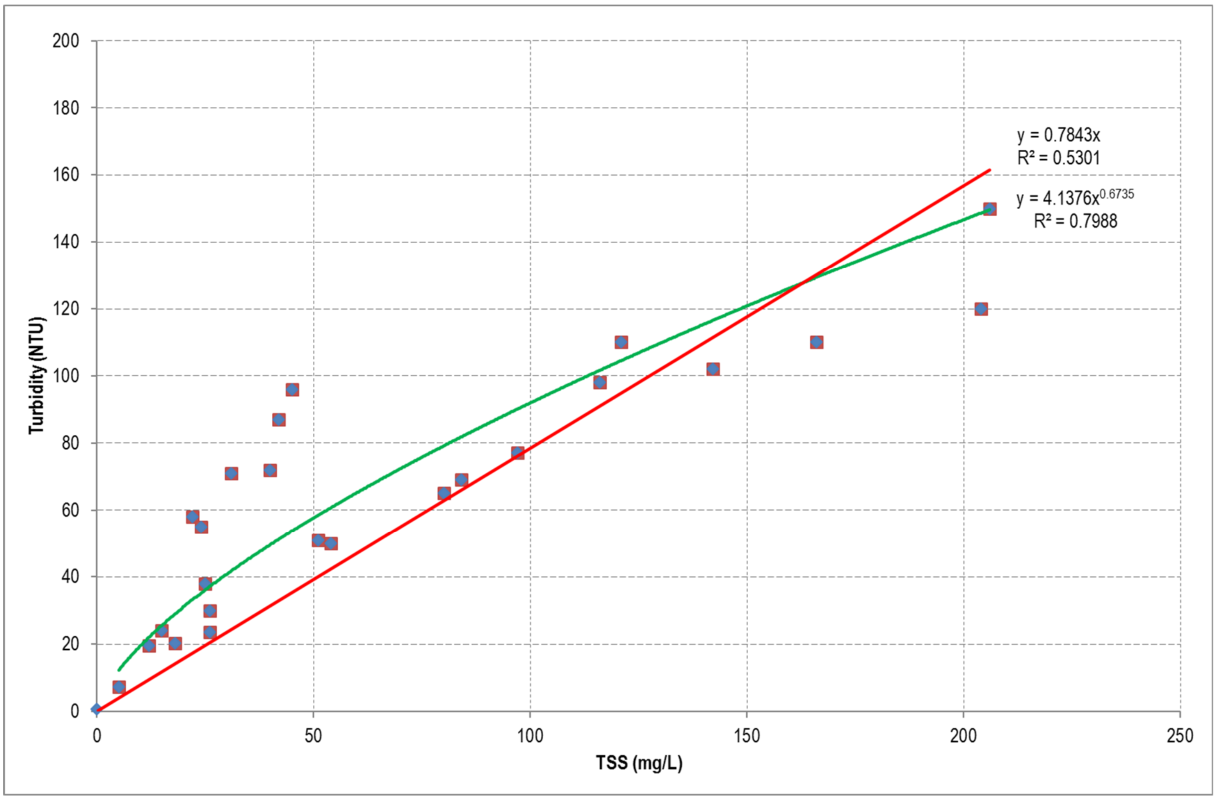
A plot of TSS versus turbidity for all data collected during testing is provided in **Graph 2**. Turbidity values used in this dataset are the measurements taken during testing (inside the glass beaker prior to sub-sampling) rather than the laboratory results[2]. This dataset is plotted with trendlines corresponding to both linear and power functions. It is evident that the power function provides a much closer fit of the data, characterised by an R^2 value of 0.80[3], whereas the linear line of best fit has a lower R^2 value of 0.53.

---

[1] The Limit of Reporting (LOR) value for TSS analysis is 5 mg/L, refer **Attachment 1**. Results for samples with TSS concentrations below the LOR value are reported as <5 mg/L.

[2] Turbidity results reported by the laboratory were compared with turbidity results obtained during testing using the Wetlab-ECO-NTU sensor. No significant differences between the turbidity datasets were evident (i.e. selection of the turbidity dataset does not significantly influence the TSS-turbidity relationship reported herein).

[3] The R^2 value, also known as the coefficient of determination, is a measure of how close the plotted data are to the fitted regression line (i.e. the line of best fit). An R^2 value of 1 indicates that the regression line perfectly fits the data.



Graph 2: TSS-turbidity results – Boggy Plain Suite crushed rock (Test 4D)

2.1.4 TSS – Turbidity Relationship

A summary of the TSS-turbidity relationships determined for the Test 4D dataset is provided in **Table 1**, including the turbidity values equivalent to a TSS concentration of 50 mg/L for each the linear and power function trendline. The selected TSS value of 50 mg/L is somewhat arbitrary and the water quality limit for the project may vary.

Table 1: Summary of TSS-turbidity relationships for Boggy Plain Suite crushed rock

Trendline Function	Number of values	R^2 value	Turbidity (NTU) equivalent to 50 mg/L TSS
Linear	25	0.53	39
Power	25	0.80	58

As noted above, the power function trendline provides a much better fit of the dataset compared to the linear trendline. Furthermore, the high R^2 value associated with the power function trendline (0.80) indicates a reasonable correlation between TSS and turbidity for the dataset, and is considered to be valid for the data collected during testing. The turbidity value equivalent to 50 mg/L suspended solids is 58 NTU for this dataset.

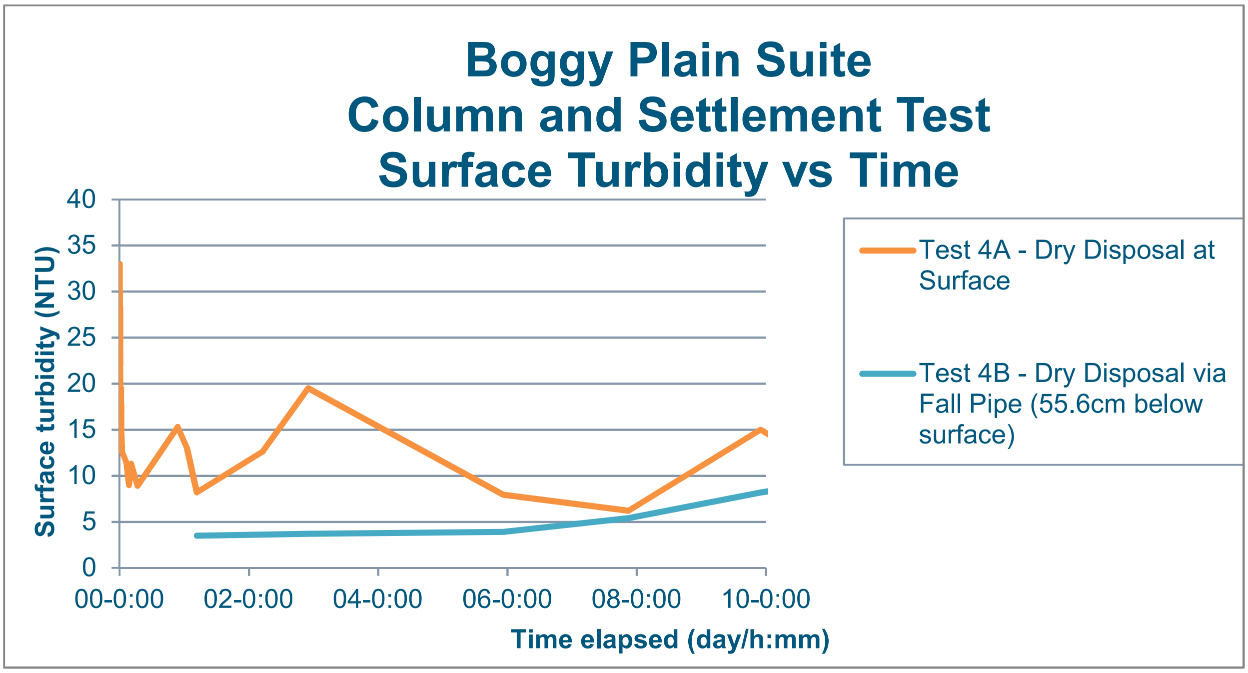
2.2 Settlement Tests

2.2.1 Overview

The two settlement tests for the Boggy Plain Suite crushed rock (Tests 4A and 4B) commenced simultaneously on the 9th October 2018 at 11:00am. Different disposal methods were simulated in the respective columns as described in **Sections 2.2.2** to **2.2.4**. The tests concluded on the 19th October 2018, approximately 10 days following commencement.

Turbidity in the two columns was measured 2 hours prior to addition of the sieved crushed rock, with results of 1.9 NTU and 1.7 NTU recorded for Test 4A and 4B respectively.

Surface turbidity measured at varying time intervals during the 10-day test duration is plotted in **Graph 3** for the two settlement tests. These results are discussed in the following sections, along with a summary of the key observations for each settlement test. Laboratory log records completed during the settlement tests are provided in **Attachment 2**.



Graph 3: Surface turbidity measured during the settlement tests – Boggy Plain Suite crushed rock (Tests 4A and 4B).

Photographs taken during the settlement tests are provided in **Figures 2** to **6**. These photographs were taken prior to commencement (**Figure 2**), 3 hours and 30 minutes after commencement (**Figure 3**), 21 hours and 25 minutes after commencement (**Figure 4**), 5 days and 22.5 hours after commencement (**Figure 5**), and 7 days and 21 hours after commencement (**Figure 6**).

TEST I.D.	4A
GEOLOGICAL UNIT	BOGGY PLAIN SUITE
START TIME	9/10/18 11:00
CURRENT TIME	9/10/18 11:00

TEST I.D.	4B
GEOLOGICAL UNIT	BOGGY PLAIN SUITE
START TIME	9/10/18 11:00
CURRENT TIME	9/10/18 11:00

Figure 2: Settlement test prior to placement of sieved crushed rock-
Left: Test 4A - Placement of dry sieved crushed rock directly onto the water surface,
Right: Test 4B - Placement of dry sieved crushed rock within a fall pipe with opening submerged 50 cm below the water surface,

TEST I.D.	4A
GEOLOGICAL UNIT	BOGGY PLAIN SUITE
START TIME	9/10/18 11:00
CURRENT TIME	9/10/18 14:30

TEST I.D.	4B
GEOLOGICAL UNIT	BOGGY PLAIN SUITE
START TIME	9/10/18 11:00
CURRENT TIME	9/10/18 14:30

Figure 3: Settlement test 3 hours and 30 minutes following placement of sieved crushed rock-
Left: Test 4A - Placement of dry sieved crushed rock directly onto the water surface,
Right: Test 4B - Placement of dry sieved crushed rock within a fall pipe with opening submerged 50 cm below the water surface.

TEST I.D.	4A
GEOLOGICAL UNIT	BOGGY PLAIN SUITE
START TIME	9/10/18 11:00
CURRENT TIME	10/10/18 8:25

TEST I.D.	4B
GEOLOGICAL UNIT	BOGGY PLAIN SUITE
START TIME	9/10/18 11:00
CURRENT TIME	10/10/18

Figure 4: Settlement test 21 hours and 25 minutes following placement of sieved crushed rock-
Left: Test 4A - Placement of dry sieved crushed rock directly onto the water surface,
Right: Test 4B - Placement of dry sieved crushed rock within a fall pipe with opening submerged 50 cm below the water surface.

TEST I.D.	4A
GEOLOGICAL UNIT	BOGGY PLAIN SUITE
START TIME	9/10/18 11:00
CURRENT TIME	15/10/18 9:30

TEST I.D.	4B
GEOLOGICAL UNIT	BOGGY PLAIN SUITE
START TIME	9/10/18 11:00
CURRENT TIME	15/10/18 9:30

Figure 5: Settlement test 5 days and 22.5 hours following placement of sieved crushed rock-
Left: Test 4A - Placement of dry sieved crushed rock directly onto the water surface,
Right: Test 4B - Placement of dry sieved crushed rock within a fall pipe with opening submerged 50 cm below the water surface.

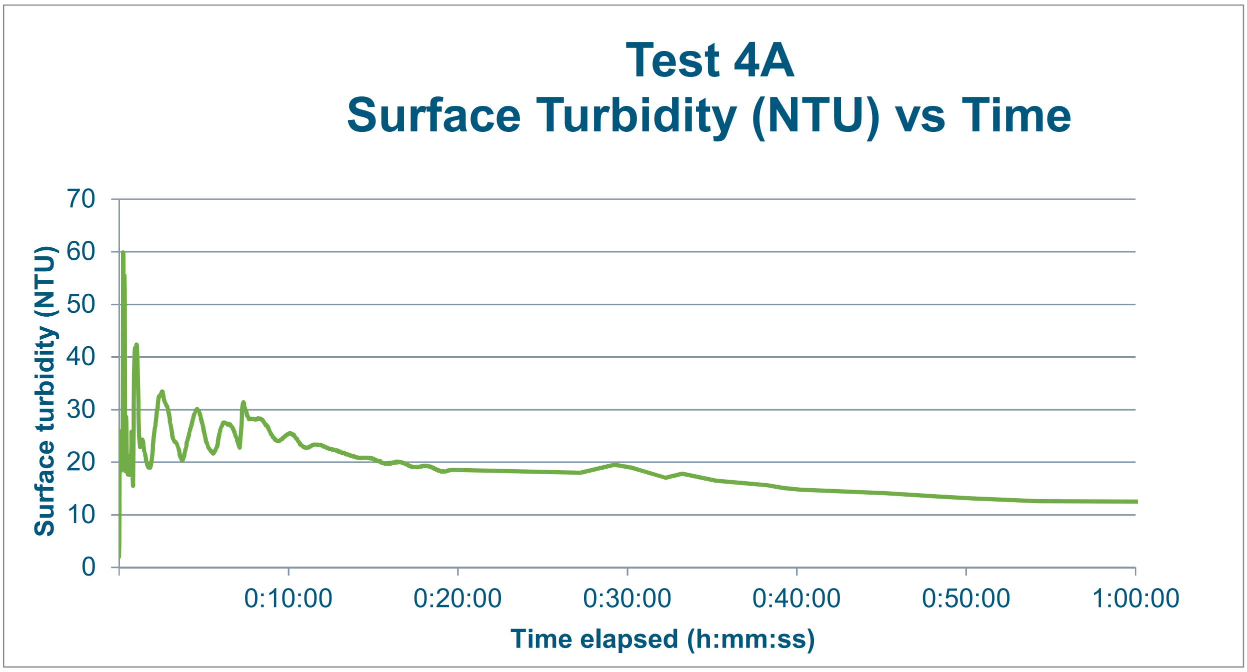
Figure 6: Settlement test 7 days and 21 hours following placement of sieved crushed rock-
Left: Test 4A - Placement of dry sieved crushed rock directly onto the water surface,
Right: Test 4B - Placement of dry sieved crushed rock within a fall pipe with opening submerged 50 cm below the water surface.

2.2.2 Test 4A - Placement of dry sieved crushed rock directly onto the water surface

For Test 4A, the sieved crushed rock was gently sprinkled onto the water surface from a height of approximately 25 cm above the water surface. Clumps of crushed rock fell to the bottom of the column relatively rapidly within approximately 10 seconds. Fine material parted from the clumps during descent and a turbid trail formed through the water column in the wake of the clumps. It is estimated that approximately 20% of the mass of crushed rock fell to the bottom of the column in clumps.

Significant diffusion and mixing of the crushed rock was observed. After approximately 35 seconds, turbidity throughout the entire water column appeared to be relatively uniform.

Surface turbidity levels were measured continuously (at one second time intervals) during the first 20 minutes of Test 4A and the Wetlab ECO-NTU sensor remained in the water column for this period. Surface turbidity levels were measured at varying time intervals thereafter. The Wetlab ECO-NTU sensor was placed in the water column for each measurement and removed after a stable reading was recorded. Surface turbidity during crushed rock placement and at various time intervals during the first hour is plotted in **Graph 4** for Test 4A**.**



Graph 4: Surface turbidity measured during the first hour following placement of Boggy Plain Suite crushed rock, Test 4A.

Surface turbidity levels increased rapidly from background levels of around 2 NTU to a maximum of around 60 NTU during placement of the sieved crushed rock (i.e. within the first minute of testing). Surface turbidity during the 10-minute period after commencement fluctuated numerous times between approximately 15 NTU and 60 NTU. Surface turbidity levels subsequently decreased to around 18 NTU approximately 20 minutes after commencement and 12.6 NTU approximately 54 minutes after commencement.

Surface turbidity measured at varying time intervals over the 10-day test duration is plotted in **Graph 3** (refer **Section 2.2.1**) for Test 4A alongside the results for Tests 4B. Surface turbidity levels continued to decrease from 12.6 NTU (20 minutes after commencement) to around 9 NTU (3 hours and 30 minutes after commencement).

After 3 hours and 30 minutes, stratification was observed in the column, approximately 8.7 cm below the water surface. This stratification boundary descended to approximately 57.4 cm below the water surface, 1 day and 1 hour after commencement at an average rate of 2.25 cm/hr and continued to gradually descend over the subsequent days.

Between approximately 4 hours and 10 days after commencement, surface turbidity fluctuated and varied between 6.2 NTU (7 days and 21 hours after commencement) and 19.5 NTU (2 days and 22 hours after commencement). The average surface turbidity recorded during this period was approximately 11 NTU. At the end of the 10-day test duration, surface turbidity was 15 NTU. At this point in time, flocculant was added to the column (**Section 2.3**).

A discussion regarding the observed increase and fluctuations in surface turbidity is provided in **Section 3**.

2.2.3 Test 4B - Placement of dry sieved crushed rock within a fall pipe with opening submerged 50 cm below the water surface

For Test 4B, the sieved crushed rock was gently sprinkled into the fall pipe with an internal diameter of approximately 50 mm. The top of the fall pipe was approximately 75 cm above the water surface. The inside of the fall pipe was rinsed with water from Talbingo Reservoir to ensure that all of the sieved crushed rock entered the column.

Significant mixing and diffusion of crushed rock was observed within the fall pipe. Clumps of crushed rock fell to the bottom of the column relatively rapidly within approximately 10 seconds. Fine material parted from the clumps during descent and a turbid trail formed through the water column in the wake of the clumps. It is estimated that approximately 10% of the mass of crushed rock fell to the bottom of the column in clumps.

The dense turbid plume in the fall pipe gradually descended and diffused throughout the water column, primarily below the base of the fall pipe. After approximately 2 minutes and 30 seconds, relatively even mixing was observed in the lower two thirds of the water column, below the base of the fall pipe. The top of the turbid plume was recorded 0.7 cm above the base of the fall pipe.

There was no immediate discernible change in turbidity above the turbid plume, with the upper 50 cm of water in the column (i.e. above the base of the fall pipe) remaining relatively clear with turbidity at background levels (refer **Graph 3**, **Section 2.2.1**). However, over the subsequent 10 days, surface turbidity increased to approximately 8.2 NTU.

The top of the turbid plume was observable for the duration of the test and gradually descended over time. After 40 minutes, the top of the plume was at 49.3 cm below the water surface, 0.7 cm above the base of the fall pipe. The top of the plume descended to 109 cm below the water surface after 9 days and 22 hours, at a rate of 6 cm/day.

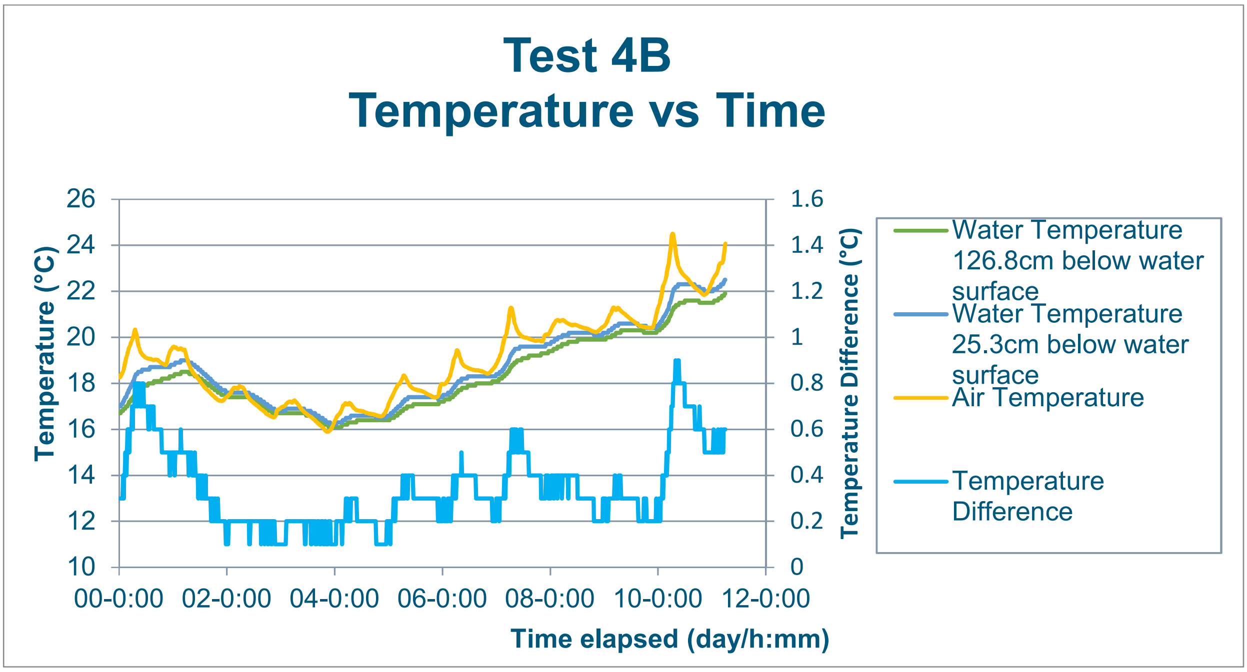
The settlement test simulating placement through a fall pipe resulted in a significant reduction in surface turbidity, compared to surface placement in Test 4A. However, after approximately 7 days and 21 hours, surface turbidity exceeded the original background turbidity levels and remained elevated for the remainder of the test.

A discussion regarding the observed increase in surface turbidity over time during Test 4B is provided in **Section 3**.

2.2.4 Air and Water Temperature

Air temperature and water temperature were recorded every 15 minutes in Test 4B for the duration of the test using Solinist Leveloggers and a Barologger. Water temperature was monitored at two depths, 25.3 cm and 126.8 cm below the water surface.

Graph 5 provides air and water temperature variation over time for Test 4B.



Graph 5: Air and water temperature in Test 4B. Elapsed time relative to commencement of Test 4A and 4B.

Air temperature in Test 4B fluctuated between approximately 15.8 °C and 24.5 °C. Block out curtains were placed across all windows for the duration of the test in an attempt to regulate air temperature within the laboratory.

Water temperature varied between 16.1 °C and 22.5 °C. Water temperature was consistently 0.1 °C to 0.9 °C warmer at the upper monitoring location and the average temperature differential between the monitoring depths was 0.34 °C. The warmer water near the top of the column would have a lower density and would therefore be buoyant compared to cooler water lower in the column.

2.3 Flocculation Test

Prior to completion of the settlement tests, a trial was undertaken to determine whether a chemical flocculant would accelerate settlement of fine particles and clarify the water. The chemical flocculant selected for the test was alum (aluminium sulphate). It should be noted that the particular chemical flocculant selected for the test was somewhat arbitrary and has not been approved for use during construction.

Flocculant was added to Test 4A on the 19th October 2018 at 9:00am, approximately 9 days and 22 hours following commencement of the settlement test. Test 4B and 4D were retained as control columns for comparison.

Surface turbidity in Test 4A, 4B and 4D on the 19th October 2018 (prior to addition of flocculant) and 22nd October 2018 (following addition of flocculant) is reported in **Table 2**. Surface turbidity in Test 4A decreased from 15 NTU to 2.1 NTU, whilst the surface turbidity in the control columns (Test 4B and 4D) remained relatively constant. This indicates that the chemical flocculant was effective in clarifying the water.

Table 2: Surface turbidity before and after the addition of flocculant to Test 4A.

Date/Time	Test 4A (NTU)	Test 4B (NTU)	Test 4D (NTU)
19th October 2018, 9:00 am	15	8.2	20.1
22nd October 2018, 9:00 am	2.1	11.6	18.6

A photograph of the three test columns taken on the 19th and 22nd October 2018 is provided in **Figure 7**. It should be noted that some of the flocculated crushed rock in Test 4A adhered to the walls of the column thereby making the column appear slightly ‘cloudy’ when viewed side on. However, when viewed from above, the water was clear as indicated by the surface turbidity reading.

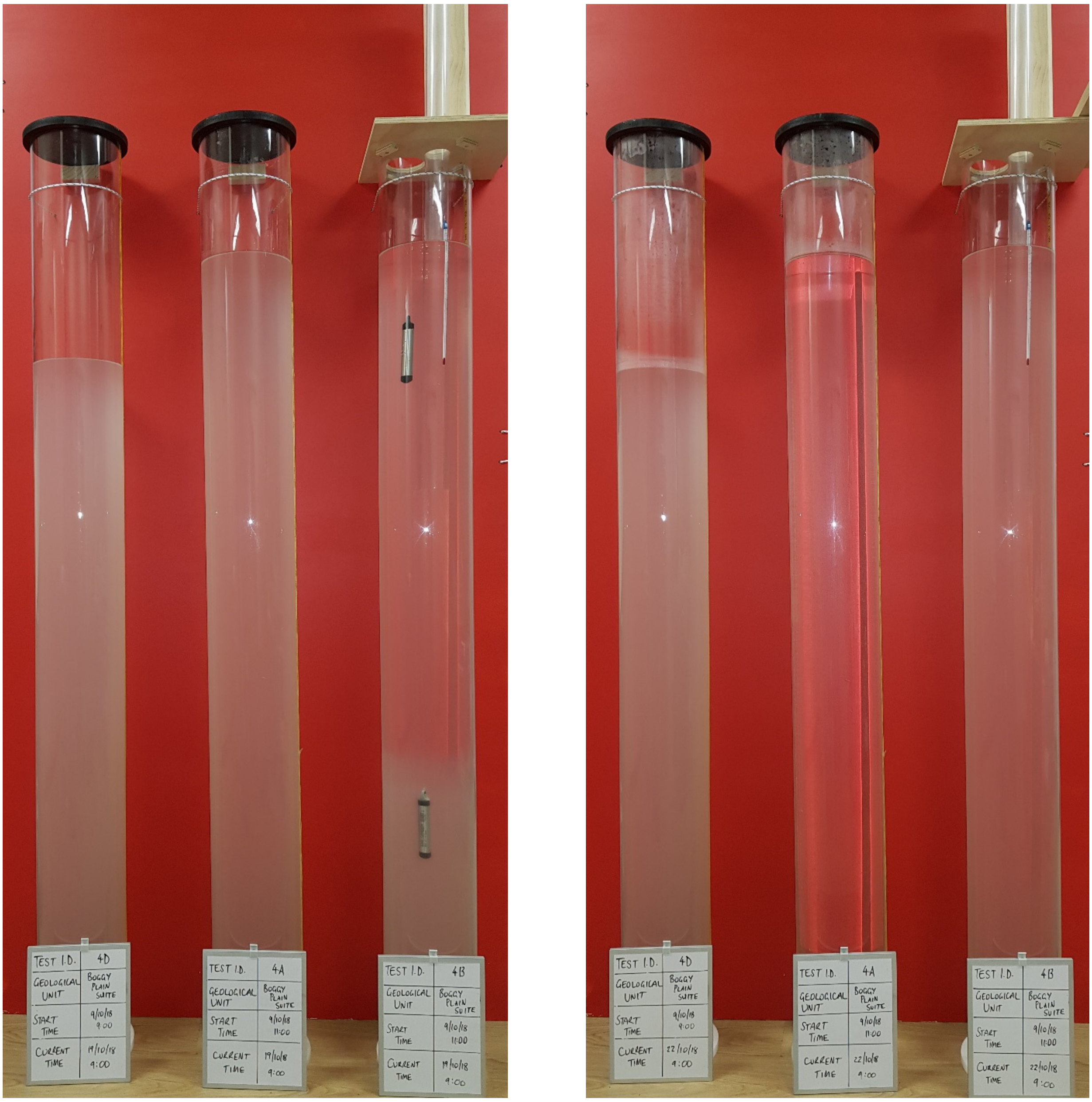


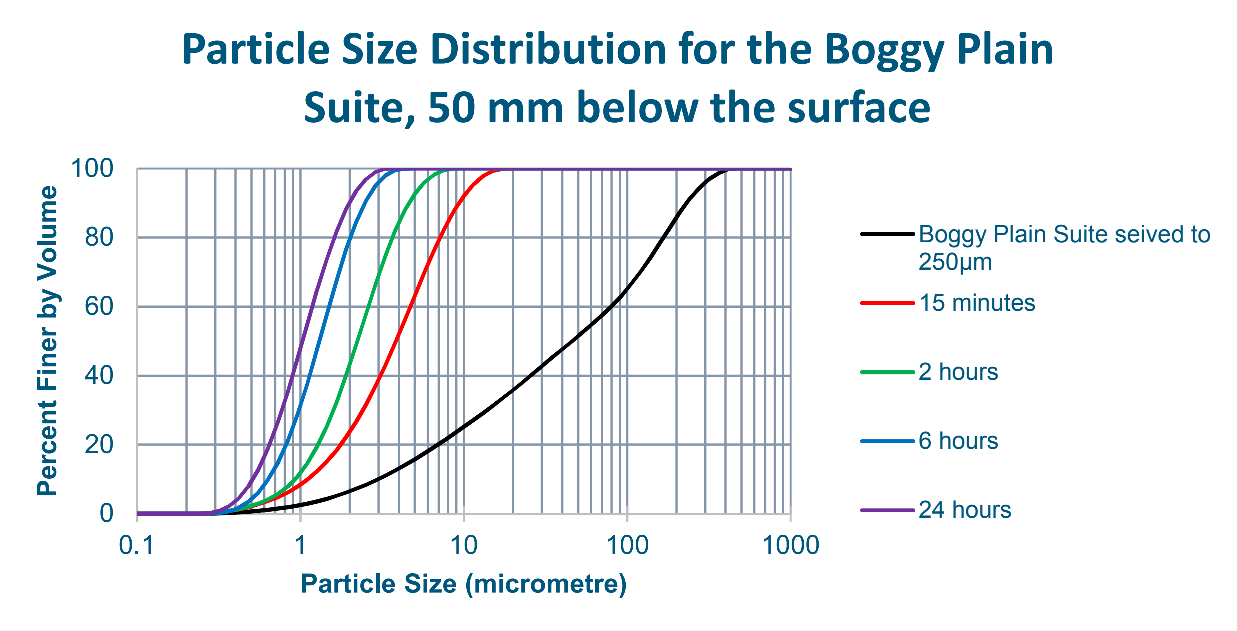
Figure 7: Column and Settlement tests prior to and following addition of chemical flocculant to Test 4A-
Left: Test 4D, 4A and 4B (from left to right) prior to the addition of flocculant to Test 4A. Photographed on the 19th October at 9:00am, approximately 9 days and 22 hours following commencement of the settlement tests.
Right: Test 4D, 4A and 4B (from left to right), following the addition of flocculant to Test 4A. Photographed on the 22nd October at 9:00 am, approximately 12 days and 22 hours following commencement of the settlement tests.

2.4 Critical Particle Size

The tests to determine the critical particle size in suspension commenced on the 9th October 2018. Particle size analysis using the Mastersizer 2000 was completed on the 9th and 10th October 2018.

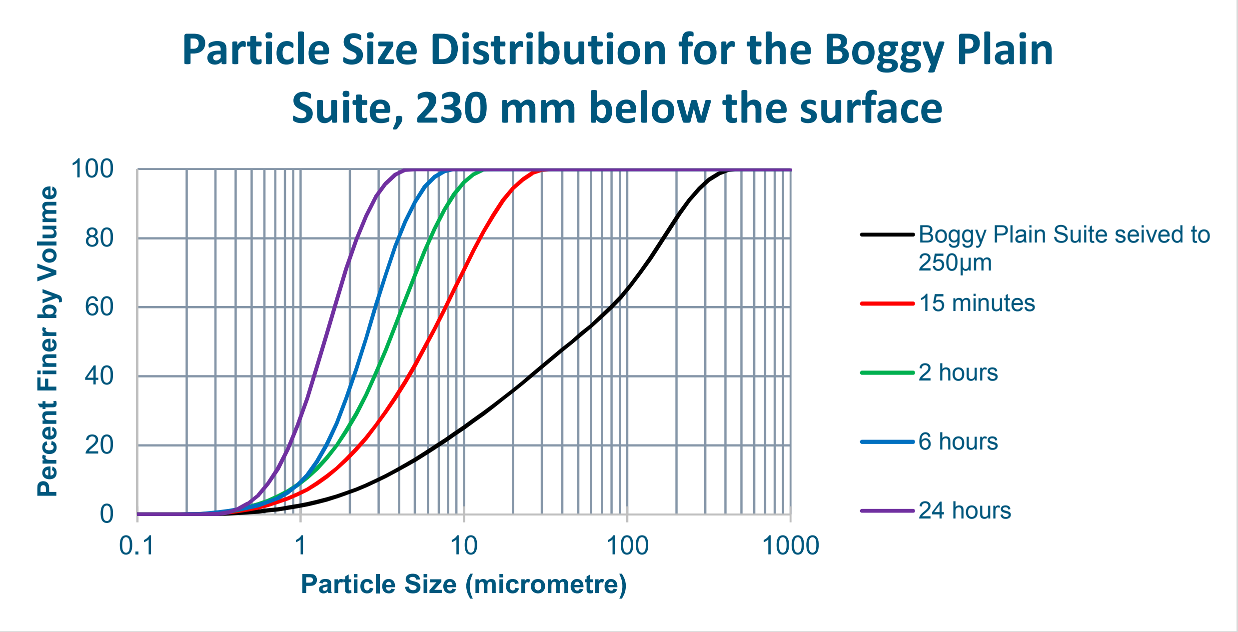
Graph 6 plots the particle size distribution of the sieved crushed rock (used for all tests) and the particle size that remains in suspension after each time interval (15 minutes, 2 hours, 6 hours, and 24 hours) at 50 mm below the water surface (850 mL mark on cylinder). The maximum particle size in suspension at

various time intervals is outlined in **Table 3**. The maximum particle size in suspension decreases over time from around 17.5 µm (15 minutes) to 3.5 µm (24 hours).



Graph 6: Particle size distribution at varying time intervals, 50 mm below the water surface.

Graph 7 plots the particle size distribution of the sieved crushed rock (used for all tests) and the particle size that remains in suspension after a given time interval (15 minutes, 2 hours, 6 hours, 24 hours and 48 hours) at 230 mm below the water surface (300 mL mark on cylinder). The maximum particle size in suspension at various time intervals is outlined in **Table 3**. The maximum particle size in suspension decreases over time from around 31 µm (15 minutes) to 4.5 µm (24 hours).



Graph 7: Particle size distribution at varying time intervals 230 mm the water surface.

Table 3: Maximum particle size in suspension at varying time intervals, 50 mm and 230 mm below the water surface.

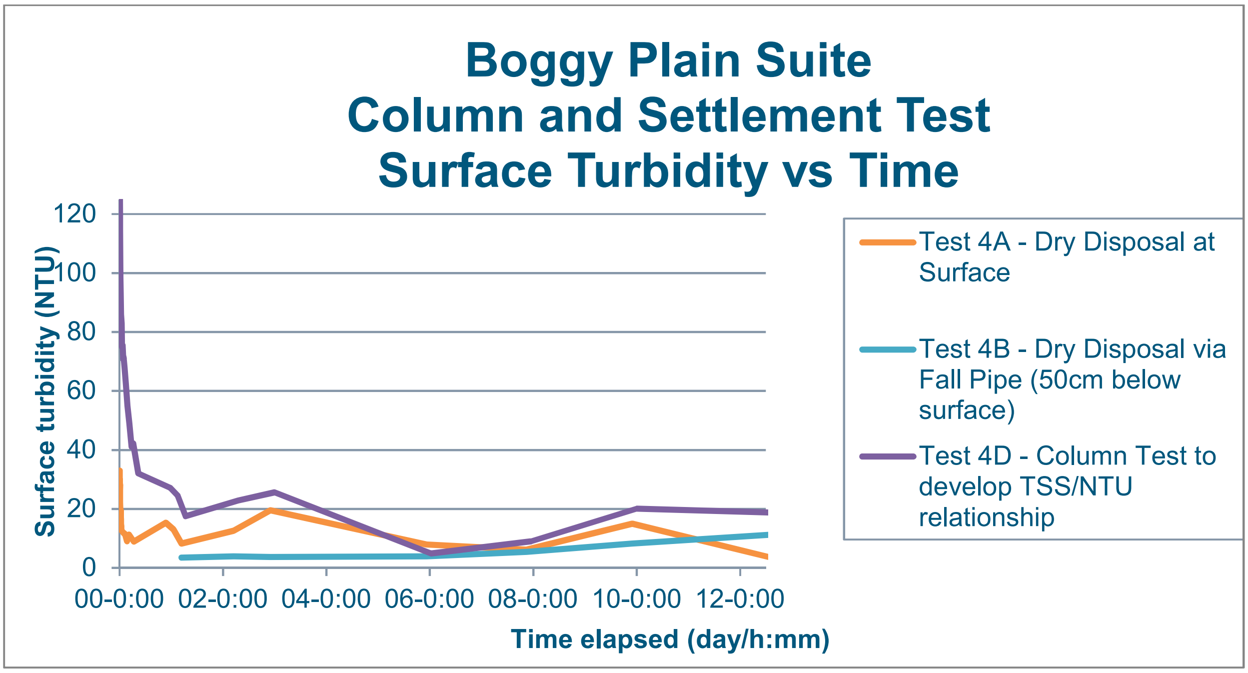
Time	Maximum particle size in suspension (µm)	
	50 mm below the water surface	230 mm below the water surface
15 minutes	17.5	31
2 hours	8	13.5
6 hours	4.5	8
24 hours	3.5	4.5

Based on the results presented above, it is evident that, for the same given time intervals, the maximum particle size in suspension is larger at greater depths within the water column, as would be expected.

3 Discussion

3.1 Fluctuating Turbidity and Increase in Surface Turbidity

As described in **Section 2**, surface turbidity in Test 4A and 4D fluctuated and surface turbidity in Test 4B increased over time. The surface turbidity for the three tests is shown in **Graph 8**. The graph includes the addition of flocculant to Test 4A, 9 days and 22 hours following commencement.



Graph 8: Surface turbidity measured during the settlement and column tests – Boggy Plain Suite (Tests 4A, 4B and 4D).

An increase in surface turbidity was unexpected, with ongoing settlement and decreasing turbidity following initial mixing considered more likely to occur. It is possible that the observations were influenced by one or more of the following factors:

1. Weak thermal convection currents within the column may result in mixing of stratified layers and rising warm water transporting suspended particles to the surface. Air temperature and water temperature was monitored for the duration of the test. The results are reported in **Section 2.2.4** and presented in **Graph 5**.

   It is apparent from **Graph 5** that the water temperature warms and cools in response to the air temperature. Further, the difference in water temperature between the top and bottom of the column increases during a warming phase and decreases during a cooling phase.

   It is inferred that heat is transferred from the air to the column and from the column to the adjacent water near the wall of the column through the process of conduction, which is the transfer of heat between objects in contact with each other, or through a substance due to the collision of molecules. Heating of water near the wall of the column would result in differential water temperature across the column with cooler water near the centre of the column. The differential water temperature would lead to two processes, conduction and convection where convection is the process of warmer water, with a lower density, rising to cooler areas in the column and cooler water, with a higher density, sinking to take the place of the warmer water. The velocity of convection currents are difficult to determine and due to a range of factors.

2. The sieved crushed rock may contain clay particles that are anionic. The repelling force between charged particles in suspension may result in suspended solids diffusing and distributing evenly throughout the water column.

3. The action of gently lowering a turbidity probe into the upper layer of the column (~3.4 cm below the water surface) may be sufficient to disturb the water column resulting in advection of very fine suspended particles.

Regardless of the reason for fluctuating and increasing surface turbidity in Test 4A, 4B and 4D, it is clear that minor disturbances to the water column are sufficient to disrupt the settlement process and redistribute fine suspended particles within the water column.

4 Conclusions

It is apparent from the column test and settlement tests that once fine crushed rock from the igneous rock in the Boggy Plain Suite geological zone enters the water column, the fine particles remain in suspension for extended periods in the order of several days to weeks. Elevated surface turbidity levels of around 15 NTU to 20 NTU were recorded at the conclusion of Tests 4A and 4D, around 10 to 12 days following commencement.

While surface turbidity levels generally appear to reduce over time, it may take an extremely long time to reach background levels of 1 NTU to 5 NTU, as reported by Cardno. Furthermore, minor disturbances to the water column are likely to disrupt the settlement process and/or re-suspend fine particles.

The critical particle size in suspension that would be contributing to prolonged surface turbidity in the water column (more than 24 hours) would be less than approximately 4.5 µm.

The results of a chemical flocculation test for the Boggy Plain Suite crushed rock indicate that the addition of flocculant may accelerate settlement of fine particles and clarify the water.

TSS-turbidity data collected during the Column Test (Test 4D) is considered to be reliable for the purpose of establishing a preliminary relationship between TSS and turbidity for the Boggy Plain Suite crushed rock. The turbidity value equivalent to 50 mg/L suspended solids is 58 NTU for this dataset. Furthermore, as the properties and grading of the crushed rock placed during construction may vary to that used in the column test, collection of field TSS-turbidity data during subaqueous excavated rock placement activities is recommended so that the relationship between turbidity and suspended solids can be continually validated and improved.

Attachment 1 – Laboratory Certificates

ALS Environmental

CERTIFICATE OF ANALYSIS

Work Order	: **ES1830022**	Page	: 1 of 12
Client	: **HASKONING AUSTRALIA- ROYAL HASKONING**	Laboratory	: Environmental Division Sydney
Contact	: MR PATRICK LAWLESS	Contact	: Customer Services ES
Address	: LEVEL 14 56 Berry Street NORTH SYDNEY 2060	Address	: 277-289 Woodpark Road Smithfield NSW Australia 2164
Telephone	: ----	Telephone	: +61-2-8784 8555
Project	: Snowy 2.0 TSS-NTU (Test 2/3)	Date Samples Received	: 10-Oct-2018 16:30
Order number	:	Date Analysis Commenced	: 11-Oct-2018
C-O-C number	: ----	Issue Date	: 17-Oct-2018 17:40
Sampler	: PATRICK LAWLESS		
Site	: ----		
Quote number	: EN/222		
No. of samples received	: 50		
No. of samples analysed	: 50		

ilac-MRA NATA

Accreditation No. 825
Accredited for compliance with
ISO/IEC 17025 - Testing

This report supersedes any previous report(s) with this reference. Results apply to the sample(s) as submitted. This document shall not be reproduced, except in full.

This Certificate of Analysis contains the following information:

- General Comments
- Analytical Results

Additional information pertinent to this report will be found in the following separate attachments: Quality Control Report, QA/QC Compliance Assessment to assist with Quality Review and Sample Receipt Notification.

Signatories

This document has been electronically signed by the authorized signatories below. Electronic signing is carried out in compliance with procedures specified in 21 CFR Part 11.

Signatories	*Position*	*Accreditation Category*
Ankit Joshi	Inorganic Chemist	Sydney Inorganics, Smithfield, NSW

General Comments

The analytical procedures used by the Environmental Division have been developed from established internationally recognized procedures such as those published by the USEPA, APHA, AS and NEPM. In house developed procedures are employed in the absence of documented standards or by client request.

Where moisture determination has been performed, results are reported on a dry weight basis.

Where a reported less than (<) result is higher than the LOR, this may be due to primary sample extract/digestate dilution and/or insufficient sample for analysis.

Where the LOR of a reported result differs from standard LOR, this may be due to high moisture content, insufficient sample (reduced weight employed) or matrix interference.

When sampling time information is not provided by the client, sampling dates are shown without a time component. In these instances, the time component has been assumed by the laboratory for processing purposes.

Where a result is required to meet compliance limits the associated uncertainty must be considered. Refer to the ALS Contact for details.

Key :
CAS Number = CAS registry number from database maintained by Chemical Abstracts Services. The Chemical Abstracts Service is a division of the American Chemical Society.
LOR = Limit of reporting
^ = This result is computed from individual analyte detections at or above the level of reporting
ø = ALS is not NATA accredited for these tests.
~ = Indicates an estimated value.

Analytical Results

Sub-Matrix: **WATER**
(Matrix: **WATER**)

			Client sample ID	**2D-20**	**2D-21**	**2D-22**	**2D-23**	**2D-24**
			Client sampling date / time	03-Oct-2018 00:00	04-Oct-2018 00:00	05-Oct-2018 00:00	06-Oct-2018 00:00	08-Oct-2018 00:00
Compound	*CAS Number*	*LOR*	*Unit*	**ES1830022-001**	**ES1830022-002**	**ES1830022-003**	**ES1830022-004**	**ES1830022-005**
				Result	Result	Result	Result	Result
EA025: Total Suspended Solids dried at 104 ± 2°C								
Suspended Solids (SS)	----	5	mg/L	**----**	<5	**16**	**----**	**----**
Suspended Solids (SS)	----	5	mg/L	**8**	**----**	**----**	**12**	**11**
EA045: Turbidity								
Turbidity	----	0.1	NTU	**32.9**	**21.2**	**30.4**	**35.5**	**23.7**

Analytical Results

Sub-Matrix: **WATER** (Matrix: **WATER**)			*Client sample ID*	**3D-17**	**3D-18**	**3D-19**	**3D-20**	**3D-21**
			Client sampling date / time	03-Oct-2018 00:00	04-Oct-2018 00:00	05-Oct-2018 00:00	06-Oct-2018 00:00	08-Oct-2018 00:00
Compound	*CAS Number*	*LOR*	*Unit*	**ES1830022-006**	**ES1830022-007**	**ES1830022-008**	**ES1830022-009**	**ES1830022-010**
				Result	Result	Result	Result	Result
EA025: Total Suspended Solids dried at 104 ± 2°C								
Suspended Solids (SS)	----	5	mg/L	**----**	**8**	**13**	**----**	**----**
Suspended Solids (SS)	----	5	mg/L	**8**	**----**	**----**	**8**	<5
EA045: Turbidity								
Turbidity	----	0.1	NTU	**30.1**	**28.7**	**28.2**	**26.8**	**22.6**

Analytical Results

Sub-Matrix: **WATER**
(Matrix: **WATER)**

			Client sample ID	**4D-1**	**4D-2**	**4D-3**	**4D-4**	**4D-5**
			Client sampling date / time	09-Oct-2018 00:00	09-Oct-2018 00:00	09-Oct-2018 00:00	09-Oct-2018 00:00	09-Oct-2018 00:00
Compound	CAS Number	LOR	Unit	**ES1830022-011**	**ES1830022-012**	**ES1830022-013**	**ES1830022-014**	**ES1830022-015**
				Result	Result	Result	Result	Result
EA025: Total Suspended Solids dried at 104 ± 2°C								
Suspended Solids (SS)	----	5	mg/L	<5	**206**	**204**	**121**	**166**
EA045: Turbidity								
Turbidity	----	0.1	NTU	**0.4**	**240**	**148**	**150**	**109**

Analytical Results

Sub-Matrix: **WATER**
(Matrix: **WATER)**

			Client sample ID	**4D-6**	**4D-7**	**4D-8**	**4D-9**	**4D-10**
			Client sampling date / time	09-Oct-2018 00:00	09-Oct-2018 00:00	09-Oct-2018 00:00	09-Oct-2018 00:00	09-Oct-2018 00:00
Compound	*CAS Number*	*LOR*	*Unit*	**ES1830022-016**	**ES1830022-017**	**ES1830022-018**	**ES1830022-019**	**ES1830022-020**
				Result	Result	Result	Result	Result
EA025: Total Suspended Solids dried at 104 ± 2°C								
Suspended Solids (SS)	----	5	mg/L	**116**	**142**	**45**	**42**	**97**
EA045: Turbidity								
Turbidity	----	0.1	NTU	**169**	**119**	**130**	**125**	**94.2**

Analytical Results

Sub-Matrix: **WATER** (Matrix: **WATER**)			Client sample ID	**4D-11**	**4D-12**	**4D-13**	**4D-14**	**4D-15**
			Client sampling date / time	09-Oct-2018 00:00	09-Oct-2018 00:00	09-Oct-2018 00:00	09-Oct-2018 00:00	09-Oct-2018 00:00
Compound	CAS Number	LOR	Unit	**ES1830022-021**	**ES1830022-022**	**ES1830022-023**	**ES1830022-024**	**ES1830022-025**
				Result	Result	Result	Result	Result
EA025: Total Suspended Solids dried at 104 ± 2°C								
Suspended Solids (SS)	----	5	mg/L	**84**	**80**	**31**	**40**	**22**
EA045: Turbidity								
Turbidity	----	0.1	NTU	**92.7**	**96.0**	**113**	**110**	**100**

Analytical Results

Sub-Matrix: **WATER**
(Matrix: **WATER)**

			Client sample ID	**4D-16**	**4D-17**	**4D-18**	**4D-19**	**5D-1**
			Client sampling date / time	09-Oct-2018 00:00	09-Oct-2018 00:00	09-Oct-2018 00:00	09-Oct-2018 00:00	09-Oct-2018 00:00
Compound	*CAS Number*	*LOR*	*Unit*	**ES1830022-026**	**ES1830022-027**	**ES1830022-028**	**ES1830022-029**	**ES1830022-030**
				Result	Result	Result	Result	Result
EA025: Total Suspended Solids dried at 104 ± 2°C								
Suspended Solids (SS)	----	5	mg/L	**24**	**54**	**51**	**25**	<5
EA045: Turbidity								
Turbidity	----	0.1	NTU	**22.8**	**25.8**	**33.1**	**29.3**	**0.5**

Analytical Results

Sub-Matrix: **WATER** (Matrix: **WATER**)			*Client sample ID*	**5D-2**	**5D-3**	**5D-4**	**5D-5**	**5D-6**
			Client sampling date / time	09-Oct-2018 00:00	09-Oct-2018 00:00	09-Oct-2018 00:00	09-Oct-2018 00:00	09-Oct-2018 00:00
Compound	*CAS Number*	*LOR*	*Unit*	**ES1830022-031**	**ES1830022-032**	**ES1830022-033**	**ES1830022-034**	**ES1830022-035**
				Result	Result	Result	Result	Result
EA025: Total Suspended Solids dried at 104 ± 2°C								
Suspended Solids (SS)	----	5	mg/L	**130**	**124**	**142**	**118**	**180**
EA045: Turbidity								
Turbidity	----	0.1	NTU	**184**	**177**	**182**	**168**	**167**

Analytical Results

Sub-Matrix: **WATER** (Matrix: **WATER**)			*Client sample ID*	**5D-7**	**5D-8**	**5D-9**	**5D-10**	**5D-11**
			Client sampling date / time	09-Oct-2018 00:00	09-Oct-2018 00:00	09-Oct-2018 00:00	09-Oct-2018 00:00	09-Oct-2018 00:00
Compound	*CAS Number*	*LOR*	*Unit*	**ES1830022-036**	**ES1830022-037**	**ES1830022-038**	**ES1830022-039**	**ES1830022-040**
				Result	Result	Result	Result	Result
EA025: Total Suspended Solids dried at 104 ± 2°C								
Suspended Solids (SS)	----	5	mg/L	**132**	**95**	**110**	**70**	**62**
EA045: Turbidity								
Turbidity	----	0.1	NTU	**130**	**107**	**101**	**60.2**	**20.8**

Analytical Results

Sub-Matrix: **WATER**
(Matrix: **WATER)**

			Client sample ID	**5D-12**	**5D-13**	**5D-14**	**5D-15**	**4D-20**
			Client sampling date / time	09-Oct-2018 00:00	09-Oct-2018 00:00	09-Oct-2018 00:00	09-Oct-2018 00:00	10-Oct-2018 00:00
Compound	*CAS Number*	*LOR*	*Unit*	**ES1830022-041**	**ES1830022-042**	**ES1830022-043**	**ES1830022-044**	**ES1830022-045**
				Result	Result	Result	Result	Result
EA025: Total Suspended Solids dried at 104 ± 2°C								
Suspended Solids (SS)	----	5	mg/L	**24**	**26**	**11**	**10**	**26**
EA045: Turbidity								
Turbidity	----	0.1	NTU	**31.2**	**19.2**	**16.3**	**16.0**	**20.9**

Analytical Results

Sub-Matrix: **WATER** (Matrix: **WATER**)				Client sample ID	**4D-21**	**5D-16**	**5D-17a**	**5D-17b**	**5D-18**
				Client sampling date / time	10-Oct-2018 00:00	10-Oct-2018 00:00	10-Oct-2018 00:00	10-Oct-2018 00:00	10-Oct-2018 00:00
Compound	CAS Number	LOR	Unit		**ES1830022-046**	**ES1830022-047**	**ES1830022-048**	**ES1830022-049**	**ES1830022-050**
					Result	Result	Result	Result	Result
EA025: Total Suspended Solids dried at 104 ± 2°C									
Suspended Solids (SS)	----	5	mg/L		**12**	**16**	**7**	**14**	**17**
EA045: Turbidity									
Turbidity	----	0.1	NTU		**17.0**	**9.2**	**7.3**	**7.8**	**9.8**

ALS Environmental

CERTIFICATE OF ANALYSIS

Work Order : **ES1831104**
Client : **HASKONING AUSTRALIA- ROYAL HASKONING**
Contact : MR PATRICK LAWLESS
Address : LEVEL 14 56 Berry Street
NORTH SYDNEY 2060
Telephone : ----
Project : Snowy 2.0 TSS-NTU (Test 4/5)
Order number :
C-O-C number : ----
Sampler : Patrick Lawless
Site : ----
Quote number : EN/222
No. of samples received : 7
No. of samples analysed : 7

Page : 1 of 4
Laboratory : Environmental Division Sydney
Contact : Customer Services ES
Address : 277-289 Woodpark Road Smithfield NSW Australia 2164
Telephone : +61-2-8784 8555
Date Samples Received : 19-Oct-2018 14:35
Date Analysis Commenced : 20-Oct-2018
Issue Date : 25-Oct-2018 12:32

ilac-MRA NATA
Accreditation No. 825
Accredited for compliance with
ISO/IEC 17025 - Testing

This report supersedes any previous report(s) with this reference. Results apply to the sample(s) as submitted. This document shall not be reproduced, except in full.

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Signatories

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Signatories	*Position*	*Accreditation Category*
Ankit Joshi	Inorganic Chemist	Sydney Inorganics, Smithfield, NSW

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Where the LOR of a reported result differs from standard LOR, this may be due to high moisture content, insufficient sample (reduced weight employed) or matrix interference.

When sampling time information is not provided by the client, sampling dates are shown without a time component. In these instances, the time component has been assumed by the laboratory for processing purposes.

Where a result is required to meet compliance limits the associated uncertainty must be considered. Refer to the ALS Contact for details.

Key : CAS Number = CAS registry number from database maintained by Chemical Abstracts Services. The Chemical Abstracts Service is a division of the American Chemical Society.
LOR = Limit of reporting
^ = This result is computed from individual analyte detections at or above the level of reporting
ø = ALS is not NATA accredited for these tests.
~ = Indicates an estimated value.

Analytical Results

Sub-Matrix: **WATER** (Matrix: **WATER**)			*Client sample ID*	**4D-22**	**4D-23**	**4D-24**	**4D-25**	**5D-19**
			Client sampling date / time	11-Oct-2018 00:00	12-Oct-2018 00:00	15-Oct-2018 00:00	19-Oct-2018 00:00	11-Oct-2018 00:00
Compound	*CAS Number*	*LOR*	*Unit*	**ES1831104-001**	**ES1831104-002**	**ES1831104-003**	**ES1831104-004**	**ES1831104-005**
				Result	Result	Result	Result	Result
EA025: Total Suspended Solids dried at 104 ± 2°C								
Suspended Solids (SS)	----	5	mg/L	----	----	<5	----	----
Suspended Solids (SS)	----	5	mg/L	**18**	**26**	----	**15**	**12**
EA045: Turbidity								
Turbidity	----	0.1	NTU	**15.9**	**16.0**	**5.8**	**21.5**	**6.6**

Analytical Results

Sub-Matrix: **WATER** (Matrix: **WATER**)			*Client sample ID*	**5D-20**	**5D-21**	**----**	**----**	**----**
			Client sampling date / time	12-Oct-2018 00:00	15-Oct-2018 00:00	----	----	----
Compound	*CAS Number*	*LOR*	*Unit*	**ES1831104-006**	**ES1831104-007**	**--------**	**--------**	**--------**
				Result	Result	----	----	----
EA025: Total Suspended Solids dried at 104 ± 2°C								
Suspended Solids (SS)	----	5	mg/L	**----**	<5	**----**	**----**	**----**
Suspended Solids (SS)	----	5	mg/L	**21**	**----**	**----**	**----**	**----**
EA045: Turbidity								
Turbidity	----	0.1	NTU	**8.9**	**3.9**	**----**	**----**	**----**

Attachment 2 – Boggy Plain Suite Laboratory Log Records

Test ID	4A	
Geological Unit	Boggy Plain Suite	
Description	Test 4A - Dry Disposal at Surface	
Start Date/Time	09-10-18 11:00	
Water volume	50 L	
Water surface level in column	172.8	cm
Mass sediment added	40 g	(sieved to <250 um)
Test Location	Geochemical Assessments Workshop, Roseville NSW	
Test Officers	Pat Lawless, Rick Plain	

Observations

Date/Time	Time since start	Turbidity (NTU)	Measurement Location (cm)	Measurement Depth (cm)	Comments
09-10-18 8:42	2 Hours Prior	1.9	169.4	3.4	Background turbidity measured 10 minutes before test start
09-10-18 11:03	00-0:03	33	169.4	3.4	
09-10-18 11:04	00-0:04	31	169.4	3.4	
09-10-18 11:04	00-0:04	24	169.4	3.4	
09-10-18 11:05	00-0:05	22	169.4	3.4	
09-10-18 11:06	00-0:06	30	169.4	3.4	
09-10-18 11:06	00-0:06	26	169.4	3.4	
09-10-18 11:07	00-0:07	22	169.4	3.4	
09-10-18 11:08	00-0:08	24.5	169.4	3.4	
09-10-18 11:09	00-0:09	28.3	169.4	3.4	
09-10-18 11:13	00-0:13	22.3	169.4	3.4	
09-10-18 11:18	00-0:18	19.1	169.4	3.4	
09-10-18 11:20	00-0:20	18.5	169.4	3.4	
09-10-18 11:28	00-0:28	18	169.4	3.4	
09-10-18 11:30	00-0:30	19.5	169.4	3.4	
09-10-18 11:31	00-0:31	19	169.4	3.4	
09-10-18 11:33	00-0:33	17	169.4	3.4	
09-10-18 11:34	00-0:34	17.8	169.4	3.4	
09-10-18 11:36	00-0:36	16.5	169.4	3.4	
09-10-18 11:39	00-0:39	15.6	169.4	3.4	
09-10-18 11:40	00-0:40	15.1	169.4	3.4	
09-10-18 11:41	00-0:41	14.8	169.4	3.4	
09-10-18 11:46	00-0:46	14.1	169.4	3.4	
09-10-18 11:49	00-0:49	13.5	169.4	3.4	
09-10-18 11:51	00-0:51	13.16	169.4	3.4	
09-10-18 11:55	00-0:55	12.6	169.4	3.4	
09-10-18 12:35	00-1:35	12.1	169.4	3.4	
09-10-18 13:35	00-2:35	11.4	169.4	3.4	
09-10-18 14:30	00-3:30	9	169.4	3.4	Stratification at 161.7 cm.
09-10-18 15:20	00-4:20	11.3	169.4	3.4	Stratification at 160.0 cm.
09-10-18 17:40	00-6:40	8.9	169.4	3.4	Stratification at 153.5 cm.
10-10-18 8:30	00-21:30	15.3	169.4	3.4	Stratification at 148 cm.
10-10-18 12:00	01-1:00	13	169.4	3.4	Stratification at 122 cm.
10-10-18 15:40	01-4:40	8.2	169.4	3.4	Stratification noted in photographs. Level not recorded.
11-10-18 16:00	02-5:00	12.6	169.4	3.4	Stratification noted in photographs. Level not recorded.
12-10-18 9:00	02-22:00	19.5	169.4	3.4	Minor stratification at 79 cm.
15-10-18 9:30	05-22:30	7.95	169.4	3.4	Gradual change below ~166 cm. Stratification noted in photographs at approximately 46 cm. Level not recorded.
17-10-18 8:00	07-21:00	6.2	169.4	3.4	Gradual change below ~166 cm.
19-10-18 9:00	09-22:00	15	169.4	3.4	**Flocculant added to the column.**
22-10-18 9:00	12-22:00	2.1	169.4	3.4	

Test ID	4B		
Geological Unit	Boggy Plain Suite	BH3106-226	
Description	Test 4B - Dry Disposal via Fall Pipe (50cm below surface)		
Start Date/Time	09-10-18 11:00		
Water volume	50 L		
Water surface level in column	172.8	cm	
Mass sediment added	40 g	(sieved to <250 um)	
Test Location	Geochemical Assessments Workshop, Roseville NSW		
Test Officers	Pat Lawless, Rick Plain		
Depth of Temperature Probes	147.5 cm	46 cm	Old Probe at Top

<u>Observations</u>

Date/Time	Time since start	Turbidity (NTU)	Measurement Location (cm)	Measurement Depth (cm)	Comments
09-10-18 8:42	2 Hours Prior	1.7	169.4	3.4	Background turbidity measured 10 minutes before test start
09-10-18 11:00	00-0:00		169.4	3.4	
09-10-18 11:10	00-0:10		169.4	3.4	
09-10-18 11:40	00-0:40		169.4	3.4	Top of plume at 123.5 cm.
09-10-18 11:58	00-0:58		169.4	3.4	Top of plume at 123.4 cm.
09-10-18 13:30	00-2:30		169.4	3.4	Top of plume at 122.6 cm.
09-10-18 14:30	00-3:30		169.4	3.4	Top of plume at 122.1 cm.
09-10-18 15:20	00-4:20		169.4	3.4	Top of plume at 121.9 cm.
09-10-18 17:40	00-6:40		169.4	3.4	Top of plume at 121.9 cm.
10-10-18 8:30	00-21:30	3.3	169.4	3.4	Top of plume at 119.8 cm. Very minor turbidity above up to ~145 cm.
10-10-18 12:00	01-1:00		169.4	3.4	Top of plume at 118.9 cm.
10-10-18 15:40	01-4:40	3.5	169.4	3.4	Top of plume at 118.9 cm.
11-10-18 16:00	02-5:00	3.85	169.4	3.4	Top of plume at 115 cm.
12-10-18 9:00	02-22:00	3.7	169.4	3.4	Top of plume at 113 cm.
15-10-18 9:30	05-22:30	3.9	169.4	3.4	Top of plume at 105 cm.
17-10-18 8:00	07-21:00	5.4	169.4	3.4	Top of plume at 71.5 cm. Haze above to approximately 141 cm.
19-10-18 9:00	09-22:00	8.2	169.4	3.4	Top of plume at 63.8 cm. Haze above to approximately 141 cm.
22-10-18 9:00	12-22:00	11.6	169.4	3.4	

Test ID	4D	
Geological Unit	Boggy Plain Suite	
Description	Test 4D - Column Test to develop TSS/NTU relationship	
Start Date/Time	09-10-18 9:00	
Water volume	50 L	
Water surface level in column	172.8	cm
Mass sediment added	47.5 g	(sieved to <250 um)
Test Location	Geochemical Assessments Workshop, Roseville NSW	
Test Officers	Pat Lawless, Rick Plain	

<u>Observations</u>

Date/Time	Time since start	Turbidity (NTU)		TSS Sample Taken?	TSS Sample ID	Column Measurements			Comments
		Inside Column	Inside Beaker			Water Surface	Measurement Location	Sensor Depth	
09-10-18 8:42	20 minutes prior	2.5	0.7	Yes	4D-1	172.8	169.4	3.4	Before commencement
09-10-18 9:03	00-0:03	140	150	Yes	4D-2	171.9	168.5	3.4	Beaker reading range 140-160 NTU.
09-10-18 9:06	00-0:06	137	120	Yes	4D-3	171.1	167.7	3.4	Beaker reading range 115-135 NTU.
09-10-18 9:10	00-0:10	119	110	Yes	4D-4	170.7	167.3	3.4	Beaker reading range 100-130 NTU.
09-10-18 9:15	00-0:15	115	110	Yes	4D-5	170.1	166.7	3.4	Beaker reading range 100-115 NTU.
09-10-18 9:22	00-0:22	99	98	Yes	4D-6	168.7	165.3	3.4	Beaker reading range 85-105 NTU.
09-10-18 9:30	00-0:30	93	102	Yes	4D-7	168.1	164.7	3.4	Beaker reading range 95-105 NTU.
09-10-18 9:40	00-0:40	86	96	Yes	4D-8	167.2	163.8	3.4	Beaker reading range 86-106 NTU.
09-10-18 9:55	00-0:55	83	87	Yes	4D-9	166.3	162.9	3.4	Beaker reading range 78-90 NTU.
09-10-18 10:05	00-1:05	75	77	Yes	4D-10	165.3	161.9	3.4	Beaker reading range 68-85 NTU.
09-10-18 10:25	00-1:25	75.5	69	Yes	4D-11	164.6	161.2	3.4	Beaker reading range 66-72 NTU.
09-10-18 10:40	00-1:40	70.8	65	Yes	4D-12	163.6	160.2	3.4	Beaker reading range 60-70 NTU.
09-10-18 10:55	00-1:55	71.4	71	Yes	4D-13	162.8	159.4	3.4	Beaker reading range 62-72 NTU.
09-10-18 11:20	00-2:20	68	72	Yes	4D-14	162	158.6	3.4	Beaker reading range 65-80 NTU.
09-10-18 11:55	00-2:55	62.5	58	Yes	4D-15	160.5	157.1	3.4	Beaker reading range 56-60 NTU.
09-10-18 12:40	00-3:40	55	55	Yes	4D-16	160	156.6	3.4	Beaker reading range 52-58 NTU.
09-10-18 13:30	00-4:30	49	50	Yes	4D-17	158.7	155.3	3.4	Fairly stable 49-51 NTU inside beaker
09-10-18 14:30	00-5:30	41	51	Yes	4D-18	157.9	154.5	3.4	
09-10-18 15:20	00-6:20	42.2		No		157	153.6	3.4	
09-10-18 17:40	00-8:40	32	38	Yes	4D-19	157	153.6	3.4	Beaker reading range 34-45 NTU.
10-10-18 8:30	00-23:30	27.1	30	Yes	4D-20	155.6	152.2	3.4	Minor stratification at 139.5 cm. Beaker reading range 26-32 NTU.
10-10-18 12:00	01-3:00	24.5		No		154.6	151.2	3.4	Minor stratification at 132.5 cm.
10-10-18 15:40	01-6:40	17.5	19.7	Yes	4D-21	154.6	151.2	3.4	
11-10-18 16:00	02-7:00	22.85	20.2	Yes	4D-22	153.5	150.1	3.4	Very minor stratification at 114 cm.
12-10-18 9:00	03-0:00	25.6	23.7	Yes	4D-23	152.4	149	3.4	Very minor stratification at 102 cm.
15-10-18 9:30	06-0:30	4.9	7.3	Yes	4D-24	151.3	147.9	3.4	Top clear to approximately 144 cm. 11.1 NTU in column after taking sample.
17-10-18 8:00	07-23:00	9		No		150.5	147.1	3.4	Top clear to approximately 144 cm. Minor stratification at 127 cm.
19-10-18 9:00	10-0:00	20.1	24	Yes	4D-25	150.5	147.1	3.4	
22-10-18 9:00	13-0:00	18.6		No		149.5	146.1	3.4	

Appendix E

TSS – Turbidity and Settling Test Results Gooandra Volcanics Geological Zone

Table of Contents

1 Introduction

The Gooandra Volcanics geological zone comprises extrusive volcanic deposits formed in deep marine environments. A 1-m long section of core from this geological zone was supplied to Royal HaskoningDHV (Haskoning) from BH3108, taken between 263 m and 264 m below the ground surface. The rock core was logged as dolerite, an intrusive igneous rock.

Water for laboratory testing was obtained from Talbingo Reservoir on the 2nd October 2018. The water was collected in 1000 L Intermediate Bulk Containers (IBC) and delivered to Haskoning on the 5th October 2018. The turbidity of the reservoir water sample used for the testing was between 1.8 and 2.7 NTU. This is within the turbidity range of field monitoring, undertaken by Cardno in 2018, which indicated typical 'background' turbidity of 1 to 5 NTU in Talbingo Reservoir.

2 Results

2.1 Test 5D – TSS-Turbidity

2.1.1 Overview

The TSS-Turbidity Test for the Gooandra Volcanics crushed rock ('Test 5D') commenced on the 9th October 2018 at 12:50pm and concluded on the 22nd October 2018, approximately 13 days following commencement.

The Certificate of Analysis provided by ALS Environmental for the TSS and turbidity analyses undertaken for samples collected during testing is provided in **Attachment 1**. Laboratory log records completed during the TSS-turbidity test are provided in **Attachment 2**, which includes turbidity measurements undertaken during testing for each sample.

Photographs taken during the column test are provided in **Figure 1**. These photographs were taken:

- prior to commencement;
- 2 hours and 25 minutes after commencement;
- 1 day and 2.7 hours after commencement;
- 5 days and 20.7 hours after commencement; and
- 12 days and 20.2 hours after commencement.

Figure 1: Column test –

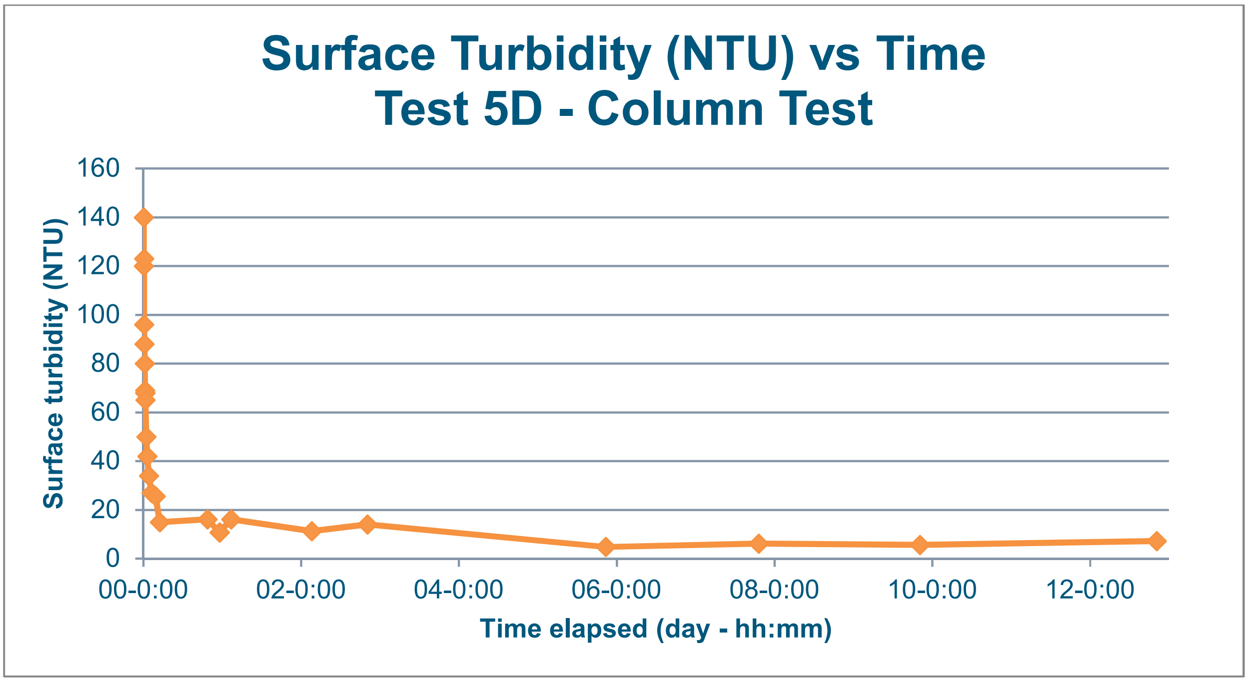
1. *Talbingo Reservoir water without addition of the sieved crushed rock,*
2. *Column test 2 hours and 25 minutes after commencement,*
3. *Column test 1 day and 2.7 hours after commencement,*
4. *Column test 5 days and 20.7 hours after commencement, and*
5. *Column test 12 days and 20.2 hours after commencement.*

2.1.2 Surface Turbidity vs Time Results

The variation in surface turbidity during Test 5D is plotted in **Graph 1**. The graph shows that surface turbidity decreased relatively rapidly from 140 NTU to 50 NTU during the first hour of testing and approximately 5 hours after commencement, surface turbidity decreased to 15 NTU.

Between approximately 6 hours after commencement and 13 days after commencement, surface turbidity fluctuated between 4.8 NTU (5 days and 21 hours after commencement) to 16.1 NTU (1 day and 3 hours after commencement). The average surface turbidity during this period was 10.3 NTU. After approximately 13 days, surface turbidity was recorded at 7.2 NTU.

A discussion regarding the observed increase and fluctuations in surface turbidity is provided in **Section 3**.



Graph 1: Surface turbidity measured during the column test – Gooandra Volcanics crushed rock (Test 5D).

2.1.3 TSS – Turbidity Results

A total of 22 samples were collected during testing for laboratory TSS and turbidity analysis. TSS values for the collected samples ranged between <5 mg/L[1] and 180 mg/L, whilst turbidity values of up to 135 NTU were recorded.

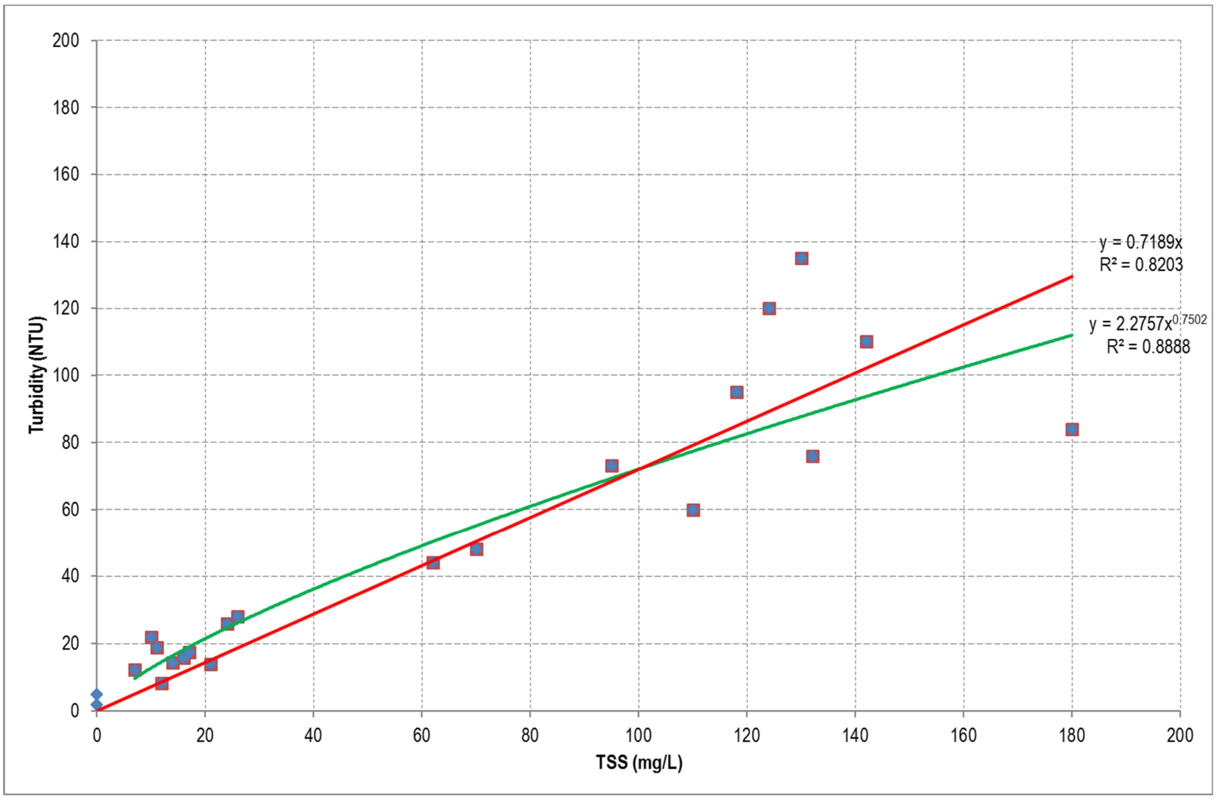
A plot of TSS versus turbidity for all data collected during testing is provided in **Graph 2**. Turbidity values used in this dataset are the measurements taken during testing (inside the glass beaker prior to sub-sampling) rather than the laboratory results[2]. This dataset is plotted with trendlines corresponding to both

---

[1] The Limit of Reporting (LOR) value for TSS analysis is 5 mg/L, refer **Attachment 1**. Results for samples with TSS concentrations below the LOR value are reported as <5 mg/L.

[2] Turbidity results reported by the laboratory were compared with turbidity results obtained during testing using the Wetlab-ECO-NTU sensor. No significant differences between the turbidity datasets were evident (i.e. selection of the turbidity dataset does not significantly influence the TSS-turbidity relationship reported herein).

linear and power functions. It is evident that the power function provides a slightly closer fit of the data, characterised by an R^2 value of 0.89[3] whereas the linear line of best fit has a lower R^2 value of 0.82.



Graph 2: TSS-turbidity results – Gooandra Volcanics crushed rock (Test 5D)

2.1.4 TSS – Turbidity Relationship

A summary of the TSS-turbidity relationships determined for the Test 5D dataset is provided in **Table 1**, including the turbidity values equivalent to a TSS concentration of 50 mg/L for each of the linear and power function trendlines. The selected TSS value of 50 mg/L is somewhat arbitrary and the water quality limit for the project may vary.

Table 1: Summary of TSS-turbidity relationships for Gooandra Volcanics crushed rock

Trendline Function	Number of values	R^2 value	Turbidity (NTU) equivalent to 50 mg/L TSS
Linear	22	0.82	36
Power	22	0.89	43

As noted above, the power function trendline provides a much better fit of the dataset compared to the linear trendline. Furthermore, the high R^2 value associated with the power function trendline (0.89) indicates a strong correlation between TSS and turbidity for the dataset, and is considered to be valid for the data collected during testing. The turbidity value equivalent to 50 mg/L suspended solids is 43 NTU for this dataset.

---

[3] The R^2 value, also known as the coefficient of determination, is a measure of how close the plotted data are to the fitted regression line (i.e. the line of best fit). An R^2 value of 1 indicates that the regression line perfectly fits the data.

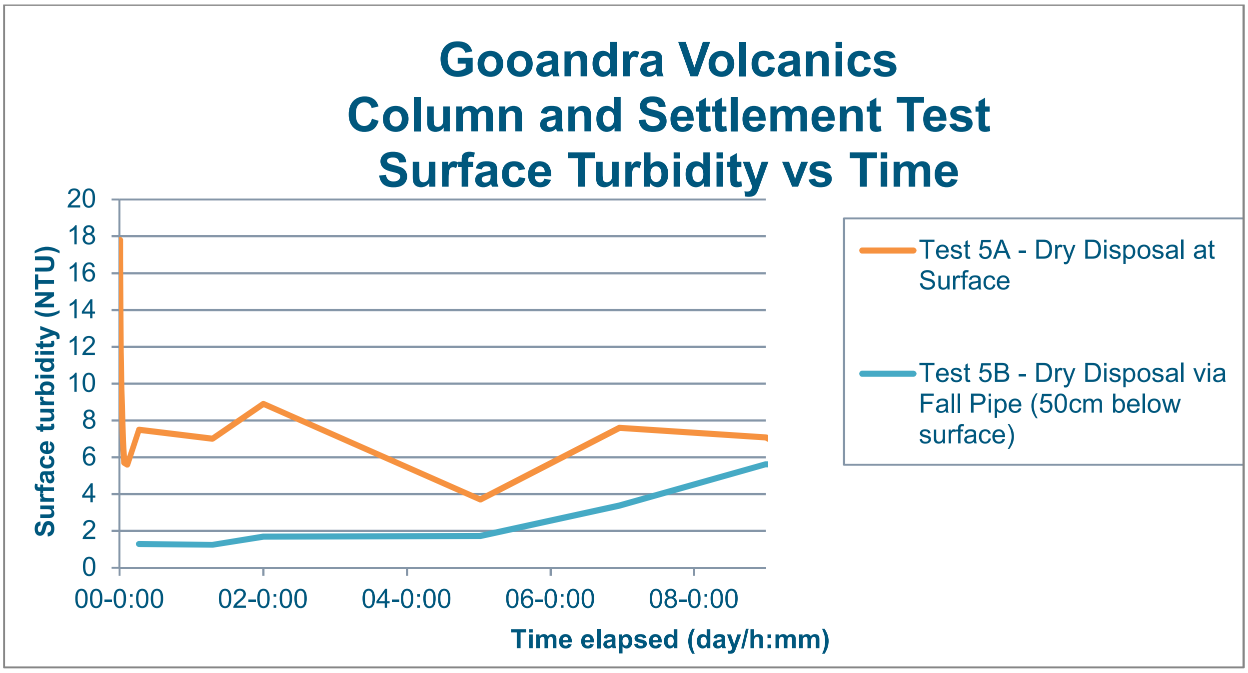
2.2 Settlement Tests

2.2.1 Overview

The two settlement tests for the Gooandra Volcanics crushed rock (Tests 5A and 5B) commenced simultaneously on the 10th October 2018 at 9:00am. Different disposal methods were simulated in the respective columns as described in **Sections 2.2.2** to **2.2.4**. The tests concluded on the 19th October 2018, approximately 9 days following commencement.

Surface turbidity in the two columns was measured 2 hours prior to addition of the crushed rock, with results of 2.7 NTU and 2.0 NTU recorded for Tests 5A and 5B respectively.

Surface turbidity measurements from varying time intervals during the 9-day test duration are plotted in **Graph 3** for the two settlement tests. These results are discussed in the following sections, along with a summary of the key observations for each settlement test. Laboratory log records completed during the settlement tests are provided in **Attachment 2**.



Graph 3: Surface turbidity measured during the settlement tests – Gooandra Volcanics crushed rock (Tests 5A and 5B).

Photographs taken during the settlement tests are provided in **Figures 2** to **6**. These photographs were taken prior to commencement (**Figure 2**), 2 hours and 40 minutes after commencement (**Figure 3**), 2 days after commencement (**Figure 4**), 5 days and 0.5 hours after commencement (**Figure 5**), and 6 days and 23 hours after commencement (**Figure 6**).

TEST I.D.	5A
GEOLOGICAL UNIT	GOOANDRA VOLCANICS
START TIME	9/10/18
CURRENT TIME	9/10/18

TEST I.D.	5B
GEOLOGICAL UNIT	GOOANDRA VOLCANICS
START TIME	9/10/18
CURRENT TIME	9/10/18

Figure 2: Settlement test prior to placement of sieved crushed rock-
Left: Test 5A - Placement of dry sieved crushed rock directly onto the water surface,
Right: Test 5B - Placement of dry sieved crushed rock within a fall pipe with opening submerged 50 cm below the water surface.

Figure 3: Settlement test 2 hours and 40 minutes following placement of sieved crushed rock-
Left: Test 5A - Placement of dry sieved crushed rock directly onto the water surface,
Right: Test 5B - Placement of dry sieved crushed rock within a fall pipe with opening submerged 50 cm below the water surface.

Figure 4: Settlement test 2 days following placement of sieved crushed rock-
Left: Test 5A - Placement of dry sieved crushed rock directly onto the water surface,
Right: Test 5B - Placement of dry sieved crushed rock within a fall pipe with opening submerged 50 cm below the water surface.

Figure 5: Settlement test 5 days and 30 minutes following placement of sieved crushed rock-
Left: Test 5A - Placement of dry sieved crushed rock directly onto the water surface,
Right: Test 5B - Placement of dry sieved crushed rock within a fall pipe with opening submerged 50 cm below the water surface.

TEST I.D.	5A
GEOLOGICAL UNIT	GOOANDRA VOLCANICS
START TIME	10/10/18 9:00
CURRENT TIME	17/10/18 8:00

TEST I.D.	5B
GEOLOGICAL UNIT	GOOANDRA VOLCANICS
START TIME	10/10/18 9:00
CURRENT TIME	17/10/18 8:00

Figure 6: Settlement test 6 days and 23 hours following placement of sieved crushed rock-
Left: Test 5A - Placement of dry sieved crushed rock directly onto the water surface,
Right: Test 5B - Placement of dry sieved crushed rock within a fall pipe with opening submerged 50 cm below the water surface.

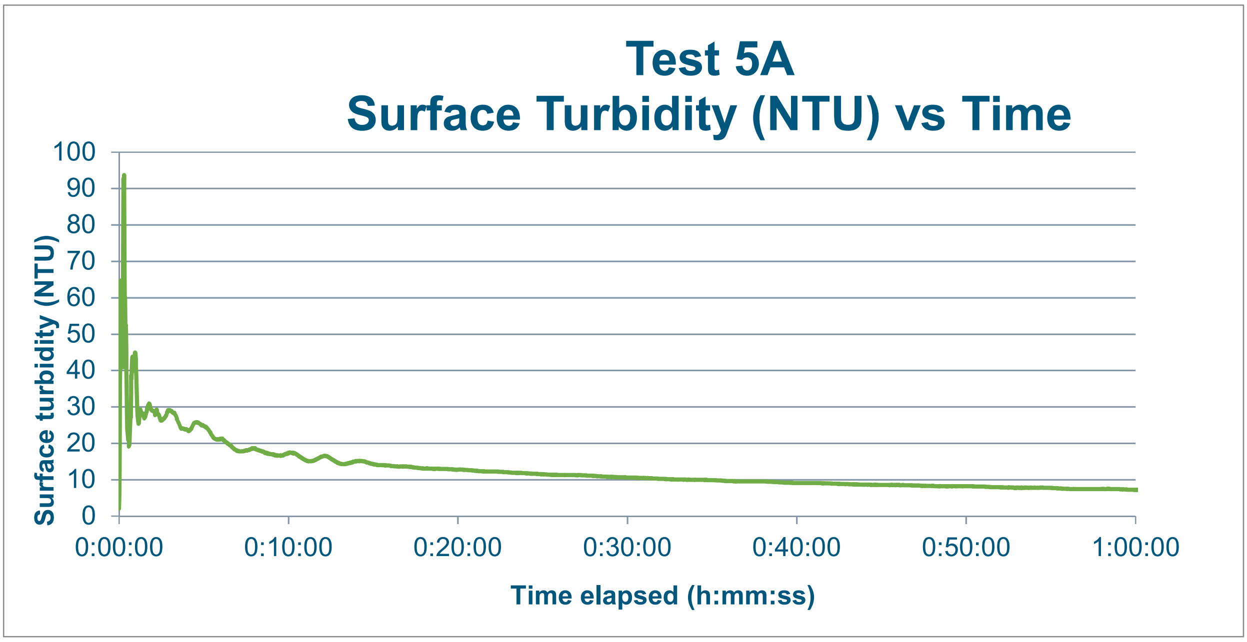
2.2.2 Test 5A - Placement of dry sieved crushed rock directly onto the water surface

For Test 5A, the sieved crushed rock was gently sprinkled onto the water surface from a height of approximately 25 cm above the water surface. Clumps of crushed rock fell through the upper portion of the column. However, fine material parted from the clumps during descent and a turbid trail formed through the water column in the wake of the clumps. The clumps generally dissipated before descending to the bottom of the column.

Significant diffusion and mixing of the crushed rock was observed after placement. After approximately 1 minute, turbidity throughout the entire water column appeared to be relatively uniform, except for near the surface. Turbidity appeared to be less in the upper 20 cm of the water column. Crushed rock appeared to fall through the upper approximately 15 cm of the water column before dispersing and mixing.

Surface turbidity levels were measured continuously (at one second time intervals) during the first 2 hours and 40 minutes of Test 5A and the Wetlab ECO-NTU sensor remained in the water column for this period. Surface turbidity levels were measured at varying time intervals thereafter. The Wetlab ECO-NTU sensor was placed in the water column for each measurement and removed after a stable reading was recorded.

Surface turbidity during the first hour after commencement of the test is plotted in **Graph 4** for Test 5A**.**



Graph 4: Surface turbidity measured during the first hour following placement of Gooandra Volcanics crushed rock, Test 5A.

Surface turbidity levels increased rapidly from background levels of around 2 NTU to a maximum of around 95 NTU during placement of the sieved crushed rock (i.e. within the first minute of testing). Surface turbidity decreased rapidly to approximately 35 NTU, 30 seconds after commencement. Over the subsequent 15 minutes, turbidity fluctuated and gradually declined. Surface turbidity 15 minutes after commencement was 14 NTU. The surface turbidity level continued to decrease and was recorded as 5.5 NTU, 2 hours and 40 minutes after commencement. At this point in time, continuous monitoring ceased.

Surface turbidity measured at varying time intervals over the 9-day test duration is plotted in **Graph 3** (refer **Section 2.2.1**) for Test 5A alongside the results for Tests 5B.

Between approximately 3 hours and 9 days after commencement, surface turbidity fluctuated and varied between 3.7 NTU (5 days after commencement) and 8.9 NTU (2 days after commencement). The average surface turbidity recorded during this period was approximately 7 NTU. At the end of the 9-day test duration, surface turbidity was 7.1 NTU. At this point in time, flocculant was added to the column (**Section 2.3**).

A discussion regarding the observed increase and fluctuations in surface turbidity is provided in **Section 3**.

2.2.3 Test 5B - Placement of dry sieved crushed rock within a fall pipe with opening submerged 50 cm below the water surface

For Test 5B, the sieved crushed rock was gently sprinkled into the fall pipe with an internal diameter of approximately 50 mm. The top of the fall pipe was approximately 75 cm above the water surface. The inside of the fall pipe was rinsed with water from Talbingo Reservoir to ensure that all of the sieved crushed rock entered the column.

Significant mixing and diffusion of crushed rock was observed within the fall pipe. Clumps of crushed rock fell through the upper portion of the column. However, fine material parted from the clumps during descent and a turbid trail formed through the water column in the wake of the clumps. The clumps generally dissipated before descending to the bottom of the column.

The dense turbid plume in the fall pipe gradually descended and diffused throughout the water column, primarily below the base of the fall pipe. After approximately 30 seconds, significant mixing was observed in the middle third of the column, below the fall pipe. After 2 minutes and 40 seconds, relatively even mixing was observed in the lower two thirds of the water column, below the base of the fall pipe. The top of the turbid plume was recorded 0.6 cm above the base of the fall pipe.

There was no immediate discernible change in turbidity above the turbid plume, with the upper 49.4 cm of water in the column (i.e. above the base of the fall pipe) remaining relatively clear with turbidity at background levels (refer **Graph 3**, **Section 2.2.1**). However, over the subsequent 9 days, surface turbidity increased to approximately 5.6 NTU.

The top of the turbid plume was observable for the first 5 days of the test and gradually descended over time. After 5 days, the top of the plume could not be distinguished. After 3 hours, the top of the plume was at 49.4 cm below the water surface, 0.6 cm above the base of the fall pipe. The top of the plume descended to 60.8 cm below the water surface after 5 days, at a rate of 2.3 cm/day.

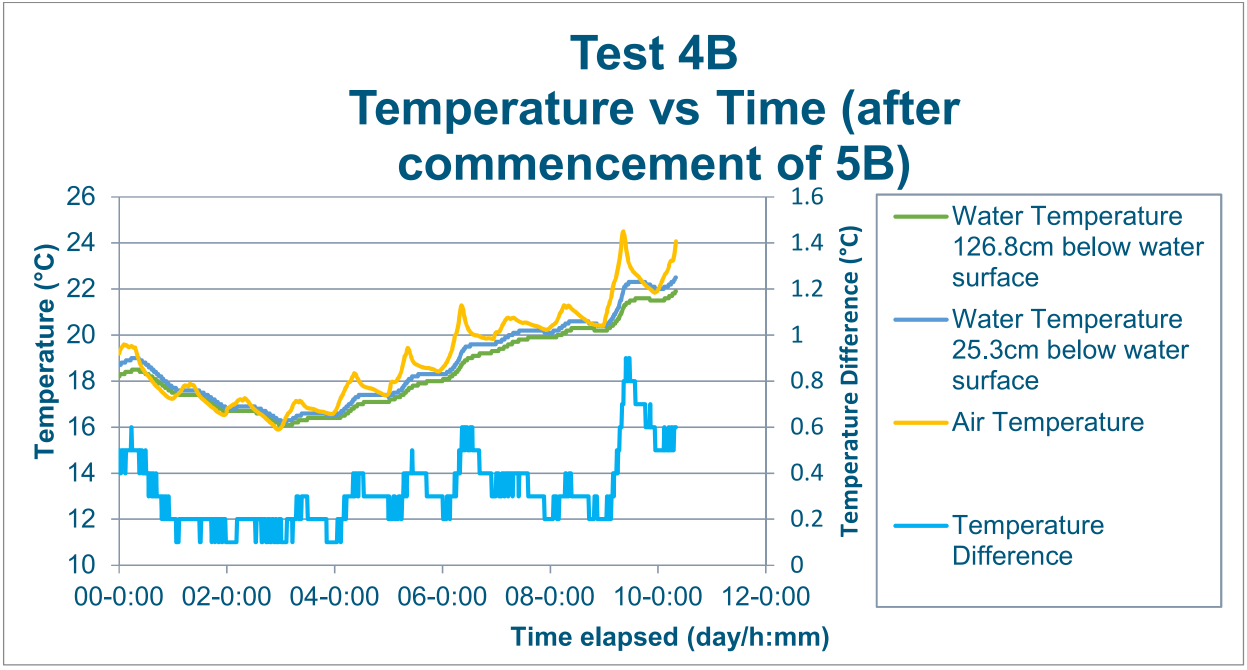
The settlement test simulating placement through a fall pipe resulted in a significant reduction in surface turbidity, compared to surface placement in Test 5A. However, after approximately 9 days, surface turbidity exceeded original background turbidity levels.

A discussion regarding the observed increase in surface turbidity over time during Test 5B is provided in **Section 3**.

2.2.4 Air and Water Temperature

Air temperature and water temperature were recorded every 15 minutes in Test 4B for the duration of the test using Solinist Leveloggers and a Barologger. Water temperature was monitored at two depths, 25.3 cm and 126.8 cm below the water surface. Test 4B commenced approximately 1 hour and 50 minutes before Test 5D and approximately 22 hours before Test 5A and 5B. Test 4B was undertaken in the same room and within approximately 2m of Test 5A, 5B and 5D.

Graph 5 provides air and water temperature variation over time for Test 4B. The elapsed time is reported relative to commencement of Test 5A and 5B.



Graph 5: Air and water temperature in Test 4B. Elapsed time relative to commencement of Test 5A and 5B.

Air temperature in Test 4B fluctuated between approximately 15.8 °C and 24.5 °C. Block out curtains were placed across all windows for the duration of the test in an attempt to regulate air temperature within the laboratory.

Water temperature varied between 16.1 °C and 22.5 °C. Water temperature was consistently 0.1°C to 0.9 °C warmer at the upper monitoring location and the average temperature differential between the monitoring depths was 0.34 °C. The warmer water near the top of the column would have a lower density and would, therefore, be buoyant compared to the cooler water lower in the column.

2.3 Flocculation Test

Prior to completion of the settlement tests, a trial was undertaken to determine whether a chemical flocculant would accelerate settlement of fine particles and clarify the water. The chemical flocculant selected for the test was alum (aluminium sulphate). It should be noted that the particular chemical flocculant selected for the test was somewhat arbitrary and has not been approved for use during construction.

Flocculant was added to Test 5A on the 19th October 2018 at 9:00am, approximately 9 days following commencement of the settlement test. Test 5B and 5D were retained as control columns for comparison.

Surface turbidity in Test 5A, 5B and 5D on the 19th October 2018 (prior to addition of flocculant) and 22nd October 2018 (following addition of flocculant) is reported below in **Table 2**. Surface turbidity in Test 5A decreased from 7.07 to 1.05 NTU while the surface turbidity in the control columns, Tests 5B and 5D, remained relatively constant at slightly elevated levels. This indicates that the chemical flocculant was effective in clarifying the water.

Table 2: Turbidity before and after the addition of flocculant to Test 5A.

Date/Time	Test 5A (NTU)	Test 5B (NTU)	Test 5D (NTU)
19th October 2018, 9:00 am	7.07	5.6	5.62
22nd October 2018, 9:00 am	1.05	5.6	7.2

A photograph of the three Test columns taken on the 19th and 22nd October 2018 is provided in **Figure 7**. It should be noted that some of the flocculated crushed rock in Test 5A adhered to the walls of the column thereby making the column appear slightly 'cloudy' when viewed side on. However, when viewed from above, the water was clear as indicated by the surface turbidity reading.

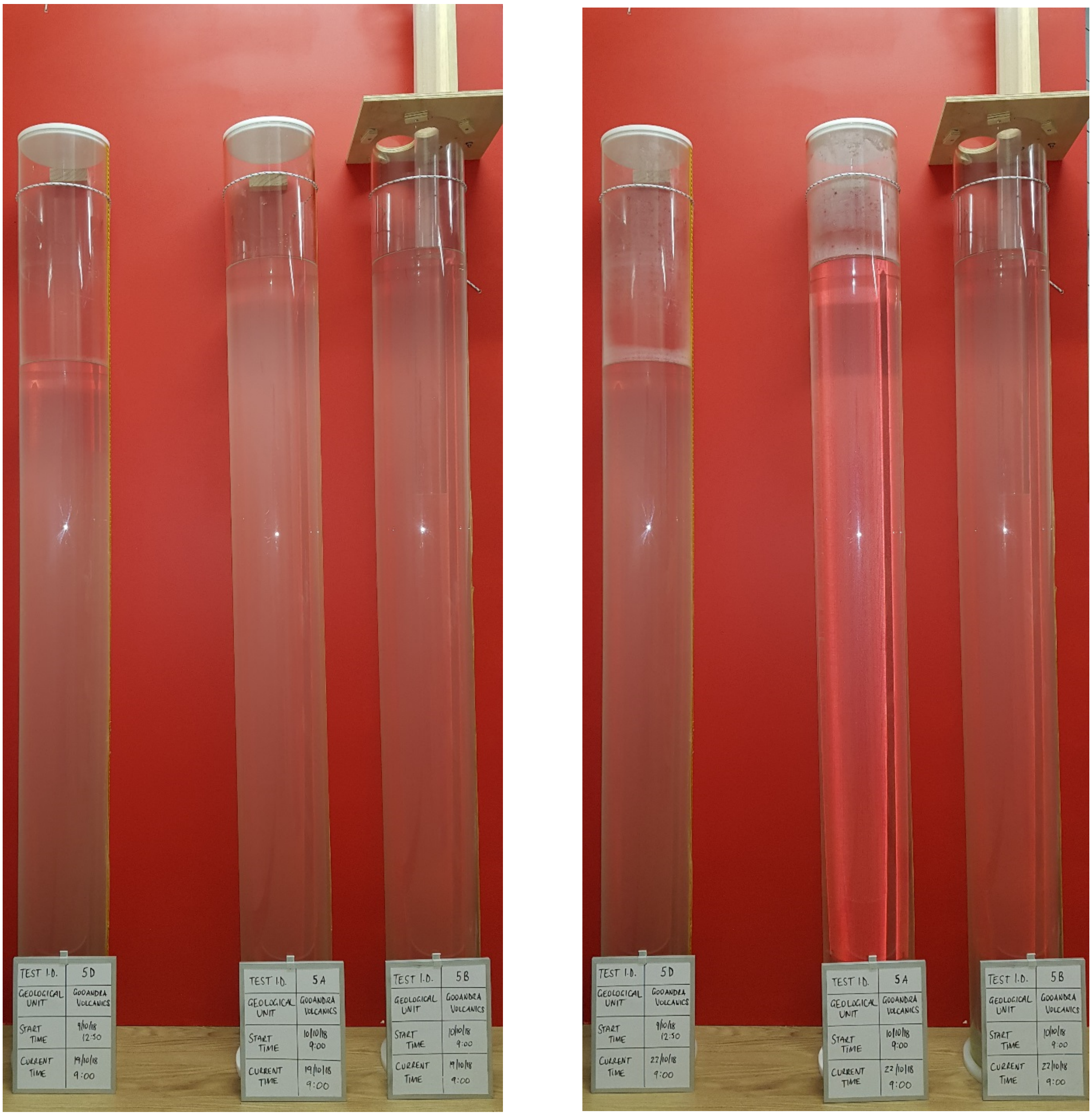
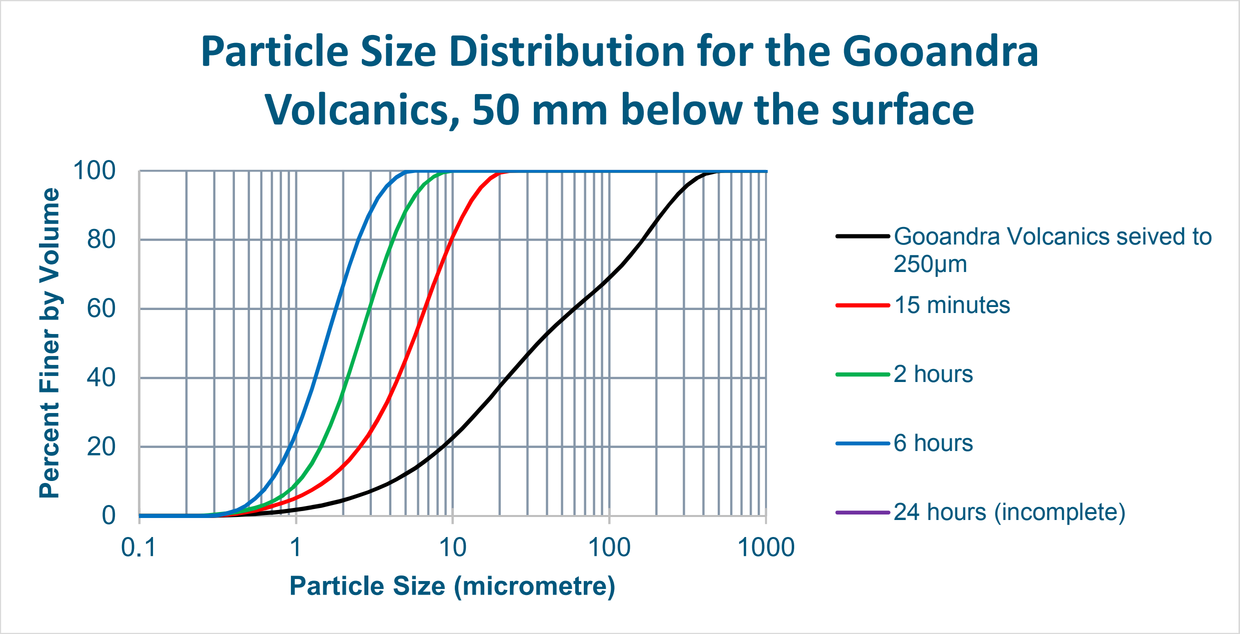


Figure 7: Column and Settlement tests prior to and following addition of chemical flocculant to Test 5A-
Left: Test 5D, 5A and 5B (from left to right) prior to the addition of flocculant to Test 5A. Photographed on the 19th October at 9:00am, approximately 9 days following commencement of the settlement tests.
Right: Test 5D, 5A and 5B (from left to right), following the addition of flocculant to Test 5A. Photographed on the 22nd October at 9:00am, approximately 12 days following commencement of the settlement tests.

2.4 Critical Particle Size

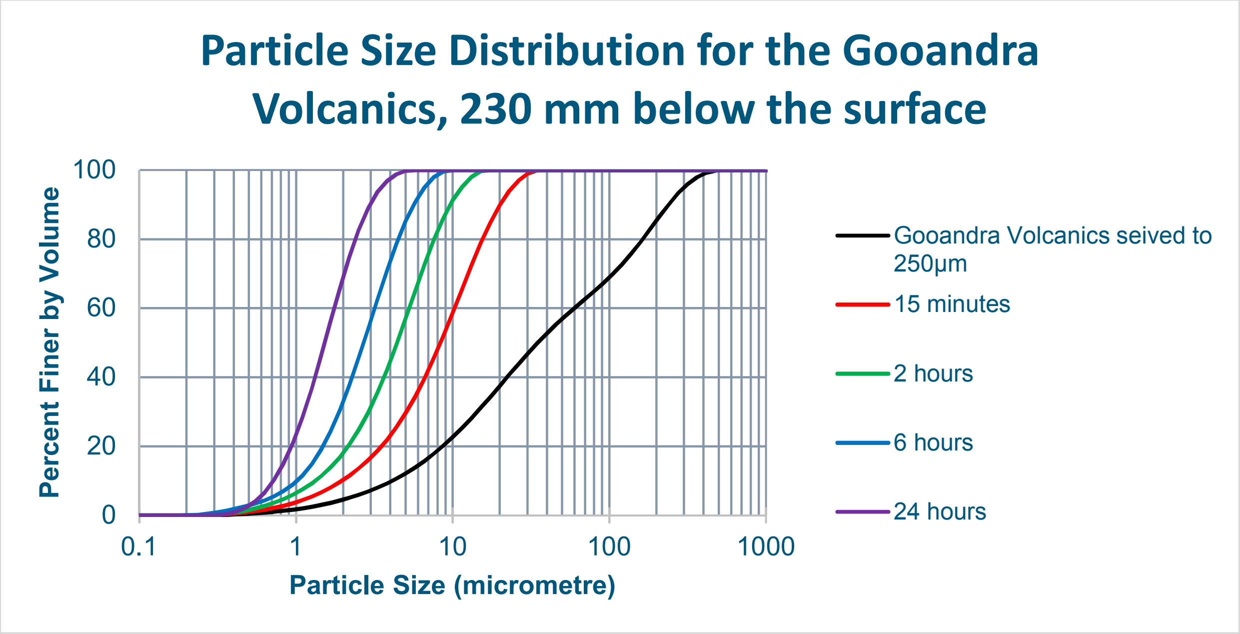
The tests to determine the critical particle size in suspension commenced on the 9th October 2018. Particle size analysis using the Mastersizer 2000 was completed on the 9th and 10th October 2018.

Graph 6 plots the particle size distribution of the sieved crushed rock (used for all tests) and the particle size that remains in suspension after each time interval (15 minutes, 2 hours and 6 hours) at 50 mm below the water surface (850 mL mark on cylinder). A test for the 24 hour time period was undertaken. However, turbidity was relatively low and obscuration of the laser was insufficient to obtain a reliable record of the particle size distribution. The maximum particle size in suspension at various time intervals is outlined in **Table 3**. The maximum particle size in suspension decreases over time from around 23 µm (15 minutes) to 5 µm (6 hours).



Graph 6: Particle size distribution at varying time intervals, 50 mm below the water surface.

Graph 7 plots the particle size distribution of the sieved crushed rock (used for all tests) and the particle size that remains in suspension after a given time interval (15 minutes, 2 hours, 6 hours, 24 hours and 48 hours) at 230 mm below the water surface (300 mL mark on cylinder). The maximum particle size in suspension at various time intervals is outlined in **Table 3**. The maximum particle size in suspension decreases over time from around 35.5 µm (15 minutes) to 5 µm (24 hours).



Graph 7: Particle size distribution at varying time intervals 230 mm the water surface.

Table 3: Maximum particle size in suspension at varying time intervals, 50 mm and 230 mm below the water surface.

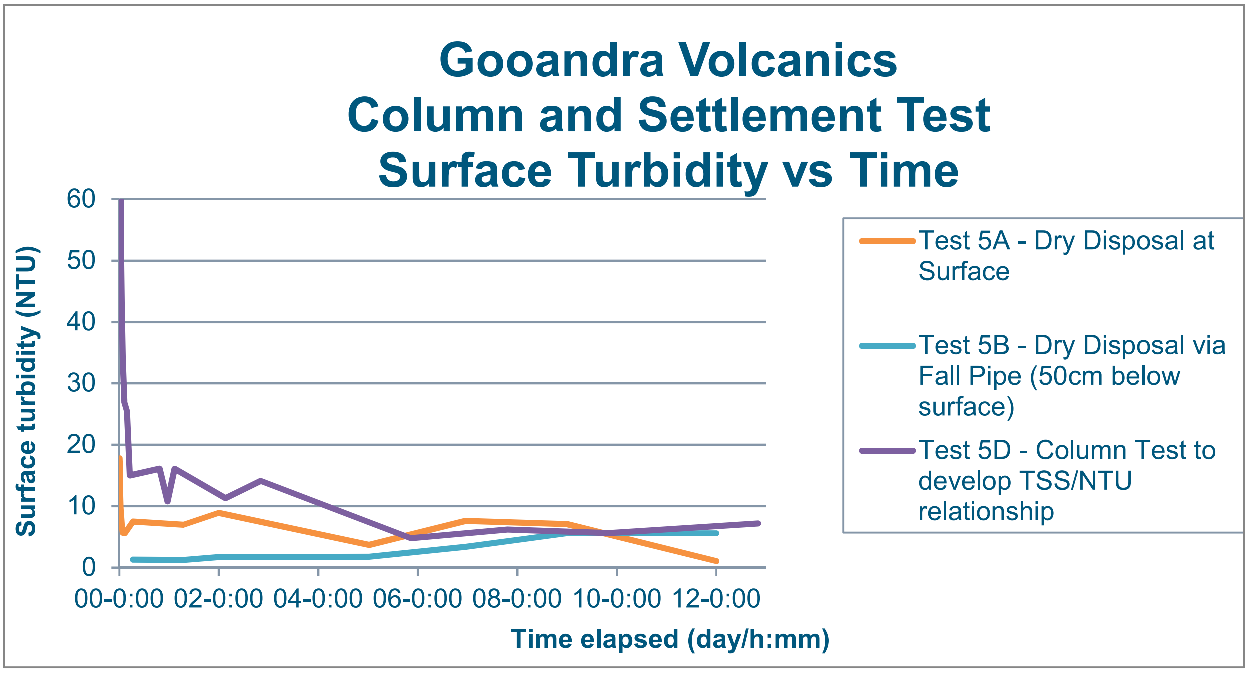
Time	Maximum particle size in suspension (µm)	
	50 mm below the water surface	230 mm below the water surface
15 minutes	23	35.5
2 hours	9	17.5
6 hours	5	9
24 hours	Test Incomplete	5

Based on the results presented above, it is evident that, for the same given time intervals, the maximum particle size in suspension is larger at greater depths within the water column, as would be expected.

3 Discussion

3.1 Fluctuating Turbidity and Increase in Surface Turbidity

As described in **Section 2**, surface turbidity in Test 5A and 5D fluctuated and surface turbidity in Test 5B increased over time. The surface turbidity for the three tests is shown in **Graph 8**. The graph includes the addition of flocculant to Test 5A, 9 days following commencement.



Graph 8: Surface turbidity measured during the settlement and column tests – Gooandra Volcanics (Tests 5A, 5B and 5D).

An increase in surface turbidity was unexpected, with ongoing settlement and decreasing turbidity following initial mixing considered more likely to occur. It is possible that the observations were influenced by one or more of the following factors:

1. Weak thermal convection currents within the column may result in mixing of stratified layers and rising warm water transporting suspended particles to the surface. Air temperature and water temperature was monitored for the duration of the test. The results are reported in **Section 2.2.4** and presented in **Graph 5**.

   It is apparent from **Graph 5** that the water temperature warms and cools in response to the air temperature. Further, the difference in water temperature between the top and bottom of the column increases during a warming phase and decreases during a cooling phase.

   It is inferred that heat is transferred from the air to the column and from the column to the adjacent water near the wall of the column through the process of conduction, which is the transfer of heat between objects in contact with each other, or through a substance due to the collision of molecules. Heating of water near the wall of the column would result in differential water temperature across the column with cooler water near the centre of the column. The differential water temperature would lead to two processes, conduction and convection where

convection is the process of warmer water, with a lower density, rising to cooler areas in the column and cooler water, with a higher density, sinking to take the place of the warmer water. The velocity of convection currents are difficult to determine and due to a range of factors.

2. The sieved crushed rock may contain clay particles that are anionic. The repelling force between charged particles in suspension may result in suspended solids diffusing and distributing evenly throughout the water column.

3. The action of gently lowering a turbidity probe into the upper layer of the column (~3.4 cm below the water surface) may be sufficient to disturb the water column resulting in advection of very fine suspended particles.

Regardless of the reason for fluctuating and increasing surface turbidity in Tests 5A, 5B and 5D, it is clear that minor disturbances to the water column dare sufficient to disrupt the settlement process and redistribute fine suspended particles within the water column.

4 Conclusions

It is apparent from the column test and settlement tests that once fine crushed rock from the igneous rock in the Gooandra Volcanics geological zone enters the water column, the fine particles remain in suspension for extended periods in the order of several days to weeks. The surface turbidity approximately 9 days after commencement of Tests 5A, 5B and 5D was between 5 NTU and 7 NTU, which represents a minimal increase relative to the background levels in Talbingo Reservoir of 1 NTU to 5 NTU, as reported by Cardno.

It is also apparent that minor disturbances to the water column are likely to disrupt the settlement process and/or re-suspend fine particles.

The critical particle size in suspension that would be contributing to prolonged surface turbidity in the water column (more than 24 hours) would be less than approximately 5 µm.

The results of a chemical flocculation test for the Gooandra Volcanics crushed rock indicate that the addition of flocculant may accelerate settlement of fine particles and clarify the water.

TSS-turbidity data collected during the Column Test (Test 5D) is considered to be reliable for the purpose of establishing a preliminary relationship between TSS and turbidity for the Gooandra Volcanics geological zone. The turbidity value equivalent to 50 mg/L suspended solids is 43 NTU for this dataset. Furthermore, as the properties and grading of the crushed rock placed during construction may vary to that used in the column test, collection of field TSS-turbidity data during subaqueous excavated rock placement activities is recommended so that the relationship between turbidity and suspended solids can be continually validated and improved.

Attachment 1 – Laboratory Certificates

ALS Environmental

CERTIFICATE OF ANALYSIS

Work Order	: **ES1830022**	Page	: 1 of 12
Client	: **HASKONING AUSTRALIA- ROYAL HASKONING**	Laboratory	: Environmental Division Sydney
Contact	: MR PATRICK LAWLESS	Contact	: Customer Services ES
Address	: LEVEL 14 56 Berry Street NORTH SYDNEY 2060	Address	: 277-289 Woodpark Road Smithfield NSW Australia 2164
Telephone	: ----	Telephone	: +61-2-8784 8555
Project	: Snowy 2.0 TSS-NTU (Test 2/3)	Date Samples Received	: 10-Oct-2018 16:30
Order number	:	Date Analysis Commenced	: 11-Oct-2018
C-O-C number	: ----	Issue Date	: 17-Oct-2018 17:40
Sampler	: PATRICK LAWLESS		
Site	: ----		
Quote number	: EN/222		
No. of samples received	: 50		
No. of samples analysed	: 50		

NATA
Accreditation No. 825
Accredited for compliance with
ISO/IEC 17025 - Testing

This report supersedes any previous report(s) with this reference. Results apply to the sample(s) as submitted. This document shall not be reproduced, except in full.

This Certificate of Analysis contains the following information:

- General Comments
- Analytical Results

Additional information pertinent to this report will be found in the following separate attachments: Quality Control Report, QA/QC Compliance Assessment to assist with Quality Review and Sample Receipt Notification.

Signatories

This document has been electronically signed by the authorized signatories below. Electronic signing is carried out in compliance with procedures specified in 21 CFR Part 11.

Signatories	*Position*	*Accreditation Category*
Ankit Joshi	Inorganic Chemist	Sydney Inorganics, Smithfield, NSW

General Comments

The analytical procedures used by the Environmental Division have been developed from established internationally recognized procedures such as those published by the USEPA, APHA, AS and NEPM. In house developed procedures are employed in the absence of documented standards or by client request.

Where moisture determination has been performed, results are reported on a dry weight basis.

Where a reported less than (<) result is higher than the LOR, this may be due to primary sample extract/digestate dilution and/or insufficient sample for analysis.

Where the LOR of a reported result differs from standard LOR, this may be due to high moisture content, insufficient sample (reduced weight employed) or matrix interference.

When sampling time information is not provided by the client, sampling dates are shown without a time component. In these instances, the time component has been assumed by the laboratory for processing purposes.

Where a result is required to meet compliance limits the associated uncertainty must be considered. Refer to the ALS Contact for details.

Key : CAS Number = CAS registry number from database maintained by Chemical Abstracts Services. The Chemical Abstracts Service is a division of the American Chemical Society.
LOR = Limit of reporting
^ = This result is computed from individual analyte detections at or above the level of reporting
ø = ALS is not NATA accredited for these tests.
~ = Indicates an estimated value.

Analytical Results

Sub-Matrix: **WATER** (Matrix: **WATER**)			Client sample ID	**2D-20**	**2D-21**	**2D-22**	**2D-23**	**2D-24**
			Client sampling date / time	03-Oct-2018 00:00	04-Oct-2018 00:00	05-Oct-2018 00:00	06-Oct-2018 00:00	08-Oct-2018 00:00
Compound	CAS Number	LOR	Unit	**ES1830022-001**	**ES1830022-002**	**ES1830022-003**	**ES1830022-004**	**ES1830022-005**
				Result	Result	Result	Result	Result
EA025: Total Suspended Solids dried at 104 ± 2°C								
Suspended Solids (SS)	----	5	mg/L	**----**	<5	**16**	**----**	**----**
Suspended Solids (SS)	----	5	mg/L	**8**	**----**	**----**	**12**	**11**
EA045: Turbidity								
Turbidity	----	0.1	NTU	**32.9**	**21.2**	**30.4**	**35.5**	**23.7**

Analytical Results

Sub-Matrix: **WATER**
(Matrix: **WATER)**

			Client sample ID	**3D-17**	**3D-18**	**3D-19**	**3D-20**	**3D-21**
			Client sampling date / time	03-Oct-2018 00:00	04-Oct-2018 00:00	05-Oct-2018 00:00	06-Oct-2018 00:00	08-Oct-2018 00:00
Compound	CAS Number	LOR	Unit	**ES1830022-006**	**ES1830022-007**	**ES1830022-008**	**ES1830022-009**	**ES1830022-010**
				Result	Result	Result	Result	Result
EA025: Total Suspended Solids dried at 104 ± 2°C								
Suspended Solids (SS)	----	5	mg/L	**----**	**8**	**13**	**----**	**----**
Suspended Solids (SS)	----	5	mg/L	**8**	**----**	**----**	**8**	<5
EA045: Turbidity								
Turbidity	----	0.1	NTU	**30.1**	**28.7**	**28.2**	**26.8**	**22.6**

Analytical Results

Sub-Matrix: **WATER**
(Matrix: **WATER)**

			Client sample ID	**4D-1**	**4D-2**	**4D-3**	**4D-4**	**4D-5**
			Client sampling date / time	09-Oct-2018 00:00	09-Oct-2018 00:00	09-Oct-2018 00:00	09-Oct-2018 00:00	09-Oct-2018 00:00
Compound	*CAS Number*	*LOR*	*Unit*	**ES1830022-011**	**ES1830022-012**	**ES1830022-013**	**ES1830022-014**	**ES1830022-015**
				Result	Result	Result	Result	Result
EA025: Total Suspended Solids dried at 104 ± 2°C								
Suspended Solids (SS)	----	5	mg/L	<5	**206**	**204**	**121**	**166**
EA045: Turbidity								
Turbidity	----	0.1	NTU	**0.4**	**240**	**148**	**150**	**109**

Analytical Results

Sub-Matrix: **WATER**
(Matrix: **WATER)**

			Client sample ID	**4D-6**	**4D-7**	**4D-8**	**4D-9**	**4D-10**
			Client sampling date / time	09-Oct-2018 00:00	09-Oct-2018 00:00	09-Oct-2018 00:00	09-Oct-2018 00:00	09-Oct-2018 00:00
Compound	*CAS Number*	*LOR*	*Unit*	**ES1830022-016**	**ES1830022-017**	**ES1830022-018**	**ES1830022-019**	**ES1830022-020**
				Result	Result	Result	Result	Result
EA025: Total Suspended Solids dried at 104 ± 2°C								
Suspended Solids (SS)	----	5	mg/L	**116**	**142**	**45**	**42**	**97**
EA045: Turbidity								
Turbidity	----	0.1	NTU	**169**	**119**	**130**	**125**	**94.2**

Analytical Results

Sub-Matrix: **WATER** (Matrix: **WATER**)			*Client sample ID*	**4D-11**	**4D-12**	**4D-13**	**4D-14**	**4D-15**
			Client sampling date / time	09-Oct-2018 00:00	09-Oct-2018 00:00	09-Oct-2018 00:00	09-Oct-2018 00:00	09-Oct-2018 00:00
Compound	*CAS Number*	*LOR*	*Unit*	**ES1830022-021**	**ES1830022-022**	**ES1830022-023**	**ES1830022-024**	**ES1830022-025**
				Result	Result	Result	Result	Result
EA025: Total Suspended Solids dried at 104 ± 2°C								
Suspended Solids (SS)	----	5	mg/L	**84**	**80**	**31**	**40**	**22**
EA045: Turbidity								
Turbidity	----	0.1	NTU	**92.7**	**96.0**	**113**	**110**	**100**

Analytical Results

Sub-Matrix: **WATER** (Matrix: **WATER**)			*Client sample ID*	**4D-16**	**4D-17**	**4D-18**	**4D-19**	**5D-1**
			Client sampling date / time	09-Oct-2018 00:00	09-Oct-2018 00:00	09-Oct-2018 00:00	09-Oct-2018 00:00	09-Oct-2018 00:00
Compound	*CAS Number*	*LOR*	*Unit*	**ES1830022-026**	**ES1830022-027**	**ES1830022-028**	**ES1830022-029**	**ES1830022-030**
				Result	Result	Result	Result	Result
EA025: Total Suspended Solids dried at 104 ± 2°C								
Suspended Solids (SS)	----	5	mg/L	**24**	**54**	**51**	**25**	<5
EA045: Turbidity								
Turbidity	----	0.1	NTU	**22.8**	**25.8**	**33.1**	**29.3**	**0.5**

Analytical Results

Sub-Matrix: **WATER** (Matrix: **WATER**)			Client sample ID	**5D-2**	**5D-3**	**5D-4**	**5D-5**	**5D-6**
			Client sampling date / time	09-Oct-2018 00:00	09-Oct-2018 00:00	09-Oct-2018 00:00	09-Oct-2018 00:00	09-Oct-2018 00:00
Compound	*CAS Number*	*LOR*	*Unit*	**ES1830022-031**	**ES1830022-032**	**ES1830022-033**	**ES1830022-034**	**ES1830022-035**
				Result	Result	Result	Result	Result
EA025: Total Suspended Solids dried at 104 ± 2°C								
Suspended Solids (SS)	----	5	mg/L	**130**	**124**	**142**	**118**	**180**
EA045: Turbidity								
Turbidity	----	0.1	NTU	**184**	**177**	**182**	**168**	**167**

Analytical Results

Sub-Matrix: **WATER** (Matrix: **WATER**)			Client sample ID	**5D-7**	**5D-8**	**5D-9**	**5D-10**	**5D-11**
			Client sampling date / time	09-Oct-2018 00:00	09-Oct-2018 00:00	09-Oct-2018 00:00	09-Oct-2018 00:00	09-Oct-2018 00:00
Compound	CAS Number	LOR	Unit	**ES1830022-036**	**ES1830022-037**	**ES1830022-038**	**ES1830022-039**	**ES1830022-040**
				Result	Result	Result	Result	Result
EA025: Total Suspended Solids dried at 104 ± 2°C								
Suspended Solids (SS)	----	5	mg/L	**132**	**95**	**110**	**70**	**62**
EA045: Turbidity								
Turbidity	----	0.1	NTU	**130**	**107**	**101**	**60.2**	**20.8**

Analytical Results

Sub-Matrix: **WATER** (Matrix: **WATER**)			*Client sample ID*	**5D-12**	**5D-13**	**5D-14**	**5D-15**	**4D-20**
			Client sampling date / time	09-Oct-2018 00:00	09-Oct-2018 00:00	09-Oct-2018 00:00	09-Oct-2018 00:00	10-Oct-2018 00:00
Compound	*CAS Number*	*LOR*	*Unit*	**ES1830022-041**	**ES1830022-042**	**ES1830022-043**	**ES1830022-044**	**ES1830022-045**
				Result	Result	Result	Result	Result
EA025: Total Suspended Solids dried at 104 ± 2°C								
Suspended Solids (SS)	----	5	mg/L	**24**	**26**	**11**	**10**	**26**
EA045: Turbidity								
Turbidity	----	0.1	NTU	**31.2**	**19.2**	**16.3**	**16.0**	**20.9**

Analytical Results

Sub-Matrix: **WATER** (Matrix: **WATER**)			*Client sample ID*	**4D-21**	**5D-16**	**5D-17a**	**5D-17b**	**5D-18**
			Client sampling date / time	10-Oct-2018 00:00	10-Oct-2018 00:00	10-Oct-2018 00:00	10-Oct-2018 00:00	10-Oct-2018 00:00
Compound	*CAS Number*	*LOR*	*Unit*	**ES1830022-046**	**ES1830022-047**	**ES1830022-048**	**ES1830022-049**	**ES1830022-050**
				Result	Result	Result	Result	Result
EA025: Total Suspended Solids dried at 104 ± 2°C								
Suspended Solids (SS)	----	5	mg/L	**12**	**16**	**7**	**14**	**17**
EA045: Turbidity								
Turbidity	----	0.1	NTU	**17.0**	**9.2**	**7.3**	**7.8**	**9.8**

CERTIFICATE OF ANALYSIS

Work Order	: **ES1831104**	Page	: 1 of 4
Client	: **HASKONING AUSTRALIA- ROYAL HASKONING**	Laboratory	: Environmental Division Sydney
Contact	: MR PATRICK LAWLESS	Contact	: Customer Services ES
Address	: LEVEL 14 56 Berry Street NORTH SYDNEY 2060	Address	: 277-289 Woodpark Road Smithfield NSW Australia 2164
Telephone	: ----	Telephone	: +61-2-8784 8555
Project	: Snowy 2.0 TSS-NTU (Test 4/5)	Date Samples Received	: 19-Oct-2018 14:35
Order number	:	Date Analysis Commenced	: 20-Oct-2018
C-O-C number	: ----	Issue Date	: 25-Oct-2018 12:32
Sampler	: Patrick Lawless		
Site	: ----		
Quote number	: EN/222		
No. of samples received	: 7		
No. of samples analysed	: 7		

NATA

Accreditation No. 825
Accredited for compliance with
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Signatories

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Signatories	*Position*	*Accreditation Category*
Ankit Joshi	Inorganic Chemist	Sydney Inorganics, Smithfield, NSW

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LOR = Limit of reporting
^ = This result is computed from individual analyte detections at or above the level of reporting
ø = ALS is not NATA accredited for these tests.
~ = Indicates an estimated value.

Analytical Results

Sub-Matrix: **WATER**
(Matrix: **WATER**)

			Client sample ID	**4D-22**	**4D-23**	**4D-24**	**4D-25**	**5D-19**
			Client sampling date / time	11-Oct-2018 00:00	12-Oct-2018 00:00	15-Oct-2018 00:00	19-Oct-2018 00:00	11-Oct-2018 00:00
Compound	*CAS Number*	*LOR*	*Unit*	**ES1831104-001**	**ES1831104-002**	**ES1831104-003**	**ES1831104-004**	**ES1831104-005**
				Result	Result	Result	Result	Result
EA025: Total Suspended Solids dried at 104 ± 2°C								
Suspended Solids (SS)	----	5	mg/L	**----**	**----**	<5	**----**	**----**
Suspended Solids (SS)	----	5	mg/L	**18**	**26**	**----**	**15**	**12**
EA045: Turbidity								
Turbidity	----	0.1	NTU	**15.9**	**16.0**	**5.8**	**21.5**	**6.6**

Analytical Results

Sub-Matrix: **WATER** (Matrix: **WATER**)			*Client sample ID*	**5D-20**	**5D-21**	**----**	**----**	**----**
			Client sampling date / time	12-Oct-2018 00:00	15-Oct-2018 00:00	----	----	----
Compound	*CAS Number*	*LOR*	*Unit*	**ES1831104-006**	**ES1831104-007**	**--------**	**--------**	**--------**
				Result	Result	----	----	----
EA025: Total Suspended Solids dried at 104 ± 2°C								
Suspended Solids (SS)	----	5	mg/L	**----**	<5	**----**	**----**	**----**
Suspended Solids (SS)	----	5	mg/L	**21**	**----**	**----**	**----**	**----**
EA045: Turbidity								
Turbidity	----	0.1	NTU	**8.9**	**3.9**	**----**	**----**	**----**

Attachment 2 – Gooandra Volcanics Laboratory Log Records

Test ID	5A	
Geological Unit	Gooandra Volcanics	
Description	Test 5A - Dry Disposal at Surface	
Start Date/Time	10-10-18 9:00	
Water volume	50 L	
Water surface level in column	172.8	cm
Mass sediment added	40 g	(sieved to <250 um)
Test Location	Geochemical Assessments Workshop, Roseville NSW	
Test Officers	Pat Lawless, Rick Plain	

Observations

Date/Time	Time since start	Turbidity (NTU)	Measurement Location (cm)	Measurement Depth (cm)	Comments
09-10-18 8:45	10 Minutes Prior	2.7	169.4	3.4	Background turbidity measured 10 minutes before test start.
10-10-18 9:08	00-0:08	17.8	169.4	3.4	Surface remained relatively clear. Gradual increase in turbidity to ~150 cm.
10-10-18 9:10	00-0:10	16.7	169.4	3.4	
10-10-18 9:25	00-0:25	11.7	169.4	3.4	
10-10-18 9:35	00-0:35	9.78	169.4	3.4	
10-10-18 10:05	00-1:05	6.9	169.4	3.4	
10-10-18 10:35	00-1:35	5.7	169.4	3.4	Battery 7.04 volts
10-10-18 11:40	00-2:40	5.6	169.4	3.4	Continuous monitoring ceased. Very clear at the surface.
10-10-18 15:30	00-6:30	7.5	169.4	3.4	Stratification at 159 cm and 147 cm.
11-10-18 16:00	01-7:00	7	169.4	3.4	Very minor stratification at 139 cm.
12-10-18 9:00	02-0:00	8.9	169.4	3.4	Very minor stratification at 112 cm.
15-10-18 9:30	05-0:30	3.7	169.4	3.4	Gradual change in column. Top clear.
17-10-18 8:00	06-23:00	7.6	169.4	3.4	Column relatively uniform.
19-10-18 9:00	09-0:00	7.07	169.4	3.4	**Flocculant added.**
22-10-18 9:00	12-0:00	1.05	169.4	3.4	

Test ID	5B	
Geological Unit	Gooandra Volcanics	
Description	Test 5B - Dry Disposal via Fall Pipe (50cm below surface)	
Start Date/Time	10-10-18 9:00	
Water volume	50 L	
Water surface level in column	172.8	cm
Mass sediment added	40 g	(sieved to <250 um)
Test Location	Geochemical Assessments Workshop, Roseville NSW	
Test Officers	Pat Lawless, Rick Plain	

Observations

Date/Time	Time since start	Turbidity (NTU)	Measurement Location (cm)	Measurement Depth (cm)	Comments
09-10-18 8:45	10 minutes prior	2	169.4	3.4	Background turbidity measured 10 minutes before test start.
10-10-18 12:00	00-3:00		169.4	3.4	Turbid plume 123.4 cm.
10-10-18 15:30	00-6:30	1.3	169.4	3.4	Turbid plume 122.5 cm.
11-10-18 16:00	01-7:00	1.25	169.4	3.4	Turbid plume 119.5 cm. Minor stratification at 96 cm.
12-10-18 9:00	02-0:00	1.7	169.4	3.4	
15-10-18 9:30	05-0:30	1.75	169.4	3.4	Turbid plume 112 cm.
17-10-18 8:00	06-23:00	3.4	169.4	3.4	Column relatively uniform.
19-10-18 9:00	09-0:00	5.6	168.4	4.4	
22-10-18 9:00	12-0:00	5.6	167.4	5.4	

Test ID	5D	
Geological Unit	Gooandra Volcanics	
Description	Test 5D - Column Test to develop TSS/NTU relationship	
Start Date/Time	09-10-18 12:50	
Water volume	50 L	
Water surface level in column	172.8	cm
Mass sediment added	47.5 g	(sieved to <250 um)
Test Location	Geochemical Assessments Workshop, Roseville NSW	
Test Officers	Pat Lawless, Rick Plain	

Observations

Date/Time	Time since start	Turbidity (NTU)		TSS Sample Taken?	TSS Sample ID	Column Measurements			Comments
		Inside Column	Inside Beaker			Water Surface	Measurement Location	Sensor Depth	
09-10-18 8:45	3 hours prior	1.8	1.8	Yes	5D-1	176.2	172.8	3.4	Before commencement
09-10-18 12:55	00-0:05	140	135	Yes	5D-2			0	
09-10-18 12:58	00-0:08	120	120	Yes	5D-3			0	Beaker reading range 110-130 NTU.
09-10-18 13:01	00-0:11	123	110	Yes	5D-4			0	Beaker reading range 105-115 NTU.
09-10-18 13:04	00-0:14	96	95	Yes	5D-5	169.4	166	3.4	Beaker reading range 80-105 NTU.
09-10-18 13:07	00-0:17	88	84	Yes	5D-6	168.7	165.3	3.4	Beaker reading range 80-86 NTU.
09-10-18 13:11	00-0:21	80	76	Yes	5D-7	167.8	164.4	3.4	Beaker reading range 73-77 NTU, reasonably stable
09-10-18 13:16	00-0:26	68	73	Yes	5D-8	166.9	163.5	3.4	Beaker reading range 69-76 NTU.
09-10-18 13:21	00-0:31	69		No		166	162.6	3.4	
09-10-18 13:23	00-0:33	68		No		166	162.6	3.4	
09-10-18 13:24	00-0:34	65	60	Yes	5D-9	166	162.6	3.4	Beaker reading range 55-70 NTU, relatively variable.
09-10-18 13:40	00-0:50	50	48	Yes	5D-10	165.1	161.7	3.4	Beaker reading range 45-55 NTU.
09-10-18 14:00	00-1:10	42	44	Yes	5D-11	164.2	160.8	3.4	Beaker reading range 43-48 NTU.
09-10-18 14:27	00-1:37	34	26	Yes	5D-12	163.5	160.1	3.4	
09-10-18 15:15	00-2:25	27	28	Yes	5D-13	162.5	159.1	3.4	
09-10-18 16:30	00-3:40	25.6	19	Yes	5D-14	161.9	158.5	3.4	Beaker reading range 18-20 NTU, Column reading range 24-28 NTU.
09-10-18 17:50	00-5:00	15	22	Yes	5D-15	160.2	156.8	3.4	Beaker reading range 21-23 NTU. Re-measure in column was 24 NTU.
10-10-18 8:15	00-19:25	16.1	15.9	Yes	5D-16	159.2	155.8	3.4	Stratification at 131.5 cm (minor).
10-10-18 12:00	00-23:10	10.8	12.4	Yes	5D-17a	158	154.6	3.4	Stratification at 120.5 cm (minor).
10-10-18 12:00	00-23:10	10.8	14.5	Yes	5D-17b	157.1	153.7	3.4	
10-10-18 15:30	01-2:40	16.1	17.5	Yes	5D-18	156.3	152.9	3.4	Stratification at 114.2 cm (minor).
11-10-18 16:00	02-3:10	11.3	8.25	Yes	5D-19	155.3	151.9	3.4	Stratification at 83 cm.
12-10-18 9:00	02-20:10	14.1	14	Yes	5D-20	154.5	151.1	3.4	Stratification at 63 cm. Beaker reading range 13.8-15 NTU.
15-10-18 9:30	05-20:40	4.8	5	Yes	5D-21	153.4	150	3.4	
17-10-18 8:00	07-19:10	6.2		No		152.4	149	3.4	
19-10-18 9:00	09-20:10	5.62		No		152.4	149	3.4	
22-10-18 9:00	12-20:10	7.2		No		153.4	150	3.4	

Appendix F

TSS – Turbidity and Settling Test Results
Byron Range Group Geological Zone

Table of Contents

1 Introduction

The Byron Range Group geological zone comprises siliciclastic deposits formed in shallow marine environments, including siltstone, shale, sandstone, conglomerate and nodular limestone. A 1-m long section of core from this geological zone was supplied to Royal HaskoningDHV (Haskoning) from BH5105 taken between 6 m and 7 m below the ground surface. The core was logged as completely weathered rock and the description was clayey gravel.

Water for laboratory testing was obtained from Talbingo Reservoir on the 2nd October 2018. The water was collected in 1000 L Intermediate Bulk Containers (IBC) and delivered to Haskoning on the 5th October 2018. The turbidity of the reservoir water sample used for the testing was between 1.7 and 2.1 NTU. This is within the turbidity range of field monitoring, undertaken by Cardno in 2018, which indicated typical 'background' turbidity of 1 to 5 NTU in Talbingo Reservoir.

2 Results

2.1 Test 6D – TSS-Turbidity

2.1.1 Overview

The TSS-Turbidity Test for the Byron Range Group ('Test 6D') commenced on the 23rd October 2018 at 8:50am and concluded on the 2nd November 2018, approximately 10 days following commencement.

The Certificate of Analysis provided by ALS Environmental for the TSS and turbidity analyses undertaken for samples collected during testing is provided in **Attachment 1**. Laboratory log records completed during the TSS-turbidity test are provided in **Attachment 2**, which includes turbidity measurements undertaken during testing for each sample.

Photographs taken during the column test are provided in **Figure 1**. These photographs were taken:

- prior to commencement;
- 1 hour and 35 minutes after commencement;
- days and 0.4 hours after commencement;
- 6 days and 0.7 hours after commencement, and
- 13 days and 1.2 hours after commencement.

Figure 1: Column test –

1. *Talbingo Reservoir water without addition of the sieved crushed rock,*
2. *Column test 1 hour and 35 minutes after commencement,*
3. *Column test 2 days and 0.4 hours after commencement,*
4. *Column test 6 days and 0.7 hours after commencement, and*
5. *Column test 13 days and 1.2 hours after commencement.*

2.1.2 Surface Turbidity vs Time Results

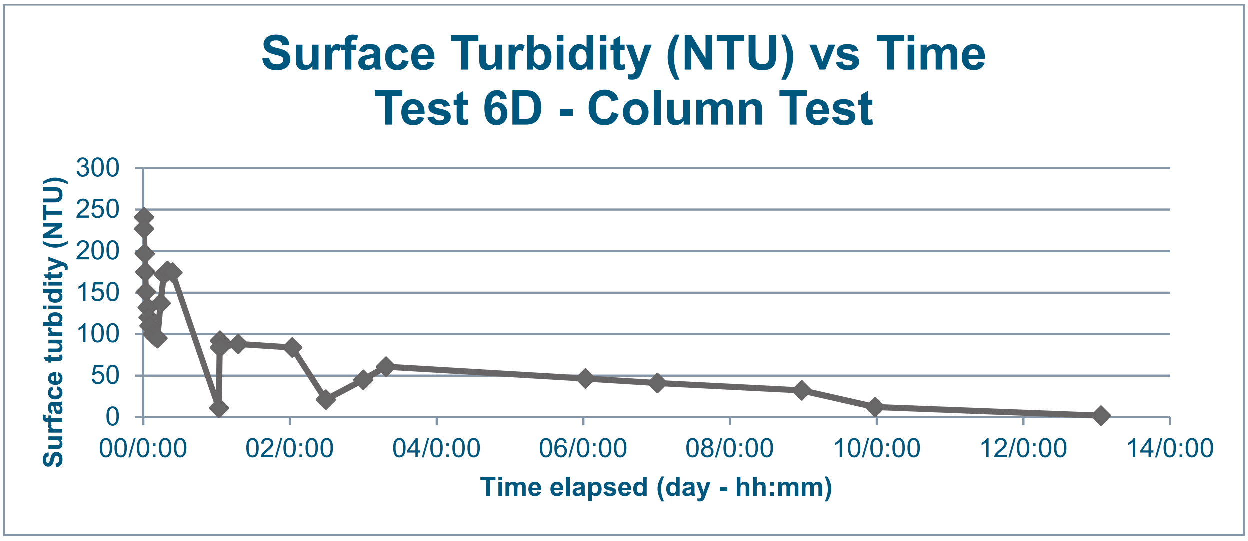
The variation in surface turbidity during Test 6D is plotted in **Graph 1**. In order to obtain a robust TSS-turbidity dataset for the purposes of establishing a relationship between TSS and turbidity, it was considered necessary to obtain samples with a wide range of TSS and turbidity values. Samples with a higher turbidity were obtained by reagitating the upper 15 cm of the column, approximately 1 day and 1 hour following commencement, and extracting samples from between 10 cm and 25 cm below the surface with a pipette at 2.5 days and 3 days following commencement. The pipette was gently placed in the water to minimise disturbance to the water columns. However, both sampling intervals corresponded to an increase in surface turbidity.

Graph 1 shows that surface turbidity decreased relatively rapidly from 250 NTU to 100 NTU during the initial three hours of testing. Approximately 4.5 hours after commencement, surface turbidity decreased to 95 NTU. Between 4.5 and 9.5 hours after commencement, surface turbidity increased to 174 NTU. The increase in surface turbidity was somewhat unexpected and a discussion is provided in **Section 3**.

Surface turbidity subsequently decreased rapidly to 11 NTU, 25 hours (1 day and 1 hour) after commencement. As previously mentioned, to obtain a wide range of turbidity and TSS values, the upper 15 cm of the column was lightly reagitated by mixing with a glass stirring rod and surface turbidity increased to 90 NTU. By approximately 2 days and 1 hour after commencement, surface turbidity decreased to approximately 84 NTU representing a minor change over a 24 hour period.

Thereafter, surface turbidity decreased rapidly and over the ensuing 12 hour period (2 days and 12 hours after commencement), surface turbidity decreased to approximately 20 NTU. In order to obtain a robust TSS-turbidity dataset, it was considered necessary to obtain samples between 20 NTU and 84 NTU. Rather than reagitate the column to achieve samples with a higher turbidity in this range, a pipette was used to extract samples from lower in the water column where turbidity was visibly higher, at 2.5 days and 3 days following commencement. During this period, surface turbidity increased to 60.8 NTU.

By 10 days after commencement, surface turbidity decreased to 12 NTU at a relatively steady rate. At this point in time, flocculant was added to the column. Refer **Section 2.3.**

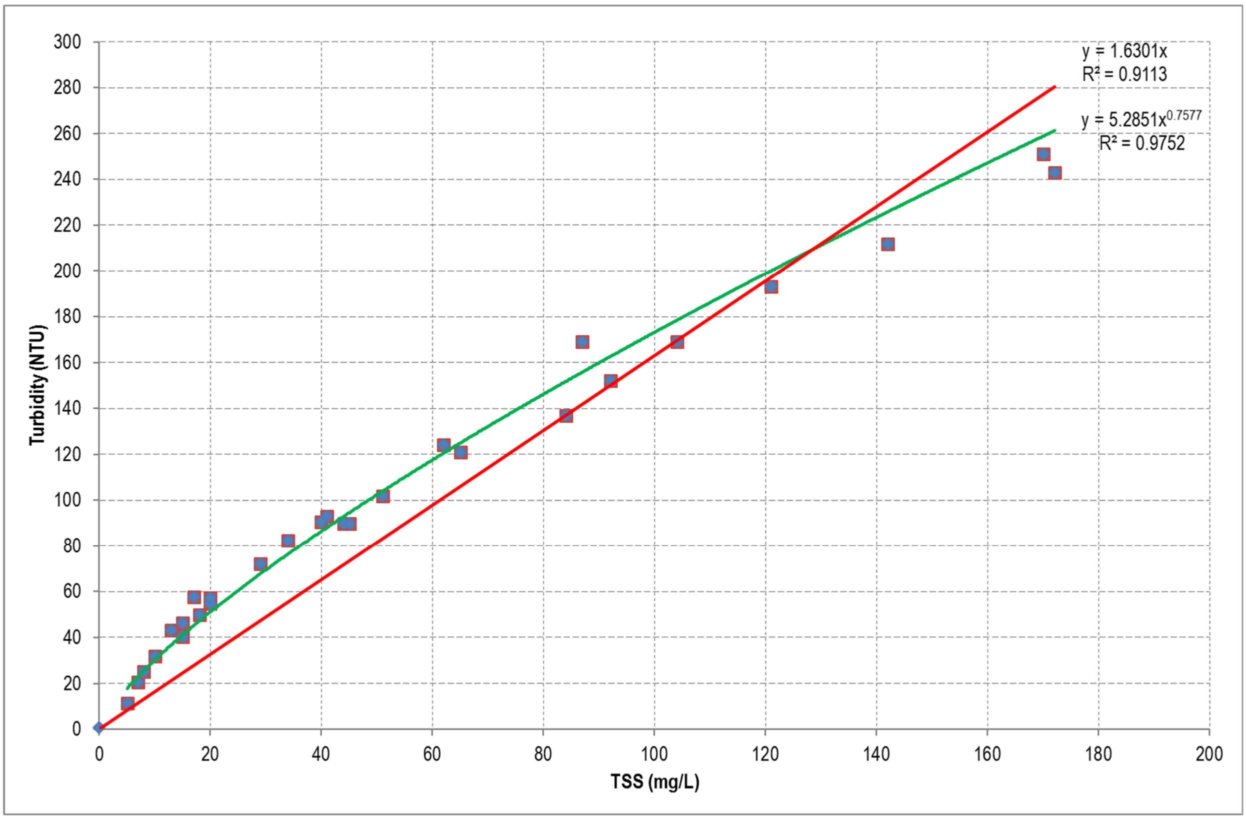


Graph 1: Surface turbidity measured during the column test – Byron Range Group crushed rock (Test 6D).

2.1.3 TSS – Turbidity Results

A total of 29 samples were collected during testing for laboratory TSS and turbidity analysis. TSS values for the collected samples ranged between <5 mg/L[1] and 172 mg/L, while turbidity values of up to around 250 NTU were recorded.

A plot of TSS versus turbidity for all data collected during testing is provided in **Graph 2**. Turbidity values used in this dataset are the measurements taken during testing (inside the glass beaker prior to sub-sampling) rather than the laboratory results[2]. This dataset is plotted with trendlines corresponding to both linear and power functions. It is evident that the power function provides a much closer fit of the data, characterised by an R^2 value of 0.98[3], whereas the linear line of best fit has a lower R^2 value of 0.91.



Graph 2: TSS-turbidity results – Byron Range Group crushed rock (Test 6D)

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[1] The Limit of Reporting (LOR) value for TSS analysis is 5 mg/L, refer **Attachment 1**. Results for samples with TSS concentrations below the LOR value are reported as <5 mg/L.

[2] Turbidity results reported by the laboratory were compared with turbidity results obtained during testing using the Wetlab-ECO-NTU sensor. No significant differences between the turbidity datasets were evident (i.e. selection of the turbidity dataset does not significantly influence the TSS-turbidity relationship reported herein).

[3] The R^2 value, also known as the coefficient of determination, is a measure of how close the plotted data are to the fitted regression line (i.e. the line of best fit). An R^2 value of 1 indicates that the regression line perfectly fits the data.

2.1.4 TSS – Turbidity Relationship

A summary of the TSS-turbidity relationships determined for the Test 6D dataset is provided in **Table 1**, including the turbidity values equivalent to a TSS concentration of 50 mg/L for each the linear and power function trendline. The selected TSS value of 50 mg/L is somewhat arbitrary and the water quality limit for the project may vary.

Table 1: Summary of TSS-turbidity relationships for Byron Range Group crushed rock

Trendline Function	Number of values	R^2 value	Turbidity (NTU) equivalent to 50 mg/L TSS
Linear	29	0.91	82
Power	29	0.98	102

As noted above, the power function trendline provides a better fit of the dataset compared to the linear trendline. Furthermore, the high R^2 value associated with the power function trendline (0.98) indicates a strong correlation between TSS and turbidity for the dataset, and is considered to be valid for the data collected during testing. The turbidity value equivalent to 50 mg/L suspended solids is 102 NTU for this dataset.

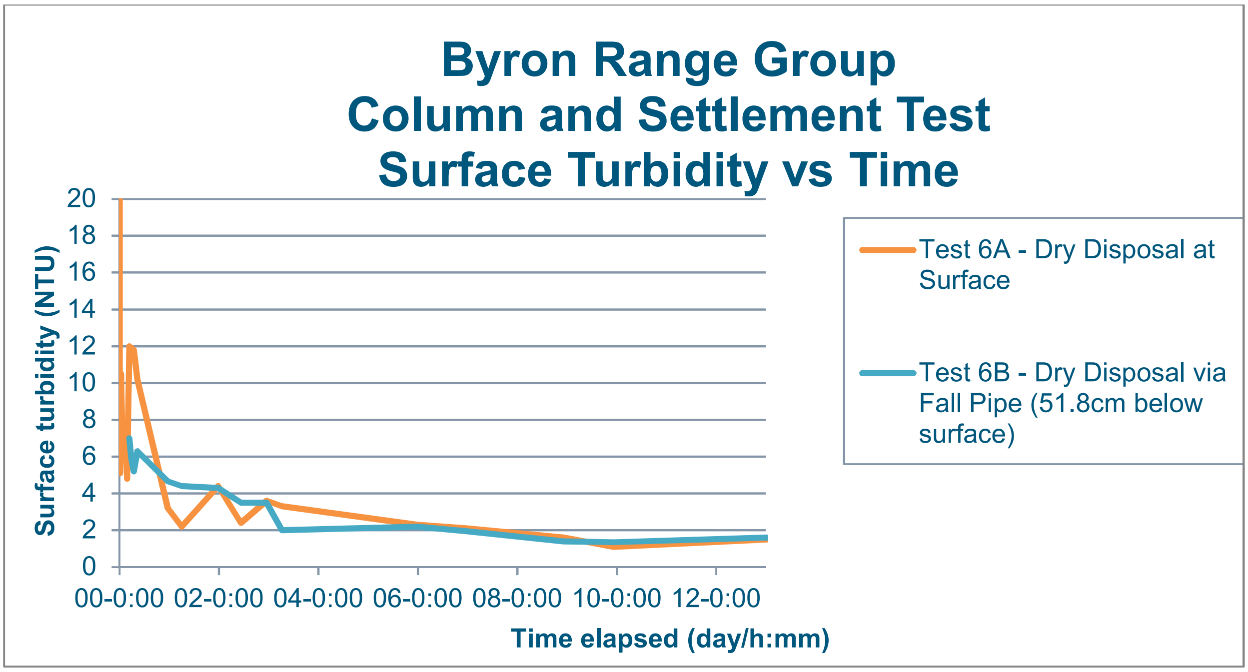
2.2 Settlement Tests

2.2.1 Overview

The two settlement tests for the Byron Range Group crushed rock (Tests 6A and 6B) commenced simultaneously on 23rd October 2018 at 9:00am. Different disposal methods were simulated in the respective columns as described in **Section 2.2.2** to **2.2.4**. The tests concluded on the 5th October 2018, approximately 13 days following commencement.

Surface turbidity in the two columns was measured 70 minutes prior to addition of the sieved crushed rock, with values of 1.9 NTU and 1.7 NTU recorded for Test 6A and 6B respectively.

Surface turbidity measured at varying time intervals during the 13-day test duration is plotted in **Graph 3** for the two settlement tests. These results are discussed in the following sections, along with a summary of the key observations for each settlement test. Laboratory log records completed during the settlement tests are provided in **Attachment 2**.



Graph 3: Surface turbidity measured during the settlement tests – Byron Range Group (Tests 6A and 6B).

Photographs taken during the settlement tests are provided in **Figures 2** to **6**. These photographs were taken prior to commencement (**Figure 2**), 18 minutes after commencement (**Figure 3**), 3 hours and 30 minutes after commencement (**Figure 4**), 5 hours and 40 minutes after commencement (**Figure 5**), and 1 days and 23.5 hours after commencement (**Figure 6**).

Figure 2: Settlement test prior to placement of sieved crushed rock-
Left: Test 6A - Placement of dry sieved crushed rock directly onto the water surface,
Right: Test 6B - Placement of dry sieved crushed rock within a fall pipe with opening submerged 51.8 cm below the water surface.

TEST I.D.	6A
GEOLOGICAL UNIT	BYRON RANGE GROUP
START TIME	23/10/18 9:50
CURRENT TIME	23/10/18 10:08

TEST I.D.	6B
GEOLOGICAL UNIT	BYRON RANGE GROUP
START TIME	23/10/18 9:50
CURRENT TIME	23/10/18 10:08

Figure 3: Settlement test 18 minutes following placement of sieved crushed rock-
Left: Test 6A - Placement of dry sieved crushed rock directly onto the water surface,
Right: Test 6B - Placement of dry sieved crushed rock within a fall pipe with opening submerged 51.8 cm below the water surface.

TEST I.D.	6A
GEOLOGICAL UNIT	BYRON RANGE GROUP
START TIME	23/10/18 9:50
CURRENT TIME	23/10/18 13:20

TEST I.D.	6B
GEOLOGICAL UNIT	BYRON RANGE GROUP
START TIME	23/10/18 9:50
CURRENT TIME	23/10/18 13:20

Figure 4: Settlement test 3 hour and 30 minutes following placement of sieved crushed rock-
Left: Test 6A - Placement of dry sieved crushed rock directly onto the water surface,
Right: Test 6B - Placement of dry sieved crushed rock within a fall pipe with opening submerged 51.8 cm below the water surface.

TEST I.D.	6A
GEOLOGICAL UNIT	BYRON RANGE GROUP
START TIME	23/10/18 9:50
CURRENT TIME	23/10/18 15:30

TEST I.D.	6B
GEOLOGICAL UNIT	BYRON RANGE GROUP
START TIME	23/10/18 9:50
CURRENT TIME	23/10/18 15:30

Figure 5: Settlement test 5 hours and 40 minutes following placement of sieved crushed rock-
Left: Test 6A - Placement of dry sieved crushed rock directly onto the water surface,
Right: Test 6B - Placement of dry sieved crushed rock within a fall pipe with opening submerged 51.8 cm below the water surface.

TEST I.D.	6A
GEOLOGICAL UNIT	BYRON RANGE GROUP
START TIME	23/10/18 9:50
CURRENT TIME	25/10/18 9:15

TEST I.D.	6B
GEOLOGICAL UNIT	BYRON RANGE GROUP
START TIME	23/10/18 9:50
CURRENT TIME	25/10/18 9:15

Figure 6: Settlement test 1 day and 23.4 hours following placement of sieved crushed rock-
Left: Test 6A - Placement of dry sieved crushed rock directly onto the water surface,
Right: Test 6B - Placement of dry sieved crushed rock within a fall pipe with opening submerged 51.8 cm below the water surface.

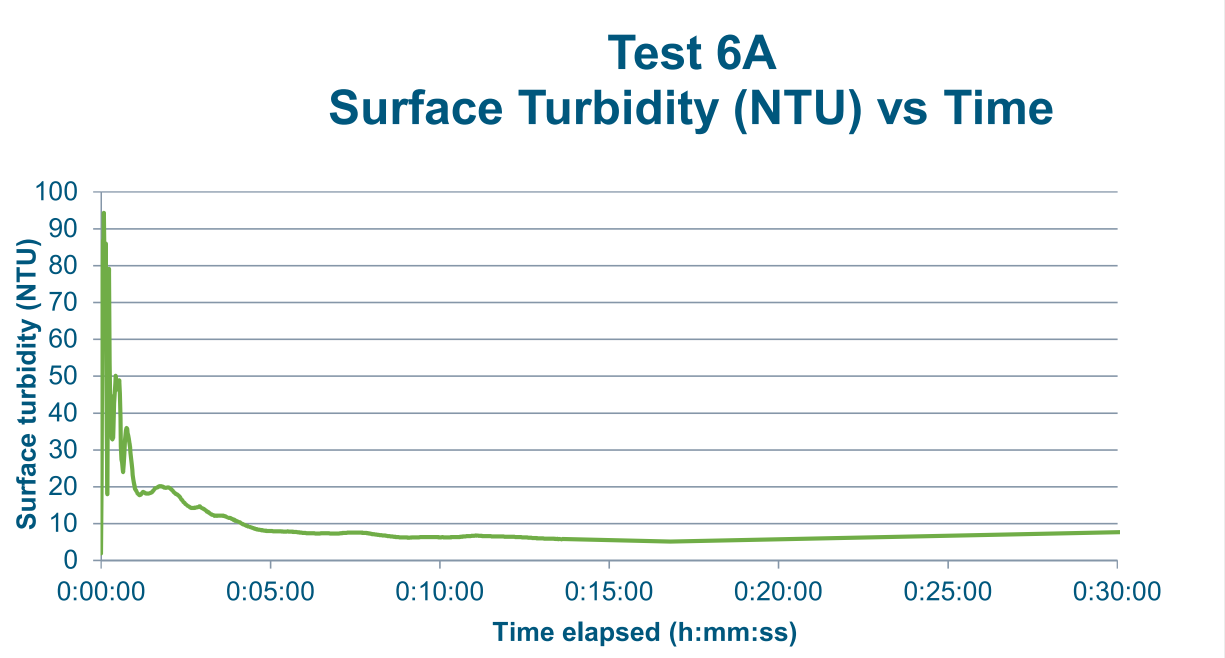
2.2.2 Test 6A - Placement of dry sieved crushed rock directly onto the water surface

For Test 6A, the sieved crushed rock was gently sprinkled onto the water surface from a height of approximately 25 cm above the water surface. Clumps of crushed rock fell to the bottom of the column within approximately 30 seconds. Fine material parted from the clumps during descent and a turbid trail formed through the water column in the wake of the clumps. It is estimated that approximately 10% of the mass of crushed rock fell to the bottom in clumps.

Significant diffusion and mixing of the crushed rock was observed after placement. After approximately 30 seconds, a dense turbid plume was observed in the middle third of the column. After approximately 45 seconds, the plume had dispersed and turbidity in the lower two thirds of the columns appeared relatively uniform. Turbidity gradually decreased towards the surface. Sediment appeared to fall through the upper approximately 15 cm of the water column before dispersing and mixing.

Surface turbidity levels were measured continuously (at one second time intervals) during the first 14 minutes of Test 6A with the Wetlab ECO-NTU sensor remaining in the water column throughout this period. Surface turbidity levels were measured at varying time intervals thereafter. The Wetlab ECO-NTU sensor was placed in the water column for each measurement and removed after a stable reading was recorded.

Surface turbidity during the first 30 minutes after commencement of the test is plotted in **Graph 4** for Test 6A**.**



Graph 4: Surface turbidity measured during the first hour following placement of Byron Range Group crushed rock, Test 6A.

Surface turbidity levels increased rapidly from background levels of around 1.9 NTU to a maximum of around 95 NTU during placement of the sieved crushed rock (i.e. within the initial 10 seconds of testing). Surface turbidity decreased rapidly to approximately 20 NTU, 60 seconds after commencement. Over the subsequent 14 minutes, surface turbidity fluctuated and gradually declined. Surface turbidity 14 minutes after commencement was approximately 6 NTU. At this point in time, continuous monitoring ceased. Surface turbidity levels remained at around 5 to 10 NTU over the subsequent 8 hours.

Surface turbidity measured at varying time intervals over the 13-day test duration is plotted in **Graph 3** (refer **Section 2.2.1**) for Test 6A, alongside the results for Tests 6B.

Between approximately 1 day and 13 days after commencement, surface turbidity gradually decreased and varied between 4.4 NTU (2 days after commencement) and 1.1 NTU (10 days after commencement). The average surface turbidity recorded during this period was approximately 2.5 NTU.

2.2.3 Test 6B - Placement of dry sieved crushed rock within a fall pipe with opening submerged 51.8 cm below the water surface

For Test 6B, the sieved crushed rock was gently sprinkled into the fall pipe with an internal diameter of approximately 50 mm. The top of the fall pipe was approximately 75 cm above the water surface. The inside of the fall pipe was rinsed with water from Talbingo Reservoir to ensure that all of the sieved crushed rock entered the column.

Significant mixing and diffusion of crushed rock was observed within the fall pipe. Clumps of crushed rock fell to the bottom of the column within approximately 30 seconds. Fine material parted from the clumps during descent and a turbid trail formed through the water column in the wake of the clumps. It is estimated that approximately 5-10% of the mass of crushed rock fell to the bottom in clumps.

The dense turbid plume in the fall pipe gradually descended and diffused throughout the water column, primarily below the base of the fall pipe. After approximately 1 minute and 50 seconds, significant mixing was observed in the middle third of the column, below the fall pipe. After 2 minutes and 40 seconds, relatively even mixing and turbidity was observed in the lower two thirds of the water column below the base of the fall pipe. The top of the turbid plume was recorded at approximately the base of the fall pipe (51.8 cm below the surface of the water).

The top of the turbid plume was clearly distinguished for the first 2 to 3 hours after commencement of the testing. There was no immediate discernible change in turbidity above turbid plume, with the upper 52 cm of water in the column (i.e. above the base of the fall pipe) remaining relatively clear with turbidity at background levels (refer **Graph 3**, **Section 2.2.1**).

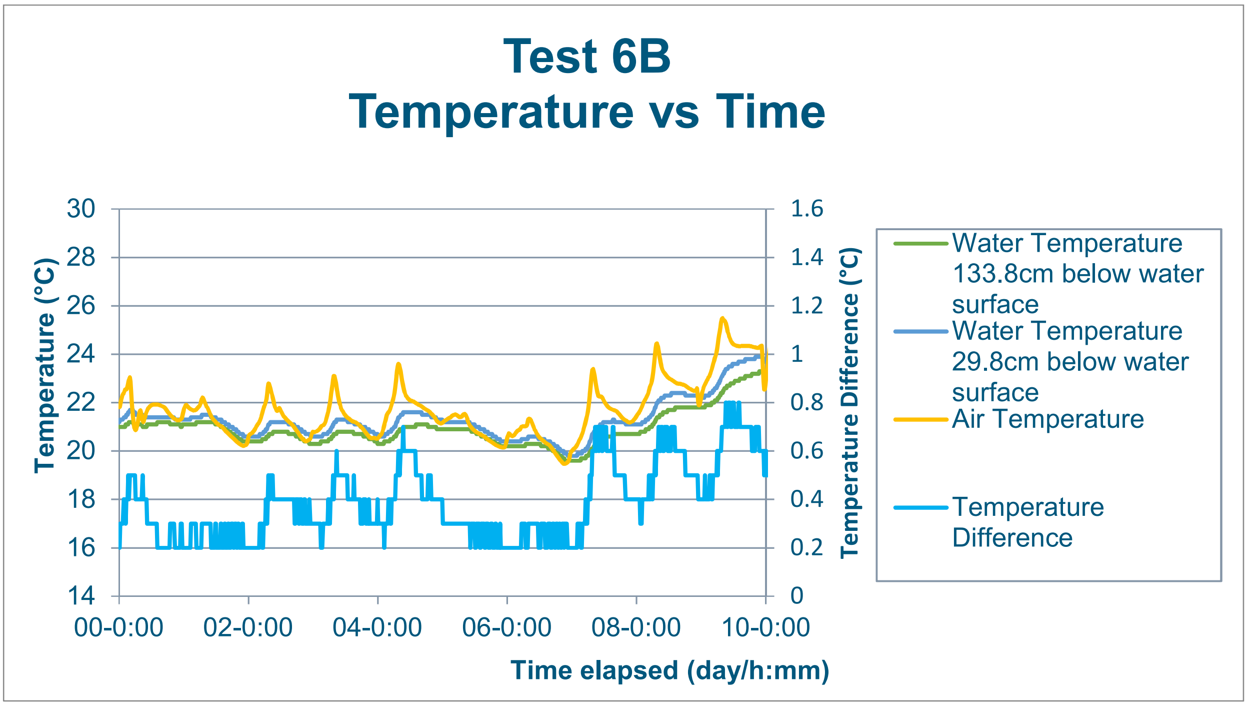
Approximately 4 to 5 hours after commencement, the turbid plume was not clearly distinguished and relatively even mixing was observed throughout the water column. Surface turbidity increased to approximately 7 NTU, approximately 4 hours and 40 minutes after commencement. A discussion regarding the observed increase in surface turbidity during Test 6B is provided in **Section 3**.

Surface turbidity gradually decreased and it was approximately 2 NTU, 6 days and 2 hours after commencement, and approximately 1.5 NTU, 13 days after commencement.

2.2.4 Air and Water Temperature

Air temperature and water temperature were recorded every 15 minutes in Test 6B for the duration of the test using Solinist Leveloggers and a Barologger. Water temperature was monitored at two depths, 29.8 cm and 133.8 cm below the water surface.

Graph 5 provides air and water temperature variation over time for Test 6B.



Graph 5: Air and water temperature in Test 6B. Elapsed time relative to commencement of Test 6A and 6B.

Air temperature in Test 6B fluctuated between approximately 19.5 °C and 28.1 °C. Block out curtains were placed across all windows for the duration of the test in an attempt to regulate air temperature within the laboratory.

Water temperature varied between 19.6 °C and 25.1 °C. Water temperature was consistently 0.2 °C to 0.9 °C warmer at the upper monitoring location and the average temperature differential between the monitoring depths was 0.39 °C. The warmer water near the top of the column would have a lower density and would, therefore, be buoyant compared to cooler water lower in the column.

2.3 Flocculation Test

Prior to completion of the settlement tests, a trial was undertaken to determine whether a chemical flocculant would accelerate settlement of finer particles and clarify the water. The chemical flocculant selected for the test was alum (aluminium sulphate). It should be noted that the particular chemical flocculant selected for the test was somewhat arbitrary and has not been approved for use during construction.

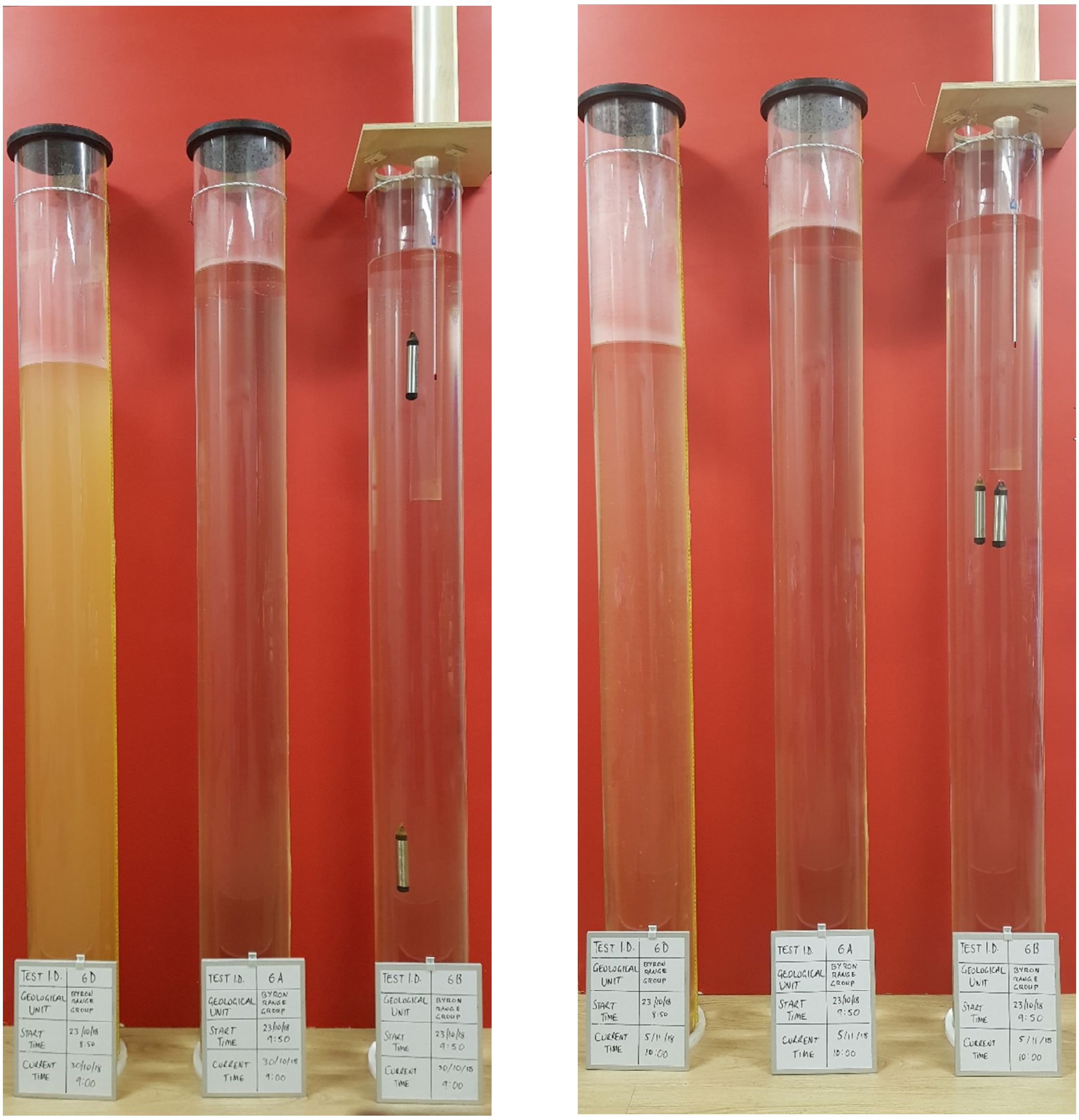
Flocculant was added to Test 6D on the 2nd November 2018 at 8:15am, approximately 10 days following commencement of the settlement test. Test 6A and 6B were retained as control columns for comparison.

Surface turbidity in Test 6A, 6B and 6D on the 2nd November 2018 (prior to addition of flocculant) and the 5th November 2018 (following addition of flocculant) is reported in **Table 2**. Surface turbidity in Test 6D decreased from 12 NTU to 1.8 NTU while the turbidity in the control columns, Test 5A and 5B, remained relatively constant (albeit initial turbidity was very low and within the range of ‘background’ turbidity). This indicates that the chemical flocculant was effective in clarifying the water.

Table 2: Turbidity before and after the addition of flocculant to Test 6A.

Date/Time	Test 6A (NTU)	Test 6B (NTU)	Test 6D (NTU)
2nd November 2018, 8:15am	1.1	1.35	12
5th November 2018, 10:10am	1.5	1.6	1.8

A photograph of the three Test columns taken on the 2nd and 5th November 2018 is provided in **Figure 7**. It should be noted that some of the flocculated crushed rock in Test 6D adhered to the walls of the column thereby making the column appear slightly ‘cloudy’ when viewed side on. However, when viewed from above, the water was clear as indicated by the surface turbidity reading.



TEST I.D.	6D
GEOLOGICAL UNIT	BYRON RANGE GROUP
START TIME	23/10/18 8:50
CURRENT TIME	30/10/18 9:00

TEST I.D.	6A
GEOLOGICAL UNIT	BYRON RANGE GROUP
START TIME	23/10/18 9:50
CURRENT TIME	30/10/18 9:00

TEST I.D.	6B
GEOLOGICAL UNIT	BYRON RANGE GROUP
START TIME	23/10/18 9:50
CURRENT TIME	30/10/18 9:00

TEST I.D.	6D
GEOLOGICAL UNIT	BYRON RANGE GROUP
START TIME	23/10/18 8:50
CURRENT TIME	5/11/18 10:00

TEST I.D.	6A
GEOLOGICAL UNIT	BYRON RANGE GROUP
START TIME	23/10/18 9:50
CURRENT TIME	5/11/18 10:00

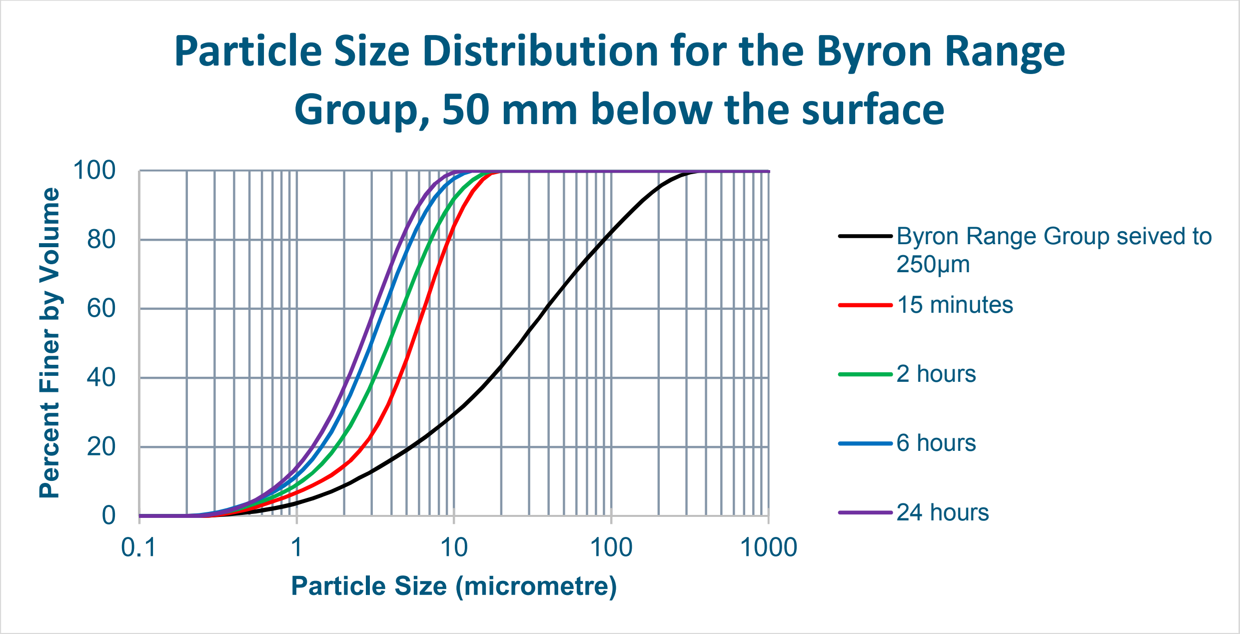
TEST I.D.	6B
GEOLOGICAL UNIT	BYRON RANGE GROUP
START TIME	23/10/18 9:50
CURRENT TIME	5/11/18 10:00

Figure 7: Column and Settlement tests prior to and following addition of chemical flocculant to Test 6A-
Left: Test 6D, 6A and 6B (from left to right) prior to the addition of flocculant to Test 6D. Photographed on the 2nd November at 9:00am, approximately 10 days following commencement of the settlement tests.
Right: Test 6D, 6A and 6B (from left to right), following the addition of flocculant to Test 6D. Photographed on the 5th November at 10:00am, approximately 12 days following commencement of the settlement tests.

2.4 Critical Particle Size

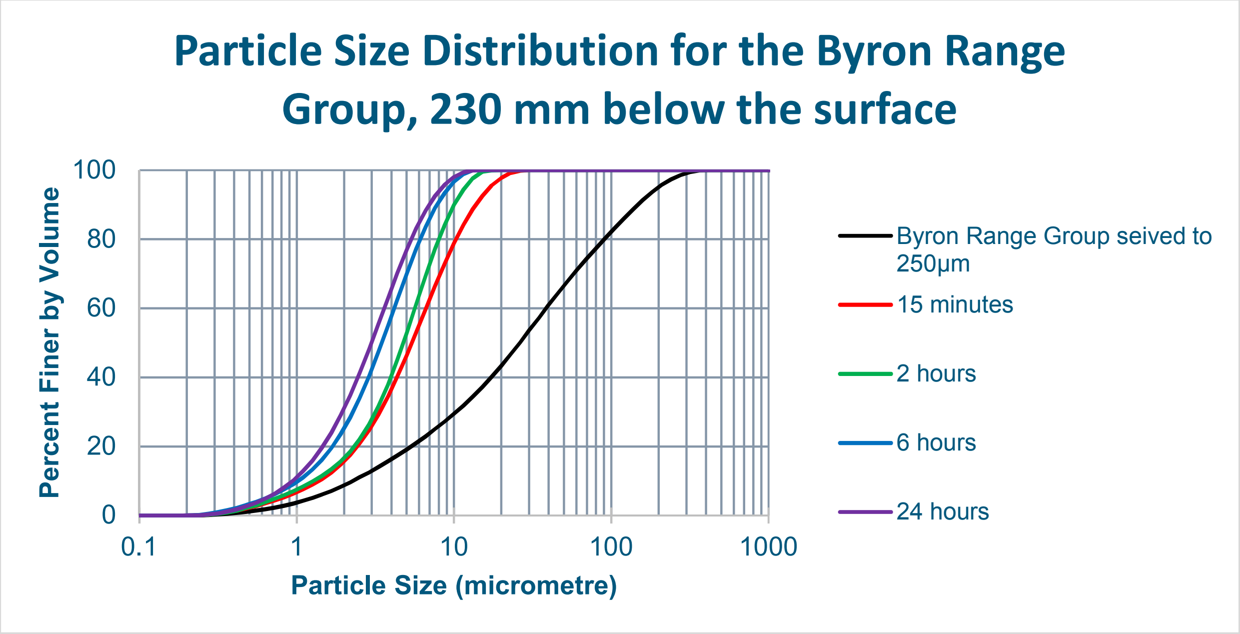
The tests to determine the critical particle size in suspension commenced on the 22nd and 23rd October 2018. Particle size analysis using the Mastersizer 2000 was completed on the 23rd October 2018.

Graph 6 plots the particle size distribution of the sieved crushed rock (used for all tests) and the particle size that remains in suspension after each time interval (15 minutes, 2 hours, 6 hours and 24 hours) at 50 mm below the water surface (850 mL mark on cylinder). The maximum particle size in suspension at various time intervals is outlined in **Table 3**. The maximum particle size in suspension decreases over time from around 20 µm (15 minutes) to 11.5 µm (24 hours).



Graph 6: Particle size distribution at varying time intervals, 50 mm below the water surface.

Graph 7 plots the particle size distribution of the sieved crushed rock (used for all tests) and the particle size that remains in suspension after a given time interval (15 minutes, 2 hours, 6 hours and 24 hours) at 230 mm below the water surface (300 mL mark on cylinder). The maximum particle size in suspension at various time intervals is outlined in **Table 3**. The maximum particle size in suspension decreases over time from around 26.5 µm (15 minutes) to 13 µm (24 hours).



Graph 7: Particle size distribution at varying time intervals 230 mm the water surface.

Table 3: Maximum particle size in suspension at varying time intervals, 50 mm and 230 mm below the water surface.

Time	Maximum particle size in suspension (µm)	
	50 mm below the water surface	230 mm below the water surface
15 minutes	20	26.5
2 hours	17.5	17.5
6 hours	13.5	13.5
24 hours	11.5	13

Based on the results presented above, it is evident that, for the same given time intervals, the maximum particle size in suspension is larger at greater depths within the water column, as would be expected.

3 Discussion

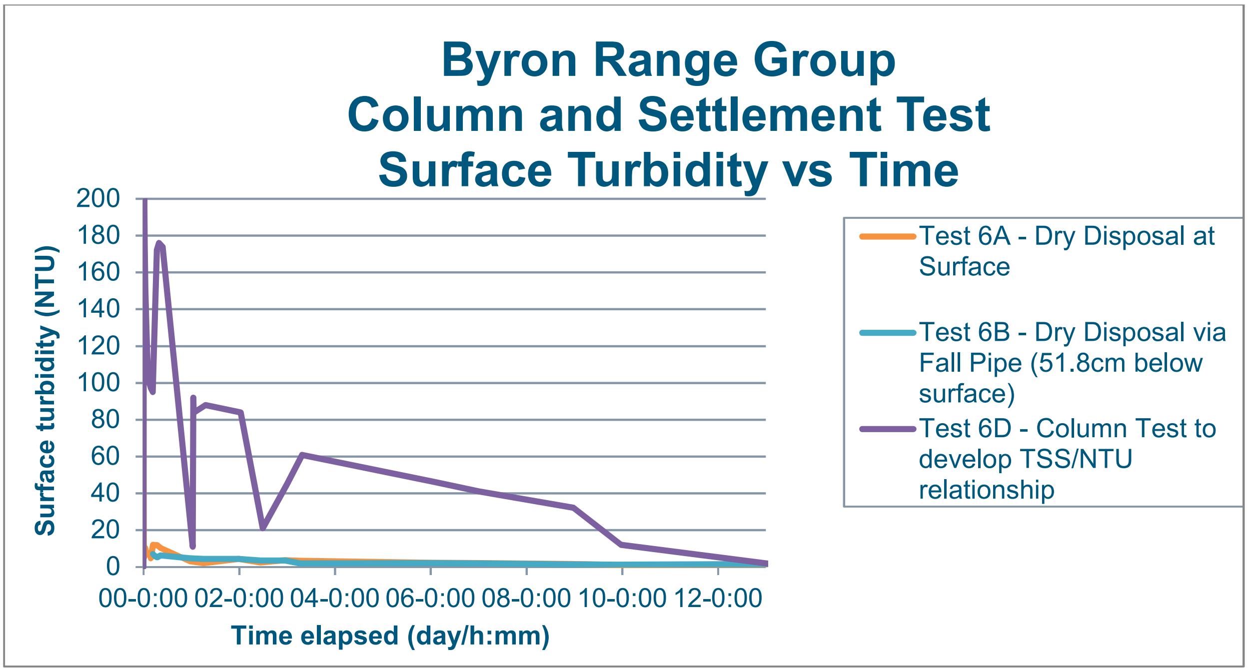
The settlement tests simulating placement of dry crushed rock on the surface (Test 6A) and through a fall pipe (Test 6B) indicate that the crushed rock from the Byron Range Group settles relatively quickly. After 24 hours, surface turbidity was less than 5 NTU, the approximate recorded background turbidity level in the reservoir.

However, when the crushed rock and water mixture was agitated for the column test (Test 6D), very high levels of turbidity were recorded for an extended period of time. The surface turbidity in Test 6D was more than 250 NTU after agitation and 170 NTU, 9.5 hours after agitation. After 7 days, surface turbidity was approximately 40 NTU (albeit, the upper portion of the water column was reagitated during the test).

The observation that crushed rock settles out of suspension relatively quickly, unless the mixture is agitated, is unexpected. It is hypothesised that individual grains of crushed rock adhere to each other, forming large particles that settle within 24 hours. Agitation of the crushed rock and water mixture may break the bond between grains of crushed rock thereby forming smaller particles that remain in suspension for a longer period of time.

3.1 Fluctuating Turbidity and Increase in Surface Turbidity

As described in **Section 2**, surface turbidity in Test 6D fluctuated and surface turbidity in Test 6B increased within 5 hours after commencement. The surface turbidity for the three tests is shown in **Graph 8**. The graph includes the addition of flocculant to Test 6D, 10 days following commencement and re-agitation of the upper portion of Test 6D, 1 day and 1 hour after commencement.



Graph 8: Surface turbidity measured during the settlement and column tests – Byron Range Group (Tests 6A, 6B and 6D).

An increase in surface turbidity was unexpected, with ongoing settlement and decreasing turbidity following initial mixing considered more likely to occur. It is possible that the observations were influenced by one or more of the following factors:

1. Weak thermal convection currents within the column may result in rising warm water transporting suspended particles to the surface. Air temperature and water temperature was monitored for the duration of the test. The results are reported in **Section 2.2.4** and presented in **Graph 5**.

   It is apparent from **Graph 5** that the water temperature warms and cools in response to the air temperature. Further, the difference in water temperature between the top and bottom of the column increases during a warming phase and decreases during a cooling phase.

   It is inferred that heat is transferred from the air to the column and from the column to the adjacent water near the wall of the column through the process of conduction, which is the transfer of heat between objects in contact with each other, or through a substance due to the collision of molecules. Heating of water near the wall of the column would result in differential water temperature across the column with cooler water near the centre of the column. The differential water temperature would lead to two processes, conduction and convection where convection is the process of warmer water, with a lower density, rising to cooler areas in the column and cooler water, with a higher density, sinking to take the place of the warmer water. The velocity of convection currents are difficult to determine and due to a range of factors.

2. The sieved crushed rock may contain clay particles that are anionic. The repelling force between charged particles in suspension may result in suspended solids diffusing and distributing evenly throughout the water column.

3. The action of gently lowering a turbidity probe into the upper layer of the column (~3.4 cm below the water surface), or extracting samples with a pipette from Test 6D (at 2.5 days and 3 days following commencement), may be sufficient to disturb the water column resulting in advection of very fine suspended particles. Indeed, re-agitation of the upper 15 cm of Test 6D, 1 day and 1 hour following commencement of the test was sufficient to increase surface turbidity.

Regardless of the reason for fluctuating and increasing surface turbidity in Tests 6B and 6D, it is clear that minor disturbances to the water column are sufficient to disrupt the settlement process and redistribute fine suspended particles within the water column.

4 Conclusions

It is apparent from the column test and settlement tests that once fine crushed rock from the clayey gravel in the Byron Range Group geological zone enters the water column, the fine particles settle out of suspension within 24 hours, unless the crushed rock and water mixture is agitated. Surface turbidity approximately 24 hours after commencement of Tests 6A and 6B was 3.2 NTU and 4.7 NTU respectively, which is within the range of background turbidity levels in Talbingo Reservoir of 1 NTU to 5 NTU, as reported by Cardno. Agitation of the water and crushed rock mixture resulted in elevated turbidity of more than 10 NTU, which persisted for more than 10 days.

Minor disturbances to the water column are likely to disrupt the settlement process and/or re-suspend fine particles.

The critical particle size in suspension that would be contributing to prolonged surface turbidity in the water column (more than 24 hours) would be less approximately 13 µm.

The results of a chemical flocculation test for the Byron Range Group crushed rock indicate that the addition of flocculant may accelerate settlement of fine particles and clarify the water.

TSS-turbidity data collected during the Column Test (Test 6D) is considered to be reliable for the purpose of establishing a preliminary relationship between TSS and turbidity for the Byron Range Group geological zone. The turbidity value equivalent to 50 mg/L suspended solids is 102 NTU for this dataset. Furthermore, as the properties and grading of the crushed rock placed during construction may vary to that used in the column test, collection of field TSS-turbidity data during subaqueous excavated rock placement activities is recommended so that the relationship between turbidity and suspended solids can be continually validated and improved.

Attachment 1 – Laboratory Certificates

CERTIFICATE OF ANALYSIS

Work Order : **ES1831595**
Client : **HASKONING AUSTRALIA- ROYAL HASKONING**
Contact : MR PATRICK LAWLESS
Address : LEVEL 14 56 Berry Street
NORTH SYDNEY 2060
Telephone : ----
Project : Snowy 2.0 TSS-NTU (Tests 6-7)
Order number :
C-O-C number : ----
Sampler : PATRICK LAWLESS
Site : ----
Quote number : EN/222
No. of samples received : 33
No. of samples analysed : 33

Page : 1 of 9
Laboratory : Environmental Division Sydney
Contact : Customer Services ES
Address : 277-289 Woodpark Road Smithfield NSW Australia 2164
Telephone : +61-2-8784 8555
Date Samples Received : 24-Oct-2018 16:55
Date Analysis Commenced : 25-Oct-2018
Issue Date : 30-Oct-2018 17:16

Accreditation No. 825
Accredited for compliance with
ISO/IEC 17025 - Testing

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This Certificate of Analysis contains the following information:

- General Comments
- Analytical Results

Additional information pertinent to this report will be found in the following separate attachments: Quality Control Report, QA/QC Compliance Assessment to assist with Quality Review and Sample Receipt Notification.

Signatories

This document has been electronically signed by the authorized signatories below. Electronic signing is carried out in compliance with procedures specified in 21 CFR Part 11.

Signatories	*Position*	*Accreditation Category*
Ankit Joshi	Inorganic Chemist	Sydney Inorganics, Smithfield, NSW

General Comments

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Where the LOR of a reported result differs from standard LOR, this may be due to high moisture content, insufficient sample (reduced weight employed) or matrix interference.

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Key :
CAS Number = CAS registry number from database maintained by Chemical Abstracts Services. The Chemical Abstracts Service is a division of the American Chemical Society.
LOR = Limit of reporting
^ = This result is computed from individual analyte detections at or above the level of reporting
ø = ALS is not NATA accredited for these tests.
~ = Indicates an estimated value.

Analytical Results

Sub-Matrix: **WATER** (Matrix: **WATER**)			*Client sample ID*	**6D-1**	**6D-2**	**6D-3**	**6D-4**	**6D-5**
			Client sampling date / time	23-Oct-2018 00:00	23-Oct-2018 00:00	23-Oct-2018 00:00	23-Oct-2018 00:00	23-Oct-2018 00:00
Compound	*CAS Number*	*LOR*	*Unit*	**ES1831595-001**	**ES1831595-002**	**ES1831595-003**	**ES1831595-004**	**ES1831595-005**
				Result	Result	Result	Result	Result
EA025: Total Suspended Solids dried at 104 ± 2°C								
Suspended Solids (SS)	----	5	mg/L	<5	**170**	**172**	**142**	**121**
EA045: Turbidity								
Turbidity	----	0.1	NTU	**0.3**	**251**	**263**	**232**	**212**

Analytical Results

Sub-Matrix: **WATER**
(Matrix: **WATER)**

			Client sample ID	**6D-6**	**6D-7**	**6D-8**	**6D-9**	**6D-10**
			Client sampling date / time	23-Oct-2018 00:00	23-Oct-2018 00:00	23-Oct-2018 00:00	23-Oct-2018 00:00	23-Oct-2018 00:00
Compound	*CAS Number*	*LOR*	*Unit*	**ES1831595-006**	**ES1831595-007**	**ES1831595-008**	**ES1831595-009**	**ES1831595-010**
				Result	Result	Result	Result	Result
EA025: Total Suspended Solids dried at 104 ± 2°C								
Suspended Solids (SS)	----	5	mg/L	**87**	**92**	**65**	**84**	**62**
EA045: Turbidity								
Turbidity	----	0.1	NTU	**175**	**162**	**122**	**146**	**137**

Analytical Results

Sub-Matrix: **WATER**
(Matrix: **WATER)**

			Client sample ID	**6D-11**	**6D-12**	**6D-13**	**6D-14**	**6D-15**
			Client sampling date / time	23-Oct-2018 00:00	23-Oct-2018 00:00	23-Oct-2018 00:00	24-Oct-2018 00:00	24-Oct-2018 00:00
Compound	CAS Number	LOR	Unit	**ES1831595-011**	**ES1831595-012**	**ES1831595-013**	**ES1831595-014**	**ES1831595-015**
				Result	Result	Result	Result	Result
EA025: Total Suspended Solids dried at 104 ± 2°C								
Suspended Solids (SS)	----	5	mg/L	**51**	**41**	**104**	**7**	**44**
EA045: Turbidity								
Turbidity	----	0.1	NTU	**101**	**87.5**	**192**	**22.8**	**98.4**

Analytical Results

Sub-Matrix: **WATER** (Matrix: **WATER**)			*Client sample ID*	**6D-16**	**6D-17**	**7D-1**	**7D-2**	**7D-3**
			Client sampling date / time	24-Oct-2018 00:00	24-Oct-2018 00:00	23-Oct-2018 00:00	23-Oct-2018 00:00	23-Oct-2018 00:00
Compound	*CAS Number*	*LOR*	*Unit*	**ES1831595-016**	**ES1831595-017**	**ES1831595-018**	**ES1831595-019**	**ES1831595-020**
				Result	Result	Result	Result	Result
EA025: Total Suspended Solids dried at 104 ± 2°C								
Suspended Solids (SS)	----	5	mg/L	**45**	**40**	<5	**239**	**212**
EA045: Turbidity								
Turbidity	----	0.1	NTU	**87.9**	**82.3**	**0.8**	**137**	**135**

Analytical Results

Sub-Matrix: **WATER**
(Matrix: **WATER**)

			Client sample ID	**7D-4**	**7D-5**	**7D-6**	**7D-7**	**7D-8**
			Client sampling date / time	23-Oct-2018 00:00	23-Oct-2018 00:00	23-Oct-2018 00:00	23-Oct-2018 00:00	23-Oct-2018 00:00
Compound	*CAS Number*	*LOR*	*Unit*	**ES1831595-021**	**ES1831595-022**	**ES1831595-023**	**ES1831595-024**	**ES1831595-025**
				Result	Result	Result	Result	Result
EA025: Total Suspended Solids dried at 104 ± 2°C								
Suspended Solids (SS)	----	5	mg/L	**186**	**156**	**154**	**136**	**120**
EA045: Turbidity								
Turbidity	----	0.1	NTU	**130**	**73.3**	**40.6**	**33.6**	**36.5**

Analytical Results

Sub-Matrix: **WATER** (Matrix: **WATER**)			*Client sample ID*	**7D-9**	**7D-10**	**7D-11**	**7D-12**	**7D-13**
			Client sampling date / time	23-Oct-2018 00:00	23-Oct-2018 00:00	24-Oct-2018 00:00	24-Oct-2018 00:00	24-Oct-2018 00:00
Compound	*CAS Number*	*LOR*	*Unit*	**ES1831595-026**	**ES1831595-027**	**ES1831595-028**	**ES1831595-029**	**ES1831595-030**
				Result	Result	Result	Result	Result
EA025: Total Suspended Solids dried at 104 ± 2°C								
Suspended Solids (SS)	----	5	mg/L	**106**	**119**	**18**	**54**	**48**
EA045: Turbidity								
Turbidity	----	0.1	NTU	**35.2**	**38.0**	**27.8**	**65.6**	**67.7**

Analytical Results

Sub-Matrix: **WATER** (Matrix: **WATER**)			*Client sample ID*	**7D-14**	**7D-15**	**7D-16**	**----**	**----**
			Client sampling date / time	24-Oct-2018 00:00	24-Oct-2018 00:00	24-Oct-2018 00:00	----	----
Compound	*CAS Number*	*LOR*	*Unit*	**ES1831595-031**	**ES1831595-032**	**ES1831595-033**	**--------**	**--------**
				Result	Result	Result	----	----
EA025: Total Suspended Solids dried at 104 ± 2°C								
Suspended Solids (SS)	----	5	mg/L	**80**	**27**	**62**	**----**	**----**
EA045: Turbidity								
Turbidity	----	0.1	NTU	**80.1**	**49.0**	**69.7**	**----**	**----**

ALS Environmental

CERTIFICATE OF ANALYSIS

Work Order : **ES1831922**
Client : **HASKONING AUSTRALIA- ROYAL HASKONING**
Contact : MR PATRICK LAWLESS
Address : LEVEL 14 56 Berry Street
NORTH SYDNEY 2060
Telephone : +61 02 8854 5000
Project : Snowy 2.0 TSS-NTU (Tests 6-7)
Order number : ----
C-O-C number : ----
Sampler : PATRICK LAWLESS
Site : ----
Quote number : EN/222
No. of samples received : 13
No. of samples analysed : 13

Page : 1 of 5
Laboratory : Environmental Division Sydney
Contact : Customer Services ES
Address : 277-289 Woodpark Road Smithfield NSW Australia 2164
Telephone : +61-2-8784 8555
Date Samples Received : 26-Oct-2018 17:00
Date Analysis Commenced : 27-Oct-2018
Issue Date : 01-Nov-2018 11:39

ilac-MRA NATA
Accreditation No. 825
Accredited for compliance with
ISO/IEC 17025 - Testing

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Ankit Joshi	Inorganic Chemist	Sydney Inorganics, Smithfield, NSW

General Comments

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Key :
CAS Number = CAS registry number from database maintained by Chemical Abstracts Services. The Chemical Abstracts Service is a division of the American Chemical Society.
LOR = Limit of reporting
^ = This result is computed from individual analyte detections at or above the level of reporting
ø = ALS is not NATA accredited for these tests.
~ = Indicates an estimated value.

Analytical Results

Sub-Matrix: **WATER** (Matrix: **WATER**)			*Client sample ID*	**7D-17**	**7D-18**	**7D-19**	**7D-20**	**7D-21**
			Client sampling date / time	25-Oct-2018 00:00	25-Oct-2018 00:00	25-Oct-2018 00:00	25-Oct-2018 00:00	25-Oct-2018 00:00
Compound	*CAS Number*	*LOR*	*Unit*	**ES1831922-001**	**ES1831922-002**	**ES1831922-003**	**ES1831922-004**	**ES1831922-005**
				Result	Result	Result	Result	Result
EA025: Total Suspended Solids dried at 104 ± 2°C								
Suspended Solids (SS)	----	5	mg/L	**46**	**12**	**47**	**21**	**38**
EA045: Turbidity								
Turbidity	----	0.1	NTU	**54.0**	**26.4**	**48.7**	**32.2**	**44.0**

Analytical Results

Sub-Matrix: **WATER**
(Matrix: **WATER)**

			Client sample ID	**6D-18**	**6D-19**	**6D-20**	**6D-21**	**6D-22**
			Client sampling date / time	25-Oct-2018 00:00	25-Oct-2018 00:00	25-Oct-2018 00:00	25-Oct-2018 00:00	26-Oct-2018 00:00
Compound	*CAS Number*	*LOR*	*Unit*	**ES1831922-006**	**ES1831922-007**	**ES1831922-008**	**ES1831922-009**	**ES1831922-010**
				Result	Result	Result	Result	Result
EA025: Total Suspended Solids dried at 104 ± 2°C								
Suspended Solids (SS)	----	5	mg/L	**34**	**8**	**29**	**20**	**13**
EA045: Turbidity								
Turbidity	----	0.1	NTU	**82.4**	**23.6**	**75.2**	**56.7**	**31.2**

Analytical Results

Sub-Matrix: **WATER**
(Matrix: **WATER**)

			Client sample ID	**6D-23**	**6D-24**	**7D-25** **6D-25**	**----**	**----**
			Client sampling date / time	26-Oct-2018 00:00	26-Oct-2018 00:00	26-Oct-2018 00:00	----	----
Compound	*CAS Number*	*LOR*	*Unit*	**ES1831922-011**	**ES1831922-012**	**ES1831922-013**	**--------**	**--------**
				Result	Result	Result	----	----
EA025: Total Suspended Solids dried at 104 ± 2°C								
Suspended Solids (SS)	----	5	mg/L	**18**	**17**	**20**	**----**	**----**
EA045: Turbidity								
Turbidity	----	0.1	NTU	**47.6**	**50.6**	**49.4**	**----**	**----**

ALS Environmental

CERTIFICATE OF ANALYSIS

Work Order : **ES1832781**
Client : **HASKONING AUSTRALIA- ROYAL HASKONING**
Contact : MR PATRICK LAWLESS
Address : LEVEL 14 56 Berry Street
NORTH SYDNEY 2060
Telephone : ----
Project : Snowy 2.0 TSS-NTU (Tests 6-7)
Order number :
C-O-C number : ----
Sampler : PATRICK LAWLESS
Site : ----
Quote number : EN/222
No. of samples received : 8
No. of samples analysed : 8

Page : 1 of 4
Laboratory : Environmental Division Sydney
Contact : Customer Services ES
Address : 277-289 Woodpark Road Smithfield NSW Australia 2164
Telephone : +61-2-8784 8555
Date Samples Received : 02-Nov-2018 15:35
Date Analysis Commenced : 03-Nov-2018
Issue Date : 07-Nov-2018 12:33

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Accreditation No. 825
Accredited for compliance with
ISO/IEC 17025 - Testing

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Signatories

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Signatories	*Position*	*Accreditation Category*
Ankit Joshi	Inorganic Chemist	Sydney Inorganics, Smithfield, NSW

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LOR = Limit of reporting
^ = This result is computed from individual analyte detections at or above the level of reporting
ø = ALS is not NATA accredited for these tests.
~ = Indicates an estimated value.

Analytical Results

Sub-Matrix: **WATER** (Matrix: **WATER**)			*Client sample ID*	**7D-22**	**7D-23**	**7D-24**	**7D-25**	**6D-26**
			Client sampling date / time	29-Oct-2018 00:00	30-Oct-2018 00:00	01-Nov-2018 00:00	02-Nov-2018 00:00	29-Oct-2018 00:00
Compound	*CAS Number*	*LOR*	*Unit*	**ES1832781-001**	**ES1832781-002**	**ES1832781-003**	**ES1832781-004**	**ES1832781-005**
				Result	Result	Result	Result	Result
EA025: Total Suspended Solids dried at 104 ± 2°C								
Suspended Solids (SS)	----	5	mg/L	**76**	**30**	**24**	**9**	**15**
EA045: Turbidity								
Turbidity	----	0.1	NTU	**40.6**	**39.0**	**34.5**	**15.7**	**35.2**

Analytical Results

Sub-Matrix: **WATER** (Matrix: **WATER**)			*Client sample ID*	**6D-27**	**6D-28**	**6D-29**	**----**	**----**
			Client sampling date / time	30-Oct-2018 00:00	01-Nov-2018 00:00	02-Nov-2018 00:00	----	----
Compound	*CAS Number*	*LOR*	*Unit*	**ES1832781-006**	**ES1832781-007**	**ES1832781-008**	**--------**	**--------**
				Result	Result	Result	----	----
EA025: Total Suspended Solids dried at 104 ± 2°C								
Suspended Solids (SS)	----	5	mg/L	**15**	**10**	**5**	**----**	**----**
EA045: Turbidity								
Turbidity	----	0.1	NTU	**29.9**	**23.8**	**11.3**	**----**	**----**

Attachment 2 – Byron Range Group Laboratory Log Records

Test ID	6A	
Geological Unit	Byron Range Group	
Description	Test 6A - Dry Disposal at Surface	
Start Date/Time	23-10-18 9:50	
Water volume	50 L	
Water surface level in column	172.8	cm
Mass sediment added	40 g	(sieved to <250 um)
Test Location	Geochemical Assessments Workshop, Roseville NSW	
Test Officers	Pat Lawless, Rick Plain	

Observations

Date/Time	Time since start	Turbidity (NTU)	Measurement Location (cm)	Measurement Depth (cm)	Comments
23-10-18 8:40	70 Minutes Prior	1.9	169.4	3.4	
23-10-18 9:51	00-0:01	87	169.4	3.4	87 NTU immediately following addition of sediment. Rapid settlement thereafter.
23-10-18 9:53	00-0:03	14.2	169.4	3.4	
23-10-18 9:56	00-0:06	7.9	169.4	3.4	
23-10-18 9:56	00-0:06	7.5	169.4	3.4	
23-10-18 9:59	00-0:09	6.9	169.4	3.4	
23-10-18 10:00	00-0:10	6.2	169.4	3.4	Plume becomes gradually more dense with depth, dense plume below 132 cm.
23-10-18 10:04	00-0:14	5.9	169.4	3.4	WetLAB continuous monitoring stopped.
23-10-18 10:07	00-0:17	5.1	169.4	3.4	
23-10-18 10:35	00-0:45	10.5	169.4	3.4	
23-10-18 11:00	00-1:10	8	169.4	3.4	
23-10-18 12:00	00-2:10	7.7	169.4	3.4	
23-10-18 12:40	00-2:50	7.3	169.4	3.4	
23-10-18 13:29	00-3:39	4.8	169.4	3.4	
23-10-18 14:30	00-4:40	12	169.4	3.4	
23-10-18 15:30	00-5:40	11.9	169.4	3.4	
23-10-18 16:40	00-6:50	11.8	169.4	3.4	
23-10-18 18:20	00-8:30	10.2	169.4	3.4	
24-10-18 9:00	00-23:10	3.2	169.4	3.4	
24-10-18 15:50	01-6:00	2.2	169.4	3.4	
25-10-18 9:30	01-23:40	4.4	169.4	3.4	
25-10-18 20:30	02-10:40	2.4	169.4	3.4	
26-10-18 8:45	02-22:55	3.6	169.4	3.4	
26-10-18 16:15	03-6:25	3.3	169.4	3.4	
29-10-18 9:30	05-23:40	2.3	169.4	3.4	
30-10-18 9:00	06-23:10	2.1	169.4	3.4	
01-11-18 8:15	08-22:25	1.6	169.4	3.4	
02-11-18 8:15	09-22:25	1.1	169.4	3.4	
05-11-18 10:10	13-0:20	1.5	169.4	3.4	

Test ID	6B		
Geological Unit	Byron Range Group		
Description	Test 6B - Dry Disposal via Fall Pipe (51.8cm below surface)		
Start Date/Time	23-10-18 9:50		
Water volume	50 L		
Water surface level in column	173.8	cm	
Mass sediment added	40 g	(sieved to <250 um)	
Test Location	Geochemical Assessments Workshop, Roseville NSW		
Test Officers	Pat Lawless, Rick Plain		
Depth of Temperature Probes	144cm	40cm	Old Probe at Bottom

Observations

Date/Time	Time since start	Turbidity (NTU)	Measurement Location (cm)	Measurement Depth (cm)	Comments
23-10-18 8:42	10 minutes prior	1.7	170.4	3.4	Background turbidity measured 10 minutes before test start
23-10-18 10:00	00-0:10		170.4	3.4	Plume below base of fall pipe (approximately 121 cm). Sediment swirling around within fall pipe.
23-10-18 11:30	00-1:40		170.4	3.4	Top of plume ~115 cm, however, not clearly defined
23-10-18 14:30	00-4:40	7	170.4	3.4	Column starting to become visibly turbid near surface.
23-10-18 15:30	00-5:40	5.9	170.4	3.4	
23-10-18 16:40	00-6:50	5.2	170.4	3.4	
23-10-18 18:20	00-8:30	6.3	170.4	3.4	
24-10-18 9:00	00-23:10	4.67	170.4	3.4	
24-10-18 15:50	01-6:00	4.4	170.4	3.4	
25-10-18 9:30	01-23:40	4.3	170.4	3.4	
25-10-18 20:30	02-10:40	3.5	170.4	3.4	
26-10-18 8:45	02-22:55	3.5	170.4	3.4	
26-10-18 16:15	03-6:25	2	170.4	3.4	
29-10-18 9:30	05-23:40	2.2	170.4	3.4	
30-10-18 9:00	06-23:10	1.95	170.4	3.4	
01-11-18 8:15	08-22:25	1.4	170.4	3.4	
02-11-18 8:15	09-22:25	1.35	170.4	3.4	
05-11-18 10:10	13-0:20	1.6	170.4	3.4	

Test ID	6D	
Geological Unit	Byron Range Group	
Description	Test 6D - Column Test to develop TSS/NTU relationship	
Start Date/Time	23-10-18 8:50	
Water volume	50 L	
Water surface level in column	172.8	cm
Mass sediment added	47.5 g	(sieved to <250 um)
Test Location	Geochemical Assessments Workshop, Roseville NSW	
Test Officers	Pat Lawless, Rick Plain	

<u>Observations</u>

Date/Time	Time since start	Turbidity (NTU)		TSS Sample Taken?	TSS Sample ID	Column Measurements			Comments
		Inside Column	Inside Beaker			Water Surface	Measurement Location	Sensor Depth	
23-10-18 8:40	10 minutes prior	2.1	0.9	Yes	6D-1	172.8	169.4	3.4	Before commencement
23-10-18 8:50	00-0:00	>250	>250	Yes	6D-2	172.3	168.9	3.4	Maximum at 250 NTU.
23-10-18 9:00	00-0:10	241	243	Yes	6D-3	171.9	168.5	3.4	
23-10-18 9:03	00-0:13	227	212	Yes	6D-4	171	167.6	3.4	
23-10-18 9:12	00-0:22	197	193	Yes	6D-5	170.2	166.8	3.4	
23-10-18 9:27	00-0:37	175	169	Yes	6D-6	169.5	166.1	3.4	
23-10-18 9:43	00-0:53	151	152	Yes	6D-7	169	165.6	3.4	
23-10-18 10:11	00-1:21	132	121	Yes	6D-8	168.3	164.9	3.4	
23-10-18 10:30	00-1:40	120	137	Yes	6D-9	167.6	164.2	3.4	
23-10-18 10:50	00-2:00	110	124	Yes	6D-10	166.6	163.2	3.4	
23-10-18 11:50	00-3:00	100	102	Yes	6D-11	165.7	162.3	3.4	
23-10-18 12:40	00-3:50	97		No		164.9	161.5	3.4	
23-10-18 13:26	00-4:36	95	93	Yes	6D-12	164.1	160.7	3.4	
23-10-18 14:30	00-5:40	137		No		163.6	160.2	3.4	
23-10-18 15:30	00-6:40	172	169	Yes	6D-13	163.6	160.2	3.4	
23-10-18 16:40	00-7:50	176		No		162.6	159.2	3.4	
23-10-18 18:20	00-9:30	174		No		162.6	159.2	3.4	
24-10-18 9:30	01-0:40	11	20.7	Yes	6D-14	162.6	159.2	3.4	Top of column beginning to clarify. Gradual change to approximately 153 cm. 28 NTU after sample taken.
24-10-18 9:50	01-1:00	92	90	Yes	6D-15	161.3	157.9	3.4	Top ~15 cm re-agitated. Beaker reading 89-94 NTU.
24-10-18 9:54	01-1:04	83.8	90	Yes	6D-16	161.8	158.4	3.4	Beaker reading range 89-92 NTU.
24-10-18 15:50	01-7:00	88	90.5	Yes	6D-17	160.3	156.9	3.4	
25-10-18 9:30	02-0:40	84	82.5	Yes	6D-18	159.4	156	3.4	
25-10-18 20:30	02-11:40	21	25.3	Yes	6D-19	158.6	155.2	3.4	Top 2-3cm of column beginning to clarify.
25-10-18 20:45	02-11:55		72.3	Yes	6D-20	157.8	154.4	3.4	Pipette sample extracted from ~138 cm.
25-10-18 21:00	02-12:10		54.8	Yes	6D-21	157.1	153.7	3.4	Pipette sample extracted from ~147 cm.
26-10-18 8:45	02-23:55	45	43.2	Yes	6D-22	156.4	153	3.4	
26-10-18 9:10	03-0:20		50	Yes	6D-23	155.5	152.1	3.4	Pipette sample extracted from ~143 cm.
26-10-18 9:20	03-0:30		57.5	Yes	6D-24	154.7	151.3	3.4	Pipette sample extracted from ~131 cm.
26-10-18 16:15	03-7:25	60.8	57.2	Yes	6D-25	154	150.6	3.4	
29-10-18 9:30	06-0:40	46.5	46.5	Yes	6D-26	152.9	149.5	3.4	
30-10-18 9:00	07-0:10	41	40.3	Yes	6D-27	152.2	148.8	3.4	
01-11-18 8:15	08-23:25	32.2	31.8	Yes	6D-28	151.2	147.8	3.4	
02-11-18 8:15	09-23:25	12	11.3	Yes	6D-29	150.4	147	3.4	**Flocculant added.**
05-11-18 10:10	13-1:20	1.8		No		149.5	146.1	3.4	

Appendix G

TSS – Turbidity and Settling Test Results
Kellys Plain Volcanics Geological Zone

Table of Contents

1 Introduction

The Kellys Plain Volcanics geological zone comprises terrestrial volcaniclastic deposits including dacite, ignimbrite, rhyodacite ignimbrite, tuff, agglomerate, rhyolite; and porphyritic monzogranite. These volcanics were likely deposited as ash-flow and ash-fall tuffs and ignimbrites. A 1 m long section of core from this geological zone was supplied to Royal HaskoningDHV (Haskoning) from BH1115 taken between 14 m and 15 m below the ground surface. The core was logged as dacite, an extrusive igneous rock.

Water for laboratory testing was obtained from Tantangara Reservoir on the 2nd October 2018. The water was collected in 1000 L Intermediate Bulk Containers (IBC) and delivered to Haskoning on the 5th October 2018. The turbidity of the reservoir water sample used for the testing was between 2.3 and 2.7 NTU. This is within the turbidity range of field monitoring, as undertaken by Cardno in 2018, which indicated typical 'background' turbidity of 2 to 10 NTU in Tantangara Reservoir.

2 Results

2.1 Test 7D – TSS-Turbidity

2.1.1 Overview

The TSS-Turbidity Test for the Kellys Plain Volcanics ('Test 7D') commenced on the 23rd October 2018 at 1:00pm and concluded on the 5th November 2018, approximately 13 days following commencement.

The Certificate of Analysis provided by ALS Environmental for the TSS and turbidity analyses undertaken for samples collected during testing is provided in **Attachment 1**. Laboratory log records completed during the TSS-turbidity test are provided in **Attachment 2**, which includes turbidity measurements undertaken during testing for each sample.

Photographs taken during the column test are provided in **Figure 1**. These photographs were taken:

- prior to commencement;
- 1 hour and 40 minutes after commencement;
- 1 day and 20.5 hours after commencement;
- 5 days and 2.5 hours after commencement; and,
- 12 days and 21 minutes after commencement.


TEST I.D. 7D
GEOLOGICAL UNIT KELLYS PLAIN VOLCANICS
START TIME 23/10/18
CURRENT TIME 23/10/18

TEST I.D. 7D
GEOLOGICAL UNIT KELLYS PLAIN VOLCANICS
START TIME 23/10/18 13:00
CURRENT TIME 23/10/18 14:40

TEST I.D. 7D
GEOLOGICAL UNIT KELLYS PLAIN VOLCANICS
START TIME 23/10/18 13:00
CURRENT TIME 25/10/18 9:15

TEST I.D. 7D
GEOLOGICAL UNIT KELLYS PLAIN VOLCANICS
START TIME 23/10/18 13:00
CURRENT TIME 29/10/18 9:30

TEST I.D. 7D
GEOLOGICAL UNIT KELLYS PLAIN VOLCANICS
START TIME 23/10/18 13:00
CURRENT TIME 5/11/18 10:00

Figure 1: Column test –

1. *Tantangara Reservoir water without addition of the sieved crushed rock,*
2. *Column test 1 hours and 40 minutes after commencement,*
3. *Column test 1 day and 20.25 hours after commencement,*
4. *Column test 5 days and 2.5 hours after commencement, and*
5. *Column test 12 days and 21 hours after commencement.*

2.1.2 Surface Turbidity vs Time Results

The variation in surface turbidity during Test 7D is plotted in **Graph 1**. The upper 15 cm of the column was re-agitated approximately 20 hours following commencement to obtain surface samples with a higher turbidity[1]. A pipette was used to extract samples from below the water surface at the following time intervals:

- 20 hours following commencement, sample extract from approximately 49 cm below the surface;
- 1 day and 3 hours following commencement, sample extracted from approximately 48 cm below the surface; and,
- 2 days and 8 hours following commencement, sample extracted from 13 cm below the water surface.

The varying depths were selected to target a wide range of turbidity values. The pipette was gently placed in the water to minimise disturbance to the water column. However, the latter 2 samples corresponded to an increase in surface turbidity at the subsequent measurement interval.

Graph 1 shows surface turbidity decreased relatively rapidly from 130 NTU to 75 NTU during the initial hour of testing. Between approximately 1.5 and 4 hours after commencement, surface turbidity increased from 71.3 NTU to 85.1 NTU.

Surface turbidity subsequently decreased rapidly to 30 NTU, 20 hours after commencement. As previously mentioned, to obtain a wide range of turbidity and TSS values, the upper 15 cm of the column was lightly reagitated with a glass stirring rod and surface turbidity increased to 57 NTU. A pipette was used to extract a sample from lower within the water column.

By approximately 1 days and 3 hours after commencement, surface turbidity decreased to approximately 35 NTU and a pipette was used to extract a sample, with a higher turbidity, from lower within the water column. After approximately 1 day and 20 hours, surface turbidity had increased to 52 NTU.

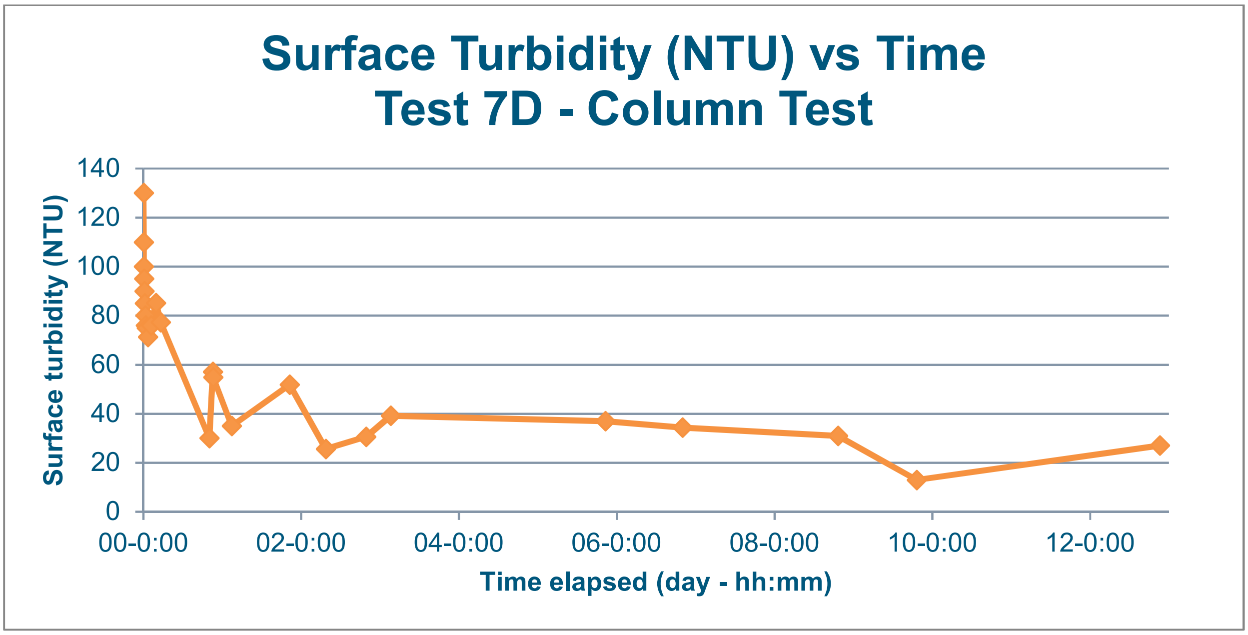
Surface turbidity decreased to 26 NTU, 2 days and 7 hours after commencement of the test and a pipette was used to extract a sample, with a higher turbidity, from lower within the water column. Turbidity remained relatively constant for the remainder of the test duration. However, turbidity was noted to increase during the following time intervals:

- Between 2 days and 8 hours following commencement and 2 days and 20 hours following commencement, surface turbidity increased from 26 NTU to 31 NTU, corresponding with extraction of a sample via a pipette at the earlier interval;
- Between 2 days and 20 hours following commencement and 3 days and 3 hours following commencement, surface turbidity increased from 31 NTU to 39 NTU; and,
- Between 9 days and 19 hours following commencement and 12 days and 21 hours following commencement, surface turbidity increased from 13 NTU to 27 NTU.

The increase in surface turbidity at the various time intervals is somewhat unexpected and a discussion is provided in **Section 3**.

---

[1] It was necessary to collect water samples covering a wide range of TSS and turbidity values to ensure that a robust TSS-turbidity dataset could be established for the purposes of defining a meaningful relationship between turbidity and suspended solids.



Graph 1: Surface turbidity measured during the column test – Kellys Plain Volcanics crushed rock (Test 7D).

2.1.3 TSS – Turbidity Results

A total of 25 samples were collected during testing for laboratory TSS and turbidity analysis. TSS values for the collected samples ranged between <5 mg/L[2] and 239 mg/L, while turbidity values of up to 125 NTU were recorded.

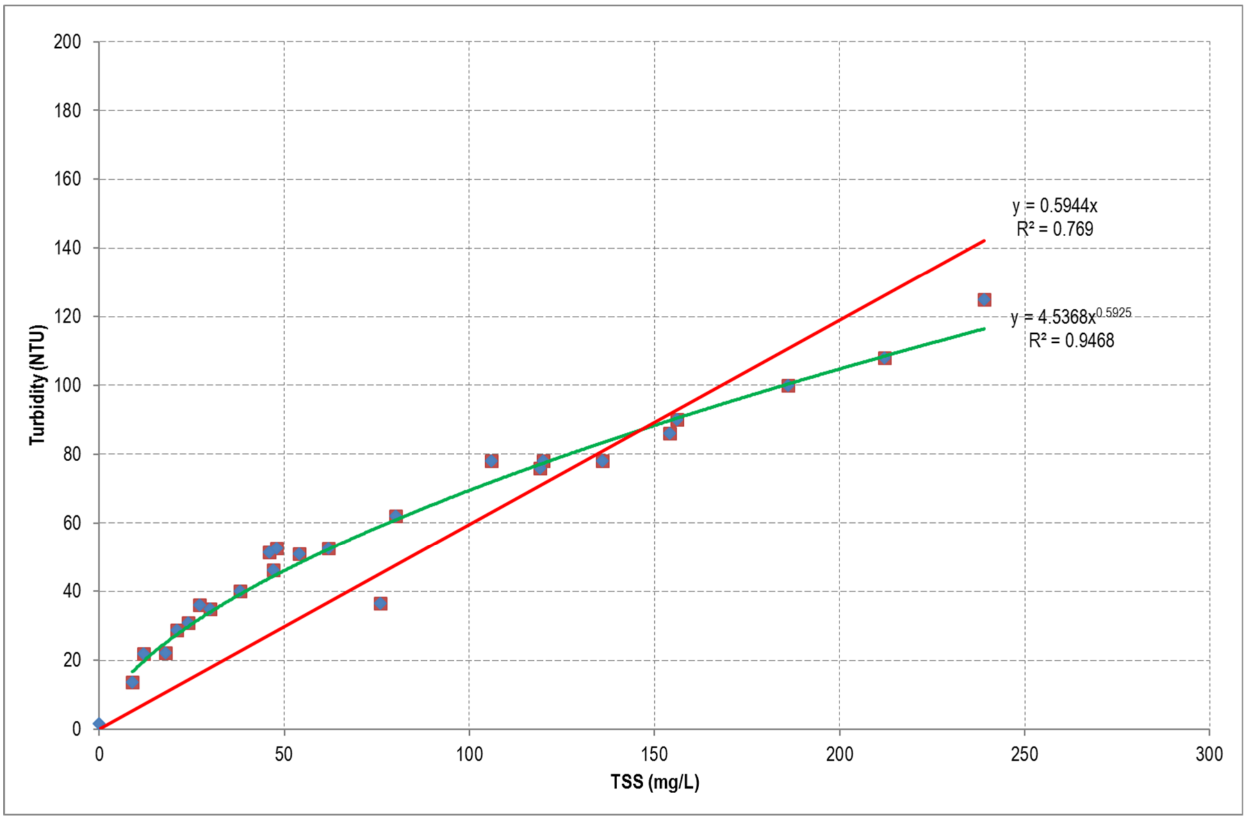
A plot of TSS versus turbidity for all data collected during testing is provided in **Graph 2**. Turbidity values used in this dataset are the measurements taken during testing (inside the glass beaker prior to sub-sampling) rather than the laboratory results[3]. This dataset is plotted with trendlines corresponding to both linear and power functions. It is evident that the power function provides a much closer fit of the data, characterised by an R^2 value of 0.95[4] whereas the linear line of best fit has a lower R^2 value of 0.77.

---

[2] The Limit of Reporting (LOR) value for TSS analysis is 5 mg/L, refer **Attachment 1**. Results for samples with TSS concentrations below the LOR value are reported as <5 mg/L.

[3] Turbidity results reported by the laboratory were compared with turbidity results obtained during testing using the Wetlab-ECO-NTU sensor. No significant differences between the turbidity datasets were evident (i.e. selection of the turbidity dataset does not significantly influence the TSS-turbidity relationship reported herein).

[4] The R^2 value, also known as the coefficient of determination, is a measure of how close the plotted data are to the fitted regression line (i.e. the line of best fit). An R^2 value of 1 indicates that the regression line perfectly fits the data.



Graph 2: TSS-turbidity results – Kellys Plain Volcanics crushed rock (Test 7D)

2.1.4 TSS – Turbidity Relationship

A summary of the TSS-turbidity relationships determined for the Test 7D dataset is provided in **Table 1**, including the turbidity values equivalent to a TSS concentration of 50 mg/L for each of the linear and power function trendlines. The selected TSS value of 50 mg/L is somewhat arbitrary and the water quality limit for the project may vary.

Table 1: Summary of TSS-turbidity relationships for Kellys Plain Volcanics crushed rock

Trendline Function	Number of values	R^2 value	Turbidity (NTU) equivalent to 50 mg/L TSS
Linear	25	0.77	30
Power	25	0.95	46

As noted above, the power function trendline provides a much better fit of the dataset compared to the linear trendline. Furthermore, the high R^2 value associated with the power function trendline (0.95) indicates a strong correlation between TSS and turbidity for the dataset, and is considered to be valid for the data collected during testing. The turbidity value equivalent to 50 mg/L suspended solids is 46 NTU for this dataset.

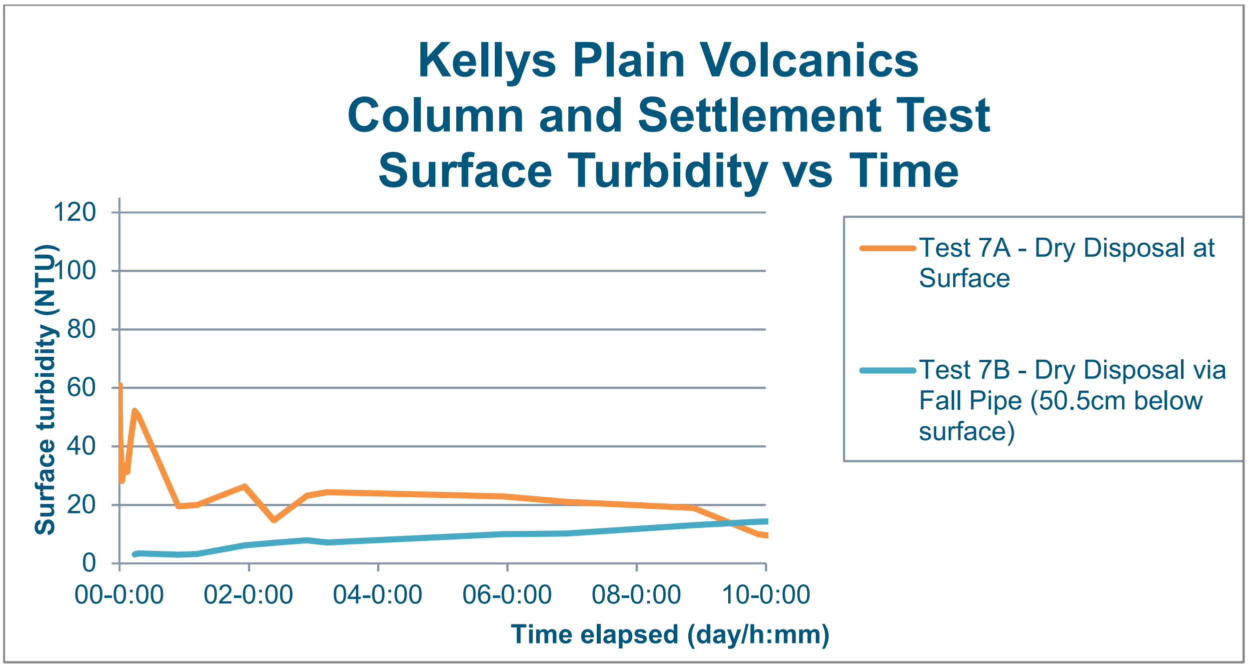
2.2 Settlement Tests

2.2.1 Overview

The two settlement tests for the Kellys Plain Volcanics crushed rock (Tests 7A and 7B) commenced simultaneously on the 23rd October 2018 at 11:10am. Different disposal methods were simulated in the respective columns as described in **Sections 2.2.2** to **2.2.4**. The tests concluded on the 2nd October 2018, approximately 10 days following commencement.

Turbidity in the two columns was measured approximately 3 hours prior to addition of the crushed rock, with values of 2.7 NTU and 2.3 NTU recorded for Test 7A and 7B respectively.

Surface turbidity measured at varying time intervals during the 10-day test duration is plotted in **Graph 3** for the two settlement tests. These results are discussed in the following sections, along with a summary of the key observations for each settlement test. Laboratory log records completed during the settlement tests are provided in **Attachment 2**.



Graph 3: Surface turbidity measured during the settlement tests – Kellys Plain Volcanics (Tests 7A and 7B).

Photographs taken during the settlement tests are provided in **Figures 2** to **6**. These photographs were taken immediately prior to commencement (**Figure 2**), 2 hours and 25 minutes after commencement (**Figure 3**), 1 day and 22.1 hours after commencement (**Figure 4**), 5 days and 22.3 hours after commencement (**Figure 5**), and 10 days and 7.8 hours after commencement (**Figure 6**).

TEST I.D. 7A
GEOLOGICAL UNIT KELLYS PLAIN VOLCANICS
START TIME 23/10/18
CURRENT TIME 23/10/18

TEST I.D. 7B
GEOLOGICAL UNIT KELLYS PLAIN VOLCANICS
START TIME 23/10/18
CURRENT TIME 23/10/18

Figure 2: Settlement test prior to placement of sieved crushed rock-
Left: Test 7A - Placement of dry sieved crushed rock directly onto the water surface,
Right: Test 7B - Placement of dry sieved crushed rock within a fall pipe with opening submerged 50.5 cm below the water surface.

Figure 3: Settlement test 2 hours and 25 minutes following placement of sieved crushed rock-
Left: Test 7A - Placement of dry sieved crushed rock directly onto the water surface,
Right: Test 7B - Placement of dry sieved crushed rock within a fall pipe with opening submerged 50.5 cm below the water surface.

Figure 4: Settlement test 1 day and 22.1 hours following placement of sieved crushed rock-
Left: Test 7A - Placement of dry sieved crushed rock directly onto the water surface,
Right: Test 7B - Placement of dry sieved crushed rock within a fall pipe with opening submerged 50.5 cm below the water surface.

Figure 5: Settlement test 5 days and 22.3 hours following placement of sieved crushed rock-
Left: Test 7A - Placement of dry sieved crushed rock directly onto the water surface,
Right: Test 7B - Placement of dry sieved crushed rock within a fall pipe with opening submerged 50.5 cm below the water surface.

Figure 6: Settlement test 10 days and 7.8 hours following placement of sieved crushed rock-
Left: Test 7A - Placement of dry sieved crushed rock directly onto the water surface,
Right: Test 7B - Placement of dry sieved crushed rock within a fall pipe with opening submerged 50.5 cm below the water surface.

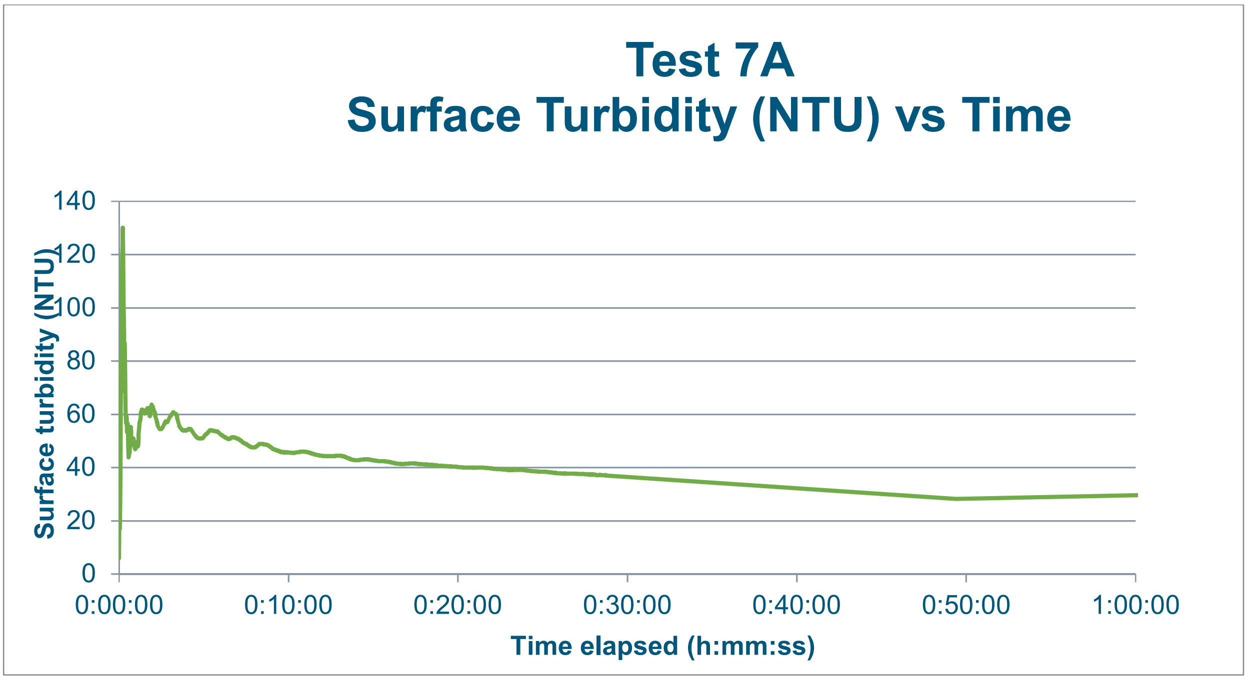
2.2.2 Test 7A - Placement of dry sieved crushed rock directly onto the water surface

For Test 7A, the sieved crushed rock was gently sprinkled onto the water surface from a height of approximately 25 cm above the water surface. Clumps of crushed rock fell to the bottom of the column within approximately 30 seconds. Fine material parted from the clumps during descent and a turbid trail formed through the water column in the wake of the clumps. It is estimated that approximately 10 to 20% of the mass of crushed rock fell to the bottom in clumps.

Significant diffusion and mixing of the crushed rock was observed after placement. After approximately 30 seconds, a dense turbid plume was observed in the upper half of the column. After approximately 2 minutes, turbidity throughout the entire column appeared to be relatively uniform.

Surface turbidity levels were measured continuously (at one second time intervals) during the first 29 minutes of Test 7A, with the Wetlab ECO-NTU sensor remaining in the water column throughout this period. Surface turbidity levels were measured at varying time intervals thereafter. The Wetlab ECO-NTU sensor was placed in the water column for each measurement and removed after a stable reading was recorded.

Surface turbidity during the first 1 hour after commencement of the test is plotted in **Graph 4** for Test 7A**.**



Graph 4: Surface turbidity measured during the first hour following placement of Kellys Plain Volcanics crushed rock, Test 7A.

Surface turbidity levels increased rapidly from background levels of around 2.7 NTU to a maximum of around 130 NTU during placement of the sieved crushed rock (i.e. within the initial 15 seconds of testing). Surface turbidity decreased rapidly to approximately 50-60 NTU, 25 seconds after commencement. Over the subsequent 28 minutes, turbidity fluctuated and gradually declined. Surface turbidity 29 minutes after commencement was approximately 37 NTU.

Surface turbidity measured at varying time intervals over the 10-day test duration is plotted in **Graph 3** (refer **Section 2.2.1**) for Test 7A, alongside the results for Tests 7B.

Surface turbidity decreased to approximately 30 NTU approximately 1 hour after commencement and remained relatively constant for the following 2 hours. Between approximately 3.2 hours and 5.5 hours after commencement, surface turbidity increased from 35 NTU to 52 NTU.

Surface turbidity decreased to approximately 20 NTU, 22 hours after commencement and remained relatively constant for the following 8 days. During this time, the maximum surface turbidity was recorded as 26.3 NTU and the minimum surface turbidity was recorded as 14.7 NTU. Surface turbidity was noted to increase during the following time intervals:

- Between 1 day and 5 hours following commencement and 1 days and 23 hours following commencement, surface turbidity increased from 20 NTU to 26.3 NTU;
- Between 2 days and 9 hours following commencement and 2 days and 22 hours following commencement, surface turbidity increased from 14.7 NTU to 23.1 NTU, and continued to increase to 24.3 NTU, 5 days and 22 hours following commencement.

The increase in surface turbidity at the various time intervals was somewhat unexpected and a discussion is provided in **Section 3**.

By 8 days and 21 hours following commencement, surface turbidity was 19 NTU. Surface turbidity decreased to 10 NTU approximately 9 days and 22 hours following commencement. At this point in time, flocculant was added to the column (**Section 2.3**).

2.2.3 Test 7B - Placement of dry sieved crushed rock within a fall pipe with opening submerged 50.5 cm below the water surface

For Test 7B, the sieved crushed rock was gently sprinkled into the fall pipe with an internal diameter of approximately 50 mm. The top of the fall pipe was approximately 75 cm above the water surface. The inside of the fall pipe was rinsed with water from Tantangara Reservoir to ensure that all of the sieved crushed rock entered the column.

Significant mixing and diffusion of crushed rock was observed within the fall pipe. A few clumps of crushed rock fell through the upper portion of the column. However, fine material parted from the clumps during descent and a turbid trail formed through the water column in the wake of the clumps. The clumps generally dissipated before descending to the bottom of the column.

The dense turbid plume in the fall pipe gradually descended and diffused throughout the water column, primarily below the base of the fall pipe. After approximately 1 minute and 30 seconds, significant mixing was observed in the middle third of the column, immediately below the fall pipe. After 2 minutes and 20 seconds, elevated turbidity was observed in the lower two thirds of the water column, below the base of the fall pipe. However, the turbid plume in the middle third of the column was noticeably denser than the turbid plume in the lower third of the column. After approximately 6 to 7 minutes, relatively even mixing was observed in the lower two thirds of the water column, below the base of the fall pipe.

The top of the turbid plume was recorded approximately 2 cm above the base of the fall pipe immediately after placement. There was no immediate discernible change in turbidity above the turbid layer, with the upper 48.5 cm of water in the column (i.e. above the base of the fall pipe) remaining relatively clear with turbidity at approximately 2 to 3 NTU, which was the background level (refer **Graph 3**, **Section 2.2.1**).

The top of the turbid plume was clearly distinguishable for the duration of the test. The top of the plume descended to 42 cm after 9 days 21 hours, at a rate of 8.4 cm/day.

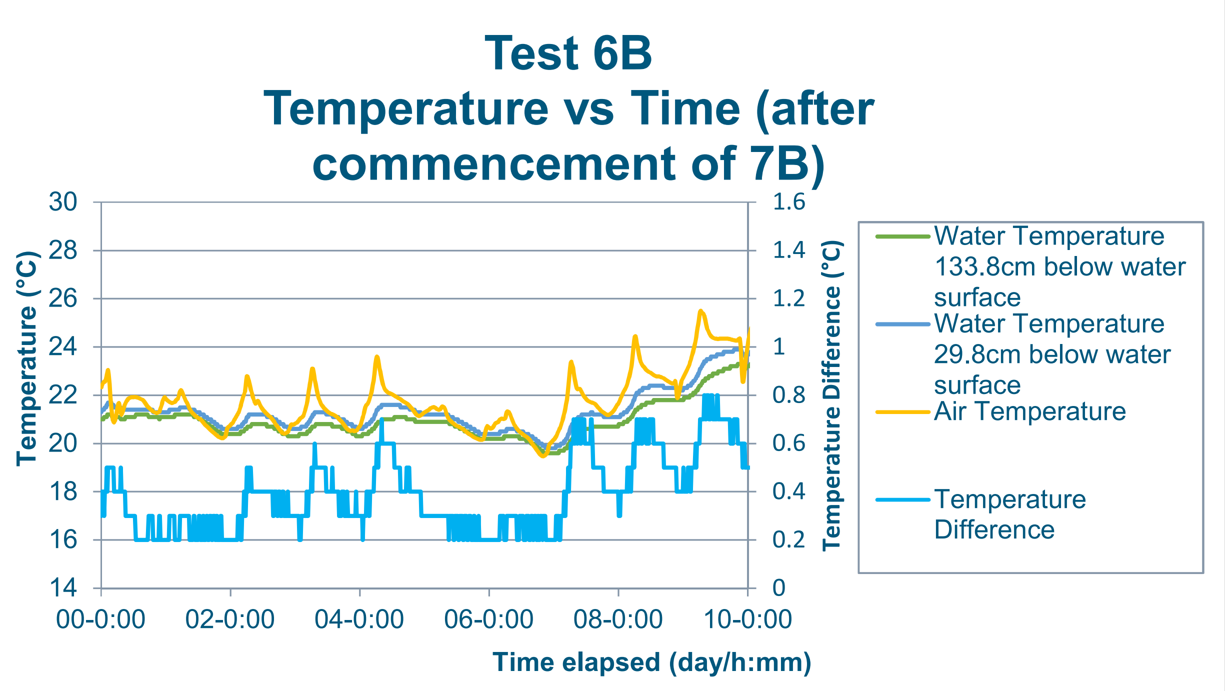
A haze was noticeable above the denser plume (below the base of the fall pipe) approximately 2 days and 9 hours following commencement and remained for the duration of the test. Surface turbidity gradually increased to approximately 7 NTU, 2 days and 9 hours following commencement and continued to increase to approximately 14 NTU, 9 days and 21 hours following commencement. The column was retained following conclusion of the test and surface turbidity increased to 16 NTU approximately 13 days following commencement.

A discussion regarding the observed increase in surface turbidity during Test 6B is provided in **Section 3**.

2.2.4 Air and Water Temperature

Air temperature and water temperature was recorded every 15 minutes in Test 6B for the duration of the test using Solinist Leveloggers and a Barologger. Water temperature was monitored at two depths, 29.8 cm and 133.8 cm below the water surface. Test 6B commenced approximately 1 hour and 20 minutes before Test 7A and 7B and approximately 3 hours and 10 minutes before Test 7D. Test 6B was undertaken in the same room and within approximately 2 m of Test 7A, 7B and 7D.

Graph 5 provides air and water temperature variation over time for Test 7B. The elapsed time is reported relative to commencement of Test 7A and 7B.



Graph 5: Air and water temperature in Test 6B. Elapsed time relative to commencement of Test 7A and 7B.

Air temperature in Test 6B fluctuated between approximately 19.5 °C and 28.1 °C. Block out curtains were placed across all windows for the duration of the test in an attempt to regulate air temperature within the laboratory.

Water temperature varied between 19.6 °C and 25.1 °C. Water temperature was consistently 0.2 °C to 0.9 °C warmer at the upper monitoring location and the average temperature differential between the monitoring depths was 0.4 °C. The warmer water near the top of the column would have a lower density and would, therefore, be buoyant compared to the cooler water lower in the column.

2.3 Flocculation Test

Prior to completion of the settlement tests, a trial was undertaken to determine whether a chemical flocculant would accelerate settlement of fine particles and clarify the water. The chemical flocculant selected for the test was alum (aluminium sulphate). It should be noted that the particular chemical flocculant selected for the test was somewhat arbitrary and has not been approved for use during construction.

Flocculant was added to Test 7A on the 2nd November 2018 at 8:15am, approximately 10 days following commencement of the settlement test. Tests 7B and 7D were retained as control columns for comparison.

Turbidity in Tests 7A, 7B and 7D on the 2nd November 2018 (prior to addition of flocculant) and the 5th November 2018 (following addition of flocculant) is reported in **Table 2**. Turbidity in Test 7A decreased from 10 NTU to 1.4 NTU while the turbidity in the control columns, Tests 7B and 7D, increased. This indicates that the chemical flocculant was effective in clarifying the water.

Table 2: Turbidity before and after the addition of flocculant to Test 7A.

Date/Time	Test 7A (NTU)	Test 7B (NTU)	Test 7D (NTU)
2nd November 2018, 8:15am	10	14.3	13
5th November 2018, 10:10am	1.4	16.1	27

Photographs of the three Test columns taken on the 2nd and 5th November 2018 are provided in **Figure 7**. It should be noted that some of the flocculated crushed rock in Test 7A adhered to the walls of the column thereby making the column appear slightly ‘cloudy’ when viewed side on. However, when viewed from above, the water was clear as indicated by the surface turbidity reading.

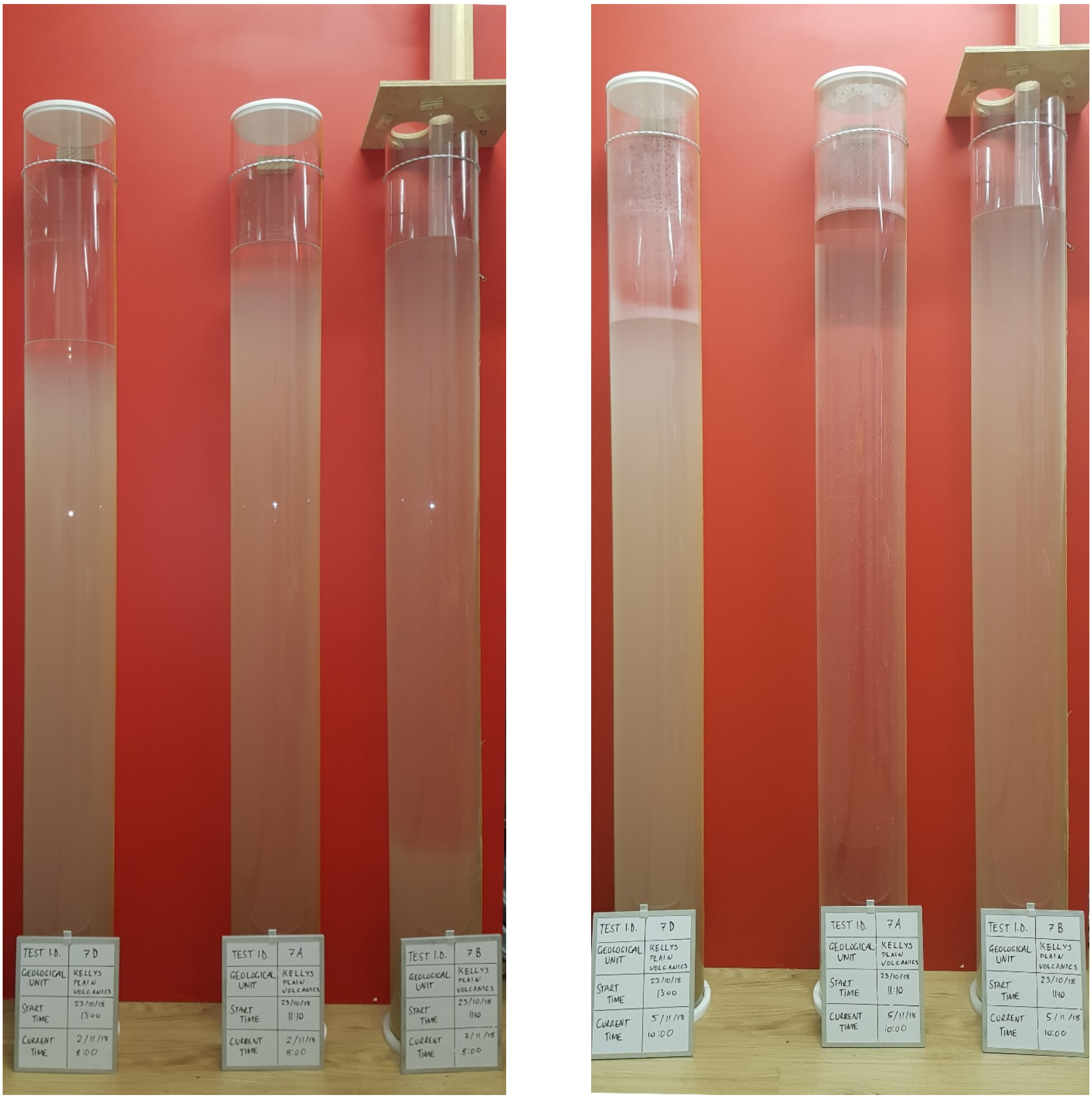
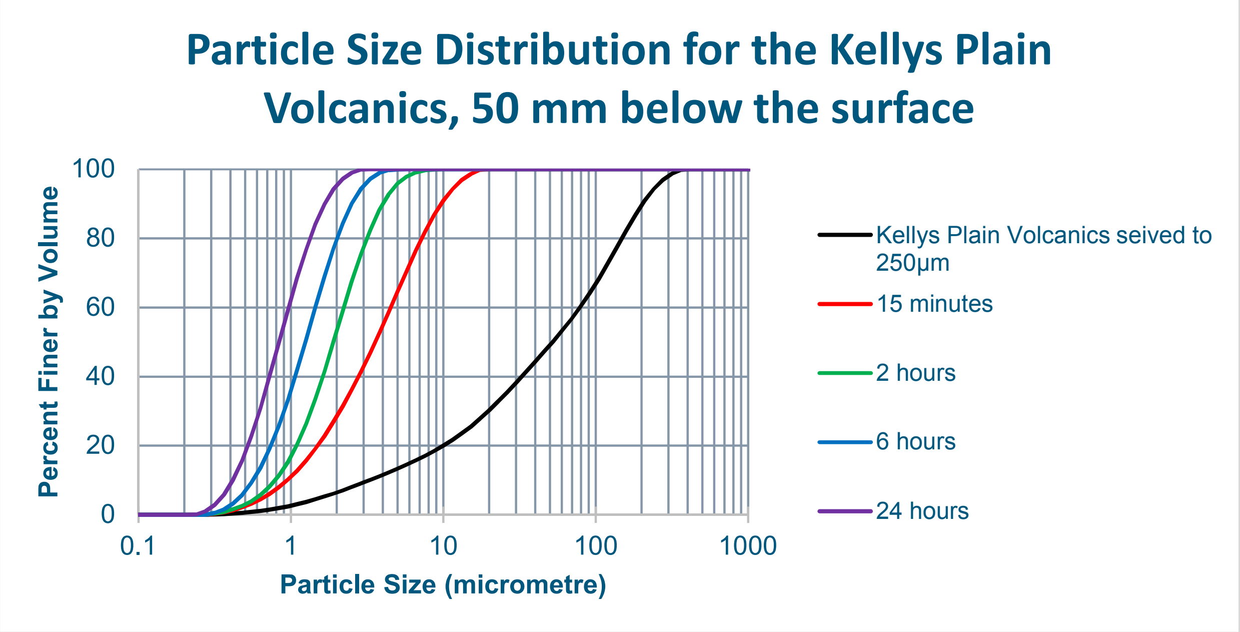


Figure 7: Column and Settlement tests prior to and following addition of chemical flocculant to Test 7A-
Left: Test 7D, 7A and 7B (from left to right) prior to the addition of flocculant to Test 7A. Photographed on the 2nd November at 8:00am, approximately 9 days and 20.8 hours following commencement of the settlement tests.
Right: Test 7D, 7A and 7B (from left to right), following the addition of flocculant to Test 7A. Photographed on the 5th November at 10:00am, approximately 12 days and 22.8 hours following commencement of the settlement tests.

2.4 Critical Particle Size

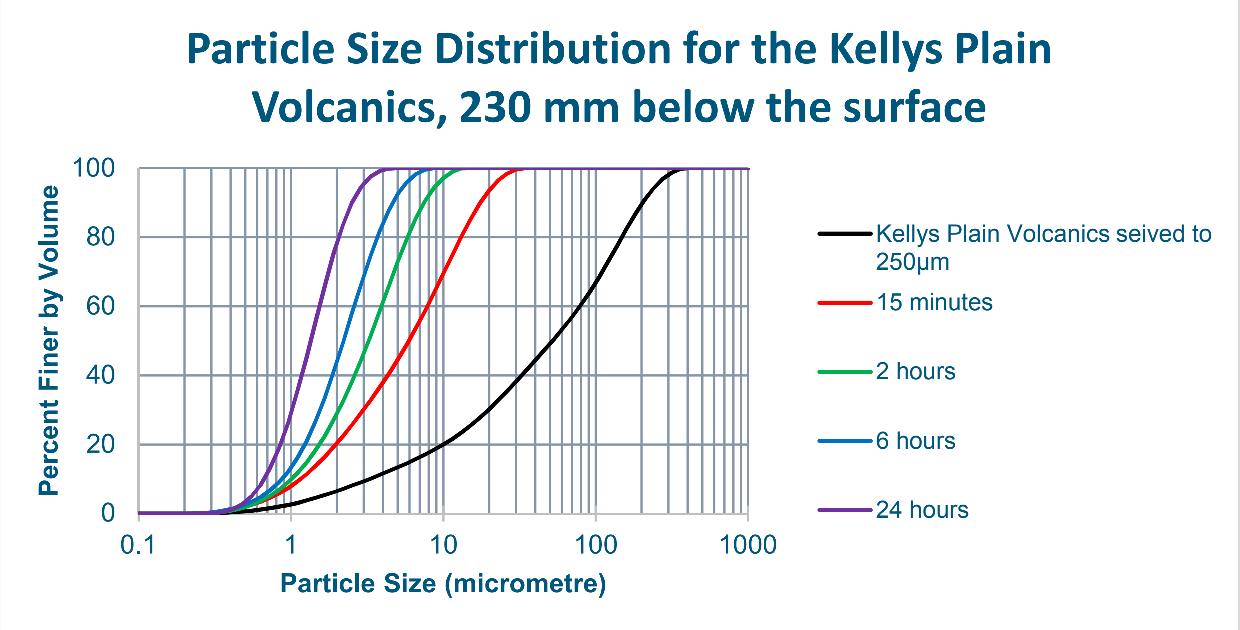
The tests to determine the critical particle size in suspension commenced on the 22nd and 23rd October 2018. Particle size analysis using the Mastersizer 2000 was completed on the 23rd October 2018.

Graph 6 plots the particle size distribution of the sieved crushed rock (used for all tests) and the particle size that remains in suspension after each time interval (15 minutes, 2 hours, 6 hours and 24 hours) at 50 mm below the water surface (850 mL mark on cylinder). The maximum particle size in suspension at various time intervals is outlined in **Table 3**. The maximum particle size in suspension decreases over time from around 17.5 µm (15 minutes) to 3 µm (24 hours).



Graph 6: Particle size distribution at varying time intervals, 50 mm below the water surface.

Graph 7 plots the particle size distribution of the sieved crushed rock (used for all tests) and the particle size that remains in suspension after a given time interval (15 minutes, 2 hours, 6 hours and 24 hours) at 230 mm below the water surface (300 mL mark on cylinder). The maximum particle size in suspension at various time intervals is outlined in **Table 3**. The maximum particle size in suspension decreases over time from around 31.5 µm (15 minutes) to 4.5 µm (24 hours).



Graph 7: Particle size distribution at varying time intervals 230 mm the water surface.

Table 3: Maximum particle size in suspension at varying time intervals, 50 mm and 230 mm below the water surface.

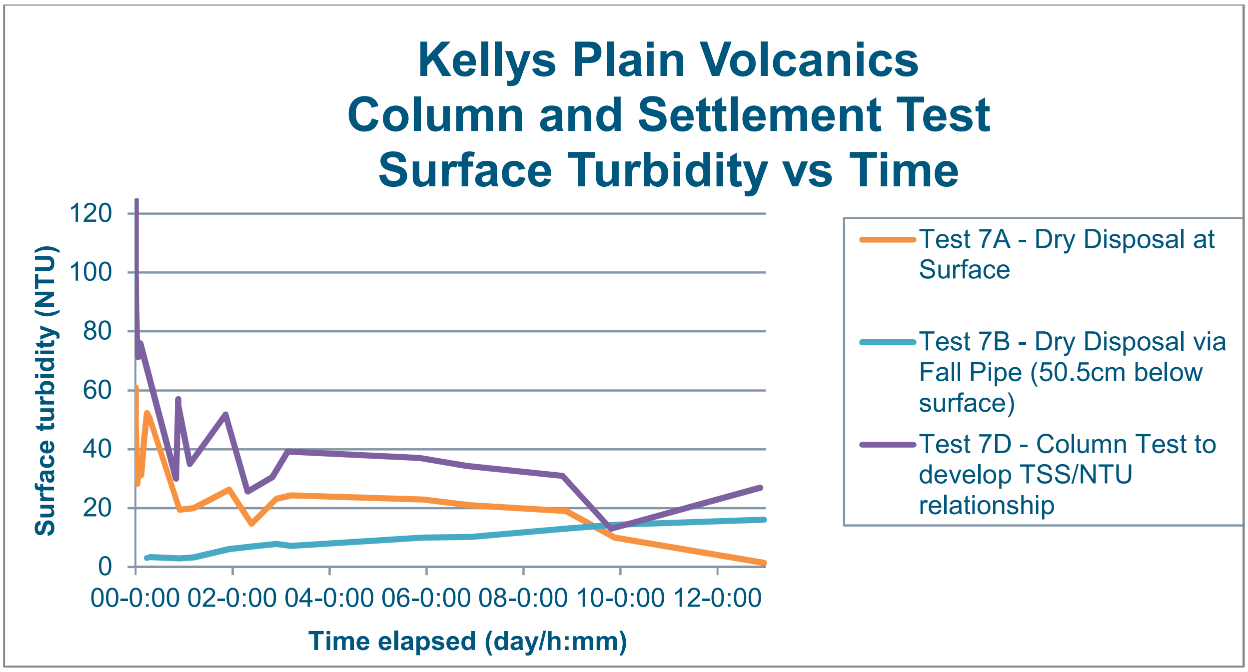
Time	**Maximum particle size in suspension (µm)**	
	50 mm below the water surface	**230 mm below the water surface**
15 minutes	17.5	31.5
2 hours	9	13.5
6 hours	5	8
24 hours	3	4.5

Based on the results presented above, it is evident that, for the same given time intervals, the maximum particle size in suspension is larger at greater depths within the water column, as would be expected.

3 Discussion

3.1 Fluctuating Turbidity and Increase in Surface Turbidity

As described in **Section 2**, surface turbidity in Tests 7A and 7D fluctuated and surface turbidity in Test 7B increased during the test duration. The variation in surface turbidity for the three tests is shown in **Graph 8**. The graph includes the addition of flocculant to Test 7A, 10 days following commencement and re-agitation of the upper portion of Test 7D, 20 hours after commencement.



Graph 8: Surface turbidity measured during the settlement and column tests – Kellys Plain Volcanics crushed rock (Tests 7A, 7B and 7D).

An increase in surface turbidity was unexpected, with ongoing settlement and decreasing turbidity following initial mixing considered more likely to occur. It is possible that the observations were influenced by one or more of the following factors:

1. Weak thermal convection currents within the column may result in mixing of stratified layers and rising warm water transporting suspended particles to the surface. Air temperature and water temperature was monitored for the duration of the test. The results are reported in **Section 2.2.4** and presented in **Graph 5**.

   It is apparent from **Graph 5** that the water temperature warms and cools in response to the air temperature. Further, the difference in water temperature between the top and bottom of the column increases during a warming phase and decreases during a cooling phase.

   It is inferred that heat is transferred from the air to the column and from the column to the adjacent water near the wall of the column through the process of conduction, which is the transfer of heat between objects in contact with each other, or through a substance due to the collision of molecules. Heating of water near the wall of the column would result in differential water temperature across the column with cooler water near the centre of the column. The differential water temperature would lead to two processes, conduction and convection where

convection is the process of warmer water, with a lower density, rising to cooler areas in the column and cooler water, with a higher density, sinking to take the place of the warmer water. The velocity of convection currents are difficult to determine and due to a range of factors.

2. The sieved crushed rock may contain clay particles that are anionic. The repelling force between charged particles in suspension may result in suspended solids diffusing and distributing evenly throughout the water column.

3. The action of gently lowering a turbidity probe into the upper layer of the column (~3.4 cm below the water surface), or extracting samples with a pipette from Test 7D (at 1 day and 3 hours following commencement and 2 days and 8 hours following commencement) may be sufficient to disturb the water column resulting in advection of very fine suspended particles. Indeed, re-agitation of the upper 15 cm of Test 7D, 20 hours following commencement of the test was sufficient to increase surface turbidity.

Regardless of the reason for fluctuating and increasing surface turbidity in Tests 7A, 7B and 7D, it is clear that minor disturbances to the water column are sufficient to disrupt the settlement process and redistribute fine suspended particles within the water column.

4 Conclusions

It is apparent from the column test and settlement tests that once fine material from the igneous rock in the Kellys Plain Volcanics geological zone enters the water column, the fine particles remain in suspension for extended periods in the order of several days to weeks. The surface turbidity approximately 10 days after commencement of Tests 7A, 7B and 7D was between 10 NTU and 27 NTU.

While surface turbidity levels generally appear to reduce over time, it may take in excess of 10 days to reach background levels of 2 NTU to 10 NTU, as reported by Cardno. Minor disturbances to the water column are likely to disrupt the settlement process and/or re-suspend fine particles.

The critical particle size in suspension that would be contributing to prolonged surface turbidity in the water column (more than 24 hours) would be less than approximately 5 µm.

The results of a chemical flocculation test for the Kellys Plain Volcanics crushed rock indicate that the addition of flocculant may accelerate settlement of fine particles and clarify the water.

TSS-turbidity data collected during the Column Test (Test 7D) is considered to be reliable for the purpose of establishing a preliminary relationship between TSS and turbidity for the Kellys Plain Volcanics geological zone. The turbidity value equivalent to 50 mg/L suspended solids is 46 NTU for this dataset. Furthermore, as the properties and grading of the material placed during construction may vary to that used in the column test, collection of field TSS-turbidity data during subaqueous excavated rock placement activities is recommended so that the relationship between turbidity and suspended solids can be continually validated and improved.

Attachment 1 – Laboratory Certificates

ALS Environmental

CERTIFICATE OF ANALYSIS

Work Order : **ES1831595**
Client : **HASKONING AUSTRALIA- ROYAL HASKONING**
Contact : MR PATRICK LAWLESS
Address : LEVEL 14 56 Berry Street
NORTH SYDNEY 2060
Telephone : ----
Project : Snowy 2.0 TSS-NTU (Tests 6-7)
Order number :
C-O-C number : ----
Sampler : PATRICK LAWLESS
Site : ----
Quote number : EN/222
No. of samples received : 33
No. of samples analysed : 33

Page : 1 of 9
Laboratory : Environmental Division Sydney
Contact : Customer Services ES
Address : 277-289 Woodpark Road Smithfield NSW Australia 2164
Telephone : +61-2-8784 8555
Date Samples Received : 24-Oct-2018 16:55
Date Analysis Commenced : 25-Oct-2018
Issue Date : 30-Oct-2018 17:16

ilac-MRA NATA
Accreditation No. 825
Accredited for compliance with
ISO/IEC 17025 - Testing

This report supersedes any previous report(s) with this reference. Results apply to the sample(s) as submitted. This document shall not be reproduced, except in full.

This Certificate of Analysis contains the following information:

- General Comments
- Analytical Results

Additional information pertinent to this report will be found in the following separate attachments: Quality Control Report, QA/QC Compliance Assessment to assist with Quality Review and Sample Receipt Notification.

Signatories

This document has been electronically signed by the authorized signatories below. Electronic signing is carried out in compliance with procedures specified in 21 CFR Part 11.

Signatories	*Position*	*Accreditation Category*
Ankit Joshi	Inorganic Chemist	Sydney Inorganics, Smithfield, NSW

General Comments

The analytical procedures used by the Environmental Division have been developed from established internationally recognized procedures such as those published by the USEPA, APHA, AS and NEPM. In house developed procedures are employed in the absence of documented standards or by client request.

Where moisture determination has been performed, results are reported on a dry weight basis.

Where a reported less than (<) result is higher than the LOR, this may be due to primary sample extract/digestate dilution and/or insufficient sample for analysis.

Where the LOR of a reported result differs from standard LOR, this may be due to high moisture content, insufficient sample (reduced weight employed) or matrix interference.

When sampling time information is not provided by the client, sampling dates are shown without a time component. In these instances, the time component has been assumed by the laboratory for processing purposes.

Where a result is required to meet compliance limits the associated uncertainty must be considered. Refer to the ALS Contact for details.

Key :
CAS Number = CAS registry number from database maintained by Chemical Abstracts Services. The Chemical Abstracts Service is a division of the American Chemical Society.
LOR = Limit of reporting
^ = This result is computed from individual analyte detections at or above the level of reporting
ø = ALS is not NATA accredited for these tests.
~ = Indicates an estimated value.

Analytical Results

Sub-Matrix: **WATER** **(**Matrix: **WATER)**			*Client sample ID*	**6D-1**	**6D-2**	**6D-3**	**6D-4**	**6D-5**
			Client sampling date / time	23-Oct-2018 00:00	23-Oct-2018 00:00	23-Oct-2018 00:00	23-Oct-2018 00:00	23-Oct-2018 00:00
Compound	*CAS Number*	*LOR*	*Unit*	**ES1831595-001**	**ES1831595-002**	**ES1831595-003**	**ES1831595-004**	**ES1831595-005**
				Result	Result	Result	Result	Result
EA025: Total Suspended Solids dried at 104 ± 2°C								
Suspended Solids (SS)	----	5	mg/L	<5	**170**	**172**	**142**	**121**
EA045: Turbidity								
Turbidity	----	0.1	NTU	**0.3**	**251**	**263**	**232**	**212**

Analytical Results

Sub-Matrix: **WATER** (Matrix: **WATER**)			*Client sample ID*	**6D-6**	**6D-7**	**6D-8**	**6D-9**	**6D-10**
			Client sampling date / time	23-Oct-2018 00:00	23-Oct-2018 00:00	23-Oct-2018 00:00	23-Oct-2018 00:00	23-Oct-2018 00:00
Compound	*CAS Number*	*LOR*	*Unit*	**ES1831595-006**	**ES1831595-007**	**ES1831595-008**	**ES1831595-009**	**ES1831595-010**
				Result	Result	Result	Result	Result
EA025: Total Suspended Solids dried at 104 ± 2°C								
Suspended Solids (SS)	----	5	mg/L	**87**	**92**	**65**	**84**	**62**
EA045: Turbidity								
Turbidity	----	0.1	NTU	**175**	**162**	**122**	**146**	**137**

Analytical Results

Sub-Matrix: **WATER**
(Matrix: **WATER)**

			Client sample ID	**6D-11**	**6D-12**	**6D-13**	**6D-14**	**6D-15**
			Client sampling date / time	23-Oct-2018 00:00	23-Oct-2018 00:00	23-Oct-2018 00:00	24-Oct-2018 00:00	24-Oct-2018 00:00
Compound	CAS Number	LOR	Unit	**ES1831595-011**	**ES1831595-012**	**ES1831595-013**	**ES1831595-014**	**ES1831595-015**
				Result	Result	Result	Result	Result
EA025: Total Suspended Solids dried at 104 ± 2°C								
Suspended Solids (SS)	----	5	mg/L	**51**	**41**	**104**	**7**	**44**
EA045: Turbidity								
Turbidity	----	0.1	NTU	**101**	**87.5**	**192**	**22.8**	**98.4**

Analytical Results

Sub-Matrix: **WATER**
(Matrix: **WATER)**

			Client sample ID	**6D-16**	**6D-17**	**7D-1**	**7D-2**	**7D-3**
			Client sampling date / time	24-Oct-2018 00:00	24-Oct-2018 00:00	23-Oct-2018 00:00	23-Oct-2018 00:00	23-Oct-2018 00:00
Compound	*CAS Number*	*LOR*	*Unit*	**ES1831595-016**	**ES1831595-017**	**ES1831595-018**	**ES1831595-019**	**ES1831595-020**
				Result	Result	Result	Result	Result
EA025: Total Suspended Solids dried at 104 ± 2°C								
Suspended Solids (SS)	----	5	mg/L	**45**	**40**	<5	**239**	**212**
EA045: Turbidity								
Turbidity	----	0.1	NTU	**87.9**	**82.3**	**0.8**	**137**	**135**

Analytical Results

Sub-Matrix: **WATER** (Matrix: **WATER**)			*Client sample ID*	**7D-4**	**7D-5**	**7D-6**	**7D-7**	**7D-8**
			Client sampling date / time	23-Oct-2018 00:00	23-Oct-2018 00:00	23-Oct-2018 00:00	23-Oct-2018 00:00	23-Oct-2018 00:00
Compound	*CAS Number*	*LOR*	*Unit*	**ES1831595-021**	**ES1831595-022**	**ES1831595-023**	**ES1831595-024**	**ES1831595-025**
				Result	Result	Result	Result	Result
EA025: Total Suspended Solids dried at 104 ± 2°C								
Suspended Solids (SS)	----	5	mg/L	**186**	**156**	**154**	**136**	**120**
EA045: Turbidity								
Turbidity	----	0.1	NTU	**130**	**73.3**	**40.6**	**33.6**	**36.5**

Analytical Results

Sub-Matrix: **WATER** (Matrix: **WATER**)			*Client sample ID*	**7D-9**	**7D-10**	**7D-11**	**7D-12**	**7D-13**
			Client sampling date / time	23-Oct-2018 00:00	23-Oct-2018 00:00	24-Oct-2018 00:00	24-Oct-2018 00:00	24-Oct-2018 00:00
Compound	*CAS Number*	*LOR*	*Unit*	**ES1831595-026**	**ES1831595-027**	**ES1831595-028**	**ES1831595-029**	**ES1831595-030**
				Result	Result	Result	Result	Result
EA025: Total Suspended Solids dried at 104 ± 2°C								
Suspended Solids (SS)	----	5	mg/L	**106**	**119**	**18**	**54**	**48**
EA045: Turbidity								
Turbidity	----	0.1	NTU	**35.2**	**38.0**	**27.8**	**65.6**	**67.7**

Analytical Results

Sub-Matrix: **WATER** (Matrix: **WATER**)			*Client sample ID*	**7D-14**	**7D-15**	**7D-16**	**----**	**----**
			Client sampling date / time	24-Oct-2018 00:00	24-Oct-2018 00:00	24-Oct-2018 00:00	----	----
Compound	*CAS Number*	*LOR*	*Unit*	**ES1831595-031**	**ES1831595-032**	**ES1831595-033**	**--------**	**--------**
				Result	Result	Result	----	----
EA025: Total Suspended Solids dried at 104 ± 2°C								
Suspended Solids (SS)	----	5	mg/L	**80**	**27**	**62**	**----**	**----**
EA045: Turbidity								
Turbidity	----	0.1	NTU	**80.1**	**49.0**	**69.7**	**----**	**----**

CERTIFICATE OF ANALYSIS

Work Order	: **ES1831922**	Page	: 1 of 5
Client	: **HASKONING AUSTRALIA- ROYAL HASKONING**	Laboratory	: Environmental Division Sydney
Contact	: MR PATRICK LAWLESS	Contact	: Customer Services ES
Address	: LEVEL 14 56 Berry Street NORTH SYDNEY 2060	Address	: 277-289 Woodpark Road Smithfield NSW Australia 2164
Telephone	: +61 02 8854 5000	Telephone	: +61-2-8784 8555
Project	: Snowy 2.0 TSS-NTU (Tests 6-7)	Date Samples Received	: 26-Oct-2018 17:00
Order number	: ----	Date Analysis Commenced	: 27-Oct-2018
C-O-C number	: ----	Issue Date	: 01-Nov-2018 11:39
Sampler	: PATRICK LAWLESS		
Site	: ----		
Quote number	: EN/222		
No. of samples received	: 13		
No. of samples analysed	: 13		

NATA

Accreditation No. 825
Accredited for compliance with
ISO/IEC 17025 - Testing

This report supersedes any previous report(s) with this reference. Results apply to the sample(s) as submitted. This document shall not be reproduced, except in full.

This Certificate of Analysis contains the following information:

- General Comments
- Analytical Results

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Signatories

This document has been electronically signed by the authorized signatories below. Electronic signing is carried out in compliance with procedures specified in 21 CFR Part 11.

Signatories	*Position*	*Accreditation Category*
Ankit Joshi	Inorganic Chemist	Sydney Inorganics, Smithfield, NSW

General Comments

The analytical procedures used by the Environmental Division have been developed from established internationally recognized procedures such as those published by the USEPA, APHA, AS and NEPM. In house developed procedures are employed in the absence of documented standards or by client request.

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Where the LOR of a reported result differs from standard LOR, this may be due to high moisture content, insufficient sample (reduced weight employed) or matrix interference.

When sampling time information is not provided by the client, sampling dates are shown without a time component. In these instances, the time component has been assumed by the laboratory for processing purposes.

Where a result is required to meet compliance limits the associated uncertainty must be considered. Refer to the ALS Contact for details.

Key :
CAS Number = CAS registry number from database maintained by Chemical Abstracts Services. The Chemical Abstracts Service is a division of the American Chemical Society.
LOR = Limit of reporting
^ = This result is computed from individual analyte detections at or above the level of reporting
ø = ALS is not NATA accredited for these tests.
~ = Indicates an estimated value.

Analytical Results

Sub-Matrix: **WATER** (Matrix: **WATER**)			Client sample ID	**7D-17**	**7D-18**	**7D-19**	**7D-20**	**7D-21**
			Client sampling date / time	25-Oct-2018 00:00	25-Oct-2018 00:00	25-Oct-2018 00:00	25-Oct-2018 00:00	25-Oct-2018 00:00
Compound	CAS Number	LOR	Unit	**ES1831922-001**	**ES1831922-002**	**ES1831922-003**	**ES1831922-004**	**ES1831922-005**
				Result	Result	Result	Result	Result
EA025: Total Suspended Solids dried at 104 ± 2°C								
Suspended Solids (SS)	----	5	mg/L	**46**	**12**	**47**	**21**	**38**
EA045: Turbidity								
Turbidity	----	0.1	NTU	**54.0**	**26.4**	**48.7**	**32.2**	**44.0**

Analytical Results

Sub-Matrix: **WATER** (Matrix: **WATER**)			Client sample ID	**6D-18**	**6D-19**	**6D-20**	**6D-21**	**6D-22**
			Client sampling date / time	25-Oct-2018 00:00	25-Oct-2018 00:00	25-Oct-2018 00:00	25-Oct-2018 00:00	26-Oct-2018 00:00
Compound	CAS Number	LOR	Unit	**ES1831922-006**	**ES1831922-007**	**ES1831922-008**	**ES1831922-009**	**ES1831922-010**
				Result	Result	Result	Result	Result
EA025: Total Suspended Solids dried at 104 ± 2°C								
Suspended Solids (SS)	----	5	mg/L	**34**	**8**	**29**	**20**	**13**
EA045: Turbidity								
Turbidity	----	0.1	NTU	**82.4**	**23.6**	**75.2**	**56.7**	**31.2**

Analytical Results

Sub-Matrix: **WATER** (Matrix: **WATER**)			*Client sample ID*	**6D-23**	**6D-24**	**7D-25** **6D-25**	**----**	**----**
			Client sampling date / time	26-Oct-2018 00:00	26-Oct-2018 00:00	26-Oct-2018 00:00	----	----
Compound	*CAS Number*	*LOR*	*Unit*	**ES1831922-011**	**ES1831922-012**	**ES1831922-013**	**--------**	**--------**
				Result	Result	Result	----	----
EA025: Total Suspended Solids dried at 104 ± 2°C								
Suspended Solids (SS)	----	5	mg/L	**18**	**17**	**20**	**----**	**----**
EA045: Turbidity								
Turbidity	----	0.1	NTU	**47.6**	**50.6**	**49.4**	**----**	**----**

CERTIFICATE OF ANALYSIS

Work Order	: **ES1832781**	Page	: 1 of 4
Client	: **HASKONING AUSTRALIA- ROYAL HASKONING**	Laboratory	: Environmental Division Sydney
Contact	: MR PATRICK LAWLESS	Contact	: Customer Services ES
Address	: LEVEL 14 56 Berry Street NORTH SYDNEY 2060	Address	: 277-289 Woodpark Road Smithfield NSW Australia 2164
Telephone	: ----	Telephone	: +61-2-8784 8555
Project	: Snowy 2.0 TSS-NTU (Tests 6-7)	Date Samples Received	: 02-Nov-2018 15:35
Order number	:	Date Analysis Commenced	: 03-Nov-2018
C-O-C number	: ----	Issue Date	: 07-Nov-2018 12:33
Sampler	: PATRICK LAWLESS		
Site	: ----		
Quote number	: EN/222		
No. of samples received	: 8		
No. of samples analysed	: 8		

Accreditation No. 825
Accredited for compliance with
ISO/IEC 17025 - Testing

This report supersedes any previous report(s) with this reference. Results apply to the sample(s) as submitted. This document shall not be reproduced, except in full.

This Certificate of Analysis contains the following information:

- General Comments
- Analytical Results

Additional information pertinent to this report will be found in the following separate attachments: Quality Control Report, QA/QC Compliance Assessment to assist with Quality Review and Sample Receipt Notification.

Signatories

This document has been electronically signed by the authorized signatories below. Electronic signing is carried out in compliance with procedures specified in 21 CFR Part 11.

Signatories	*Position*	*Accreditation Category*
Ankit Joshi	Inorganic Chemist	Sydney Inorganics, Smithfield, NSW

General Comments

The analytical procedures used by the Environmental Division have been developed from established internationally recognized procedures such as those published by the USEPA, APHA, AS and NEPM. In house developed procedures are employed in the absence of documented standards or by client request.

Where moisture determination has been performed, results are reported on a dry weight basis.

Where a reported less than (<) result is higher than the LOR, this may be due to primary sample extract/digestate dilution and/or insufficient sample for analysis.

Where the LOR of a reported result differs from standard LOR, this may be due to high moisture content, insufficient sample (reduced weight employed) or matrix interference.

When sampling time information is not provided by the client, sampling dates are shown without a time component. In these instances, the time component has been assumed by the laboratory for processing purposes.

Where a result is required to meet compliance limits the associated uncertainty must be considered. Refer to the ALS Contact for details.

Key : CAS Number = CAS registry number from database maintained by Chemical Abstracts Services. The Chemical Abstracts Service is a division of the American Chemical Society.
LOR = Limit of reporting
^ = This result is computed from individual analyte detections at or above the level of reporting
ø = ALS is not NATA accredited for these tests.
~ = Indicates an estimated value.

Analytical Results

Sub-Matrix: **WATER** (Matrix: **WATER**)			*Client sample ID*	**7D-22**	**7D-23**	**7D-24**	**7D-25**	**6D-26**
			Client sampling date / time	29-Oct-2018 00:00	30-Oct-2018 00:00	01-Nov-2018 00:00	02-Nov-2018 00:00	29-Oct-2018 00:00
Compound	*CAS Number*	*LOR*	*Unit*	**ES1832781-001**	**ES1832781-002**	**ES1832781-003**	**ES1832781-004**	**ES1832781-005**
				Result	Result	Result	Result	Result
EA025: Total Suspended Solids dried at 104 ± 2°C								
Suspended Solids (SS)	----	5	mg/L	**76**	**30**	**24**	**9**	**15**
EA045: Turbidity								
Turbidity	----	0.1	NTU	**40.6**	**39.0**	**34.5**	**15.7**	**35.2**

Analytical Results

Sub-Matrix: **WATER** (Matrix: **WATER**)			Client sample ID	**6D-27**	**6D-28**	**6D-29**	**----**	**----**
			Client sampling date / time	30-Oct-2018 00:00	01-Nov-2018 00:00	02-Nov-2018 00:00	----	----
Compound	CAS Number	LOR	Unit	**ES1832781-006**	**ES1832781-007**	**ES1832781-008**	**--------**	**--------**
				Result	Result	Result	----	----
EA025: Total Suspended Solids dried at 104 ± 2°C								
Suspended Solids (SS)	----	5	mg/L	**15**	**10**	**5**	**----**	**----**
EA045: Turbidity								
Turbidity	----	0.1	NTU	**29.9**	**23.8**	**11.3**	**----**	**----**

Attachment 2 – Kellys Plain Volcanics Laboratory Log Records

Test ID	7A	
Geological Unit	Kellys Plain Volcanics	
Description	Test 7A - Dry Disposal at Surface	
Start Date/Time	23-10-18 11:10	
Water volume	50 L	
Water surface level in column	172.8	cm
Mass sediment added	40 g	(sieved to <250 um)
Test Location	Geochemical Assessments Workshop, Roseville NSW	
Test Officers	Pat Lawless, Rick Plain	

Observations

Date/Time	Time since start	Turbidity (NTU)	Measurement Location (cm)	Measurement Depth (cm)	Comments
23-10-18 8:30	3 hours prior	2.7	169.4	3.4	Background turbidity measured 3 hours before test start.
23-10-18 11:12	00-0:02	61	169.4	3.4	61 NTU immediately after sediment added.
23-10-18 11:16	00-0:06	53	169.4	3.4	More uniform mixing within 7A compared to 7B (clearer at bottom/top in 7B).
23-10-18 11:19	00-0:09	48.6	169.4	3.4	Video Stopped.
23-10-18 11:23	00-0:13	44.3	169.4	3.4	
23-10-18 11:29	00-0:19	41.2	169.4	3.4	
23-10-18 11:40	00-0:30	37.1	169.4	3.4	WetLAB file stopped.
23-10-18 12:00	00-0:50	28.2	169.4	3.4	
23-10-18 12:37	00-1:27	33	169.4	3.4	
23-10-18 13:30	00-2:20	33.4	169.4	3.4	Stratification at 162 cm.
23-10-18 14:00	00-2:50	31.2	169.4	3.4	
23-10-18 14:25	00-3:15	35	169.4	3.4	Stratification at 159 cm.
23-10-18 15:23	00-4:13	43	169.4	3.4	
23-10-18 16:45	00-5:35	52.2	169.4	3.4	
23-10-18 18:15	00-7:05	50.4	169.4	3.4	
24-10-18 9:00	00-21:50	19.5	169.4	3.4	Top ~2 cm starting to clarify.
24-10-18 15:50	01-4:40	20	169.4	3.4	Top ~2 cm starting to clarify.
25-10-18 9:30	01-22:20	26.3	169.4	3.4	
25-10-18 20:30	02-9:20	14.7	169.4	3.4	
26-10-18 8:45	02-21:35	23.1	169.4	3.4	
26-10-18 16:15	03-5:05	24.3	169.4	3.4	
29-10-18 9:30	05-22:20	22.9	169.4	3.4	
30-10-18 9:00	06-21:50	21	169.4	3.4	
01-11-18 8:15	08-21:05	19	169.4	3.4	
02-11-18 8:15	09-21:05	10	169.4	3.4	Stratification at 164.5 cm. Flocculent added.
05-11-18 10:10	12-23:00	1.4	169.4	3.4	

Test ID	7B	
Geological Unit	Kellys Plain Volcanics	
Description	Test 7B - Dry Disposal via Fall Pipe (50.5cm below surface)	
Start Date/Time	23-10-18 11:10	
Water volume	50 L	
Water surface level in column	173.4	cm
Mass sediment added	40 g	(sieved to <250 um)
Test Location	Geochemical Assessments Workshop, Roseville NSW	
Test Officers	Pat Lawless, Rick Plain	

Observations

Date/Time	Time since start	Turbidity (NTU)	Measurement Location (cm)	Measurement Depth (cm)	Comments
23-10-18 8:30	3 hours prior	2.3	170	3.4	Background turbidity measured 3 hours before test start.
23-10-18 11:14	00-0:04		170	3.4	Top of plume at 125 cm
23-10-18 12:37	00-1:27		170	3.4	Top of plume at 124.2 cm.
23-10-18 16:45	00-5:35	3.1	170	3.4	Top of plume at 122.9 cm.
23-10-18 18:15	00-7:05	3.4	170	3.4	Top of plume at 122.4 cm. Higher at front compared to the back.
24-10-18 9:00	00-21:50	2.95	170	3.4	Top of plume at 123.5 cm.
24-10-18 15:50	01-4:40	3.24	170	3.4	Top of plume at 122.5 cm.
25-10-18 9:30	01-22:20	6.1	170	3.4	Top of plume at 117 cm. Stratification at 107.5 cm.
25-10-18 20:30	02-9:20	7	170	3.4	Top of plume at 109 cm. Slight haze above.
26-10-18 8:45	02-21:35	7.85	170	3.4	Top of plume at 108 cm. Slight haze above.
26-10-18 16:15	03-5:05	7.18	170	3.4	Top of plume at 107 cm. Slight haze above.
29-10-18 9:30	05-22:20	10	170	3.4	Top of plume at 87 cm. Slight haze above.
30-10-18 9:00	06-21:50	10.25	170	3.4	Top of plume at 82 cm. Slight haze above.
01-11-18 8:15	08-21:05	13	170	3.4	Top of plume at 56.5 cm. Turbidity above.
02-11-18 8:15	09-21:05	14.3	170	3.4	Top of plume at 42 cm. Turbidity above.
05-11-18 10:10	12-23:00	16.1	170	3.4	Fairly well mixed throughout column.

Test ID	7D	
Geological Unit	Kellys Plain Volcanics	
Description	Test 7D - Column Test to develop TSS/NTU relationship	
Start Date/Time	23-10-18 13:00	
Water volume	50 L	
Water surface level in column	172.8	cm
Mass sediment added	47.5 g	(sieved to <250 um)
Test Location	Geochemical Assessments Workshop, Roseville NSW	
Test Officers	Pat Lawless, Rick Plain	

Observations

Date/Time	Time since start	Turbidity (NTU)		TSS Sample Taken?	TSS Sample ID	Column Measurements			Comments
		Inside Column	Inside Beaker			Water Surface	Measurement Location	Sensor Depth	
23-10-18 8:30	4.5 hours prior	2.7	1.7	Yes	7D-1	176.2	172.8	3.4	Before commencement
23-10-18 12:50	10 mins prior			No					Placed material without agitating to see if would get different results to initial stage of Test 7A. Material 'dumped' rather than 'trickled' into column. Material generally fell through column leaving the surface turbidity fairly low (max ~25 NTU) then settled to <10 NTU within minutes.
23-10-18 13:00	00-0:00			No					Agitation undertaken. Test commenced.
23-10-18 13:03	00-0:03	130	125	Yes	7D-2				Turbidity falling steadily.
23-10-18 13:06	00-0:06	110	108	Yes	7D-3				Varying 103-118 NTU.
23-10-18 13:08	00-0:08	100	100	Yes	7D-4				
23-10-18 13:12	00-0:12	95		No					Readings starting to stabilise.
23-10-18 13:15	00-0:15	90	90	Yes	7D-5	169.1	165.7	3.4	Beaker reading range 85-100 NTU.
23-10-18 13:23	00-0:23	85	86	Yes	7D-6	168.7	165.3	3.4	Beaker reading range 83-90 NTU.
23-10-18 13:33	00-0:33	80	78	Yes	7D-7	168.4	165	3.4	
23-10-18 13:42	00-0:42	76	78	Yes	7D-8	167.3	163.9	3.4	Beaker reading range 75-80 NTU.
23-10-18 13:58	00-0:58	75		No		166.2	162.8	3.4	
23-10-18 14:23	00-1:23	71.3	78	Yes	7D-9	165.8	162.4	3.4	Beaker reading range 73-84 NTU.
23-10-18 15:20	00-2:20	76	76	Yes	7D-10	165.3	161.9	3.4	Beaker reading range 74-82 NTU.
23-10-18 16:45	00-3:45	85.1		No		164.4	161	3.4	
23-10-18 18:15	00-5:15	77.3		No		164.4	161	3.4	
24-10-18 9:00	00-20:00	30	22.2	Yes	7D-11	164.4	161	3.4	
24-10-18 10:05	00-21:05	57	51	Yes	7D-12	163.6	160.2	3.4	Top 15 cm of column re-agitated.
24-10-18 10:10	00-21:10	54.8	52.5	Yes	7D-13	162.7	159.3	3.4	
24-10-18 10:30	00-21:30		62	Yes	7D-14	161.9	158.5	3.4	Pipette sample extracted from ~110 cm. Beaker reading range 57-63 NTU.
24-10-18 15:50	01-2:50	35	36	Yes	7D-15	161.1	157.7	3.4	
24-10-18 16:10	01-3:10		52.5	Yes	7D-16	160.2	156.8	3.4	Pipette sample extracted from ~109 cm. Beaker reading range 51-53 NTU.
25-10-18 9:30	01-20:30	51.8	51.3	Yes	7D-17	159.2	155.8	3.4	
25-10-18 20:30	02-7:30	25.6	21.9	Yes	7D-18	158.3	154.9	3.4	
25-10-18 20:45	02-7:45		46.2	Yes	7D-19	157.5	154.1	3.4	Pipette sample extracted from ~145 cm.
26-10-18 8:45	02-19:45	30.5	28.8	Yes	7D-20	157	153.6	3.4	Top ~1cm clear. Stratification at 137 cm.
26-10-18 16:15	03-3:15	39.2	40.1	Yes	7D-21	156.7	153.3	3.4	
29-10-18 9:30	05-20:30	37	36.5	Yes	7D-22	154.6	151.2	3.4	
30-10-18 9:00	06-20:00	34.3	35	Yes	7D-23	153.8	150.4	3.4	
01-11-18 8:15	08-19:15	31	31	Yes	7D-24	153.2	149.8	3.4	
02-11-18 8:15	09-19:15	13	13.6	Yes	7D-25	152.3	148.9	3.4	Stratification at 147.2 cm and 150 cm.
05-11-18 10:10	12-21:10	27		No		151.4	148	3.4	

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Appendix H

TSS – Turbidity and Settling Test Results Tantangara Formation Geological Zone

Table of Contents

1 Introduction

The Tantangara Formation comprises deep marine siliciclastic deposits including sandstone, siltstone, shale and quartzite. dacite, ignimbrite, rhyodacite, tuff, agglomerate, rhyolite and porphyritic monzogranite. A 1-m long section of core from this geological zone was supplied to Royal HaskoningDHV (Haskoning) from BH2103 taken between 113 m and 114 m below the ground surface. The core was logged as interbedded metasandstone, a metamorphosed sedimentary rock.

Water for laboratory testing was obtained from Tantangara Reservoir on the 2nd October 2018. The water was collected in 1000 L Intermediate Bulk Containers (IBC) and delivered to Haskoning on the 5th October 2018. The turbidity of the reservoir water sample used for the testing was between 2.0 and 2.6 NTU. This is within the turbidity range of field monitoring, as undertaken by Cardno in 2018, which indicated typical 'background' turbidity of 2 to 10 NTU in Tantangara Reservoir.

2 Results

2.1 Test 8D – TSS-Turbidity

2.1.1 Overview

The TSS-Turbidity Test for the Tantangara Formation ('Test 8D') commenced on the 6th November 2018 at 9:30am and concluded on the 19th November 2018, approximately 13 days following commencement.

The Certificate of Analysis provided by ALS Environmental for the TSS and turbidity analyses undertaken for samples collected during testing is provided in **Attachment 1**. Laboratory log records completed during the TSS-turbidity test are provided in **Attachment 2**, which includes turbidity measurements undertaken during testing for each sample.

Photographs taken during the column test are provided in **Figure 1**. These photographs were taken

- prior to commencement;
- 1 hour and 33 minutes after commencement;
- 1 day and 23 hours after commencement;
- 2 days and 22.5 hours after commencement; and
- 13 days and 4.5 hours after commencement.

TEST I.D.	8 D
GEOLOGICAL UNIT	TANTANGARA FORMATION
START TIME	6/11/18
CURRENT TIME	6/11/18

TEST I.D.	8 D
GEOLOGICAL UNIT	TANTANGARA FORMATION
START TIME	6/11/18 9:30
CURRENT TIME	6/11/18 11:03

TEST I.D.	8 D
GEOLOGICAL UNIT	TANTANGARA FORMATION
START TIME	6/11/18 9:30
CURRENT TIME	8/11/18 8:30

TEST I.D.	8 D
GEOLOGICAL UNIT	TANTANGARA FORMATION
START TIME	6/11/18 9:30
CURRENT TIME	9/11/18 8:00

TEST I.D.	8 D
GEOLOGICAL UNIT	TANTANGARA FORMATION
START TIME	6/11/18 9:30
CURRENT TIME	19/11/18 14:00

Figure 1: Column test –

1. *Tantangara Reservoir water without addition of the sieved crushed rock,*
2. *Column test 1 hours and 33 minutes after commencement,*
3. *Column test 1 day and 23 hours after commencement,*
4. *Column test 2 days and 22.5 hours after commencement, and*
5. *Column test 13 days and 4.5 hours after commencement.*

2.1.2 Surface Turbidity vs Time Results

The variation in surface turbidity during Test 8D is plotted in **Graph 1**. The graph shows that surface turbidity decreased from 230 NTU to 70.5 NTU during the initial 5 hours of testing. Between approximately 5 hours and 20 minutes after commencement and 6 hours and 45 minutes after commencement, surface turbidity increased from 70.5 NTU to 113 NTU.

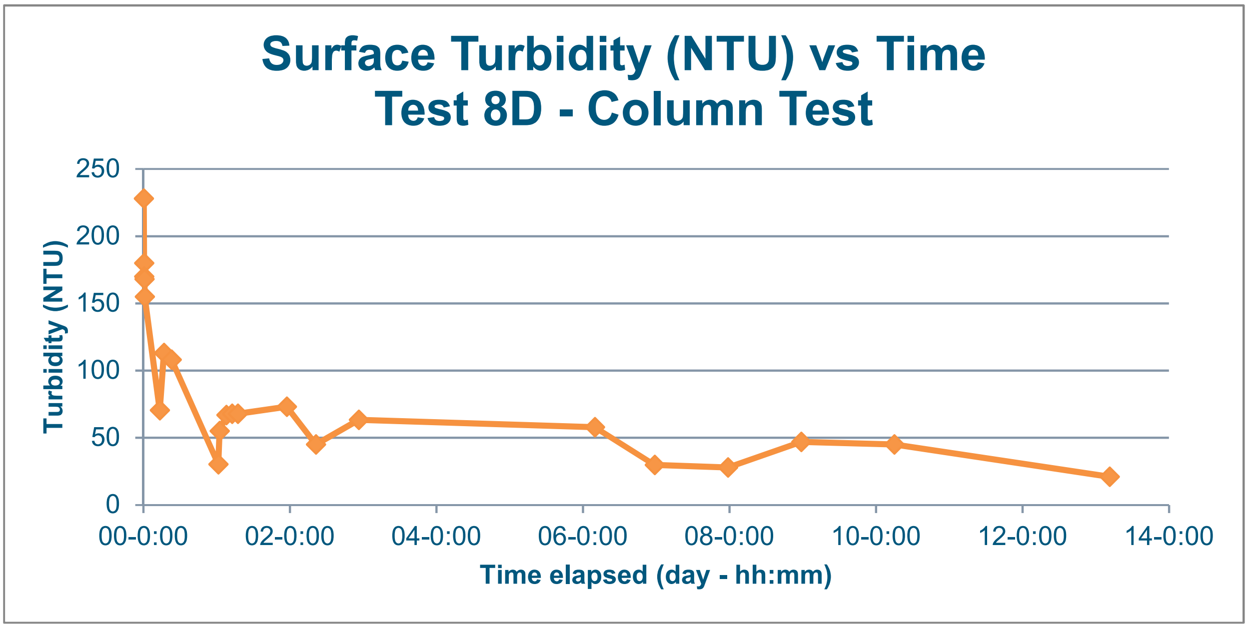
Surface turbidity subsequently decreased rapidly to 30.4 NTU, 1 day after commencement. At this point, a pipette was used to extract samples, with a higher turbidity, from approximately 10 cm to 20 cm below the water surface[1]. The pipette was gently placed in the water to minimise disturbance to the water column. However, a surface sample was obtained following extraction of the sub-surface samples via a pipette and the surface turbidity had increased from 30.4 NTU to 55 NTU.

Surface turbidity continued to increase to 67 NTU, 1 day and 3 hours after commencement and 73.2 NTU, 1 days and 23 hours after commencement. Surface turbidity fluctuated and gradually declined for the remainder of the test. Surface turbidity was noted to increase during the following time intervals:

- between 2 days and 8 hours following commencement and 2 days and 23 hours following commencement, surface turbidity increased from 45 NTU to 63.3 NTU; and,
- between 8 days following commencement and 9 days following commencement, surface turbidity increased from 28 NTU to 47 NTU.

Surface turbidity was 21 NTU, 13 days and 4 hours following commencement.

The increase in surface turbidity at the various time intervals is somewhat unexpected and a discussion is provided in **Section 3**.



Graph 1: Surface turbidity measured during the column test – Tantangara Formation crushed rock (Test 8D).

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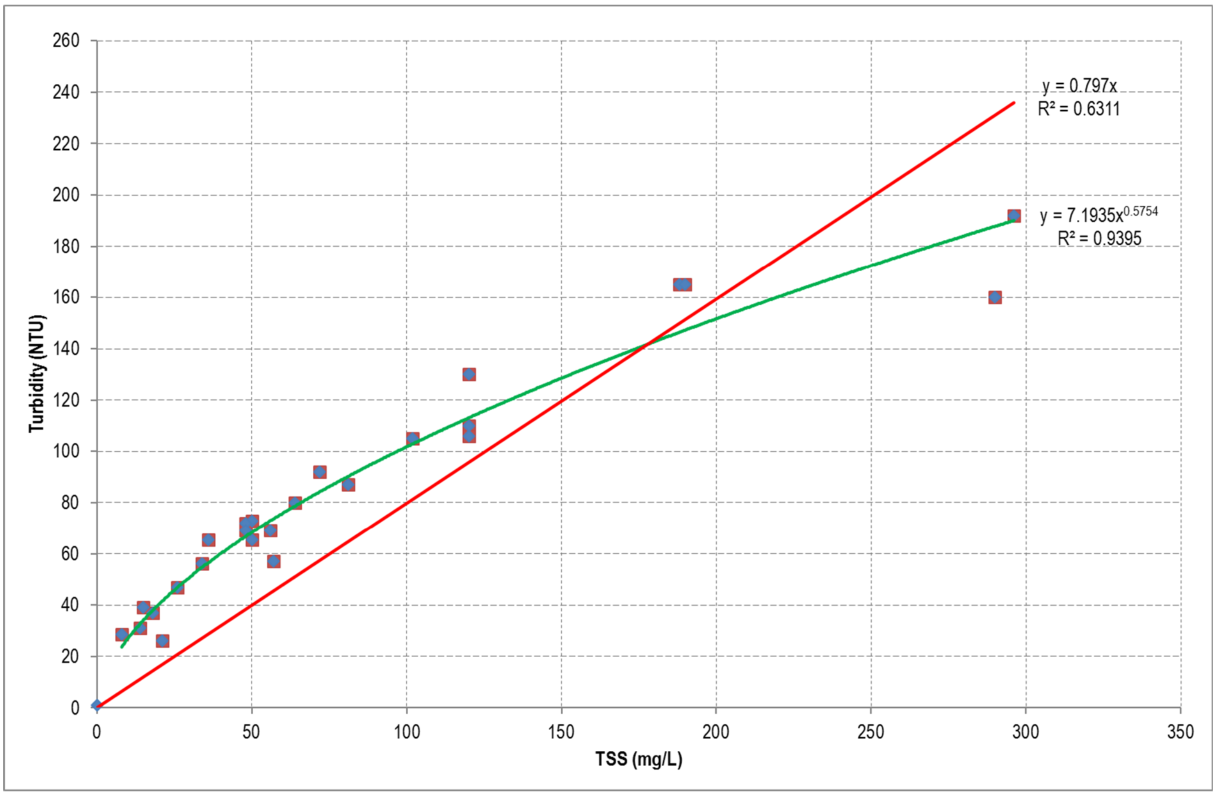
[1] It was necessary to collect water samples covering a wide range of TSS and turbidity values to ensure that a robust TSS-turbidity dataset could be established for the purposes of defining a meaningful relationship between turbidity and suspended solids.

2.1.3 TSS – Turbidity Results

A total of 26 samples were collected during testing for laboratory TSS and turbidity analysis. TSS values for the collected samples ranged between <5 mg/L[2] and 296 mg/L, while turbidity values of up to around 190 NTU were recorded.

A plot of TSS versus turbidity for all data collected during testing is provided in **Graph 2**. Turbidity values used in this dataset are the measurements taken during testing (inside the glass beaker prior to sub-sampling) rather than the laboratory results[3]. This dataset is plotted with trendlines corresponding to both linear and power functions. It is evident that the power function provides a much closer fit of the data, characterised by an R^2 value of 0.94[4] whereas the linear line of best fit has a lower R^2 value of 0.63.



Graph 2: TSS-turbidity results – Tantangara Formation crushed rock (Test 8D)

2.1.4 TSS – Turbidity Relationship

A summary of the TSS-turbidity relationships determined for the Test 8D dataset is provided in **Table 1**, including the turbidity values equivalent to a TSS concentration of 50 mg/L for each of the linear and power function trendlines. The selected TSS value of 50 mg/L is somewhat arbitrary and the water quality limit for the project may vary.

---

[2] The Limit of Reporting (LOR) value for TSS analysis is 5 mg/L, refer **Attachment 1**. Results for samples with TSS concentrations below the LOR value are reported as <5 mg/L.

[3] Turbidity results reported by the laboratory were compared with turbidity results obtained during testing using the Wetlab-ECO-NTU sensor. No significant differences between the turbidity datasets were evident (i.e. selection of the turbidity dataset does not significantly influence the TSS-turbidity relationship reported herein).

[4] The R^2 value, also known as the coefficient of determination, is a measure of how close the plotted data are to the fitted regression line (i.e. the line of best fit). An R^2 value of 1 indicates that the regression line perfectly fits the data.

Table 1: Summary of TSS-turbidity relationships for Tantangara Formation crushed rock type

Trendline Function	Number of values	R^2 value	Turbidity (NTU) equivalent to 50 mg/L TSS
Linear	26	0.63	30
Power	26	0.94	68

As noted above, the power function trendline provides a much better fit of the dataset compared to the linear trendline. Furthermore, the high R^2 value associated with the power function trendline (0.94) indicates a strong correlation between TSS and turbidity for the dataset, and is considered to be valid for the data collected during testing. The turbidity value equivalent to 50mg/L suspended solids is 68 NTU for this dataset.

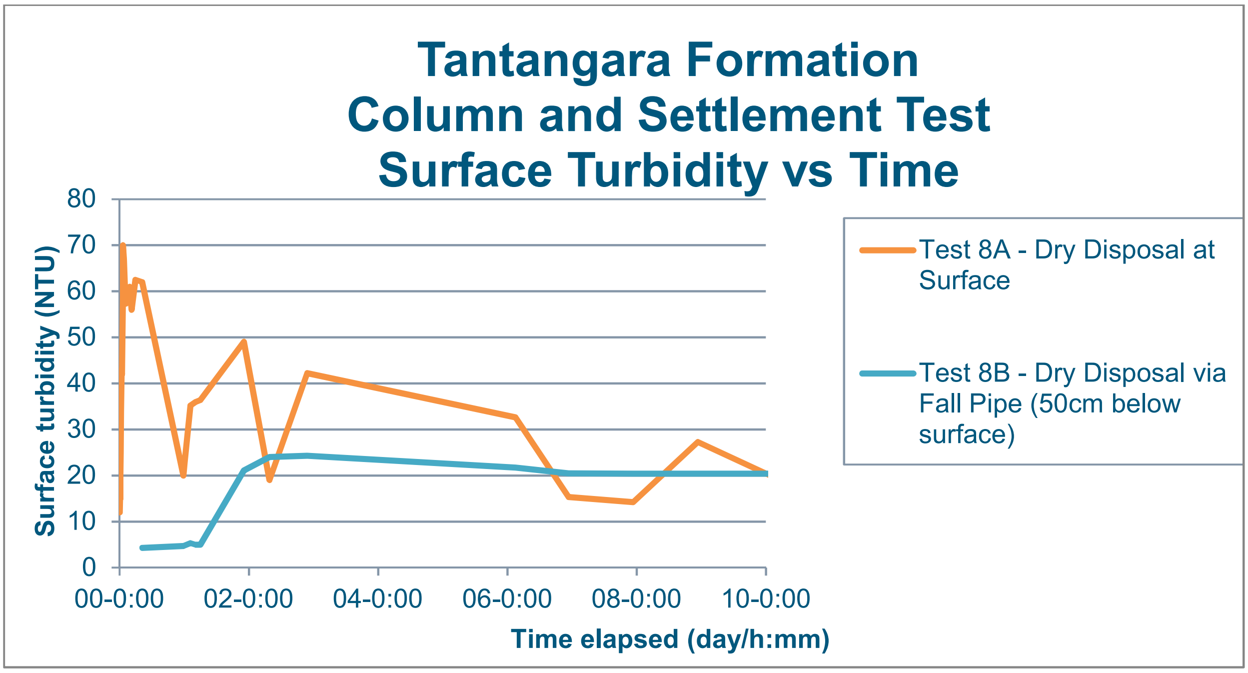
2.2 Settlement Tests

2.2.1 Overview

The two settlement tests for the Tantangara Formation (Tests 8A and 8B) commenced simultaneously on the 6th November 2018 at 10:20am. Different disposal methods were simulated in the respective columns as described in **Sections 2.2.2** to **2.2.4**. The tests concluded on the 16th November 2018, approximately 10 days and 6 hours following commencement.

Surface turbidity in the two columns was measured approximately 70 minutes prior to addition of the crushed rock and it was 2.6 and 2.2 NTU for Test 8A and 8B respectively.

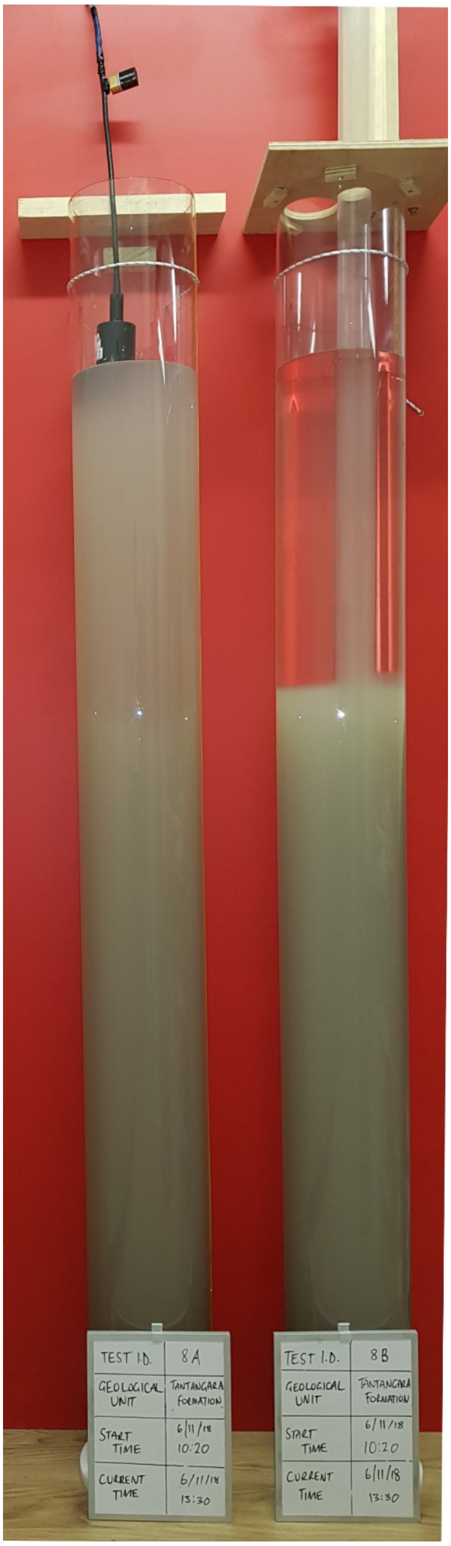
Surface turbidity measured at varying time intervals during the 10-day test duration is plotted in **Graph 3** for the two settlement tests. These results are discussed in the following sections, along with a summary of the key observations for each settlement test. Laboratory log records completed during the settlement tests are provided in **Attachment 2**.



Graph 3: Surface turbidity measured during the settlement tests – Tantangara Formation (Tests 8A and 8B).

Photographs taken during the settlement tests are provided in **Figures 2** to **6**. These photographs were taken prior to commencement (**Figure 2**), 2 hours and 10 minutes after commencement (**Figure 3**), 1 day and 22.2 hours after commencement (**Figure 4**), 6 days and 2.7 hours after commencement (**Figure 5**), and 10 days and 5.2 hours after commencement (**Figure 6**).

Figure 2: Settlement test prior to placement of sieved crushed rock-
Left: Test 8A - Placement of dry sieved crushed rock directly onto the water surface,
Right: Test 8B - Placement of dry sieved crushed rock within a fall pipe with opening submerged 50 cm below the water surface.



TEST I.D.	8A
GEOLOGICAL UNIT	TANTANGARA FORMATION
START TIME	6/11/18 10:20
CURRENT TIME	6/11/18 13:30

TEST I.D.	8B
GEOLOGICAL UNIT	TANTANGARA FORMATION
START TIME	6/11/18 10:20
CURRENT TIME	6/11/18 13:30

Figure 3: Settlement test 2 hours and 10 minutes following placement of sieved crushed rock-
Left: Test 8A - Placement of dry sieved crushed rock directly onto the water surface,
Right: Test 8B - Placement of dry sieved crushed rock within a fall pipe with opening submerged 50 cm below the water surface.

TEST I.D.	8A
GEOLOGICAL UNIT	TANTANGARA FORMATION
START TIME	6/11/18 10:20
CURRENT TIME	8/11/18 8:30

TEST I.D.	8B
GEOLOGICAL UNIT	TANTANGARA FORMATION
START TIME	6/11/18 10:20
CURRENT TIME	8/11/18 8:30

Figure 4: Settlement test 1 day and 22.2 hours following placement of sieved crushed rock-
Left: Test 8A - Placement of dry sieved crushed rock directly onto the water surface,
Right: Test 8B - Placement of dry sieved crushed rock within a fall pipe with opening submerged 50 cm below the water surface.

TEST I.D.	8A
GEOLOGICAL UNIT	TANTANGARA FORMATION
START TIME	6/11/18 10:20
CURRENT TIME	12/11/18 13:00

TEST I.D.	8B
GEOLOGICAL UNIT	TANTANGARA FORMATION
START TIME	6/11/18 10:20
CURRENT TIME	12/11/18 13:00

Figure 5: Settlement test 6 days and 2.7 hours following placement of sieved crushed rock-
Left: Test 8A - Placement of dry sieved crushed rock directly onto the water surface,
Right: Test 8B - Placement of dry sieved crushed rock within a fall pipe with opening submerged 50 cm below the water surface.

TEST I.D.	8A
GEOLOGICAL UNIT	TANTANGARA FORMATION
START TIME	6/11/18 10:20
CURRENT TIME	16/11/18 15:30

TEST I.D.	8B
GEOLOGICAL UNIT	TANTANGARA FORMATION
START TIME	6/11/18 10:20
CURRENT TIME	16/11/18 15:30

Figure 6: Settlement test 10 days and 5.2 hours following placement of sieved crushed rock-
Left: Test 8A - Placement of dry sieved crushed rock directly onto the water surface,
Right: Test 8B - Placement of dry sieved crushed rock within a fall pipe with opening submerged 50 cm below the water surface.

2.2.2 Test 8A - Placement of dry sieved crushed rock directly onto the water surface

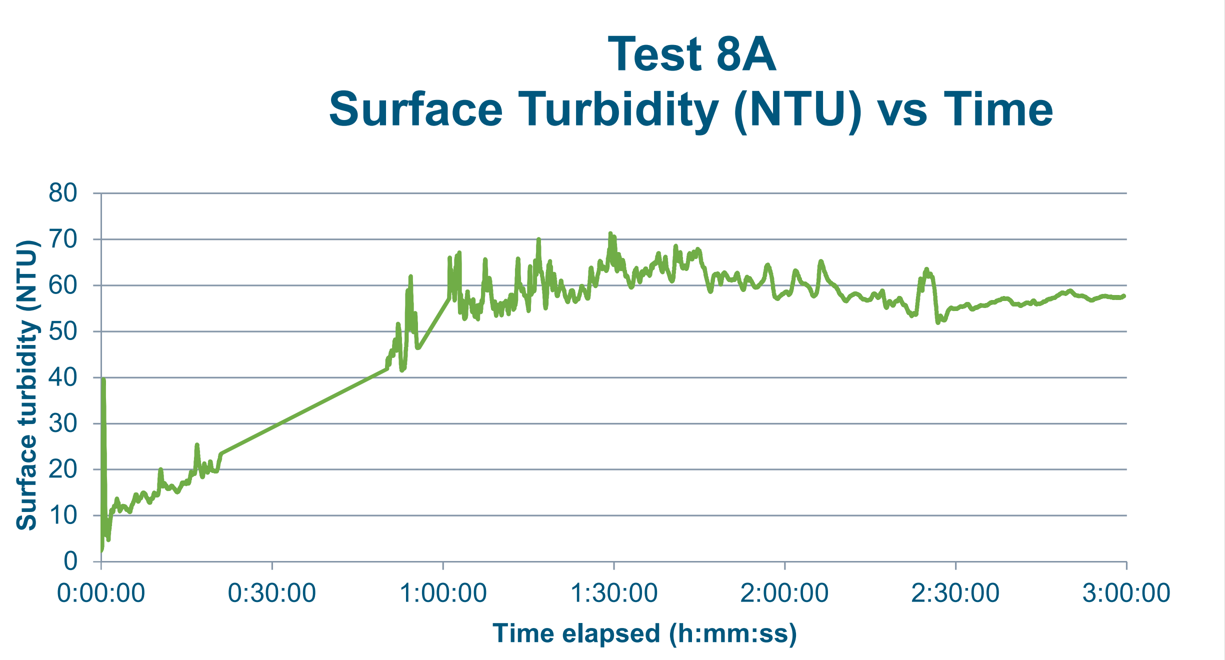
For Test 8A, the sieved crushed rock was gently sprinkled onto the water surface from a height of approximately 25 cm above the water surface. Rapid descent of crushed rock was observed through the upper quarter of the water column. Clumps of crushed rock fell to the bottom of the column within approximately 30 seconds. Fine crushed rock parted from the clumps during descent and a turbid trail formed through the water column in the wake of the clumps. It is estimated that approximately 10 to 20% of the mass of crushed rock fell to the bottom in clumps.

Mixing and diffusion of crushed rock was observed in the middle third of the water column after approximately 40 seconds. After approximately 1 minute, mixing and diffusion was observed throughout the entire column. However, the upper 10 to 15 cm of the column remained relatively clear. Advection of the crushed rock was visible within the column.

After approximately 20 minutes, stratification was observed approximately 10 to 15 cm below the water surface. The upper layer was visually clearer with noticeably higher turbidity lower in the column. The elevation of this stratification layer decreased over time. However, turbidity above the stratified layer visibly increased.

Surface turbidity levels were measured continuously (at one second time intervals) during the first 21 minutes, between 50 and 56 minutes after commencement and between 61 minutes and 3 hours after commencement of Test 8A. The Wetlab ECO-NTU sensor remained in the water column during the initial 3 hours. Surface turbidity levels were measured at varying time intervals thereafter. The Wetlab ECO-NTU sensor was placed in the water column for each measurement and removed after a stable reading was recorded.

Surface turbidity during the first 3 hours after commencement of the test is plotted in **Graph 4** for Test 8A**.**



Graph 4: Surface turbidity measured during the first hour following placement of Tantangara Formation crushed rock, Test 8A.

Surface turbidity levels increased rapidly from background levels of around 2.6 NTU to a maximum of around 40 NTU during placement of the sieved crushed rock (i.e. within the initial 30 seconds of testing). Surface turbidity then decreased rapidly to approximately 5-6 NTU, 50 seconds after commencement. Over the subsequent 1 hour, turbidity fluctuated and gradually increased to 55-60 NTU. At approximately 1 hour and 30 minutes after commencement, surface turbidity was approximately 65 NTU. The increase in turbidity was consistent with visual observations.

Surface turbidity gradually decreased and was 57 NTU, 3 hours after commencement.

Surface turbidity measured at varying time intervals over the 10-day test duration is plotted in **Graph 3** (refer **Section 2.2.1**) for Test 8A, alongside the results for Tests 8B.

Surface turbidity remained relatively stable between 56 NTU and 63 NTU, between 3 hours and 8.5 hours after commencement.

Surface turbidity decreased to approximately 20 NTU, 24 hours after commencement, before gradually increasing to approximately 49 NTU, 1 day and 22 hours after commencement. Surface turbidity was measured at 5 discrete time intervals between 24 hours and 1 day and 22 hours following commencement with each measurement indicating increasing surface turbidity.

Surface turbidity gradually decreased and fluctuated for the remainder of the test period. Surface turbidity was noted to increase between the following time intervals:

- between 2 days and 8 hours following commencement and 2 days and 22 hours following commencement, surface turbidity increased from 19 NTU to 42.2 NTU; and,
- between 7 days and 23 hours following commencement and 8 days and 23 hours following commencement, surface turbidity increased from 14.2 NTU to 27.3 NTU.

The increase in surface turbidity at the various time intervals was somewhat unexpected and a discussion is provided in **Section 3**. At this point in time, flocculant was added to the column (**Section 2.3**).

By 8 days and 22 hours following commencement, surface turbidity was 27.3 NTU. Surface turbidity decreased to 19 NTU approximately 10 days and 5 hours following commencement.

2.2.3 Test 8B - Placement of dry sieved crushed rock within a fall pipe with opening submerged 50 cm below the water surface

For Test 8B, the sieved crushed rock was gently sprinkled into the fall pipe with an internal diameter of approximately 50 mm. The top of the fall pipe was approximately 75 cm above the water surface. The inside of the fall pipe was rinsed with water from Tantangara Reservoir to ensure that all of the sieved crushed rock entered the column.

Significant mixing and diffusion of crushed rock was observed within the fall pipe. Clumps of crushed rock fell to the bottom of the column within approximately 30 seconds. Fine material parted from the clumps during descent and a turbid trail formed through the water column in the wake of the clumps. It is estimated that approximately 10 to 20% of the mass of placed crushed rock fell to the bottom in clumps.

The dense turbid plume in the fall pipe gradually descended and diffused throughout the water column, primarily below the base of the fall pipe. After approximately 1 minute and 30 seconds, significant mixing was observed in the middle third of the column, below the fall pipe. After 2-3 minutes, elevated turbidity was observed in the lower two thirds of the water column, below the base of the fall pipe.

The top of the turbid plume was recorded at approximately 1.6 cm above the base of the fall pipe, immediately after placement. There was no immediate discernible change in turbidity above the turbid plume, with the upper 48.6 cm of water in the column (i.e. above the base of the fall pipe) remaining relatively clear with turbidity at approximately 2 to 3 NTU, which was the background level (refer **Graph 3**, **Section 2.2.1**).

The top of the turbid plume was clearly distinguishable up to 7 days and 23 hours following commencement. The top of the plume descended to 117.8 cm below the water surface after 7 days and 23 hours, at a rate of 7.9 cm/day.

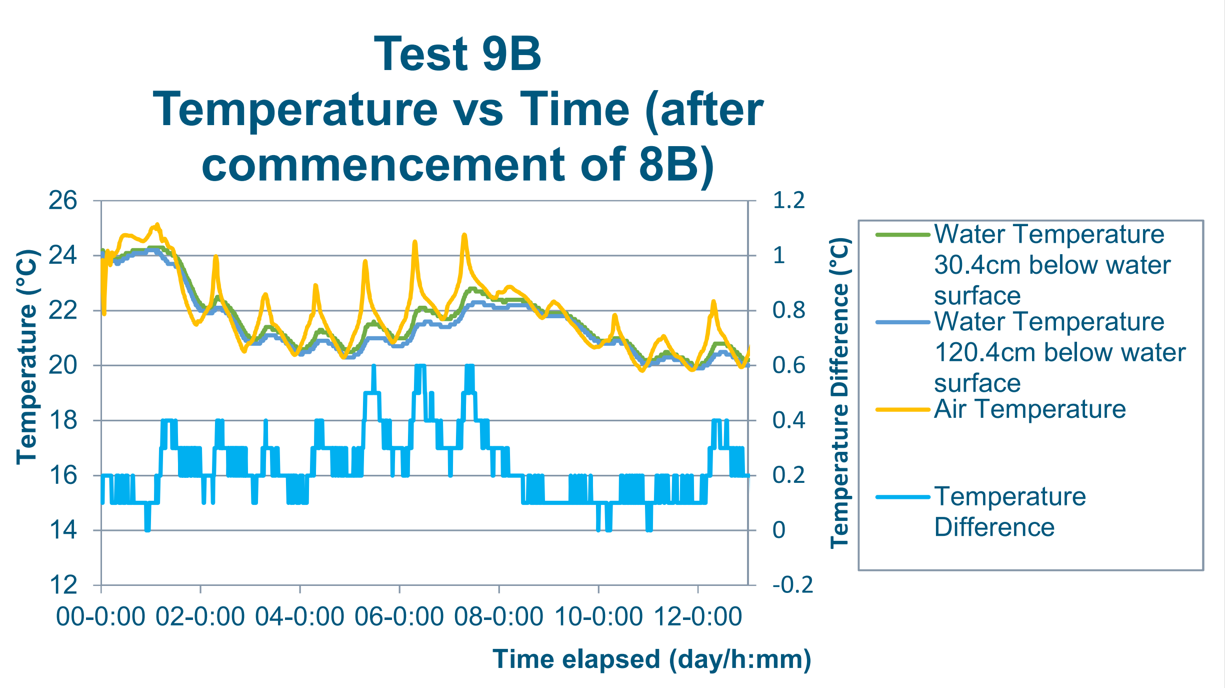
A haze was noticeable above the denser plume (below the base of the fall pipe) approximately 1 day and 22 hours following commencement and remained for the duration of the test. Surface turbidity gradually increased to 5 NTU (from a background of 2.2 NTU), 1 day and 6 hours following commencement before rapidly increasing to 21.1 NTU, 1 day and 22 hours following commencement. Surface turbidity remained relatively constant for the remainder of the test, increasing to 24.3 NTU, 2 days and 22 hours following commencement before gradually declining to 20.5 NTU, 10 days and 5 hours following commencement.

A discussion regarding the observed increase in surface turbidity during Test 8B is provided in **Section 3**.

2.2.4 Air and Water Temperature

Air temperature and water temperature was recorded every 15 minutes in Test 9B for the duration of the test using Solinist Leveloggers and a Barologger. Water temperature was monitored at two depths, 30.4 cm and 120.4 cm below the water surface. Test 9B commenced approximately 1 day, 2 hours and 25 minutes after Test 8A and 8B and approximately 1 day, 3 hours and 15 minutes before Test 8D. Test 9B was undertaken in the same room and within approximately 2 m of Test 8A, 8B and 8D.

Graph 5 provides air and water temperature variation over time for Test 9B. The elapsed time is reported relative to commencement of Test 8A and 8B.



Graph 5: Air and water temperature in Test 9B. Elapsed time relative to commencement of Test 8A and 8B.

Air temperature in Test 9B fluctuated between approximately 19.8 °C and 25.1 °C. Block out curtains were placed across all windows for the duration of the test in an attempt to regulate air temperature within the laboratory.

Water temperature varied between 19.9 °C and 24.3 °C. Water temperature was consistently 0 °C to 0.6 °C warmer at the upper monitoring location and the average temperature differential between the monitoring depths was 0.24 °C. The warmer water near the top of the column would have a lower density and would, therefore, be buoyant compared to the cooler water lower in the column.

2.3 Flocculation Test

Prior to completion of the settlement tests, a trial was undertaken to determine whether a chemical flocculant would accelerate settlement of fine particles and clarify the water. The chemical flocculant selected for the test was alum (aluminium sulphate). It should be noted that the particular chemical flocculant selected for the test was somewhat arbitrary and has not been approved for use during construction.

Flocculant was added to Test 8A on the 16th November 2018 at 3:30pm, approximately 10 days and 5 hours following commencement of the settlement test. Tests 8B and 8D were retained as control columns for comparison.

Surface turbidity in Tests 8A, 8B and 8D on the 16th November 2018 (prior to addition of flocculant) and the 19th November 2018 (following addition of flocculant) is reported in **Table 2**. Surface turbidity in Test 8A decreased from 19 NTU to 1.2 NTU while the turbidity in the control columns, Tests 8B and 8D, remained relatively elevated. This indicates that the chemical flocculant was effective in clarifying the water.

Table 2: Turbidity before and after the addition of flocculant to Test 8A.

Date/Time	Test 8A (NTU)	Test 8B (NTU)	Test 8D (NTU)
16th November 2018, 3:30pm	19	20.4	45
19th November 2018, 2pm	1.2	20.5	21

A photograph of the three Test columns taken on the 16th and 19th November 2018 is provided in **Figure 7**. It should be noted that some of the flocculated crushed rock in Test 8A adhered to the walls of the column thereby making the column appear slightly ‘cloudy’ when viewed side on. However, when viewed from above, the water was clear as indicated by the surface turbidity reading.

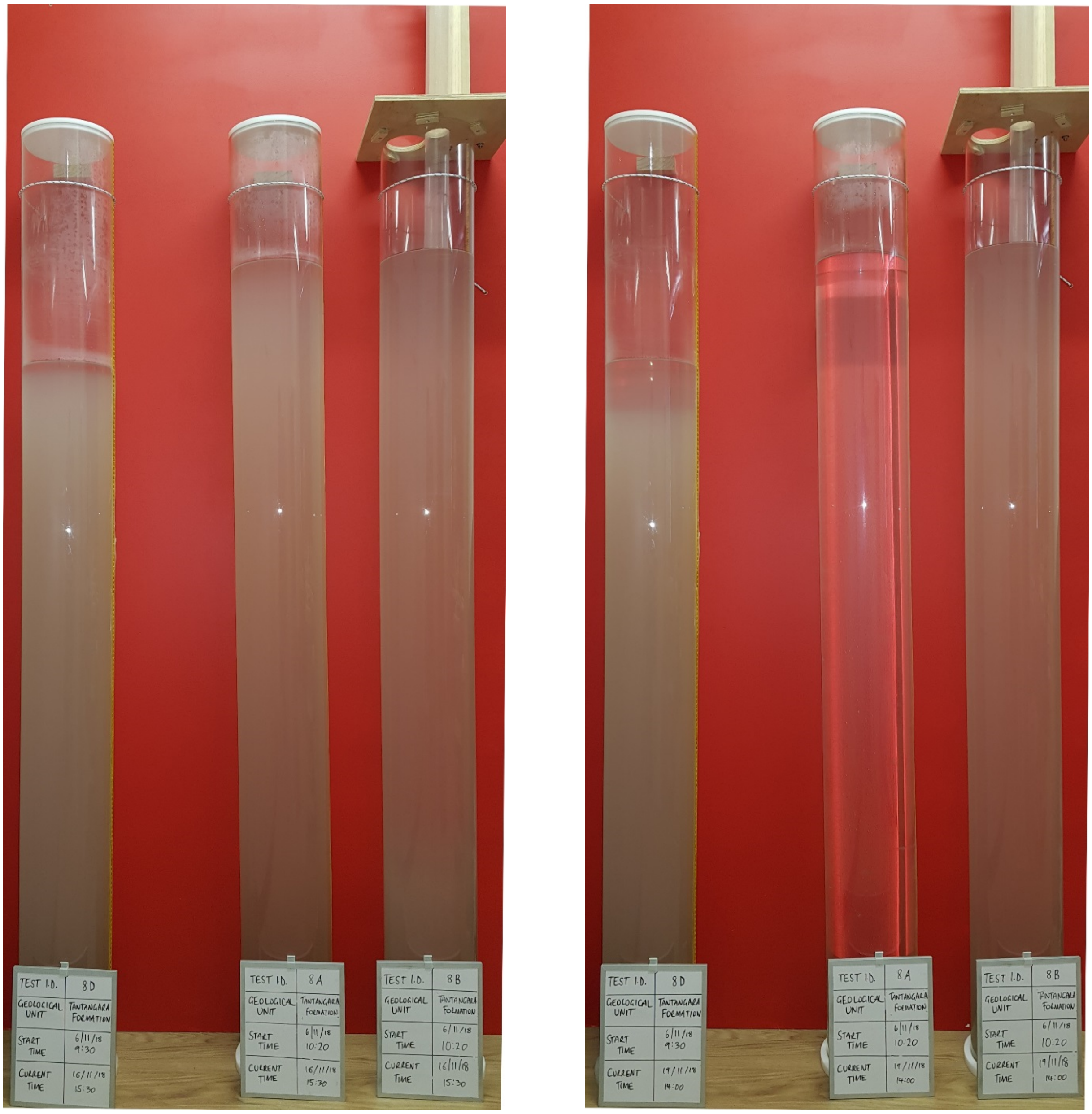
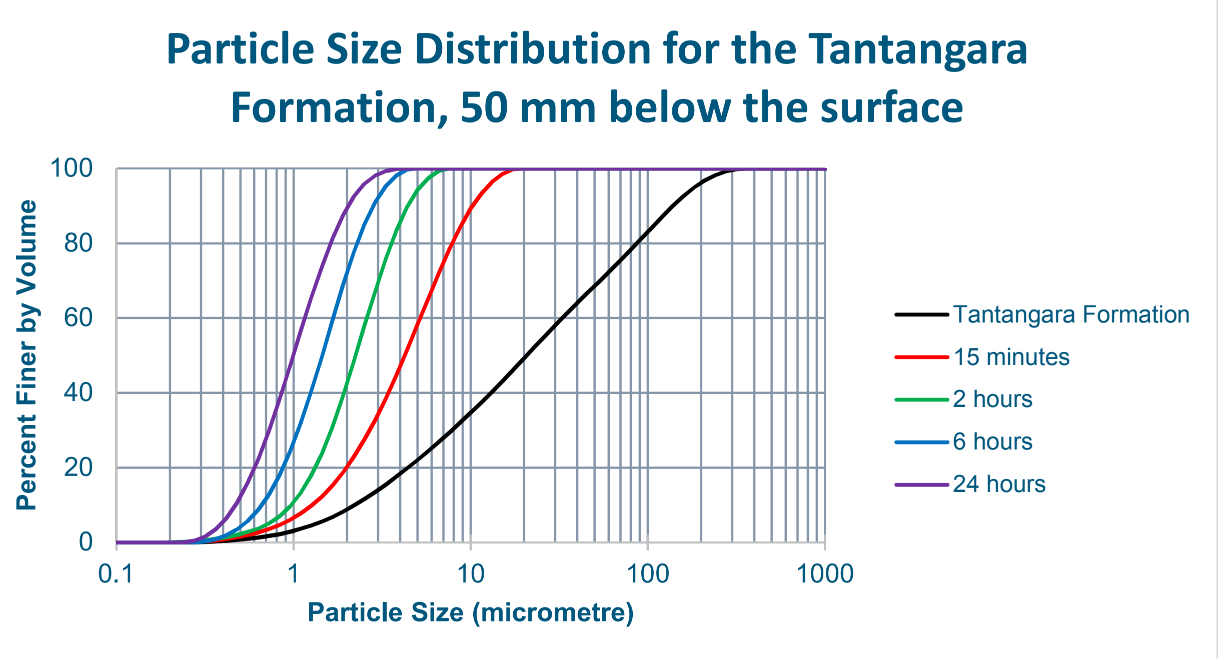


Figure 7: Column and Settlement tests prior to and following addition of chemical flocculant to Test 8A-
Left: Test 8D, 8A and 8B (from left to right) prior to the addition of flocculant to Test 8A. Photographed on the 16th November at 3:30pm, approximately 10 days and 5.2 hours following commencement of the settlement tests.
Right: Test 8D, 8A and 8B (from left to right), following the addition of flocculant to Test 8A. Photographed on the 19th November at 2:00pm, approximately 13 days and 3.7 hours following commencement of the settlement tests.

2.4 Critical Particle Size

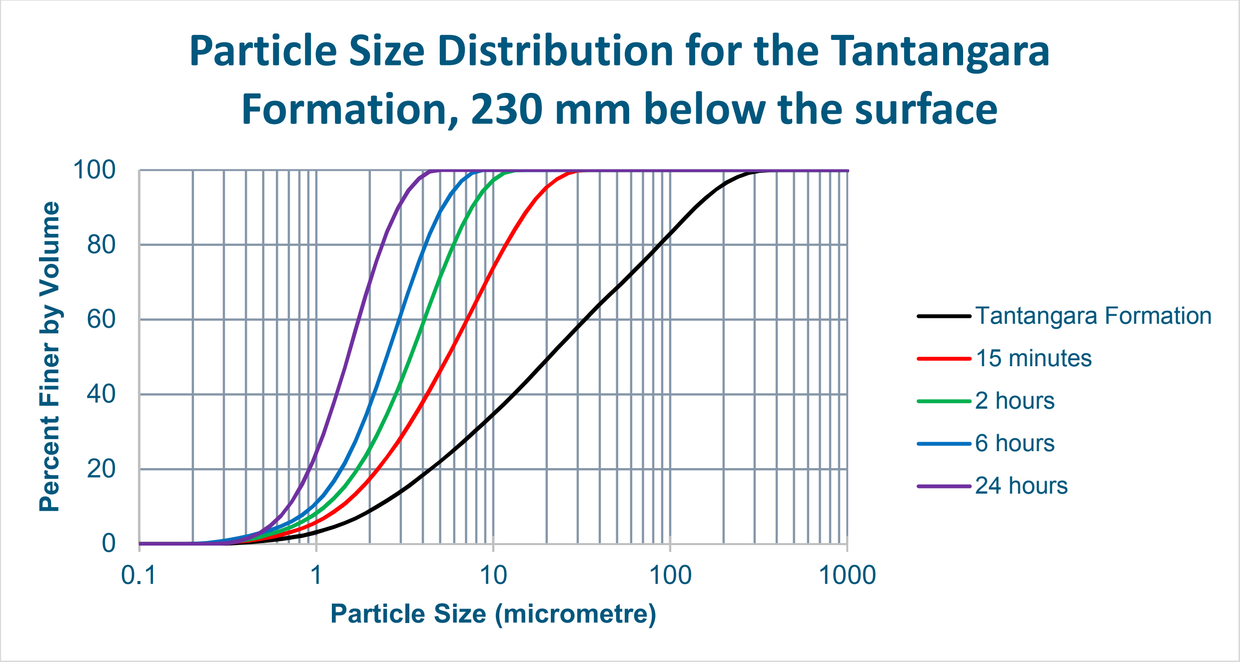
The tests to determine the critical particle size in suspension commenced on the 5th and 6th November 2018. Particle size analysis using the Mastersizer 2000 was completed on the 6th November 2018.

Graph 6 plots the particle size distribution of the sieved crushed rock (used for all tests) and the particle size that remains in suspension after each time interval (15 minutes, 2 hours, 6 hours and 24 hours) at 50 mm below the water surface (850 mL mark on cylinder). The maximum particle size in suspension at various time intervals is outlined in **Table 3**. The maximum particle size in suspension decreases over time from around 17.5 µm (15 minutes) to 4 µm (24 hours).



Graph 6: Particle size distribution at varying time intervals, 50 mm below the water surface.

Graph 7 plots the particle size distribution of the sieved crushed rock (used for all tests) and the particle size that remains in suspension after a given time interval (15 minutes, 2 hours, 6 hours and 24 hours) at 230 mm below the water surface (300 mL mark on cylinder). The maximum particle size in suspension at various time intervals is outlined in **Table 3**. The maximum particle size in suspension decreases over time from around 31 µm (15 minutes) to 4.5 µm (24 hours).



Graph 7: Particle size distribution at varying time intervals 230 mm the water surface.

Table 3: Maximum particle size in suspension at varying time intervals, 50 mm and 230 mm below the water surface.

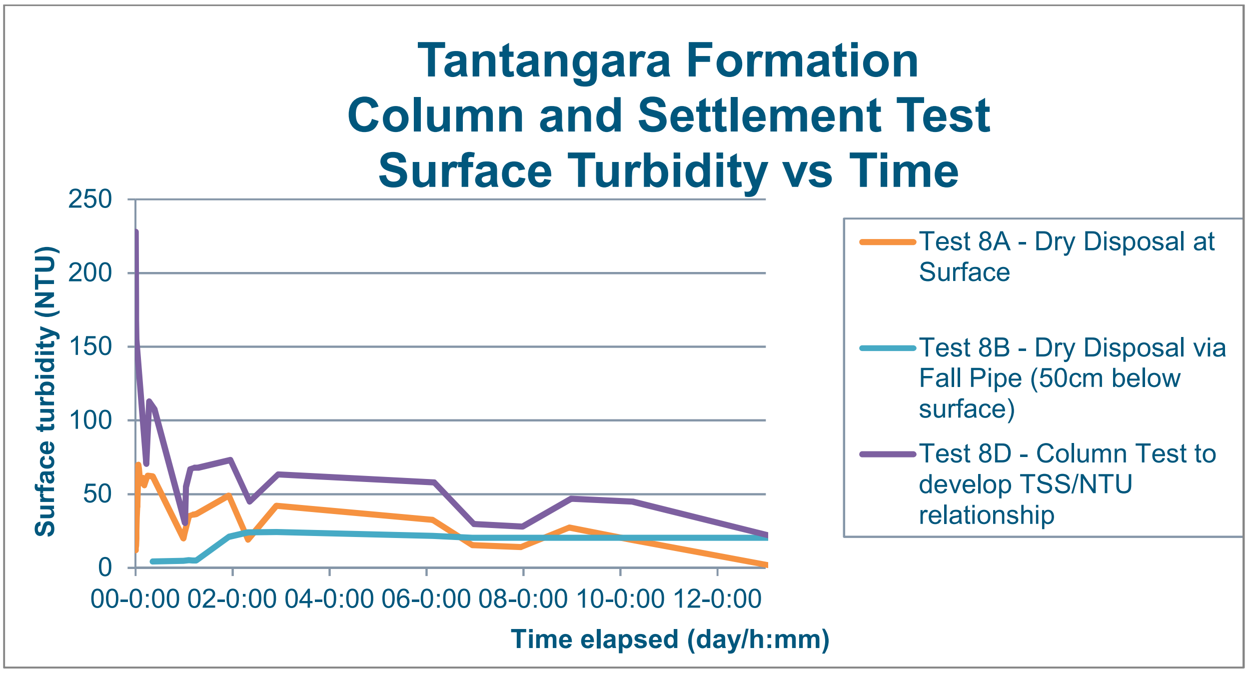
Time	Maximum particle size in suspension (µm)	
	50 mm below the water surface	230 mm below the water surface
15 minutes	17.5	31
2 hours	7	13
6 hours	4.5	8
24 hours	4	4.5

Based on the results presented above, it is evident that, for the same given time intervals, the maximum particle size in suspension is larger at greater depths within the water column, as would be expected.

3 Discussion

3.1 Fluctuating Turbidity and Increase in Surface Turbidity

As described in **Section 2**, surface turbidity in Test 8A and 8D fluctuated and surface turbidity in Test 8B increased during the test duration. The surface turbidity for the three tests is shown in **Graph 8**. The graph includes the addition of flocculant to Test 8A, 10 days and 5 hours following commencement.



Graph 8: Surface turbidity measured during the settlement and column tests – Tantangara Formation (Tests 8A, 8B and 8D).

An increase in surface turbidity was unexpected, with ongoing settlement and decreasing turbidity following initial mixing considered more likely to occur. It is possible that the observations were influenced by one or more of the following factors:

1. Weak thermal convection currents within the column may result in mixing of stratified layers and rising warm water transporting suspended particles to the surface. Air temperature and water temperature was monitored for the duration of the test. The results are reported in **Section 2.2.4** and presented in **Graph 5**.

   It is apparent from **Graph 5** that the water temperature warms and cools in response to the air temperature. Further, the difference in water temperature between the top and bottom of the column increases during a warming phase and decreases during a cooling phase.

   It is inferred that heat is transferred from the air to the column and from the column to the adjacent water near the wall of the column through the process of conduction, which is the transfer of heat between objects in contact with each other, or through a substance due to the collision of molecules. Heating of water near the wall of the column would result in differential water temperature across the column with cooler water near the centre of the column. The differential water temperature would lead to two processes, conduction and convection where convection is the process of warmer water, with a lower density, rising to cooler areas in the column and cooler water, with a higher density, sinking to take the place of the warmer water. The velocity of convection currents are difficult to determine and due to a range of factors.

2. The sieved crushed rock may contain clay particles that are anionic. The repelling force between charged particles in suspension may result in suspended solids diffusing and distributing evenly throughout the water column.

3. The action of gently lowering a turbidity probe into the upper layer of the column (~3.4 cm below the water surface), or extracting samples with a pipette from Test 8D (at 1 day following commencement) may be sufficient to disturb the water column resulting in advection of very fine suspended particles.

Regardless of the reason for fluctuating and increasing surface turbidity in Tests 8A, 8B and 8D, it is clear that minor disturbances to the water column are sufficient to disrupt the settlement process and redistribute fine suspended particles within the water column.

4 Conclusions

It is apparent from the column test and settlement tests that once fine crushed rock from the metamorphic rock in the Tantangara Formation enters the water column, the fine particles remain in suspension for extended periods in the order of several days to weeks. The surface turbidity approximately 10 days after commencement of Tests 8A, 8B and 8D was between 19 NTU and 45 NTU.

Minor disturbances to the water column are likely to disrupt the settlement process and/or re-suspend fine particles.

The critical particle size in suspension that would be contributing to prolonged surface turbidity in the water column (more than 24 hours) would be less than approximately 4.5 µm.

The results of a chemical flocculation test for the Tantangara Formation crushed rock indicate that the addition of flocculant may accelerate settlement of fine particles and clarify the water.

TSS-turbidity data collected during the Column Test (Test 8D) is considered to be reliable for the purpose of establishing a preliminary relationship between TSS and turbidity for the Tantangara Formation. The turbidity value equivalent to 50 mg/L suspended solids is 68 NTU for this dataset. Furthermore, as the properties and grading of the crushed rock placed during construction may vary to that used in the column test, collection of field TSS-turbidity data during subaqueous excavated rock placement activities is recommended so that the relationship between turbidity and suspended solids can be continually validated and improved.

Attachment 1 – Laboratory Certificates

ALS Environmental

CERTIFICATE OF ANALYSIS

Work Order : **ES1833519**
Client : **HASKONING AUSTRALIA- ROYAL HASKONING**
Contact : MR PATRICK LAWLESS
Address : LEVEL 14 56 Berry Street
NORTH SYDNEY 2060
Telephone : ----
Project : SNOWY 2.0 TSS-NTU (Tests 8-9)
Order number :
C-O-C number : ----
Sampler : PATRICK LAWLESS
Site : ----
Quote number : EN/222
No. of samples received : 22
No. of samples analysed : 22

Page : 1 of 7
Laboratory : Environmental Division Sydney
Contact : Customer Services ES
Address : 277-289 Woodpark Road Smithfield NSW Australia 2164
Telephone : +61-2-8784 8555
Date Samples Received : 09-Nov-2018 18:30
Date Analysis Commenced : 10-Nov-2018
Issue Date : 15-Nov-2018 10:46

ilac-MRA NATA
Accreditation No. 825
Accredited for compliance with
ISO/IEC 17025 - Testing

This report supersedes any previous report(s) with this reference. Results apply to the sample(s) as submitted. This document shall not be reproduced, except in full.

This Certificate of Analysis contains the following information:

- General Comments
- Analytical Results

Additional information pertinent to this report will be found in the following separate attachments: Quality Control Report, QA/QC Compliance Assessment to assist with Quality Review and Sample Receipt Notification.

Signatories

This document has been electronically signed by the authorized signatories below. Electronic signing is carried out in compliance with procedures specified in 21 CFR Part 11.

Signatories	*Position*	*Accreditation Category*
Ankit Joshi	Inorganic Chemist	Sydney Inorganics, Smithfield, NSW

General Comments

The analytical procedures used by the Environmental Division have been developed from established internationally recognized procedures such as those published by the USEPA, APHA, AS and NEPM. In house developed procedures are employed in the absence of documented standards or by client request.

Where moisture determination has been performed, results are reported on a dry weight basis.

Where a reported less than (<) result is higher than the LOR, this may be due to primary sample extract/digestate dilution and/or insufficient sample for analysis.

Where the LOR of a reported result differs from standard LOR, this may be due to high moisture content, insufficient sample (reduced weight employed) or matrix interference.

When sampling time information is not provided by the client, sampling dates are shown without a time component. In these instances, the time component has been assumed by the laboratory for processing purposes.

Where a result is required to meet compliance limits the associated uncertainty must be considered. Refer to the ALS Contact for details.

Key :
CAS Number = CAS registry number from database maintained by Chemical Abstracts Services. The Chemical Abstracts Service is a division of the American Chemical Society.
LOR = Limit of reporting
^ = This result is computed from individual analyte detections at or above the level of reporting
ø = ALS is not NATA accredited for these tests.
~ = Indicates an estimated value.

Analytical Results

Sub-Matrix: **WATER** (Matrix: **WATER**)			*Client sample ID*	**8D-1**	**8D-2**	**8D-3**	**8D-4**	**8D-5**
			Client sampling date / time	06-Nov-2018 00:00	06-Nov-2018 00:00	06-Nov-2018 00:00	06-Nov-2018 00:00	06-Nov-2018 00:00
Compound	*CAS Number*	*LOR*	*Unit*	**ES1833519-001**	**ES1833519-002**	**ES1833519-003**	**ES1833519-004**	**ES1833519-005**
				Result	Result	Result	Result	Result
EA025: Total Suspended Solids dried at 104 ± 2°C								
Suspended Solids (SS)	----	5	mg/L	<5	**89**	**296**	**290**	**188**
EA045: Turbidity								
Turbidity	----	0.1	NTU	**0.8**	**81.7**	**189**	**170**	**65.6**

Analytical Results

Sub-Matrix: **WATER**
(Matrix: **WATER)**

			Client sample ID	8D-6	8D-7	8D-8	8D-9	8D-10
			Client sampling date / time	06-Nov-2018 00:00	06-Nov-2018 00:00	06-Nov-2018 00:00	06-Nov-2018 00:00	06-Nov-2018 00:00
Compound	CAS Number	LOR	Unit	**ES1833519-006**	**ES1833519-007**	**ES1833519-008**	**ES1833519-009**	**ES1833519-010**
				Result	Result	Result	Result	Result
EA025: Total Suspended Solids dried at 104 ± 2°C								
Suspended Solids (SS)	----	5	mg/L	**190**	**120**	**120**	**81**	**50**
EA045: Turbidity								
Turbidity	----	0.1	NTU	**163**	**124**	**108**	**94.3**	**79.3**

Analytical Results

Sub-Matrix: **WATER** (Matrix: **WATER**)			*Client sample ID*	**8D-11**	**8D-12**	**8D-13**	**8D-14**	**8D-15**
			Client sampling date / time	06-Nov-2018 00:00	06-Nov-2018 00:00	07-Nov-2018 00:00	07-Nov-2018 00:00	07-Nov-2018 00:00
Compound	*CAS Number*	*LOR*	*Unit*	**ES1833519-011**	**ES1833519-012**	**ES1833519-013**	**ES1833519-014**	**ES1833519-015**
				Result	Result	Result	Result	Result
EA025: Total Suspended Solids dried at 104 ± 2°C								
Suspended Solids (SS)	----	5	mg/L	**102**	**120**	**8**	**50**	**72**
EA045: Turbidity								
Turbidity	----	0.1	NTU	**118**	**111**	**31.2**	**67.7**	**83.1**

Analytical Results

Sub-Matrix: **WATER** (Matrix: **WATER**)			*Client sample ID*	**8D-16**	**8D-17**	**8D-18**	**8D-19**	**8D-20**
			Client sampling date / time	07-Nov-2018 00:00	07-Nov-2018 00:00	07-Nov-2018 00:00	07-Nov-2018 00:00	08-Nov-2018 00:00
Compound	*CAS Number*	*LOR*	*Unit*	**ES1833519-016**	**ES1833519-017**	**ES1833519-018**	**ES1833519-019**	**ES1833519-020**
				Result	Result	Result	Result	Result
EA025: Total Suspended Solids dried at 104 ± 2°C								
Suspended Solids (SS)	----	5	mg/L	**34**	**48**	**48**	**56**	**64**
EA045: Turbidity								
Turbidity	----	0.1	NTU	**62.0**	**69.6**	**73.8**	**69.7**	**61.3**

Analytical Results

Sub-Matrix: **WATER**
(Matrix: **WATER)**

			Client sample ID	**8D-21**	**8D-22**	**----**	**----**	**----**
			Client sampling date / time	08-Nov-2018 00:00	09-Nov-2018 00:00	----	----	----
Compound	*CAS Number*	*LOR*	*Unit*	**ES1833519-021**	**ES1833519-022**	**--------**	**--------**	**--------**
				Result	Result	----	----	----
EA025: Total Suspended Solids dried at 104 ± 2°C								
Suspended Solids (SS)	----	5	mg/L	**18**	**36**	**----**	**----**	**----**
EA045: Turbidity								
Turbidity	----	0.1	NTU	**20.2**	**35.0**	**----**	**----**	**----**

ALS Environmental

CERTIFICATE OF ANALYSIS

Work Order	: **ES1834368**	Page	: 1 of 4
Client	: **HASKONING AUSTRALIA- ROYAL HASKONING**	Laboratory	: Environmental Division Sydney
Contact	: MR PATRICK LAWLESS	Contact	: Customer Services ES
Address	: LEVEL 14 56 Berry Street NORTH SYDNEY 2060	Address	: 277-289 Woodpark Road Smithfield NSW Australia 2164
Telephone	: +61 02 8854 5000	Telephone	: +61-2-8784 8555
Project	: Snowy 2.0 Test 839 PA 1904	Date Samples Received	: 16-Nov-2018 16:25
Order number	:	Date Analysis Commenced	: 17-Nov-2018
C-O-C number	: ----	Issue Date	: 22-Nov-2018 11:17
Sampler	: ----		
Site	: ----		
Quote number	: EN/222		
No. of samples received	: 10		
No. of samples analysed	: 10		

NATA

Accreditation No. 825
Accredited for compliance with
ISO/IEC 17025 - Testing

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Signatories

This document has been electronically signed by the authorized signatories below. Electronic signing is carried out in compliance with procedures specified in 21 CFR Part 11.

Signatories	*Position*	*Accreditation Category*
Ankit Joshi	Inorganic Chemist	Sydney Inorganics, Smithfield, NSW

General Comments

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Key : CAS Number = CAS registry number from database maintained by Chemical Abstracts Services. The Chemical Abstracts Service is a division of the American Chemical Society.
LOR = Limit of reporting
^ = This result is computed from individual analyte detections at or above the level of reporting
ø = ALS is not NATA accredited for these tests.
~ = Indicates an estimated value.

Analytical Results

Sub-Matrix: **WATER**
(Matrix: **WATER)**

			Client sample ID	8D-23	8D-24	8D-25	8D-26	8D-27
			Client sampling date / time	12-Nov-2018 00:00	13-Nov-2018 00:00	14-Nov-2018 00:00	15-Nov-2018 00:00	16-Nov-2018 00:00
Compound	CAS Number	LOR	Unit	ES1834368-001	ES1834368-002	ES1834368-003	ES1834368-004	ES1834368-005
				Result	Result	Result	Result	Result
EA025: Total Suspended Solids dried at 104 ± 2°C								
Suspended Solids (SS)	----	5	mg/L	**57**	**21**	**14**	**26**	**15**
EA045: Turbidity								
Turbidity	----	0.1	NTU	**51.6**	**28.7**	**37.0**	**48.9**	**44.3**

Analytical Results

Sub-Matrix: **WATER** (Matrix: **WATER**)			*Client sample ID*	**9D-19**	**9D-20**	**9D-21**	**9D-22**	**9D-23**
			Client sampling date / time	12-Nov-2018 00:00	13-Nov-2018 00:00	14-Nov-2018 00:00	15-Nov-2018 00:00	16-Nov-2018 00:00
Compound	*CAS Number*	*LOR*	*Unit*	**ES1834368-006**	**ES1834368-007**	**ES1834368-008**	**ES1834368-009**	**ES1834368-010**
				Result	Result	Result	Result	Result
EA025: Total Suspended Solids dried at 104 ± 2°C								
Suspended Solids (SS)	----	5	mg/L	**38**	**15**	<5	**18**	**17**
EA045: Turbidity								
Turbidity	----	0.1	NTU	**48.5**	**19.8**	**25.9**	**41.7**	**34.8**

Attachment 2 – Tantangara Formation Laboratory Log Records

Test ID	8A	
Geological Unit	Tantangara Formation	
Description	Test 8A - Dry Disposal at Surface	
Start Date/Time	06-11-18 10:20	
Water volume	50 L	
Water surface level in column	172.8	cm
Mass sediment added	40 g	(sieved to <250 um)
Test Location	Geochemical Assessments Workshop, Roseville NSW	
Test Officers	Pat Lawless, Rick Plain	

Observations

Date/Time	Time since start	Turbidity (NTU)	Measurement Location (cm)	Measurement Depth (cm)	Comments
06-11-18 9:15	70 Minutes Prior	2.6	169.4	3.4	
06-11-18 10:23	00-0:03	12	169.4	3.4	Turbid below ~166 cm. Top of the column very clear.
06-11-18 10:27	00-0:07	15	169.4	3.4	
06-11-18 10:34	00-0:14	15	169.4	3.4	Turbidity below 163.4 cm. Top of column clear.
06-11-18 10:41	00-0:21	20	169.4	3.4	Stratification at 160.5 cm. Not as distinct.
06-11-18 10:45	00-0:25	25	169.4	3.4	
06-11-18 10:55	00-0:35	34	169.4	3.4	
06-11-18 11:08	00-0:48	43	169.4	3.4	
06-11-18 11:13	00-0:53	42	169.4	3.4	Increased to 51 NTU and dropped to 42 NTU by 11:13 a.m.
06-11-18 11:35	00-1:15	59	169.4	3.4	
06-11-18 11:38	00-1:18	70	169.4	3.4	
06-11-18 11:59	00-1:39	67	169.4	3.4	
06-11-18 12:33	00-2:13	57.3	169.4	3.4	
06-11-18 13:23	00-3:03	57.7	169.4	3.4	
06-11-18 14:05	00-3:45	61	169.4	3.4	
06-11-18 14:45	00-4:25	56	169.4	3.4	
06-11-18 16:15	00-5:55	62.5	169.4	3.4	
06-11-18 18:45	00-8:25	62	169.4	3.4	
07-11-18 10:00	00-23:40	20	169.4	3.4	Stratification at 169 cm.
07-11-18 10:30	01-0:10	23	169.4	3.4	
07-11-18 12:40	01-2:20	35.2	169.4	3.4	
07-11-18 14:34	01-4:14	36	169.4	3.4	
07-11-18 16:20	01-6:00	36.4	169.4	3.4	
08-11-18 8:30	01-22:10	49	169.4	3.4	
08-11-18 18:00	02-7:40	19	169.4	3.4	Gradual change to approximately 167 cm.
09-11-18 8:00	02-21:40	42.2	169.4	3.4	
12-11-18 13:20	06-3:00	32.6	169.4	3.4	
13-11-18 9:00	06-22:40	15.3	169.4	3.4	Stratification at 167 cm.
14-11-18 9:00	07-22:40	14.2	169.4	3.4	Stratification at 163 cm.
15-11-18 9:00	08-22:40	27.3	169.4	3.4	Lid left off from previous day.
16-11-18 15:30	10-5:10	19	169.4	3.4	**Flocculant added.**
19-11-18 14:00	13-3:40	1.2	169.4	3.4	

Test ID	8B	
Geological Unit	Tantangara Formation	
Description	Test 8B - Dry Disposal via Fall Pipe (50cm below surface)	
Start Date/Time	06-11-18 10:20	
Water volume	50 L	
Water surface level in column	173.8	cm
Mass sediment added	40 g	(sieved to <250 um)
Test Location	Geochemical Assessments Workshop, Roseville NSW	
Test Officers	Pat Lawless, Rick Plain	

Observations

Date/Time	Time since start	Turbidity (NTU)	Measurement Location (cm)	Measurement Depth (cm)	Comments
06-11-18 9:50	10 minutes prior	2.2	170.4	3.4	Background turbidity measured 10 minutes before test start.
06-11-18 10:25	00-0:05				Turbid plume at 125.4 cm.
06-11-18 10:42	00-0:22				Turbid plume at 125 cm.
06-11-18 14:42	00-4:22				Turbid plume at 123 cm.
06-11-18 18:45	00-8:25	4.3	170.4	3.4	Turbid plume at 123.5 cm.
07-11-18 10:00	00-23:40	4.7	170.4	3.4	Turbid plume at 123 cm.
07-11-18 12:40	01-2:20	5.3	170.4	3.4	Turbid plume at 122.4 cm.
07-11-18 14:35	01-4:15	4.97	170.4	3.4	Turbid plume at 122.4 cm.
07-11-18 16:20	01-6:00	5	170.4	3.4	Turbid plume at 122.9 cm.
08-11-18 8:30	01-22:10	21.1	170.4	3.4	Turbid plume at 82 cm. Noticable haze above.
08-11-18 18:00	02-7:40	24	170.4	3.4	Turbid plume at 95 cm. Noticable haze above.
09-11-18 8:00	02-21:40	24.3	170.4	3.4	Turbid plume at 94 cm. Noticable haze above.
12-11-18 13:20	06-3:00	21.7	170.4	3.4	Turbid plume at 70.5 cm. Noticable haze above.
13-11-18 9:00	06-22:40	20.5	170.4	3.4	Turbid plume at 61 cm. Noticable haze above.
14-11-18 9:00	07-22:40	20.4	170.4	3.4	Turbid plume at 56 cm. Noticable haze above.
15-11-18 9:00	08-22:40	20.4	170.4	3.4	
16-11-18 15:30	10-5:10	20.4	170.4	3.4	
19-11-18 14:00	13-3:40	20.5	170.4	3.4	

Test ID	8D	
Geological Unit	Tantangara Formation	
Description	Test 8D - Column Test to develop TSS/NTU relationship	
Start Date/Time	06-11-18 9:30	
Water volume	50 L	
Water surface level in column	172.8	cm
Mass sediment added	47.5 g	(sieved to <250 um)
Test Location	Geochemical Assessments Workshop, Roseville NSW	
Test Officers	Pat Lawless, Rick Plain	

Observations

Date/Time	Time since start	Turbidity (NTU)		TSS Sample Taken?	TSS Sample ID	Column Measurements			Comments
		Inside Column	Inside Beaker			Water Surface	Measurement Location	Sensor Depth	
06-11-18 8:50	10 minutes prior	2	1.1	Yes	8D-1	172.8	169.4	3.4	Before commencement
06-11-18 9:35	00-0:05	228	210	Yes	8D-2	172	168.6	3.4	Column reading range 180-240 NTU. Beaker reading range 200-220 NTU.
06-11-18 9:40	00-0:10	180	192	Yes	8D-3	171	167.6	3.4	
06-11-18 9:43	00-0:13	170	160	Yes	8D-4	170.3	166.9	3.4	Beaker reading range 150-180 NTU.
06-11-18 9:47	00-0:17	168	165	Yes	8D-5	169.5	166.1	3.4	Beaker reading range 150-180 NTU.
06-11-18 9:53	00-0:23	155	165	Yes	8D-6	168.6	165.2	3.4	Beaker reading range 150-180 NTU.
06-11-18 10:46	00-1:16		130	Yes	8D-7	167.9	164.5	3.4	No column reading. Probe in Test 8A. Beaker reading range 120-150 NTU.
06-11-18 11:40	00-2:10		110	Yes	8D-8	167	163.6	3.4	No column reading. Probe in Test 8A. Beaker reading range 106-120 NTU.
06-11-18 12:40	00-3:10		87	Yes	8D-9	166.2	162.8	3.4	No column reading. Probe in Test 8A. Beaker reading range 84-99 NTU.
06-11-18 14:50	00-5:20	70.5	73	Yes	8D-10	165.5	162.1	3.4	
06-11-18 16:15	00-6:45	113	105	Yes	8D-11	164.8	161.4	3.4	
06-11-18 18:45	00-9:15	108	106	Yes	8D-12	164.4	161	3.4	
07-11-18 10:00	01-0:30	30.4	28.7	Yes	8D-13	163.3	159.9	3.4	Stratification 160.5 cm.
07-11-18 10:10	01-0:40		65.5	Yes	8D-14	163.3	159.9	3.4	Sample extracted via pipette from 153 cm.
07-11-18 10:20	01-0:50		92	Yes	8D-15	162.3	158.9	3.4	Sample extracted via pipette from 141 cm.
07-11-18 10:25	01-0:55	55	56	Yes	8D-16	161.3	157.9	3.4	
07-11-18 12:40	01-3:10	67	72	Yes	8D-17	160.3	156.9	3.4	Beaker reading range 65-75 NTU.
07-11-18 14:31	01-5:01	68	69	Yes	8D-18	159.6	156.2	3.4	
07-11-18 16:25	01-6:55	68	69	Yes	8D-19	158.7	155.3	3.4	Beaker reading range 64-74 NTU.
08-11-18 8:30	01-23:00	73.2	80	Yes	8D-20	158	154.6	3.4	Beaker reading range 64-75 NTU.
08-11-18 18:00	02-8:30	45	37.1	Yes	8D-21	157.2	153.8	3.4	Minor stratification at 154.5 cm.
09-11-18 8:00	02-22:30	63.3	65.5	Yes	8D-22	156.4	153	3.4	
12-11-18 13:20	06-3:50	58	57	Yes	8D-23	155.1	151.7	3.4	
13-11-18 9:00	06-23:30	29.8	26.2	Yes	8D-24	154	150.6	3.4	Stratification at 153 cm.
14-11-18 9:00	07-23:30	28	31.1	Yes	8D-25	153.3	149.9	3.4	Stratification at 148.5 cm.
15-11-18 9:00	08-23:30	47	47	Yes	8D-26	152.4	149	3.4	Minor Stratification at 142 cm. Lid left off from previous day.
16-11-18 15:30	10-6:00	45	39.2	Yes	8D-27	151.5	148.1	3.4	Top 0.5 cm clear.
19-11-18 14:00	13-4:30	21	19.6	Yes	8D-28	150.8	147.4	3.4	Stratification at 142 cm.

Appendix I

TSS – Turbidity and Settling Test Results
Temperance Formation Geological Zone

Table of Contents

Attachment 1 – Laboratory Certificates

Attachment 2 – Temperance Formation Laboratory Log Record

1 Introduction

The Temperance Formation comprises deep marine volcaniclastic deposits including basaltic tuff, chert, and feldspathic arenite. A 1-m long section of core from this geological zone was supplied to Royal HaskoningDHV (Haskoning) from BH3102 taken between 285 m and 286 m below the ground surface. The rock core was logged as interbedded metasiltstone and metasandstone, a metamorphic rock.

Water for laboratory testing was obtained from Talbingo Reservoir on the 2nd October 2018. The water was collected in 1000 L Intermediate Bulk Containers (IBC) and delivered to Haskoning on the 5th October 2018. The turbidity of the reservoir water sample used for the testing was between 1.6 and 2.4 NTU. This is within the turbidity range of field monitoring, undertaken by Cardno in 2018, which indicated typical 'background' turbidity of 1 to 5 NTU in Talbingo Reservoir.

2 Results

2.1 Test 9D – TSS-Turbidity

2.1.1 Overview

The TSS-Turbidity Test for the Temperance Formation ('Test 9D') commenced on 7th November 2018 at 11:20am and was concluded on the 19th November 2018, approximately 12 days following commencement.

The Certificate of Analysis provided by ALS Environmental for the TSS and turbidity analyses undertaken for samples collected during testing is provided in **Attachment 1**. Laboratory log records completed during the TSS-turbidity test are provided in **Attachment 2**, which includes turbidity measurements undertaken during testing for each sample.

Photographs taken during the column test are provided in **Figure 1**. These photographs were taken:

- prior to commencement;
- 2 hours and 25 minutes after commencement;
- 1 day and 20.7 hours after commencement;
- 5 days and 21.7 hours after commencement; and
- 12 days and 2.7 hours after commencement.

Figure 1: Column test –

1. *Talbingo Reservoir water 20 minutes prior to addition of the sieved crushed rock,*
2. *Column test 2 hours and 25 minutes after commencement,*
3. *Column test 1 day and 20.7 hours after commencement,*
4. *Column test 5 days and 21.7 hours after commencement, and*
5. *Column test 12 days and 2.7 hours after commencement.*

2.1.2 Surface Turbidity vs Time Results

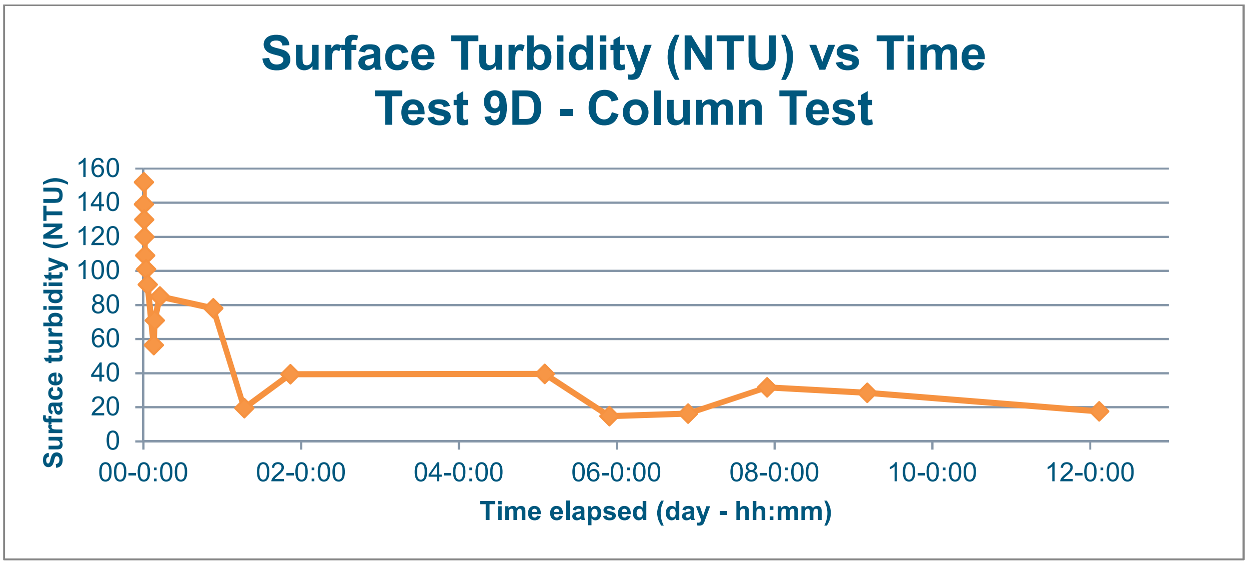
The variation in surface turbidity during Test 9D is plotted in **Graph 1**. It is evident that surface turbidity decreased relatively rapidly from 163 NTU to 101 NTU, 45 minutes after commencement of the test and 57 NTU, 3 hours following commencement of the test. At this point in time, a pipette was used to extract a sample, with a higher turbidity[1], from approximately 10 cm below the water surface. The pipette was gently placed in the water to minimise disturbance to the water column. However, a surface sample was obtained following extraction of the sub-surface sample via a pipette and the surface turbidity had increased from 56.5 NTU to 71 NTU.

Surface turbidity continued to increase to 85 NTU, 5 hours after commencement. Surface turbidity fluctuated and gradually declined for the remainder of the test. Surface turbidity was noted to increase during the following time intervals:

- between 1 days and 6 hours following commencement and 1 day and 21 hours following commencement, surface turbidity increased from 19.5 NTU to 39.5 NTU; and,
- between 6 days and 22 hours following commencement and 7 days and 22 hours following commencement, surface turbidity increased from 16.3 NTU to 31.7 NTU.

Surface turbidity was 28.5 NTU, 9 days and 4 hours following commencement and 17.6 NTU, 12 days and 3 hours following commencement.

The increase in surface turbidity at the various time intervals is somewhat unexpected and a discussion is provided in **Section 3**.



Graph 1: Surface turbidity measured during the column test – Temperance Formation (Test 9D).

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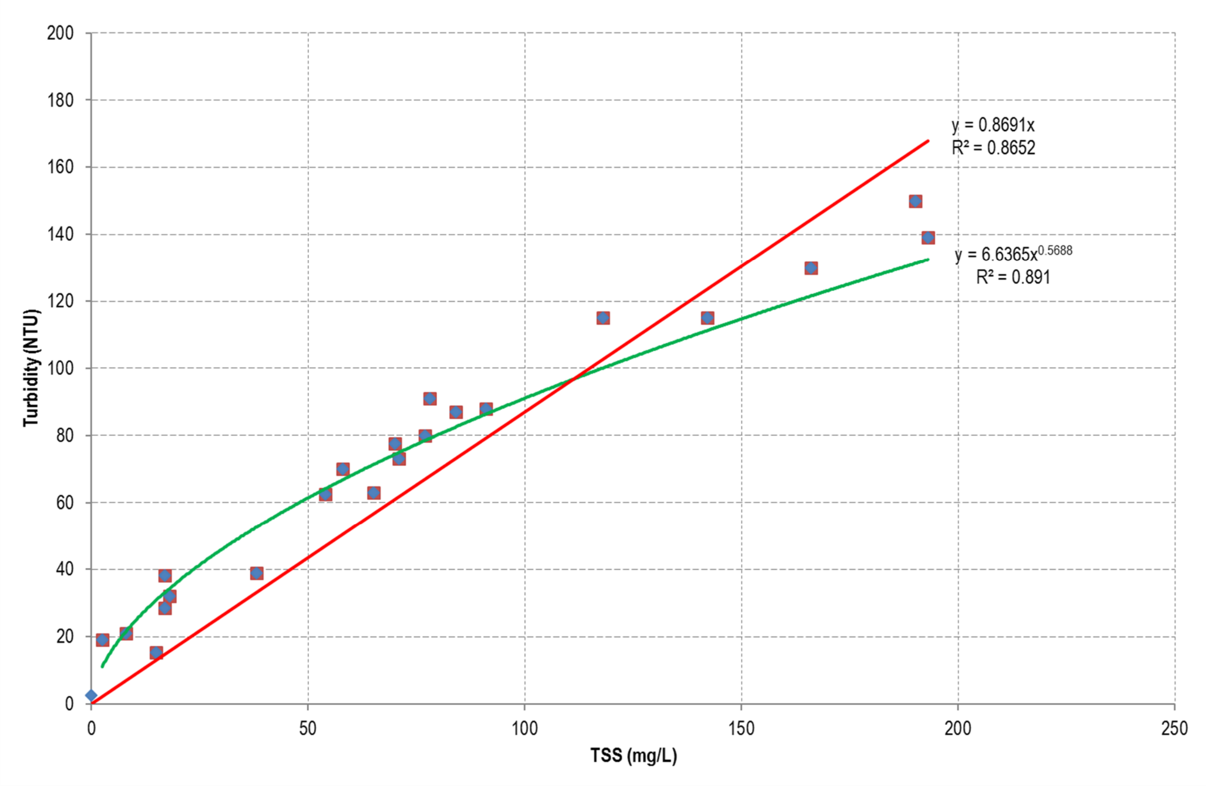
[1] It was necessary to collect water samples covering a wide range of TSS and turbidity values to ensure that a robust TSS-turbidity dataset could be established for the purposes of defining a meaningful relationship between turbidity and suspended solids.

2.1.3 TSS – Turbidity Results

A total of 22 samples were collected during testing for laboratory TSS and turbidity analysis. TSS values for the collected samples ranged between <5 mg/L[2] and 193 mg/L, while turbidity values of up to around 150 NTU were recorded.

A plot of TSS versus turbidity for all data collected during testing is provided in **Graph 2**. Turbidity values used in this dataset are the measurements taken during testing (inside the glass beaker prior to sub-sampling) rather than the laboratory results[3]. This dataset is plotted with trendlines corresponding to both linear and power functions. It is evident that the power function provides a closer fit of the data, characterised by an R^2 value of 0.89[4] whereas the linear line of best fit has a lower R^2 value of 0.87.



Graph 2: TSS-turbidity results – Temperance Formation crushed rock (Test 9D)

2.1.4 TSS – Turbidity Relationship

A summary of the TSS-turbidity relationships determined for the Test 9D dataset is provided in **Table 1**, including the turbidity values equivalent to a TSS concentration of 50 mg/L for each the linear and power function trendline. The selected TSS value of 50 mg/L is somewhat arbitrary and the water quality limit for the project may vary.

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[2] The Limit of Reporting (LOR) value for TSS analysis is 5 mg/L, refer **Attachment 1**. Results for samples with TSS concentrations below the LOR value are reported as <5 mg/L.

[3] Turbidity results reported by the laboratory were compared with turbidity results obtained during testing using the Wetlab-ECO-NTU sensor. No significant differences between the turbidity datasets were evident (i.e. selection of the turbidity dataset does not significantly influence the TSS-turbidity relationship reported herein).

[4] The R^2 value, also known as the coefficient of determination, is a measure of how close the plotted data are to the fitted regression line (i.e. the line of best fit). An R^2 value of 1 indicates that the regression line perfectly fits the data.

Table 1: Summary of TSS-turbidity relationships for Temperance Formation crushed rock type

Trendline Function	Number of values	R^2 value	Turbidity (NTU) equivalent to 50 mg/L TSS
Linear	22	0.87	43
Power	22	0.89	61

As noted above, the power function trendline provides a slightly better fit of the dataset compared to the linear trendline. Furthermore, the high R^2 value associated with the power function trendline (0.89) indicates a reasonably strong correlation between TSS and turbidity for the dataset, and is considered to be valid for the data collected during testing. The turbidity value equivalent to 50 mg/L suspended solids is 61 NTU for this dataset.

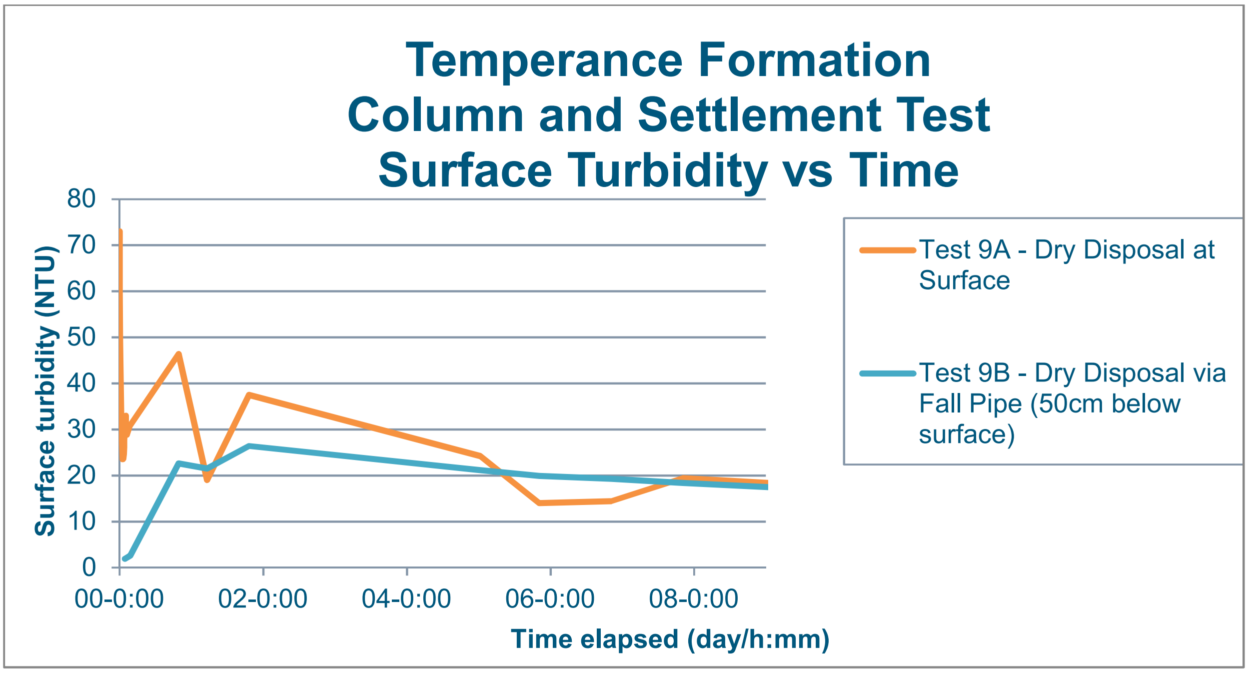
2.2 Settlement Tests

2.2.1 Overview

The two settlement tests for the Temperance Formation (Tests 9A and 9B) commenced simultaneously on 7th November 2018 at 12:45am. Different disposal methods were simulated in the respective columns as described in **Sections 2.2.2** to **2.2.4**. The tests concluded on the 16th November 2018, approximately 9 days following commencement.

Surface turbidity in the two columns was measured 1 day prior to addition of the sieved crushed rock, with values of 1.6 NTU and 2.4 NTU recorded for Tests 9A and 9B respectively.

Surface turbidity measured at varying time intervals during the 9-day test duration is plotted in **Graph 3** for the two settlement tests. These results are discussed in the following sections, along with a summary of the key observations for each settlement test. Laboratory log records completed during the settlement tests are provided in **Attachment 2**.



Graph 3: Surface turbidity measured during the settlement tests – Temperance Formation crushed rock (Tests 9A and 9B).

Photographs taken during the settlement tests are provided in **Figures 2** to **6**. These photographs were taken prior to commencement (**Figure 2**), 2 hours and 57 minutes after commencement (**Figure 3**), 1 day and 19.25 hours after commencement (**Figure 4**), 5 days and 20.25 hours after commencement (**Figure 5**), and 9 days and 2.75 hours after commencement (**Figure 6**).

Figure 2: Settlement test prior to placement of sieved crushed rock-
Left: Test 9A - Placement of dry sieved crushed rock directly onto the water surface,
Right: Test 9B - Placement of dry sieved crushed rock within a fall pipe with opening submerged 50 cm below the water surface.

Figure 3: Settlement test 2 hours and 57 minutes following placement of sieved crushed rock-
Left: Test 9A - Placement of dry sieved crushed rock directly onto the water surface,
Right: Test 9B - Placement of dry sieved crushed rock within a fall pipe with opening submerged 50 cm below the water surface.

TEST I.D.	9 A
GEOLOGICAL UNIT	TEMPERANCE FORMATION
START TIME	7/11/18 12:45
CURRENT TIME	9/11/18 8:00

TEST I.D.	9B
GEOLOGICAL UNIT	TEMPERANCE FORMATION
START TIME	7/11/18 12:45
CURRENT TIME	9/11/18 8:00

Figure 4: Settlement test 1 day and 19.25 hours following placement of sieved crushed rock-
Left: Test 9A - Placement of dry sieved crushed rock directly onto the water surface,
Right: Test 9B - Placement of dry sieved crushed rock within a fall pipe with opening submerged 50 cm below the water surface.

TEST I.D.	9 A
GEOLOGICAL UNIT	TEMPERANCE FORMATION
START TIME	7/11/18 12:45
CURRENT TIME	13/11/18 9:00

TEST I.D.	9B
GEOLOGICAL UNIT	TEMPERANCE FORMATION
START TIME	7/11/18 12:45
CURRENT TIME	13/11/18 9:00

Figure 5: Settlement test 5 days and 20.25 hours following placement of sieved crushed rock-
Left: Test 9A - Placement of dry sieved crushed rock directly onto the water surface,
Right: Test 9B - Placement of dry sieved crushed rock within a fall pipe with opening submerged 50 cm below the water surface.

TEST I.D.	9A
GEOLOGICAL UNIT	TEMPERANCE FORMATION
START TIME	7/11/18 12:45
CURRENT TIME	16/11/18 15:30

TEST I.D.	9B
GEOLOGICAL UNIT	TEMPERANCE FORMATION
START TIME	7/11/18 12:45
CURRENT TIME	16/11/18 15:30

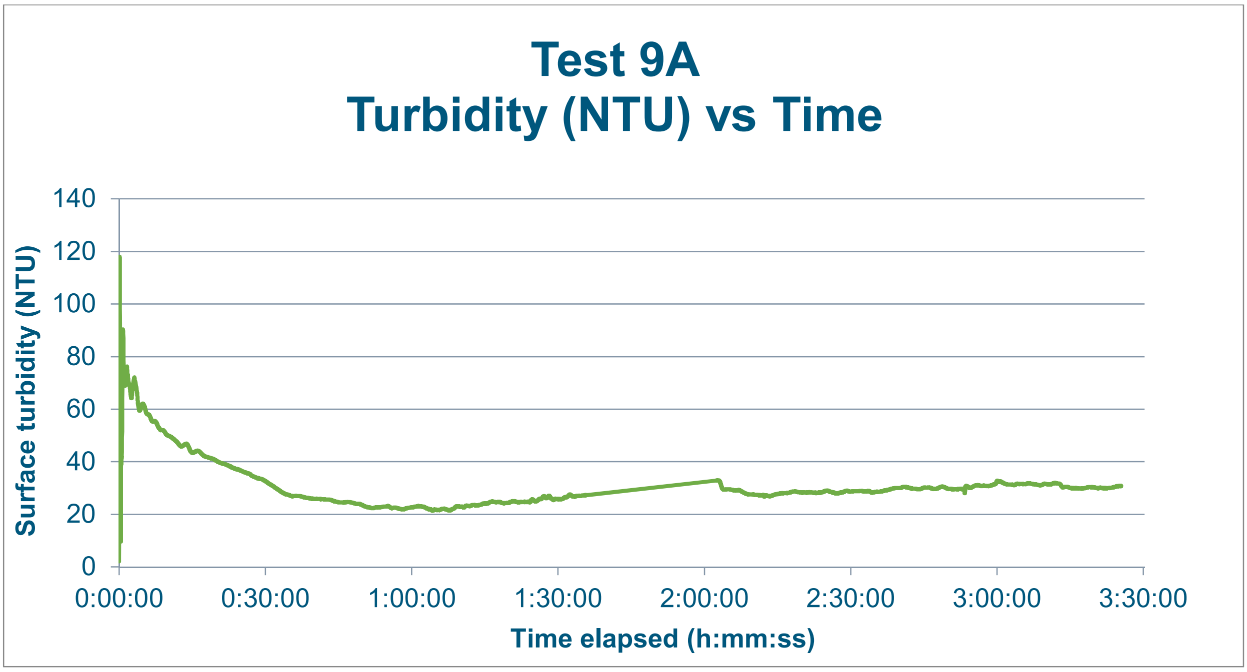
Figure 6: Settlement test 9 days and 2.75 hours following placement of sieved crushed rock-
Left: Test 9A - Placement of dry sieved crushed rock directly onto the water surface,
Right: Test 9B - Placement of dry sieved crushed rock within a fall pipe with opening submerged 50 cm below the water surface.

2.2.2 Test 9A - Placement of dry sieved crushed rock directly onto the water surface

For Test 9A, the sieved crushed rock was gently sprinkled onto the water surface from a height of approximately 25 cm above the water surface. Clumps of crushed rock fell through the upper portion of the column. However, fine material parted from the clumps during descent and a turbid trail formed through the water column in the wake of the clumps. The clumps generally dissipated before descending to the bottom of the column.

Mixing and diffusion of crushed rock was observed in the upper third to half of the column after approximately 1 minute. After approximately 2 minutes, mixing and diffusion was observed throughout the entire column.

Surface turbidity levels were measured continuously (at one second time intervals) during the first 1 hour and 36 minutes of Test 9A and the Wetlab ECO-NTU sensor remained in the water column for this period. Surface turbidity was also monitored continuously between 2 hours after commencement and 3 hours and 30 minutes after commencement. Surface turbidity levels were measured at varying time intervals thereafter. The Wetlab ECO-NTU sensor was placed in the water column for each measurement and removed after a stable reading was recorded. Surface turbidity during crushed rock placement and at various time intervals during the initial 3.5 hours is plotted in **Graph 4** for Test 9A**.**



Graph 4: Surface turbidity measured during the initial 3.5 hours following placement of Temperance Formation crushed rock, Test 9A.

Surface turbidity levels increased rapidly from background level of around 2 NTU to a maximum instantaneous peak of around 120 NTU during placement of the sieved crushed rock (i.e. within the initial 10 seconds of testing). Surface turbidity stabilised at approximately 75 NTU, 1 minute and 45 seconds after commencement. Turbidity during the 30-minute period after commencement fluctuated numerous times and gradually decreased to approximately 32 NTU. Surface turbidity continued to decrease and was measured to be approximately 22 NTU, 1 hour after commencement. Surface turbidity then gradually increased to approximately 30 NTU, 3 hours and 25 minutes after commencement.

Surface turbidity measured at varying time intervals over the 9-day test duration is plotted in **Graph 3** (refer **Section 2.2.1**) for Test 9A alongside the results for Tests 9B.

Surface turbidity gradually decreased and fluctuated for the remainder of the test period. Surface turbidity was noted to increase between the following time intervals:

- between 3 hours following commencement and 20 hours following commencement, surface turbidity increased from 30.8 NTU to 46.4 NTU;
- between 1 day and 5 hours following commencement and 1 day and 20 hours following commencement, surface turbidity increased from 19 NTU to 37.5 NTU; and,
- between 6 days and 20 hours following commencement and 7 days and 20 hours following commencement, surface turbidity increased from 14.4 NTU to 19.4 NTU.

The increase in surface turbidity at the various time intervals is somewhat unexpected and a discussion is provided in **Section 3**.

By 9 days and 3 hours following commencement, surface turbidity was 18.3 NTU. At this point in time, flocculant was added to the column (**Section 2.3**).

2.2.3 Test 9B - Placement of dry sieved crushed rock within a fall pipe with opening submerged 50 cm below the water surface

For Test 9B, the sieved crushed rock was gently sprinkled into the fall pipe with an internal diameter of approximately 50 mm. The top of the fall pipe was approximately 75 cm above the water surface. The inside of the fall pipe was rinsed with water from Talbingo Reservoir to ensure that all of the sieved crushed rock entered the column.

Significant mixing and diffusion of crushed rock was observed within the fall pipe. Clumps of crushed rock fell through the upper portion of the column. However, fine material parted from the clumps during descent and a turbid trail formed through the water column in the wake of the clumps. The clumps generally dissipated before descending to the bottom of the column.

The dense turbid plume in the fall pipe gradually descended and diffused throughout the water column, primarily below the base of the fall pipe. After approximately 1 minute, significant mixing was observed in the middle third of the column, below the fall pipe. After 3 minutes and 30 seconds, elevated turbidity was observed in the lower two thirds of the water column, below the base of the fall pipe.

There was no immediate discernible change in turbidity above the turbid plume, with the upper 50 cm of water in the column (i.e. above the base of the fall pipe) remaining relatively clear with turbidity at background levels (refer **Graph 3**, **Section 2.2.1**). However, over the subsequent 20 hours, surface turbidity increased to approximately 23 NTU.

The top of the turbid plume was recorded at approximately 1.3 cm above the base of the fall pipe, immediately after placement. Minor advection of crushed rock was observed up to 13.2 cm above the base of the fall pipe, approximately 5 minutes following commencement of the test. There was no immediate discernible change in turbidity above this level with the surface turbidity at approximately 2 NTU, which was the background level (refer **Graph 3**, **Section 2.2.1**).

The top of the turbid plume was clearly distinguishable up to 1 day and 20 hours following commencement. The top of the plume had descended to 100 cm below the water surface, at a rate of 28.8 cm/day. After this point in time, the plume was not distinguishable with relatively uniform turbidity throughout.

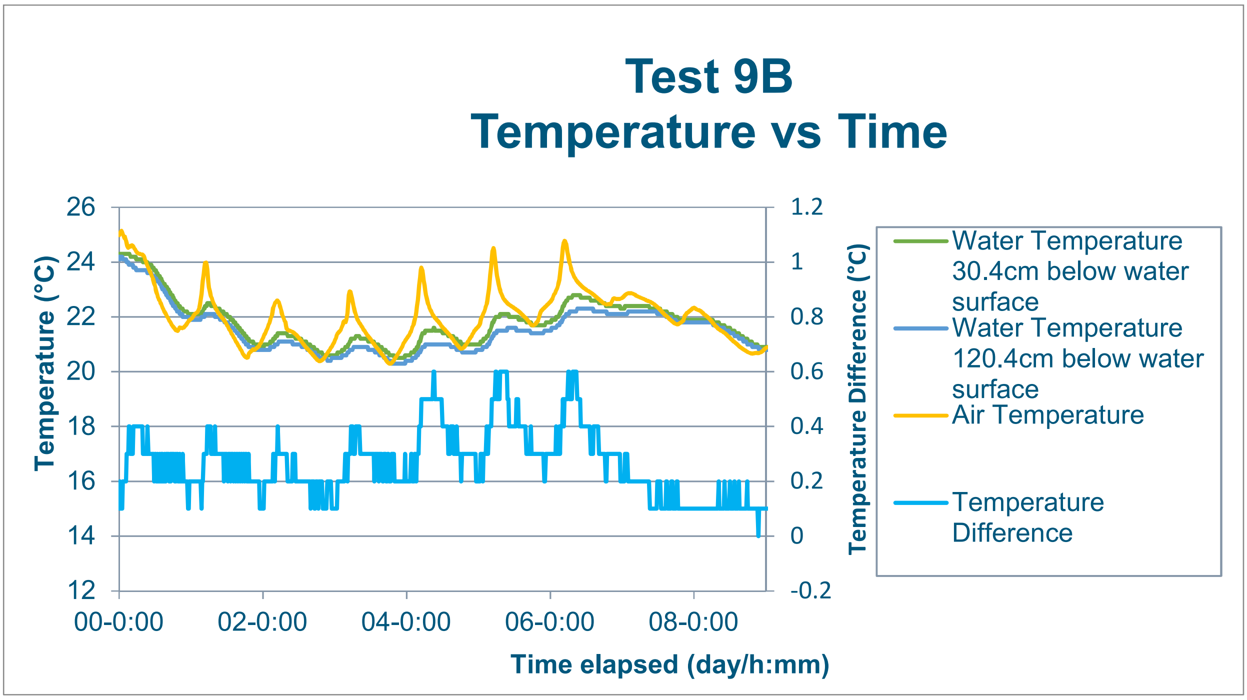
A haze was noticeable above the denser plume (below the base of the fall pipe) approximately 20 hours following commencement and remained for the duration of the test. Surface turbidity rapidly increased from 2.6 NTU to 22.6 NTU between 3 hours and 35 minutes following commencement and 19 hours and 45 minutes following commencement. Surface turbidity continued to increase to 26.4 NTU, 1 day and 19 hours following commencement before gradually decreasing for the remainder of the test. After 9 days and 3 hours, surface turbidity was 17.4 NTU.

A discussion regarding the observed increase in surface turbidity during Test 9B is provided in **Section 3**.

2.2.4 Air and Water Temperature

Air temperature and water temperature was recorded every 15 minutes in Test 9B for the duration of the test using Solinist Leveloggers and a Barologger. Water temperature was monitored at two depths, 30.4 cm and 120.4 cm below the water surface.

Graph 5 provides air and water temperature variation over time for Test 9B.



Graph 5: Air and water temperature in Test 9B. Elapsed time relative to commencement of Tests 9A and 9B.

Air temperature in Test 9B fluctuated between approximately 19.8 °C and 25.1 °C. Block out curtains were placed across all windows for the duration of the test in an attempt to regulate air temperature within the laboratory.

Water temperature varied between 19.9 °C and 24.3 °C. Water temperature was consistently 0 °C to 0.6 °C warmer at the upper monitoring location and the average temperature differential between the monitoring depths was 0.24 °C. The warmer water near the top of the column would have a lower density and would therefore be buoyant compared to the cooler water lower in the column.

2.3 Flocculation Test

Prior to completion of the settlement tests, a trial was undertaken to determine whether a chemical flocculant would accelerate settlement of fine particles and clarify the water. The chemical flocculant selected for the test was alum (aluminium sulphate). It should be noted that the particular chemical flocculant selected for the test was somewhat arbitrary and has not been approved for use during construction.

Flocculant was added to Test 9A on 16th November 2018 at 3:30pm, approximately 9 days and 3 hours following commencement of the settlement test. Tests 9B and 9D were retained as control columns for comparison.

Turbidity in Tests 9A, 9B and 9D on the 16th November 2018 (prior to addition of flocculant) and the 19th November 2018 (following addition of flocculant) is reported in **Table 2**. Turbidity in Test 9A decreased from 18.3 NTU to 0.9 NTU while the turbidity in the control columns, Tests 9B and 9D, decreased to a lesser extent. This indicates that the chemical flocculant was effective in clarifying the water

Table 2: Turbidity before and after the addition of flocculant to Test 4A.

Date/Time	Test 9A (NTU)	Test 9B (NTU)	Test 9D (NTU)
16th November 2018, 3:30 pm	18.3	17.4	28.5
19th November 2018, 2:00 pm	0.9	14.8	17.6

A photograph of the three Test columns taken on the 16th and 19th November 2018 is provided in **Figure 7**. It should be noted that some of the flocculated crushed rock in Test 9A adhered to the walls of the column thereby making the column appear slightly 'cloudy' when viewed side on. However, when viewed from above, the water was clear as indicated by the surface turbidity reading.

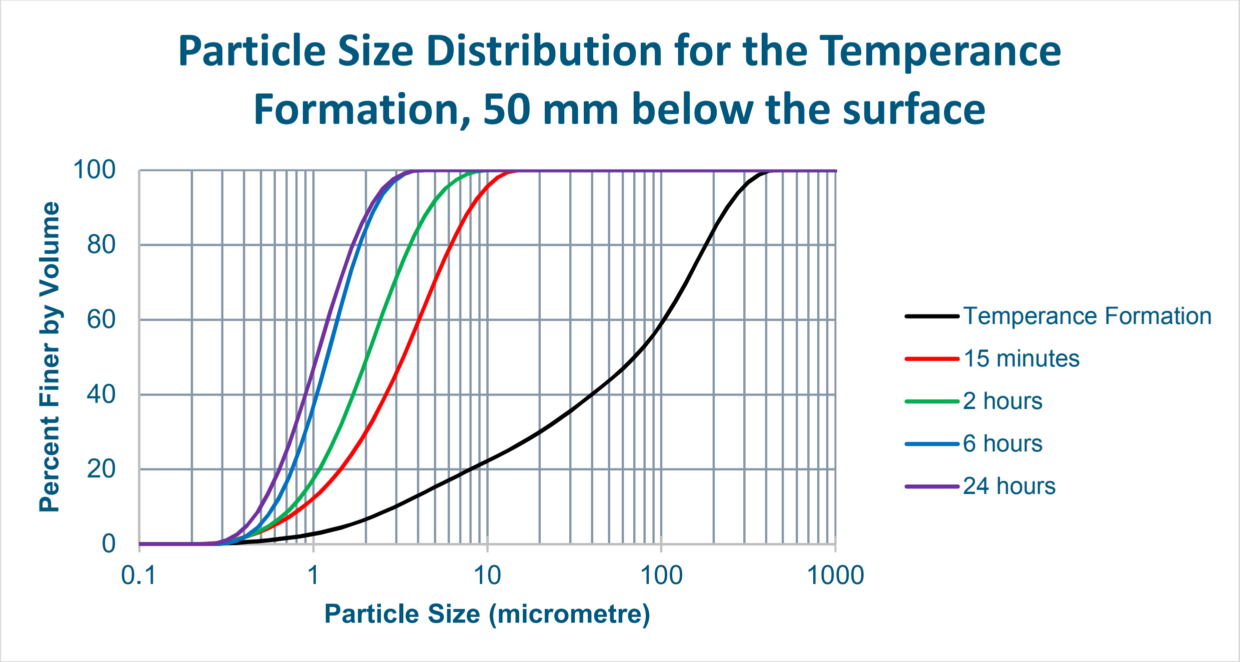
Figure 7: Column and Settlement tests prior to and following addition of chemical flocculant to Test 4A-
Left: Tests 9D, 9A and 9B (from left to right) prior to the addition of flocculant to Test 9A. Photographed on the 16th November at 3:30pm, approximately 9 days and 2.75 hours following commencement of the settlement tests.
Right: Tests 9D, 9A and 9B (from left to right), following the addition of flocculant to Test 9A. Photographed on the 19th November at 2:00pm, approximately 12 days and 1.25 hour following commencement of the settlement tests.

2.4 Critical Particle Size

The tests to determine the critical particle size in suspension commenced on the 5th and 6th November 2018. Particle size analysis using the Mastersizer 2000 was completed on the 6th November 2018.

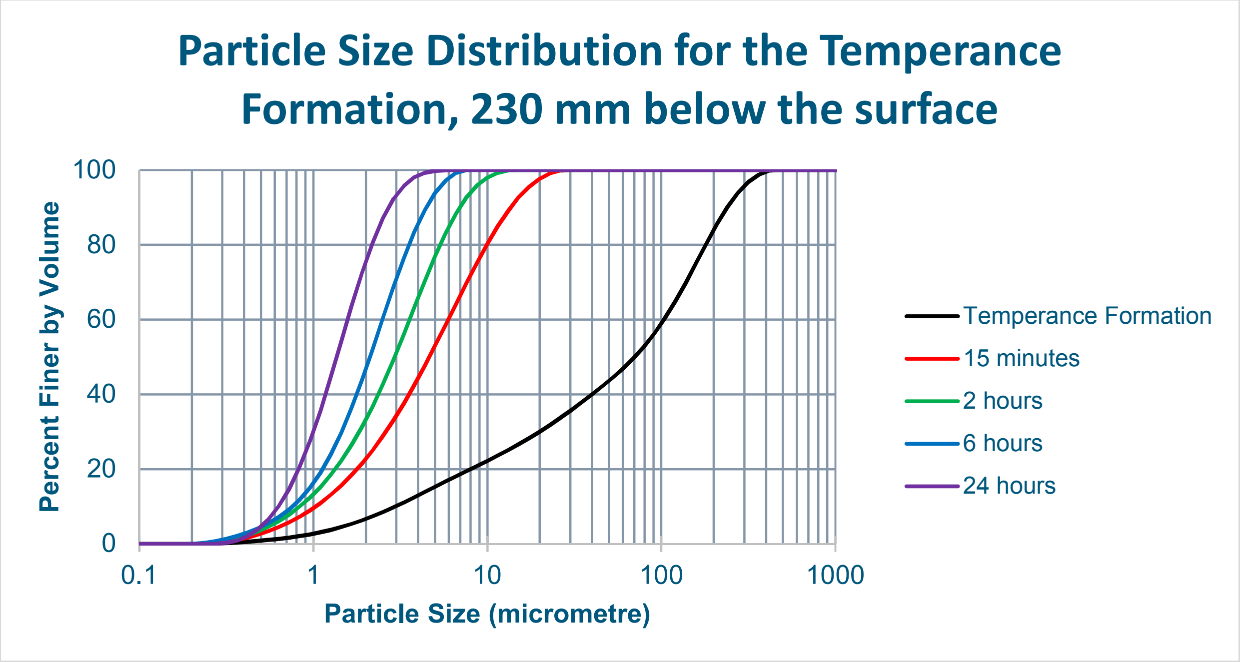
Graph 6 plots the particle size distribution of the sieved crushed rock (used for all tests) and the particle size that remains in suspension after each time interval (15 minutes, 2 hours, 6 hours, and 24 hours) at 50 mm below the water surface (850 mL mark on cylinder). The maximum particle size in suspension at

various time intervals is outlined in **Table 3**. The maximum particle size in suspension decreases over time from around 15 µm (15 minutes) to 4 µm (24 hours).



Graph 6: Particle size distribution at varying time intervals, 50 mm below the water surface.

Graph 7 plots the particle size distribution of the sieved crushed rock (used for all tests) and the particle size that remains in suspension after a given time interval (15 minutes, 2 hours, 6 hours, 24 hours and 48 hours) at 230 mm below the water surface (300 mL mark on cylinder). The maximum particle size in suspension at various time intervals is outlined in **Table 3**. The maximum particle size in suspension decreases over time from around 27 µm (15 minutes) to 6 µm (24 hours).



Graph 7: Particle size distribution at varying time intervals 230 mm the water surface.

Table 3: Maximum particle size in suspension at varying time intervals, 50 mm and 230 mm below the water surface.

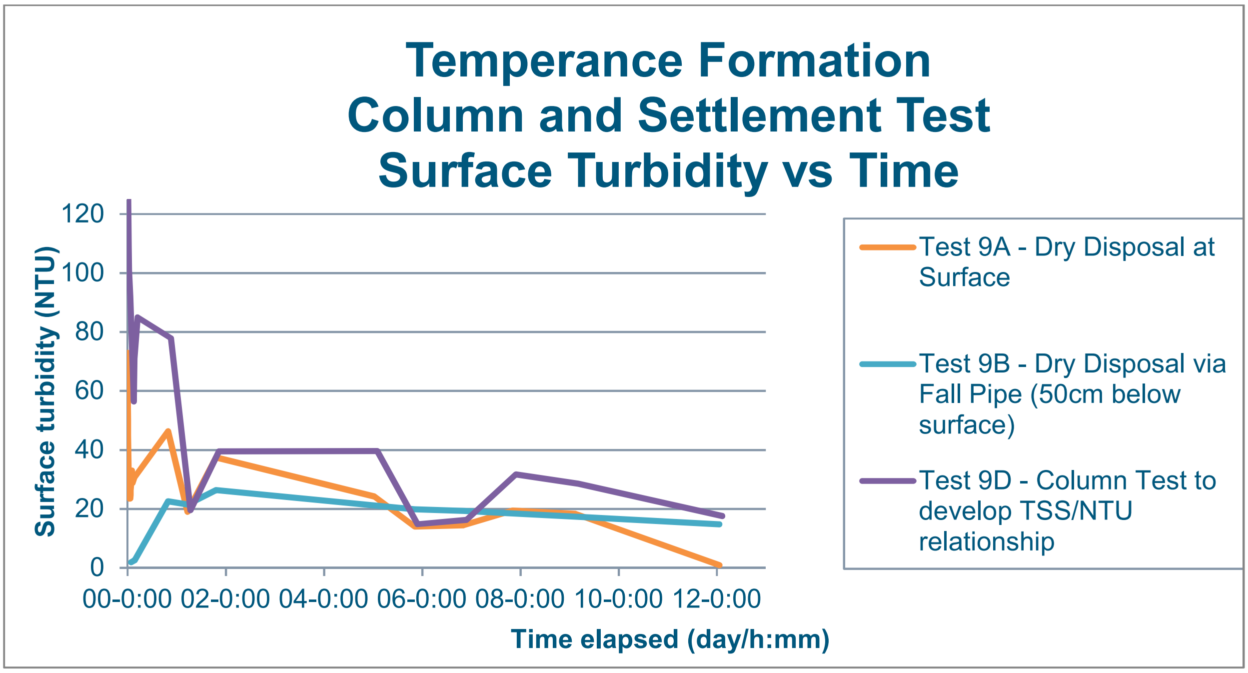
Time	Maximum particle size in suspension (µm)	
	50 mm below the water surface	230 mm below the water surface
15 minutes	15	27
2 hours	9	13.5
6 hours	4	7
24 hours	4	6

Based on the results presented above, it is evident that, for the same given time intervals, the maximum particle size in suspension is larger at greater depths within the water column, as would be expected.

3 Discussion

3.1 Fluctuating Turbidity and Increase in Surface Turbidity

As described in **Section 2**, surface turbidity in Test 9A and 9D fluctuated and surface turbidity in Test 9B increased over time. The surface turbidity for the three tests is shown in **Graph 8**. The graph includes the addition of flocculant to Test 9A, 9 days and 2 hours following commencement.



Graph 8: Surface turbidity measured during the settlement and column tests – Temperance Formation (Tests 9A, 9B and 9D).

An increase in surface turbidity was unexpected, with ongoing settlement and decreasing turbidity following initial mixing considered more likely to occur. It is possible that the observations were influenced by one or more of the following factors:

1. Weak thermal convection currents within the column may result in mixing of stratified layers and rising warm water transporting suspended particles to the surface. Air temperature and water temperature was monitored for the duration of the test. The results are reported in **Section 2.2.4** and presented in **Graph 5**.

   It is apparent from **Graph 5** that the water temperature warms and cools in response to the air temperature. Further, the difference in water temperature between the top and bottom of the column increases during a warming phase and decreases during a cooling phase.

   It is inferred that heat is transferred from the air to the column and from the column to the adjacent water near the wall of the column through the process of conduction, which is the transfer of heat between objects in contact with each other, or through a substance due to the collision of molecules. Heating of water near the wall of the column would result in differential water temperature across the column with cooler water near the centre of the column. The differential water temperature would lead to two processes, conduction and convection where

convection is the process of warmer water, with a lower density, rising to cooler areas in the column and cooler water, with a higher density, sinking to take the place of the warmer water. The velocity of convection currents are difficult to determine and due to a range of factors.

2. The sieved crushed rock may contain clay particles that are anionic. The repelling force between charged particles in suspension may result in suspended solids diffusing and distributing evenly throughout the water column.

3. The action of gently lowering a turbidity probe into the upper layer of the column (~3.4 cm below the water surface), or extracting samples with a pipette from Test 9D (at 3 hours following commencement) may be sufficient to disturb the water column resulting in advection of very fine suspended particles.

Regardless of the reason for fluctuating and increasing surface turbidity in Test 9A, 9B and 9D, it is clear that minor disturbances to the water column are sufficient to disrupt the settlement process and redistribute fine suspended particles within the water column.

4 Conclusions

It is apparent from the column test and settlement tests that once fine crushed rock from the metamorphic rock in the Temperance Formation enters the water column, the fine particles remain in suspension for extended periods in the order of several days to weeks. The surface turbidity approximately 10 days after commencement of Tests 9A, 9B and 9D was between 17 NTU and 19 NTU.

While surface turbidity levels generally appear to reduce over time, it may take an extremely long time to reach background levels of 1 NTU to 5 NTU, as reported by Cardno. Furthermore, minor disturbances to the water column are likely to disrupt the settlement process and/or re-suspend fine particles.

The critical particle size in suspension that would be contributing to prolonged surface turbidity in the water column (more than 24 hours) would be less than approximately 6 µm.

The results of a chemical flocculation test for the Temperance Formation crushed rock indicate that the addition of flocculant may accelerate settlement of fine particles and clarify the water.

TSS-turbidity data collected during the Column Test (Test 9D) is considered to be reliable for the purpose of establishing a preliminary relationship between TSS and turbidity for the Temperance Formation. The turbidity value equivalent to 50 mg/L suspended solids is 61 NTU for this dataset. Furthermore, as the properties and grading of the crushed rock placed during construction may vary to that used in the column test, collection of field TSS-turbidity data during subaqueous excavated rock placement activities is recommended so that the relationship between turbidity and suspended solids can be continually validated and improved.

Attachment 1 – Laboratory Certificates

ALS Environmental

CERTIFICATE OF ABALYSIS

Work Order : **ES1833518**
Client : **HASKONING AUSTRALIA- ROYAL HASKONING**
Contact : MR PATRICK LAWLESS
Address : LEVEL 14 56 Berry Street
NORTH SYDNEY 2060
Telephone : ----
Project : SNOWY 2.0 TSS-NTU (Tests 8-9)
Order number : ----
C-O-C number : ----
Sampler : PATRICK LAWLESS
Site : ----
Quote number : EN/222
No. of samples received : 18
No. of samples analysed : 18

Page : 1 of 6
Laboratory : Environmental Division Sydney
Contact : Customer Services ES
Address : 277-289 Woodpark Road Smithfield NSW Australia 2164
Telephone : +61-2-8784 8555
Date Samples Received : 09-Nov-2018 16:35
Date Analysis Commenced : 10-Nov-2018
Issue Date : 15-Nov-2018 11:32

ilac-MRA NATA
Accreditation No. 825
Accredited for compliance with
ISO/IEC 17025 - Testing

This report supersedes any previous report(s) with this reference. Results apply to the sample(s) as submitted. This document shall not be reproduced, except in full.

This Certificate of Analysis contains the following information:

- General Comments
- Analytical Results

Additional information pertinent to this report will be found in the following separate attachments: Quality Control Report, QA/QC Compliance Assessment to assist with Quality Review and Sample Receipt Notification.

Signatories

This document has been electronically signed by the authorized signatories below. Electronic signing is carried out in compliance with procedures specified in 21 CFR Part 11.

Signatories	*Position*	*Accreditation Category*
Ankit Joshi	Inorganic Chemist	Sydney Inorganics, Smithfield, NSW

General Comments

The analytical procedures used by the Environmental Division have been developed from established internationally recognized procedures such as those published by the USEPA, APHA, AS and NEPM. In house developed procedures are employed in the absence of documented standards or by client request.

Where moisture determination has been performed, results are reported on a dry weight basis.

Where a reported less than (<) result is higher than the LOR, this may be due to primary sample extract/digestate dilution and/or insufficient sample for analysis.

Where the LOR of a reported result differs from standard LOR, this may be due to high moisture content, insufficient sample (reduced weight employed) or matrix interference.

When sampling time information is not provided by the client, sampling dates are shown without a time component. In these instances, the time component has been assumed by the laboratory for processing purposes.

Where a result is required to meet compliance limits the associated uncertainty must be considered. Refer to the ALS Contact for details.

Key : CAS Number = CAS registry number from database maintained by Chemical Abstracts Services. The Chemical Abstracts Service is a division of the American Chemical Society.
LOR = Limit of reporting
^ = This result is computed from individual analyte detections at or above the level of reporting
ø = ALS is not NATA accredited for these tests.
~ = Indicates an estimated value.

Analytical Results

Sub-Matrix: **WATER** (Matrix: **WATER**)			*Client sample ID*	**9D-1**	**9D-2**	**9D-3**	**9D-4**	**9D-5**
			Client sampling date / time	07-Nov-2018 00:00	07-Nov-2018 00:00	07-Nov-2018 00:00	07-Nov-2018 00:00	07-Nov-2018 00:00
Compound	*CAS Number*	*LOR*	*Unit*	**ES1833518-001**	**ES1833518-002**	**ES1833518-003**	**ES1833518-004**	**ES1833518-005**
				Result	Result	Result	Result	Result
EA025: Total Suspended Solids dried at 104 ± 2°C								
Suspended Solids (SS)	----	5	mg/L	<5	**82**	**190**	**193**	**166**
EA045: Turbidity								
Turbidity	----	0.1	NTU	**0.9**	**61.6**	**98.0**	**125**	**156**

Analytical Results

Sub-Matrix: **WATER** (Matrix: **WATER**)			*Client sample ID*	**9D-6**	**9D-7**	**9D-8**	**9D-9**	**9D-10**
			Client sampling date / time	07-Nov-2018 00:00	07-Nov-2018 00:00	07-Nov-2018 00:00	07-Nov-2018 00:00	07-Nov-2018 00:00
Compound	*CAS Number*	*LOR*	*Unit*	**ES1833518-006**	**ES1833518-007**	**ES1833518-008**	**ES1833518-009**	**ES1833518-010**
				Result	Result	Result	Result	Result
EA025: Total Suspended Solids dried at 104 ± 2°C								
Suspended Solids (SS)	----	5	mg/L	**142**	**118**	**91**	**84**	**65**
EA045: Turbidity								
Turbidity	----	0.1	NTU	**147**	**137**	**84.0**	**121**	**87.0**

Analytical Results

Sub-Matrix: **WATER**
(Matrix: **WATER)**

			Client sample ID	**9D-11**	**9D-12**	**9D-13**	**9D-14**	**9D-15**
			Client sampling date / time	07-Nov-2018 00:00	07-Nov-2018 00:00	07-Nov-2018 00:00	07-Nov-2018 00:00	07-Nov-2018 00:00
Compound	CAS Number	LOR	Unit	**ES1833518-011**	**ES1833518-012**	**ES1833518-013**	**ES1833518-014**	**ES1833518-015**
				Result	Result	Result	Result	Result
EA025: Total Suspended Solids dried at 104 ± 2°C								
Suspended Solids (SS)	----	5	mg/L	**54**	**77**	**70**	**78**	**58**
EA045: Turbidity								
Turbidity	----	0.1	NTU	**66.9**	**83.0**	**89.9**	**83.9**	**69.0**

Analytical Results

Sub-Matrix: **WATER** (Matrix: **WATER**)			*Client sample ID*	**9D-16**	**9D-17**	**9D-18**	**----**	**----**
			Client sampling date / time	08-Nov-2018 00:00	08-Nov-2018 00:00	08-Nov-2018 00:00	----	----
Compound	*CAS Number*	*LOR*	*Unit*	**ES1833518-016**	**ES1833518-017**	**ES1833518-018**	**--------**	**--------**
				Result	Result	Result	----	----
EA025: Total Suspended Solids dried at 104 ± 2°C								
Suspended Solids (SS)	----	5	mg/L	**71**	**8**	**17**	**----**	**----**
EA045: Turbidity								
Turbidity	----	0.1	NTU	**24.8**	**9.6**	**12.3**	**----**	**----**

CERTIFICATE OF ANALYSIS

Work Order	: **ES1834368**	Page	: 1 of 4
Client	: **HASKONING AUSTRALIA- ROYAL HASKONING**	Laboratory	: Environmental Division Sydney
Contact	: MR PATRICK LAWLESS	Contact	: Customer Services ES
Address	: LEVEL 14 56 Berry Street NORTH SYDNEY 2060	Address	: 277-289 Woodpark Road Smithfield NSW Australia 2164
Telephone	: +61 02 8854 5000	Telephone	: +61-2-8784 8555
Project	: Snowy 2.0 Test 839 PA 1904	Date Samples Received	: 16-Nov-2018 16:25
Order number	:	Date Analysis Commenced	: 17-Nov-2018
C-O-C number	: ----	Issue Date	: 22-Nov-2018 11:17
Sampler	: ----		
Site	: ----		
Quote number	: EN/222		
No. of samples received	: 10		
No. of samples analysed	: 10		

NATA

Accreditation No. 825
Accredited for compliance with
ISO/IEC 17025 - Testing

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Signatories	*Position*	*Accreditation Category*
Ankit Joshi	Inorganic Chemist	Sydney Inorganics, Smithfield, NSW

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Key :
CAS Number = CAS registry number from database maintained by Chemical Abstracts Services. The Chemical Abstracts Service is a division of the American Chemical Society.
LOR = Limit of reporting
^ = This result is computed from individual analyte detections at or above the level of reporting
ø = ALS is not NATA accredited for these tests.
~ = Indicates an estimated value.

Analytical Results

Sub-Matrix: **WATER** (Matrix: **WATER**)			*Client sample ID*	**8D-23**	**8D-24**	**8D-25**	**8D-26**	**8D-27**
			Client sampling date / time	12-Nov-2018 00:00	13-Nov-2018 00:00	14-Nov-2018 00:00	15-Nov-2018 00:00	16-Nov-2018 00:00
Compound	*CAS Number*	*LOR*	*Unit*	**ES1834368-001**	**ES1834368-002**	**ES1834368-003**	**ES1834368-004**	**ES1834368-005**
				Result	Result	Result	Result	Result
EA025: Total Suspended Solids dried at 104 ± 2°C								
Suspended Solids (SS)	----	5	mg/L	**57**	**21**	**14**	**26**	**15**
EA045: Turbidity								
Turbidity	----	0.1	NTU	**51.6**	**28.7**	**37.0**	**48.9**	**44.3**

Analytical Results

Sub-Matrix: **WATER**
(Matrix: **WATER)**

			Client sample ID	9D-19	9D-20	9D-21	9D-22	9D-23
			Client sampling date / time	12-Nov-2018 00:00	13-Nov-2018 00:00	14-Nov-2018 00:00	15-Nov-2018 00:00	16-Nov-2018 00:00
Compound	CAS Number	LOR	Unit	ES1834368-006	ES1834368-007	ES1834368-008	ES1834368-009	ES1834368-010
				Result	Result	Result	Result	Result
EA025: Total Suspended Solids dried at 104 ± 2°C								
Suspended Solids (SS)	----	5	mg/L	**38**	**15**	<5	**18**	**17**
EA045: Turbidity								
Turbidity	----	0.1	NTU	**48.5**	**19.8**	**25.9**	**41.7**	**34.8**

Attachment 2 – Temperance Formation Laboratory Log Records

Test ID	9A	
Geological Unit	Temperance Formation	
Description	Test 9A - Dry Disposal at Surface	
Start Date/Time	07-11-18 12:45	
Water volume	50 L	
Water surface level in column	172.5	cm
Mass sediment added	40 g	(sieved to <250 um)
Test Location	Geochemical Assessments Workshop, Roseville NSW	
Test Officers	Pat Lawless, Rick Plain	

Observations

Date/Time	Time since start	Turbidity (NTU)	Measurement Location (cm)	Measurement Depth (cm)	Comments
06-11-18 13:00	1 Day Prior	1.6	169.1	3.4	Background turbidity measured 10 minutes before test start
07-11-18 12:49	00-0:04	73	169.1	3.4	
07-11-18 12:51	00-0:06	60	169.1	3.4	
07-11-18 12:57	00-0:12	50	169.1	3.4	
07-11-18 13:01	00-0:16	45	169.1	3.4	
07-11-18 13:18	00-0:33	31.5	169.1	3.4	
07-11-18 13:45	00-1:00	23.5	169.1	3.4	
07-11-18 14:00	00-1:15	23.6	169.1	3.4	
07-11-18 14:10	00-1:25	24.7	169.1	3.4	
07-11-18 14:15	00-1:30	26.2	169.1	3.4	
07-11-18 14:20	00-1:35	27.6	169.1	3.4	Probe removed
07-11-18 14:49	00-2:04	33	169.1	3.4	Probe reintroduced, leave logging .
07-11-18 14:51	00-2:06	29.5	169.1	3.4	
07-11-18 15:15	00-2:30	28.9	169.1	3.4	
07-11-18 16:12	00-3:27	30.8	169.1	3.4	Probe removed
08-11-18 8:30	00-19:45	46.4	169.1	3.4	
08-11-18 18:00	01-5:15	19	169.1	3.4	Stratification 167 cm.
09-11-18 8:00	01-19:15	37.5	169.1	3.4	Stratification 167 cm.
12-11-18 13:20	05-0:35	24.25	169.1	3.4	
13-11-18 9:00	05-20:15	14	169.1	3.4	Gradual change to 156 cm.
14-11-18 9:00	06-20:15	14.4	169.1	3.4	Minor stratification 145 cm.
15-11-18 9:00	07-20:15	19.4	169.1	3.4	Lid left off from previous day.
16-11-18 15:30	09-2:45	18.3	169.1	3.4	**Flocculant added.**
19-11-18 14:00	12-1:15	0.9	169.1	3.4	

Test ID	9B		
Geological Unit	Temperance Formation		
Description	Test 9B - Dry Disposal via Fall Pipe (50cm below surface)		
Start Date/Time	07-11-18 12:45		
Water volume	50 L		
Water surface level in column	173.4	cm	
Mass sediment added	40 g	(sieved to <250 um)	
Test Location	Geochemical Assessments Workshop, Roseville NSW		
Test Officers	Pat Lawless, Rick Plain		
Depth of Temperature Probes	143cm	53cm	Old Probe at Bottom

Observations

Date/Time	Time since start	Turbidity (NTU)	Measurement Location (cm)	Measurement Depth (cm)	Comments
06-11-18 13:00	1 day prior	2.4	170	3.4	Background turbidity measured 10 minutes before test start
07-11-18 12:50	00-0:05		170	3.4	Top of plume at 125 cm.
07-11-18 12:50	00-0:05		170	3.4	Minor mixing up to approximately 137 cm.
07-11-18 14:29	00-1:44	1.9	170	3.4	
07-11-18 16:20	00-3:35	2.6	170	3.4	Top of plume at 122 cm.
08-11-18 8:30	00-19:45	22.6	170	3.4	Top of plume at 93 cm. Noticeable haze above.
08-11-18 18:00	01-5:15	21.5	170	3.4	Top of plume at 81 cm. Noticeable haze above.
09-11-18 8:00	01-19:15	26.4	170	3.4	Top of plume at 73 cm. Noticeable haze above.
12-11-18 13:20	05-0:35	21.2	170	3.4	
13-11-18 9:00	05-20:15	19.9	170	3.4	
14-11-18 9:00	06-20:15	19.3	170	3.4	Relatively uniform turbidity throughout.
15-11-18 9:00	07-20:15	18.4	170	3.4	Relatively uniform turbidity throughout.
16-11-18 15:30	09-2:45	17.4	169	4.4	
19-11-18 14:00	12-1:15	14.8	168	5.4	

Test ID	9D	
Geological Unit	Temperance Formation	
Description	Test 9D - Column Test to develop TSS/NTU relationship	
Start Date/Time	07-11-18 11:20	
Water volume	50 L	
Water surface level in column	172.8	cm
Mass sediment added	47.5 g	(sieved to <250 um)
Test Location	Geochemical Assessments Workshop, Roseville NSW	
Test Officers	Pat Lawless, Rick Plain	

Observations

Date/Time	Time since start	Turbidity (NTU)		TSS Sample Taken?	TSS Sample ID	Column Measurements			Comments
		Inside Column	Inside Beaker			Water Surface	Measurement Location	Sensor Depth	
07-11-18 11:10	10 minutes prior	1.7	2.6	Yes	9D-1	172.8	169.4	3.4	Before commencement
07-11-18 11:22	00-0:02	163	163	Yes	9D-2	171.8	168.4	3.4	Beaker reading range 158-170 NTU.
07-11-18 11:24	00-0:04	152	150	Yes	9D-3	170.9	167.5	3.4	Beaker reading range 140-155 NTU.
07-11-18 11:28	00-0:08	139	139	Yes	9D-4	170.2	166.8	3.4	Beaker reading range 130-150 NTU.
07-11-18 11:34	00-0:14	130	130	Yes	9D-5	169.5	166.1	3.4	Beaker reading range 124-138 NTU.
07-11-18 11:40	00-0:20	120	115	Yes	9D-6	168.7	165.3	3.4	Beaker reading range 110-120 NTU.
07-11-18 11:50	00-0:30	109	115	Yes	9D-7	168	164.6	3.4	Beaker reading range 107-120 NTU.
07-11-18 12:05	00-0:45	101	88	Yes	9D-8	167.2	163.8	3.4	Beaker reading range 80-92 NTU.
07-11-18 12:35	00-1:15	92	87	Yes	9D-9	166.4	163	3.4	Beaker reading range 84-90 NTU.
07-11-18 13:03	00-1:43		63	Yes	9D-10	164.7	161.3	3.4	Sample taken while probe in use in another column, no measurement insid column 9D
07-11-18 14:25	00-3:05	56.5	62.5	Yes	9D-11	164.7	161.3	3.4	
07-11-18 14:39	00-3:19		80	Yes	9D-12	163.9	157		Slightly deeper sample taken to achieve higher NTU/TSS values. Sample collected with pipette
07-11-18 14:44	00-3:24	71	77.5	Yes	9D-13	163.5	160.1	3.4	
07-11-18 15:40	00-4:20		91	Yes	9D-14	162.7	159.3	3.4	Sample taken while probe in use in another column, no measurement insid column 9D
07-11-18 16:15	00-4:55	85	70	Yes	9D-15	162.7	159.3	3.4	
08-11-18 8:30	00-21:10	78	73	Yes	9D-16	160.8	157.4	3.4	
08-11-18 18:00	01-6:40	19.5	21.1	Yes	9D-17	160	156.6	3.4	Stratification at 165.5 cm.
09-11-18 8:00	01-20:40	39.5	38.2	Yes	9D-18	159.1	155.7	3.4	Minor stratification at 140 cm.
12-11-18 13:20	05-2:00	39.6	39	Yes	9D-19	157.8	154.4	3.4	
13-11-18 9:00	05-21:40	14.8	15.4	Yes	9D-20	157	153.6	3.4	Minor stratification 153 cm.
14-11-18 9:00	06-21:40	16.3	19.2	Yes	9D-21	156.2	152.8	3.4	Stratification at 142 cm.
15-11-18 9:00	07-21:40	31.7	32	Yes	9D-22	155.2	151.8	3.4	Lid left off from previous day.
16-11-18 15:30	09-4:10	28.5	28.6	Yes	9D-23	154.3	150.9	3.4	
19-11-18 14:00	12-2:40	17.6	19.7	Yes		153.1	149.7	3.4	

Appendix J

Quality Assurance and Sensitivity of Test Parameters

Table of Contents

1 Introduction

Snowy Hydro Limited (Snowy Hydro) has engaged Royal HaskoningDHV (Haskoning) to undertake laboratory testing to assess the settling performance of crushed rock from the geological zones that are proposed to be placed subaqueously as part of the Snowy 2.0 project. The laboratory investigations for each geological zone comprised four detailed tests, which were:

1. Column test to establish TSS-turbidity relationship;
2. Settlement test to determine the settling behaviour of crushed rock;
3. Flocculation trial to assess whether a chemical flocculant would clarify the water; and,
4. Critical particle size analysis to determine the maximum particle size in suspension.

The test methods were devised and refined in order to develop a laboratory investigation that was considered:

1. Valid - to ensure the results satisfactorily address the aims of the experiment; and
2. Reliable - to ensure the tests are repeatable.

To ensure the results from the critical particle size analysis are reliable, several Quality Assurance (QA) tests were conducted. The procedure and results from the QA tests are presented in **Section 2**.

Additional testing was also undertaken to assess the sensitivity of key parameters in the column test, settlement test and critical particle size analysis. The objectives, procedure and results from the additional tests are presented in **Section 3**.

2 Quality Assurance of Critical Particle Size Analysis

Particle size analysis was undertaken with a Mastersizer 2000. The Mastersizer 2000 uses a laser to determine the size of particles suspended in a fluid. The Mastersizer 2000 was used to determine:

- the particle size distribution of rock crushed with a hammer drill or ring mill; and
- the size of particles in suspension at varying time intervals during settlement for the critical particle size analysis.

Reliability of results from the critical particle size analysis was confirmed by validating:

- the accuracy of the Mastersizer 2000 prior to commencing each analysis batch by determining the particle size distribution of a known standard;
- the procedure of sub-sampling dry crushed rock for analysis with the Mastersizer 2000 by assessing the particle size distribution of aliquots of crushed rock;
- the procedure of sub-sampling suspended crushed rock for analysis with the Mastersizer 2000 by assessing the particle size distribution of aliquots of samples extracted from the 1 L columns;
- reliability of the procedure of the critical particle size analysis by duplicating the test for Ravine Beds crushed rock.

Results from these QA tests are presented in **Section 2.1** to **Section 2.4**.

2.1 Validation of Mastersizer 2000

Each time the Mastersizer 2000 was powered on and prior to measuring the particle size distribution of the crushed rock or suspended sediment samples, a laboratory standard was analysed. The laboratory standard used was a uniform, homogenous sample with a known particle size distribution of 150-180 µm (determined with sieve screens). The laboratory standard was measured to ensure the machine was operating as expected and producing repeatable and accurate results.

The method for analysis of the laboratory standard with the Mastersizer 2000 is similar to the method adopted for analysis of the dry crushed rock. The method is as follows:

1. Add dispersant to the mixing basin of the Mastersizer 2000 and record the background refraction. Degassed Sydney tap water was typically used as the dispersant. Sydney tap water was degassed by pouring the water into a water container and leaving it to settle for at least 24 hours.
2. Using a teaspoon, gradually add the dry granular laboratory standard (~2 g) to the mixing basin of the Mastersizer 2000 (with the dispersant) until obscuration of 5 to 10% is achieved.
3. The Mastersizer 2000 establishes the particle size distribution of the standard based on the difference in refraction between the dispersant and the suspended sediment sample. The stirrer and pump of the Mastersizer 2000 ensures particles up to approximately 1 mm to 2 mm in diameter remain in suspension.

Results from discrete measurements of the laboratory standard are provided in **Graph 1**. The measurements are from different days throughout the laboratory investigation.

The General Purpose model based on the Mie Theory was adopted for particle size analysis with the Mastersizer 2000. The refractive index for clean water (tap water and Talbingo Reservoir water) was adopted with the default value of 1.33. The refractive index and absorption properties of the standard were adopted with the default value of 1.52 and 0.1 respectively.

The first two measurements of the laboratory standard were undertaken with different dispersants. The first measurement was undertaken using degassed Sydney tap water ("15/08/2018 – Tap Water") as the dispersant and the second measurement was undertaken using Talbingo Reservoir water ("15/08/2018 – Talbingo Water") as the dispersant. As expected, **Graph 1** indicates that there was no discernible difference between these two measurements. Degassed Sydney tap water was used throughout the remainder of the testing program for analysis of the laboratory standard.

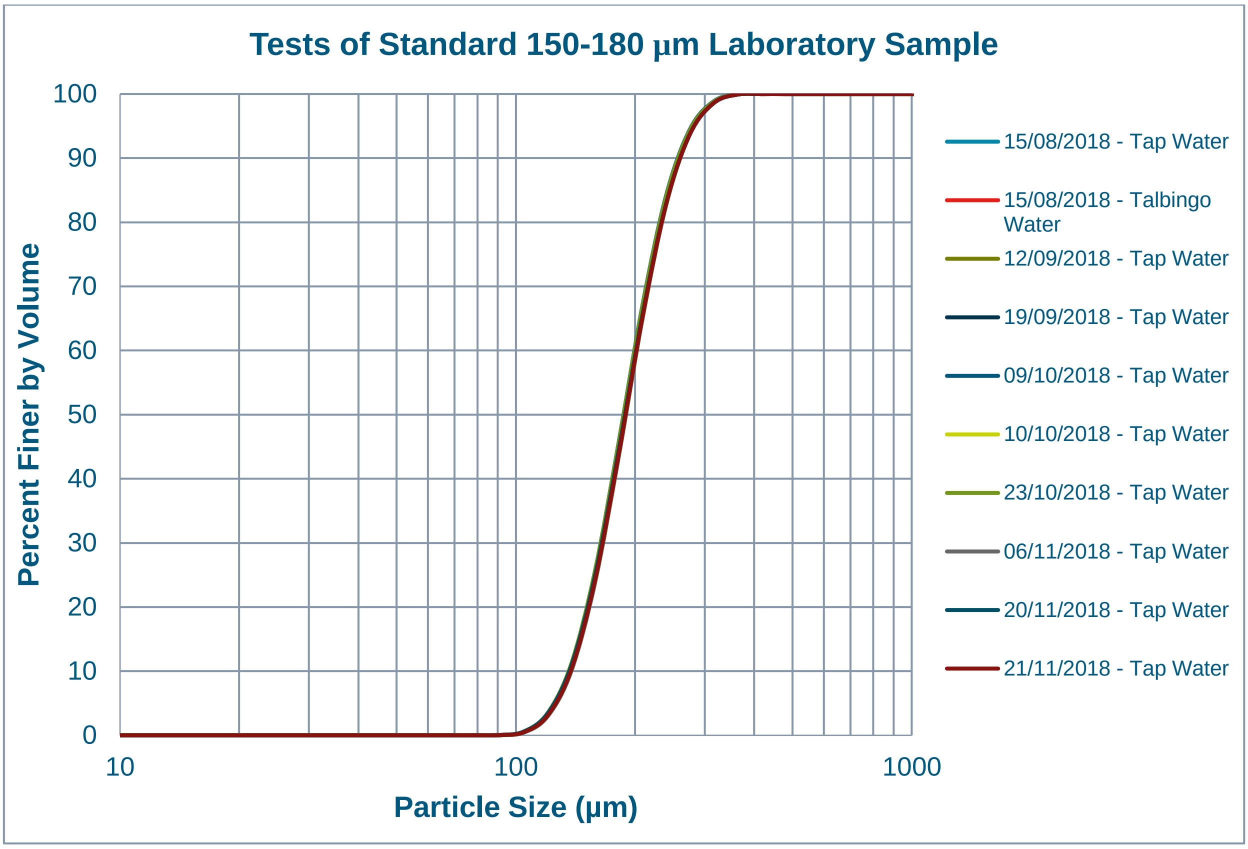
Additional tests of the laboratory standard, conducted throughout the test program, are shown in **Graph 1**. The Mastersizer 2000 reports volume of suspended sediment in a size 'bin' (discrete size range) as a percent of the total volume of sediment in suspension. The laboratory standard particle size was reported to range between 79.43 µm and 416.86 µm. The volume in each size bin was reported as 'percent finer by volume' as shown in **Graph 1**. The size bins within the range of the laboratory standard are reported in **Table 1**.

Table 1: Particle size 'bins' within the range of the laboratory standard.

Lower extent of size 'bin' (µm)	Upper extent of size 'bin' (µm)
79.43	91.20
91.20	104.71
104.71	120.23
120.23	138.04
138.04	158.49
158.49	181.97
181.97	208.93
208.93	239.88
239.88	275.42
275.42	316.23
316.23	363.08
363.08	416.87

Graph 1 indicates that the Mastersizer 2000 produced consistent and near-identical measurements of the laboratory standard over various days. The maximum difference in the percent finer by volume for each discrete particle size in **Table 1** was 2.25%.

These results suggest that the Mastersizer 2000 produced reliable measurements of sediment samples when used under normal operating conditions.



Graph 1: Multiple tests of the laboratory standard using Mastersizer 2000 on various days.

2.2 Validating Sub-Sampling of Dry Crushed Rock

The particle size distribution of crushed rock from the nine geological zones was determined using the Mastersizer 2000 in accordance with the method described in **Section 3.1.3** of **Settlement characteristics of fine crushed rock, Laboratory Assessment Factual Report (Haskoning, 2018).**

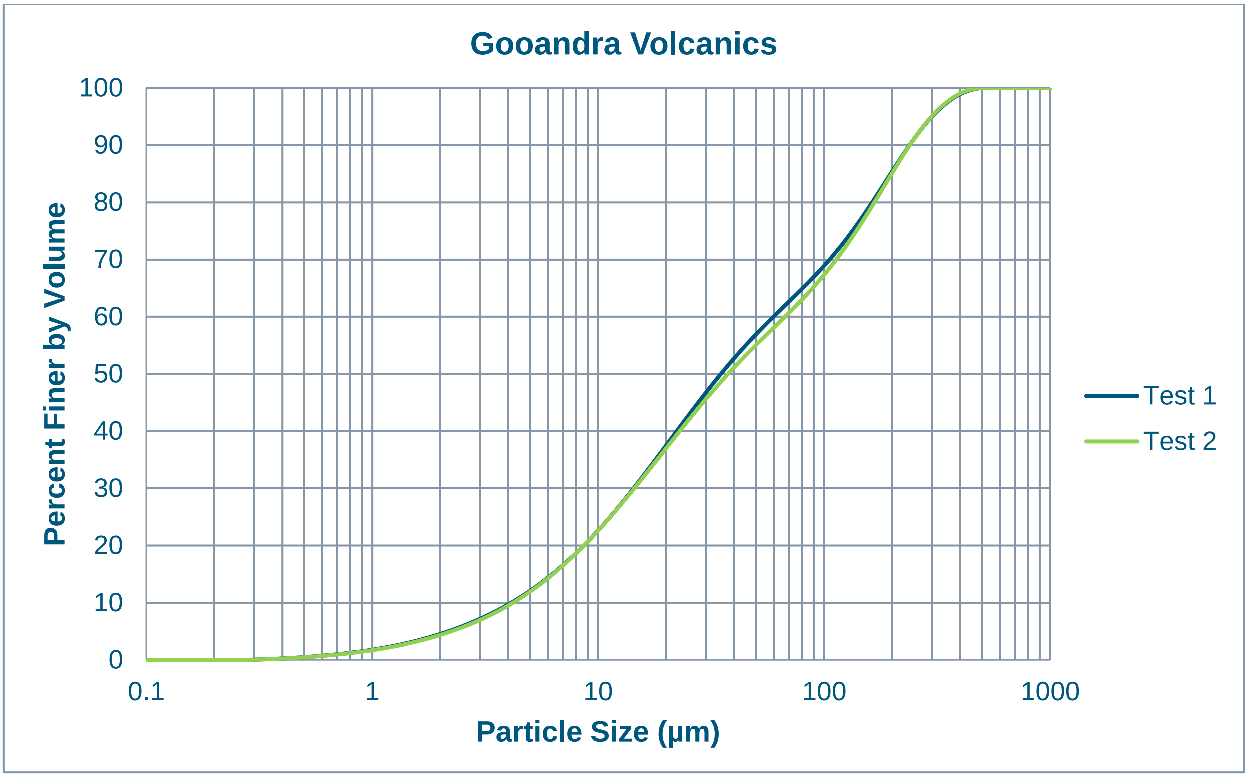
The Mastersizer 2000 requires only a small representative sample of crushed rock in suspension to achieve the desired obscuration and conduct a particle size distribution analysis. The necessary amount of suspended particles varies depending on several factors including colour and particle size. However, the required quantity of dry crushed rock was generally ~2 g per sample. This was extracted from a sub-sample of crushed rock. The crushed rock produced with the hammer drill was evenly divided into sub-samples while the crushed rock produced with the ring mill was divided into ~5 g sub-samples using a riffle splitter. Crushed rock was randomly selected from the sub-sample using a teaspoon.

A test was conducted to validate that the method of selecting the dry crushed rock from the 5 g sub-sample produced repeatable results with the Mastersizer 2000. This involved determining the particle size distribution of aliquots (fractional part of a whole) of the 5 g sub-sample. Aliquots were collected on different days using the method described above for analysis with the Mastersizer 2000. Results from these tests are presented in **Graph 2a** and **Graph 2b**.

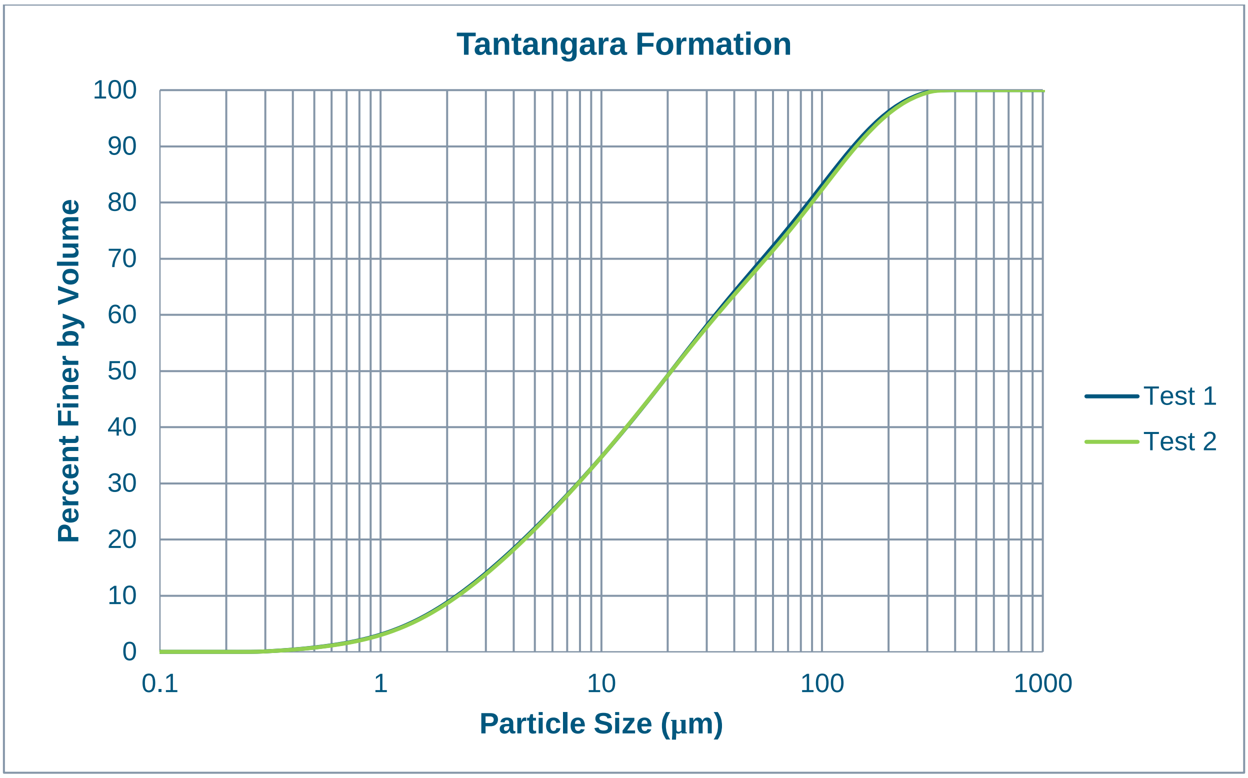
The Mastersizer 2000 reports volume of suspended sediment in a size ‘bin’ (discrete size range) as a percent of the total volume of sediment in suspension. The Gooandra Volcanics results were reported to be between 0.24 µm and 549.54 µm while the Tantangara Formation results were reported to be between 0.24 µm and 416.87 µm. The size range of each 'bin' decreases as particle size decrease. For example, at the upper end of recorded particle size, the 'bin' was from 416.87 µm to 478.63 µm (range 61.76 µm) while at the lower end of recorded particle size, the 'bin' was from 0.24 µm to 0.28 µm (range 0.04 µm). The volume in each size 'bin' was reported as 'percent finer by volume' as shown in **Graph 2a** and **Graph 2b**.

The results presented in **Graph 2a** and **Graph 2b** indicate minimal difference between the particle size distribution for repeated tests of crushed rock samples. The maximum difference in the measured percent finer by volume for each discrete particle size reported was 1.96 % and 0.78 % respectively for these two tests.

These results provide validation that the method of sub-sampling dry crushed rock, from the sub-sample, produces consistent and reliable results.



Graph 2a: Aliquots of dry crushed rock from Gooandra Volcanics.



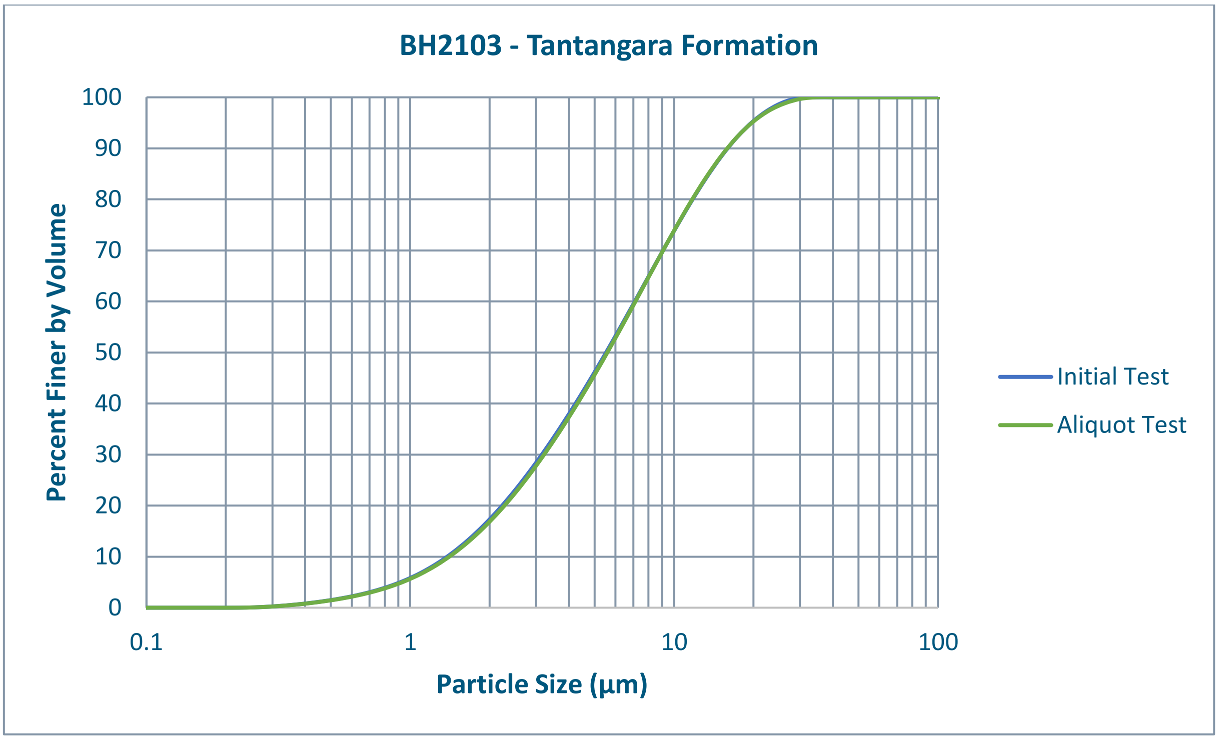
Graph 2b: Aliquots of dry crushed rock from Tantangara Formation.

2.3 Validating Sub-Sampling of Suspended Crushed Rock

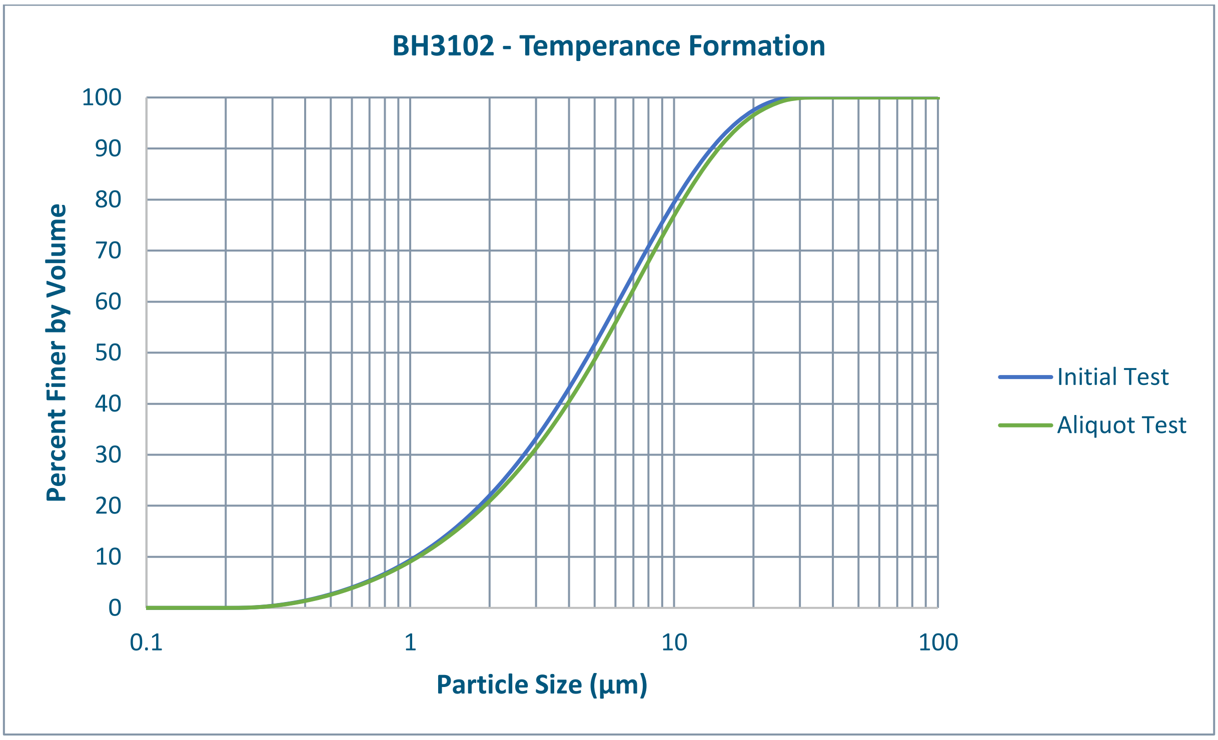
The particle size distribution of crushed rock from the nine geological zones was determined using the Mastersizer 2000 in accordance with the method described in **Section 3.3.4** of **Settlement characteristics of fine crushed rock, Laboratory Assessment Factual Report (Haskoning, 2018).**

Approximately 100 mL to 150 mL of the water and suspended crushed rock mixture was sub-sampled from the 1 L columns used for the critical particle size analysis. The required volume for particle size analysis with the Mastersizer 2000 varied primarily depending on the size, concentration and colour of crushed rock in suspension. Typically, the full quantity of solution (i.e. 100 mL to 150 mL) was required for the 6 hour and 24 hour sub-samples. However, approximately half of the volume extracted for the 15 minute and 2 hour sub-samples was generally required to achieve the desired obscuration for analysis.

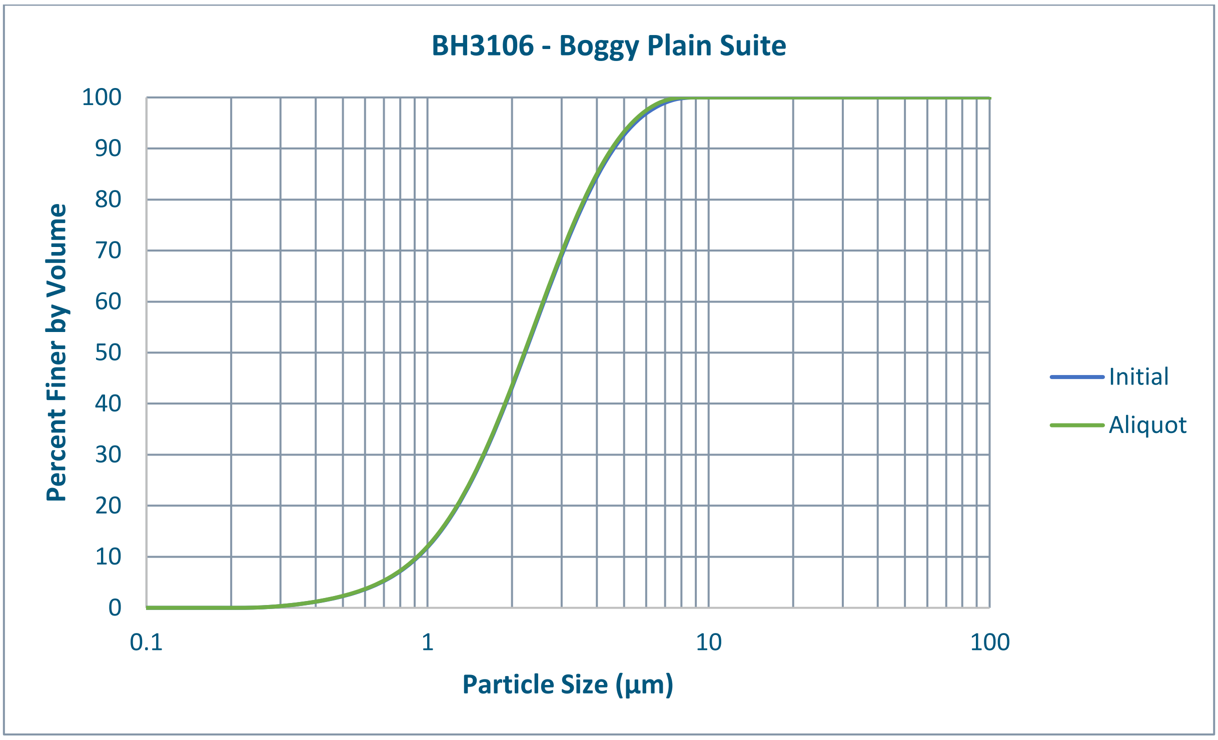
Following extraction of the sub-sample from the 1 L columns via pipette, the sub-sample was placed into a glass beaker. The sub-sample in the beaker was thoroughly agitated with a rotary mixer and the required quantity for analysis with the Mastersizer 2000 was either extracted with a clean syringe or decanted. A test was then conducted to validate that the methods of sub-sampling (with a syringe or decanting) produced repeatable results with the Mastersizer 2000. This involved determining the particle size distribution of aliquots from the suspended crushed rock sub-samples in the beaker. The particle size of suspended crushed rock in the aliquots was then analysed with the Mastersizer 2000. A selection of results from the initial and the aliquot tests are presented in **Graph 3a** to **Graph 3h**. The graphs show ‘percent finer by volume’ based on the volume in each size ‘bin’ reported by the Mastersizer 2000.



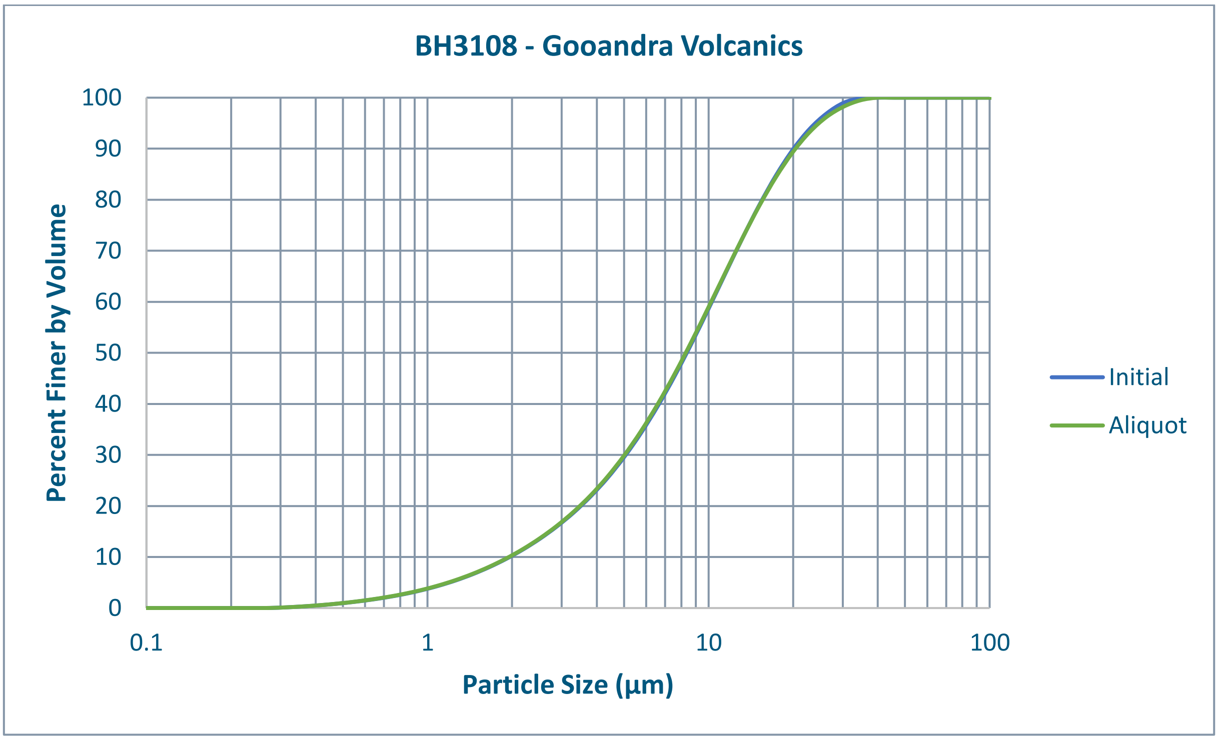
Graph 3a: Initial and aliquot test of particle size distribution for Tantangara Formation at 50 mm below surface and 15 minutes after crushed rock was added to the column. Maximum difference in percent finer by volume is 0.61% at particle size of 3.31 µm.



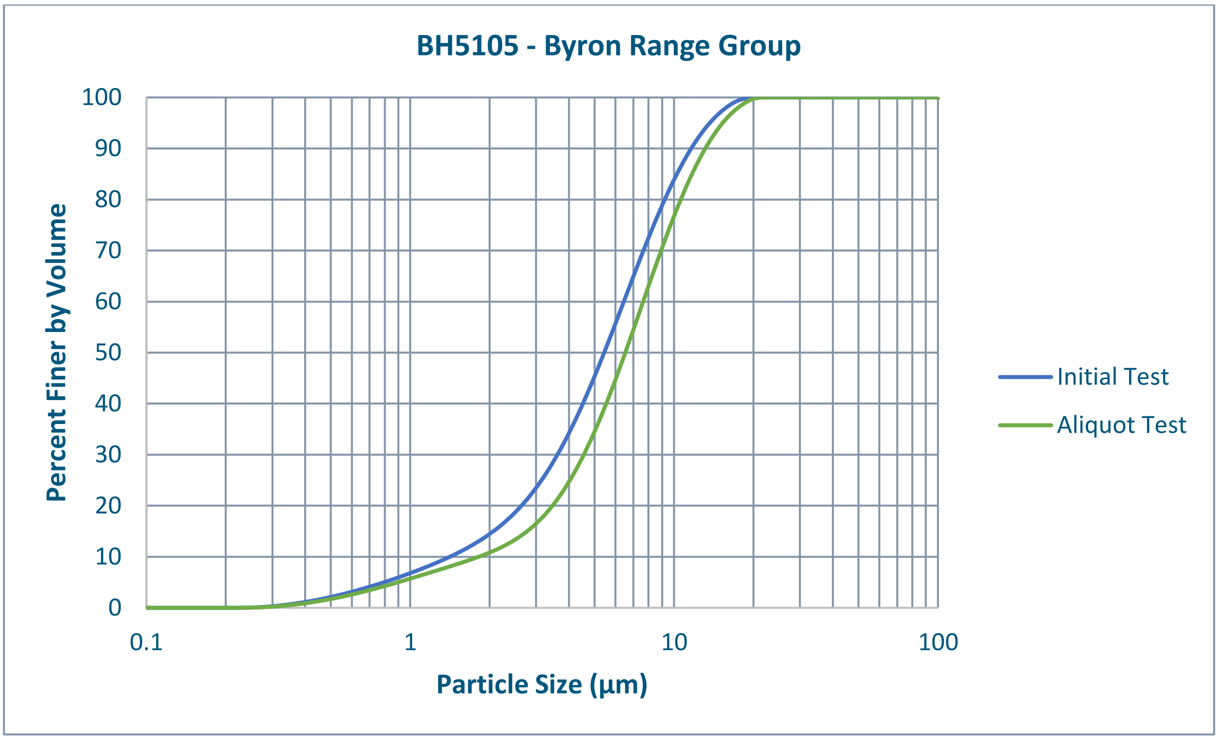
Graph 3b: Initial and aliquot test of particle size distribution for Temperance Formation at 50 mm below surface and 15 minutes after crushed rock was added to the column. Maximum difference in percent finer by volume is 3.10% at particle size of 6.61 µm.



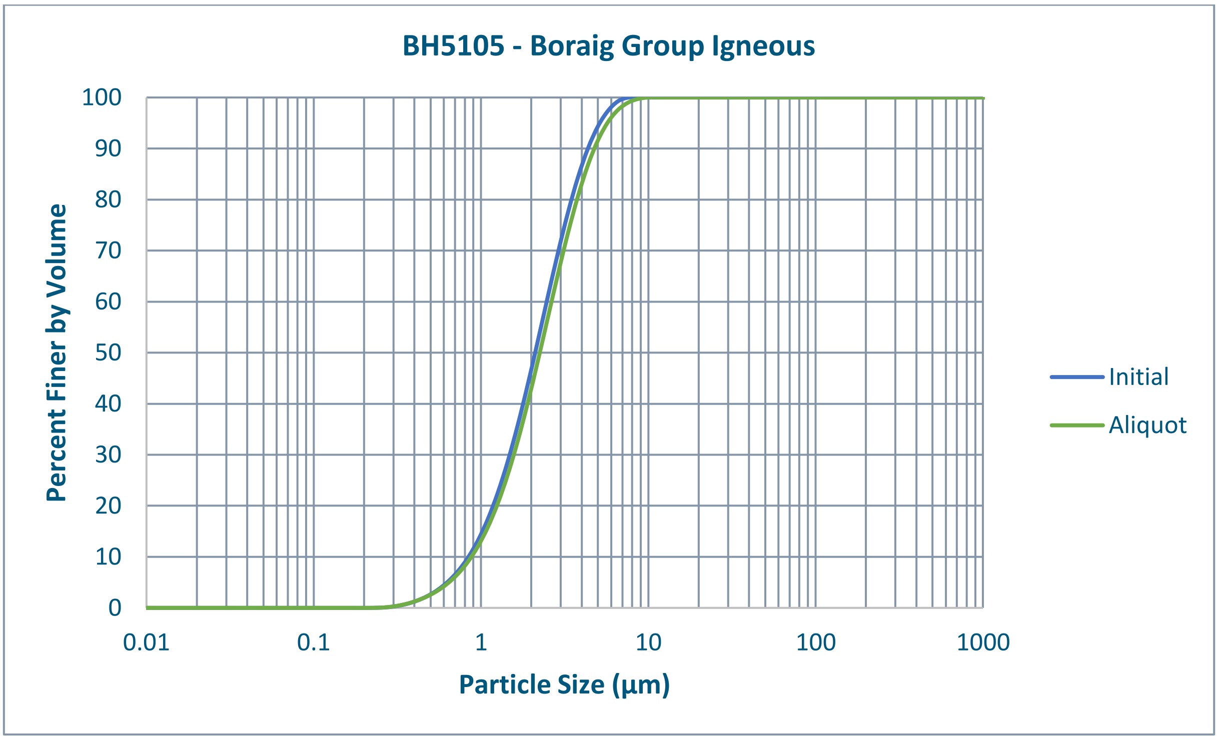
Graph 3c: Initial and aliquot test of particle size distribution for Boggy Plain Suite at 230 mm below surface and 2 hours after crushed rock was added to the column. Maximum difference in percent finer by volume is 0.59% at particle size of 5.75 µm.



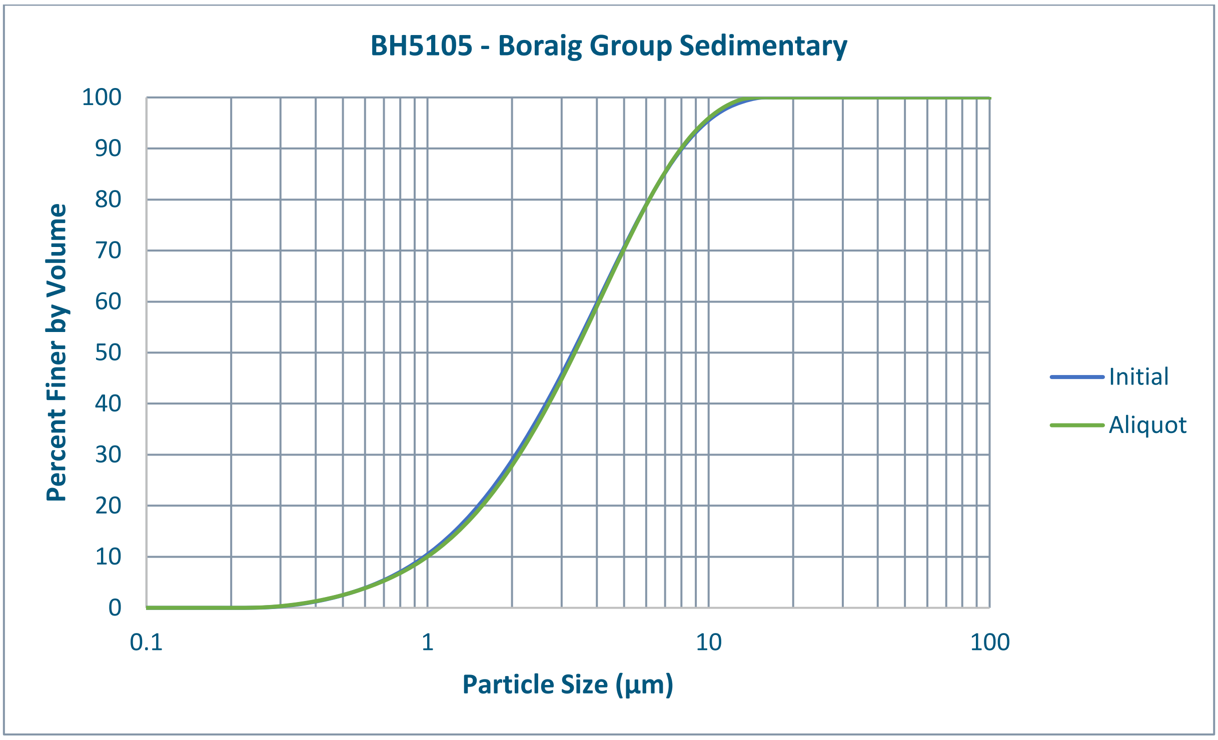
Graph 3d: Initial and aliquot test of particle size distribution for Gooandra Volcanics at 50 mm below surface and 15 minutes after crushed rock was added to the column. Maximum difference in percent finer by volume is 0.74% at particle size of 30.20 µm.



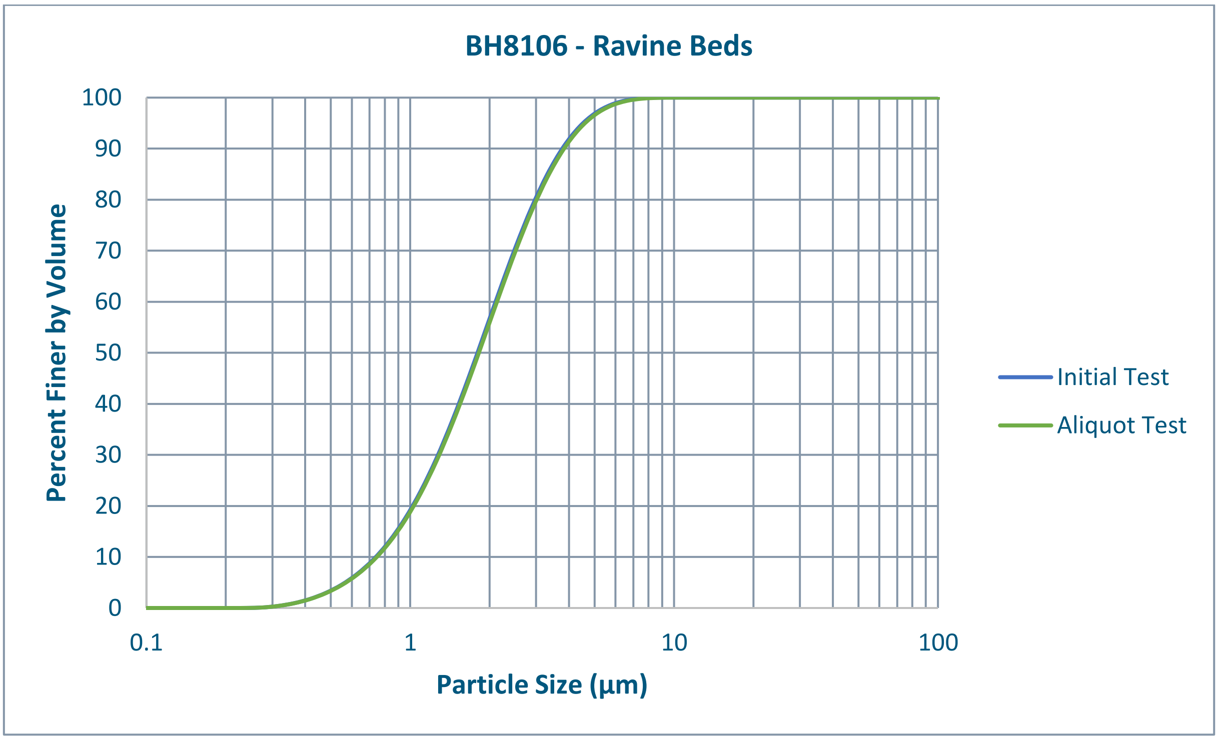
Graph 3e: Initial and aliquot test of particle size distribution for Byron Range Group at 50 mm below surface and 15 minutes after crushed rock was added to the column. Maximum difference in percent finer by volume is 11.03% at particle size of 4.37 µm.



Graph 3f: Initial and aliquot test of particle size distribution for Boraig Group igneous rock at 50 mm below surface and 6 hours after crushed rock was added to the column. Maximum difference in percent finer by volume is 4.16% at particle size of 2.88 µm.



Graph 3g: Initial and aliquot test of particle size distribution for Boraig Group sedimentary rock at 50 mm below surface and 2 hours after crushed rock was added to the column. Maximum difference in percent finer by volume is 1.05% at particle size of 2.19 µm.



Graph 3h: Initial and aliquot test of particle size distribution for Ravine Beds at 230 mm below surface and 2 hours after crushed rock was added to the column. Maximum difference in percent finer by volume is 0.77% at particle size of 2.19 µm.

Graph 3a to **Graph 3h** show minor differences between the particle size distribution for initial and aliquot tests of suspended crushed rock samples. The maximum difference in the measured percent finer by volume for each discrete particle size reported was less than 5%, with the exception of Sample 5105-6 (**Graph 3e**), which showed a maximum difference of 11.03%. This deviation typically occurs in the middle of the particle size distribution curves. However, it can be seen that the maximum particle size for the initial and aliquot tests, which is of most interest for the critical particle size analysis, was nearly identical for all samples. Therefore, the observed deviation in the middle of the particle size distribution curves was not considered significant in terms of determining the maximum particle size in suspension.

Notably, crushed rock from the Byron Range Group behaved differently to the other geological zones. Crushed rock used in the settlement test settled out of suspension within a few hours, which was faster than the other settlement tests. However, elevated turbidity (i.e. higher than other column tests) was observed for an extended duration in the column test. Furthermore, the critical particle size analysis indicates relatively coarse particles in suspension after 2 hours, 6 hours and 24 hours compared to the other geological zones. Suspended crushed rock from Byron Range Group also responded to ultrasonication with the Mastersizer 2000, whereby the ultrasound appeared to break apart particles resulting in a notably finer particle size distribution. It is unclear whether the ultrasound broke apart flocs that formed following mixing or broke apart individual particles placed into the column. In comparison, ultrasonication appeared to have minimal impact on other geological zones. It is hypothesised that the zone and/or dissipation of flocs resulted in the apparent difference in the particle size distribution for the initial and the aliquot tests for the Byron Range Group.

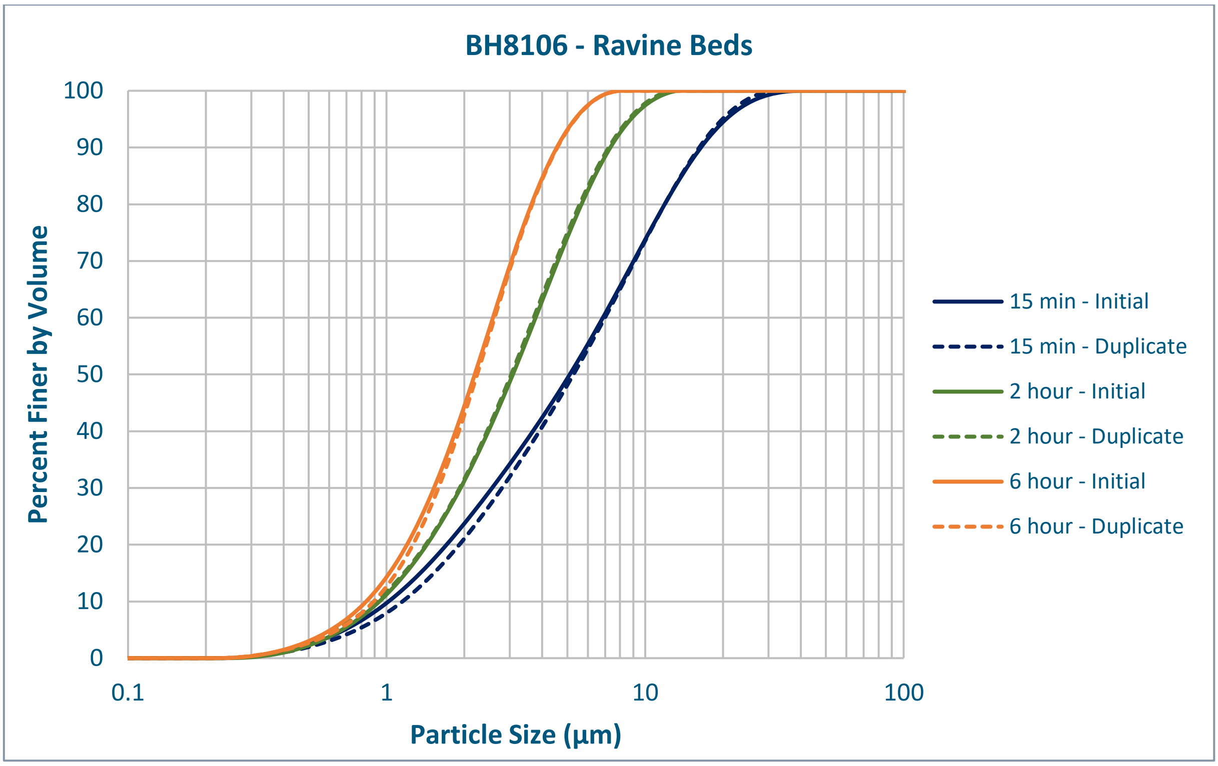
Overall, the initial and the aliquot test results are generally consistent and validate the methodology used to sub-sample suspended crushed rock from the beaker.

2.4 Duplicate Test on Ravine Beds

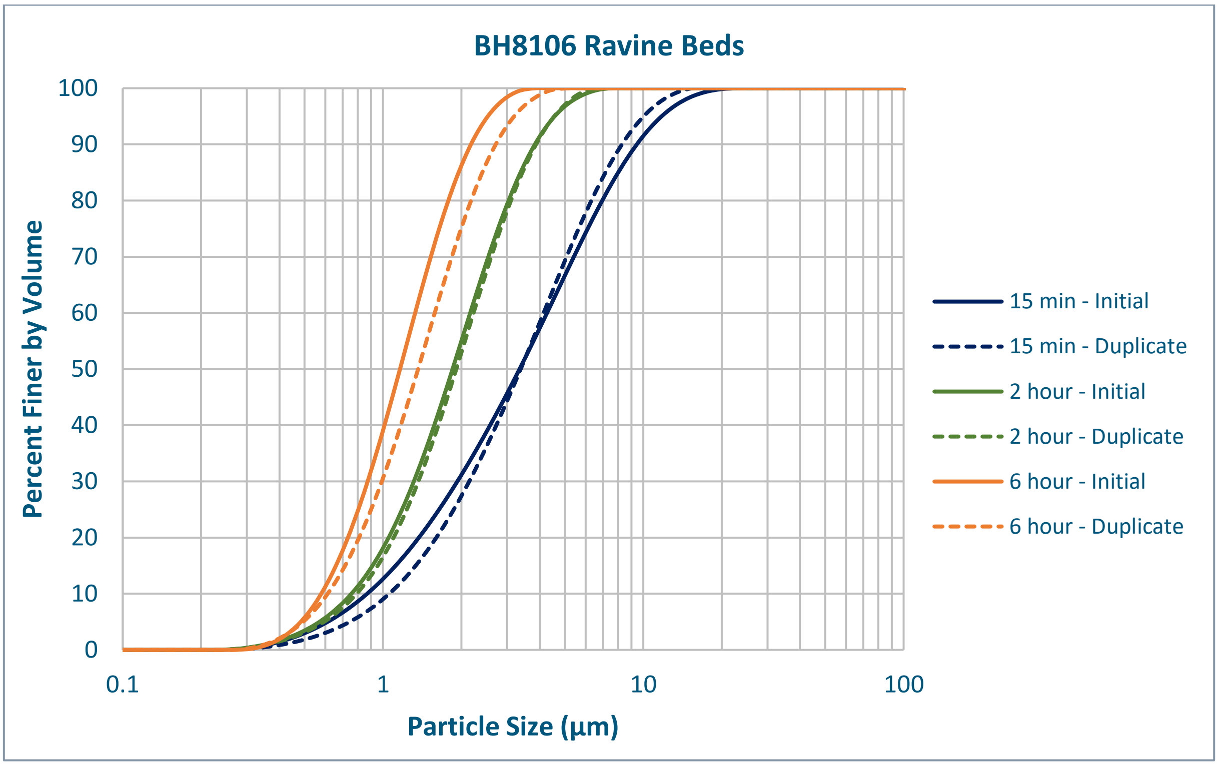
The maximum particle size in suspension after a given time interval was determined in accordance with the method described in **Section 3.3.4** of **Settlement characteristics of fine crushed rock, Laboratory Assessment Factual Report (Haskoning, 2018).**

To validate that the procedure produces repeatable and reliable results, a duplicate test was conducted using crushed rock from the Ravine Beds geological zone (BH8106). Unlike an aliquot, a duplicate test is an independent repeat of a complete test. It should be noted that the original test was conducted on rock crushed using a hammer drill while the duplicate test was conducted on rock crushed with a ring mill. Details of the rock crushing process are outlined in **Section 3.1** of **Settlement characteristics of fine crushed rock, Laboratory Assessment Factual Report (Haskoning, 2018)**. The initial critical particle size analysis on rock crushed with the hammer drill was undertaken on the 20th and 21st August 2018. The duplicate critical particle size analysis on rock crushed with a ring mill was undertaken on the 21st and 22nd October 2018.

A comparison of the particle size distribution results from the initial and duplicate test for Ravine Beds is presented in **Graph 4a** and **Graph 4b**. The samples were obtained 15 minutes, 2 hours and 6 hours after addition of crushed rock and at 50 mm and 230 mm below the water surface. The **Graphs** show ‘percent finer by volume’ based on the volume in each size ‘bin’ reported by the Mastersizer 2000.



Graph 4a: Initial and duplicate test results for Ravine Beds at various time intervals and 50 mm below water surface.



Graph 4b: Initial and duplicate test results for Ravine Beds at various time intervals and 230 mm below water surface.

Graph 4a and **Graph 4b** show minimal difference between the particle size distribution results for the initial and duplicate tests. The maximum difference in the measured percent finer by volume for each discrete particle size reported was less than 12%. As noted earlier, initial and duplicate samples were generated by crushing rock using different methods; a hammer drill and ring mill respectively. Furthermore, the columns were at room temperature, which varied throughout each test and also between tests, noting that water temperature can influence the settling behaviour of suspended particles. Deviations in the particle size distribution results for the initial and duplicate tests may therefore be due to variations in:

1. Particle size distribution of crush rock generated by the different rock crushing methods; and/or
2. Water temperature or change in water temperature throughout the test.

The deviation between the initial and duplicate tests shown in **Graph 4a** and **Graph 4b** was most pronounced in the middle of the particle size distribution curves. However, the maximum particle sizes, which are the most important characteristic for critical particle size analyses, were consistent across the tests. Overall, the duplicate test results were consistent and validate that the methodology used to conduct critical particle size analyses was reliable.

3 Sensitivity of Test Parameters

3.1 Overview

The objectives of the sensitivity tests and the respective test procedures are outlined in **Table 2**.

Table 2: Objective and procedure of sensitivity tests.

Objective No.	Objective Description	Test Procedure
1	To determine whether water temperature influences settlement velocity and the size of particles in suspension after a given period.	The critical particle size analysis was duplicated for Ravine Beds crushed rock. One set of columns (3 in total) were maintained at approximately 3.5 °C while a second set of columns were maintained at approximately 21.2 °C.
2	To determine whether the depth of the fall pipe influences surface turbidity.	Settlement Test B (dry placement through a fall pipe) was duplicated in two columns simultaneously with varying length fall pipes.
3	To determine whether the lid of the settlement columns has an influence on settlement velocity and surface turbidity.	Settlement Test A (dry placement on the surface) was duplicated in two columns simultaneously, with and without a lid on the columns.
4	To determine whether placing small quantities of crushed rock progressively over a number of days influences surface turbidity compared to a bulk one-off placement.	Settlement Test A (dry placement on the surface) was duplicated in two columns simultaneously. A total of 40 g of sieved crushed rock was placed in the first column at the start of the tests, while 5 g of sieved crushed rock was placed in the second column each day for 8 days (40 g in total).
5	To determine whether temperature fluctuations influence settlement of crushed rock in the Settlement Tests.	The following settlement tests were duplicated: • Test A (dry placement on the surface); and, • Test B (dry placement through a fall pipe, approximately 50 cm below the surface). The original tests were undertaken in the absence of block-out curtains across the laboratory windows (block-out curtains were installed for all other testing in an attempt to regulate room temperature). The air conditioning was set at 23 °C for the duplicate test in an attempt to further regulate air temperature. It is noted that temperature was not measured during the original tests but would be expected to have varied in comparison to the duplicate tests.

The sensitivity tests were undertaken with rock from the Ravine Beds geological zone (BH8106) typically crushed with a ring mill. Results from the sensitivity tests are presented in **Sections 3.2** to **3.7**.

3.2 Summary of Additional Settlement Tests

The additional settlement tests (undertaken to satisfy Objectives 2 to 5 in **Table 2**) were carried out within large settling columns with a diameter of 200 mm and an overall height of 2000 mm. The test procedure was similar to that outlined in **Section 3.3.2** of **Settlement characteristics of fine crushed rock, Laboratory Assessment Factual Report (Haskoning, 2018)**. A total of 40 g of crushed rock was required for each test. Surface turbidity inside the columns was measured using a Wetlab ECO-NTU sensor gently lowered to a depth of approximately 3.4 cm below the water surface.

Water for laboratory testing was obtained from Talbingo Reservoir on 2nd October 2018. The water was collected in 1000 L Intermediate Bulk Containers (IBC) and delivered to Haskoning on the 5th October 2018. The turbidity of the reservoir water sample used for the testing was between 0.9 NTU and 2.7 NTU.

Different crushed rock placement techniques were investigated in the additional settlement tests to satisfy Objectives 2 to 5 in **Table 2**, as set out below:

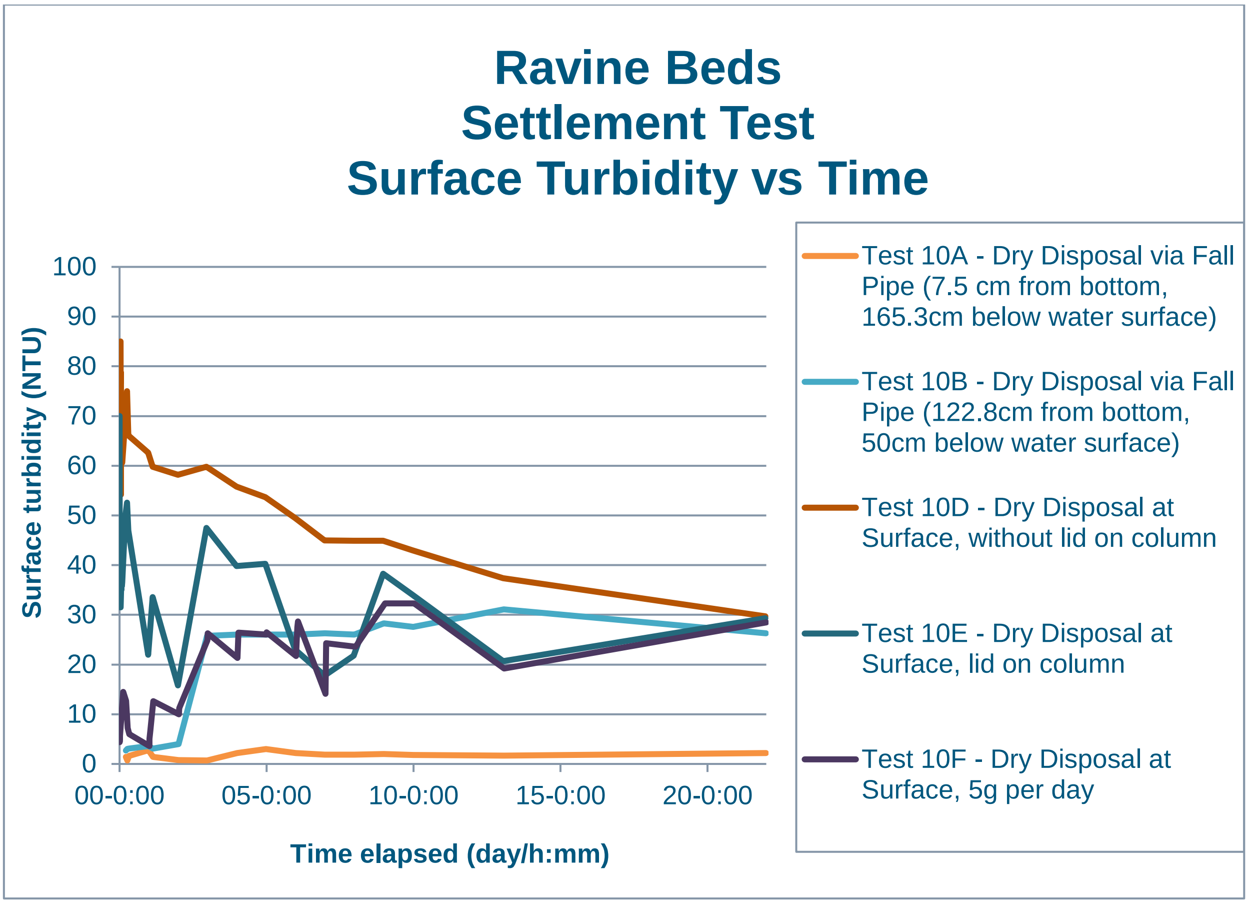
- Test 10A – placement of dry crushed rock through a long fall pipe (Objective 2).
- Test 10B – placement of dry crushed rock through a short fall pipe (Objective 2).
- Test 10D – placement of dry crushed rock directly onto the water surface in a column without a lid (Objective 3).
- Test 10E – placement of dry crushed rock directly onto the water surface in a column with a lid installed immediately after rock placement (Objective 3 and Objective 4).
- Test 10F – progressive placement of 5 g of dry crushed rock directly onto the water surface in a column with a lid (Objective 4).

These tests were undertaken in a controlled environment with block-out curtains across the windows and air conditioning set at 23 °C in an attempt to regulate air temperature inside the laboratory. Solinist Leveloggers were placed inside the Test 10A column to measure water temperature and a Solinist Barologger was placed next to the Test 10A column to measure air temperature.

The air conditioner was operated for the first 10 days of Test 10. After this point, the air conditioner was turned off. However, block-out curtains remained across the windows. Detailed results from the additional column tests, during the 10-day test period, are presented in **Sections 3.4** to **3.7**, including a discussion regarding air and water temperature during Test 10A in **Section 3.7**.

The columns were retained following the 10-day test period with infrequent monitoring up to 22 days after placement of crushed rock in the column. Surface turbidity measured at varying time intervals during the 22-day test duration is plotted in **Graph 5** for the five settlement tests. Laboratory log records completed during the additional settlement tests are provided in **Attachment 1**.

Initial surface turbidity varied depending on the placement scenario. Initial surface turbidity was between ~1.5 NTU (Test 10A and Test 10B) and ~85 NTU (Test 10D). Surface turbidity 22 days after commencement was similar for all tests, except for Test 10A. Surface turbidity in Test 10A, 22 days after commencement, was 2.2 NTU. Surface turbidity in the other tests varied between 26.3 NTU (Test 10B) and 29.7 NTU (Test 10D).



Graph 5: Surface turbidity measured during additional settlement tests on Ravine Beds.

3.3 Temperature in Critical Particle Size Analysis

3.3.1 Overview

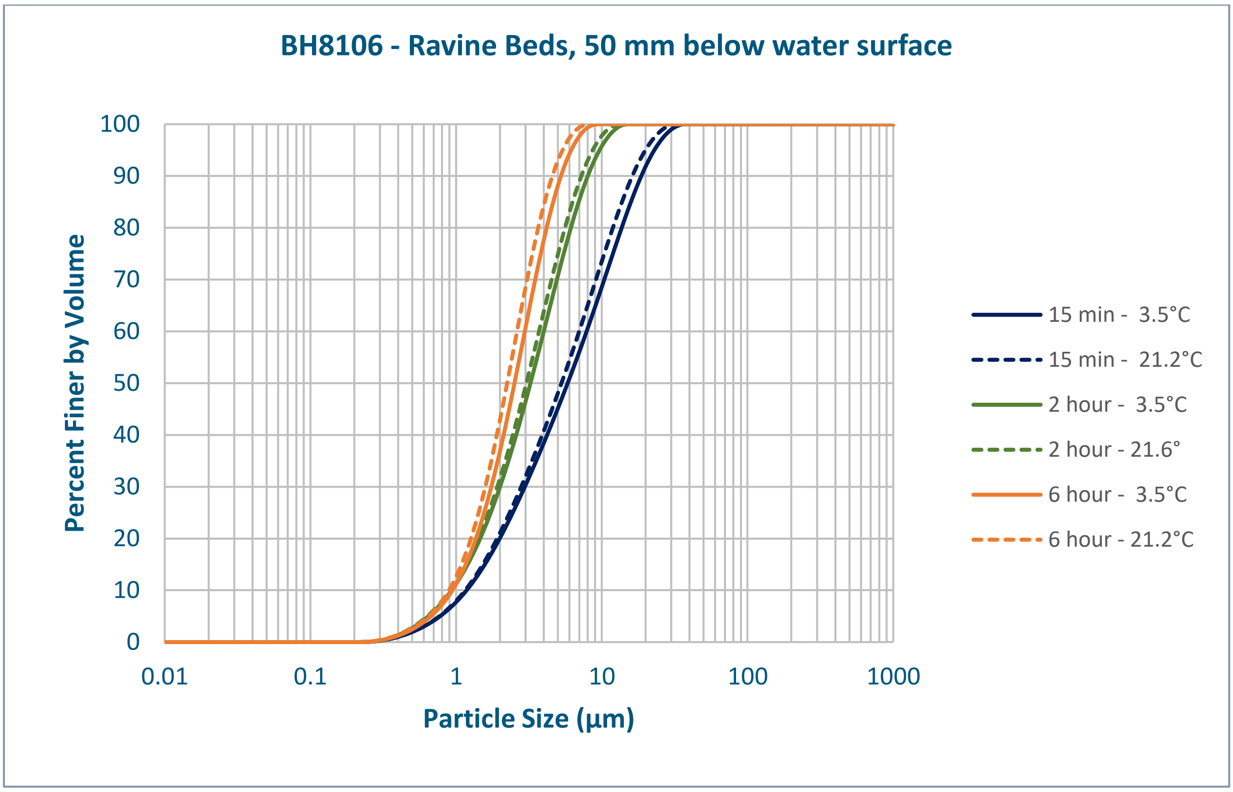
The maximum particle size in suspension after a given time interval was determined in accordance with the method described in **Section 3.3.4** of **Settlement characteristics of fine crushed rock, Laboratory Assessment Factual Report (Haskoning, 2018)**. The tests were typically undertaken at ambient room temperature, which was uncontrolled and typically around 15 °C to 25 °C. The water temperature in Talbingo and Tantangara Reservoirs would typically be lower than this range.

To investigate the effect of temperature on settling performance, a duplicate of the critical particle size analysis was undertaken on Ravine Beds (BH8106) on the 21st October 2018. One set of columns was maintained at room temperature while a second set of columns was placed in a refrigerator at 3.5 °C.

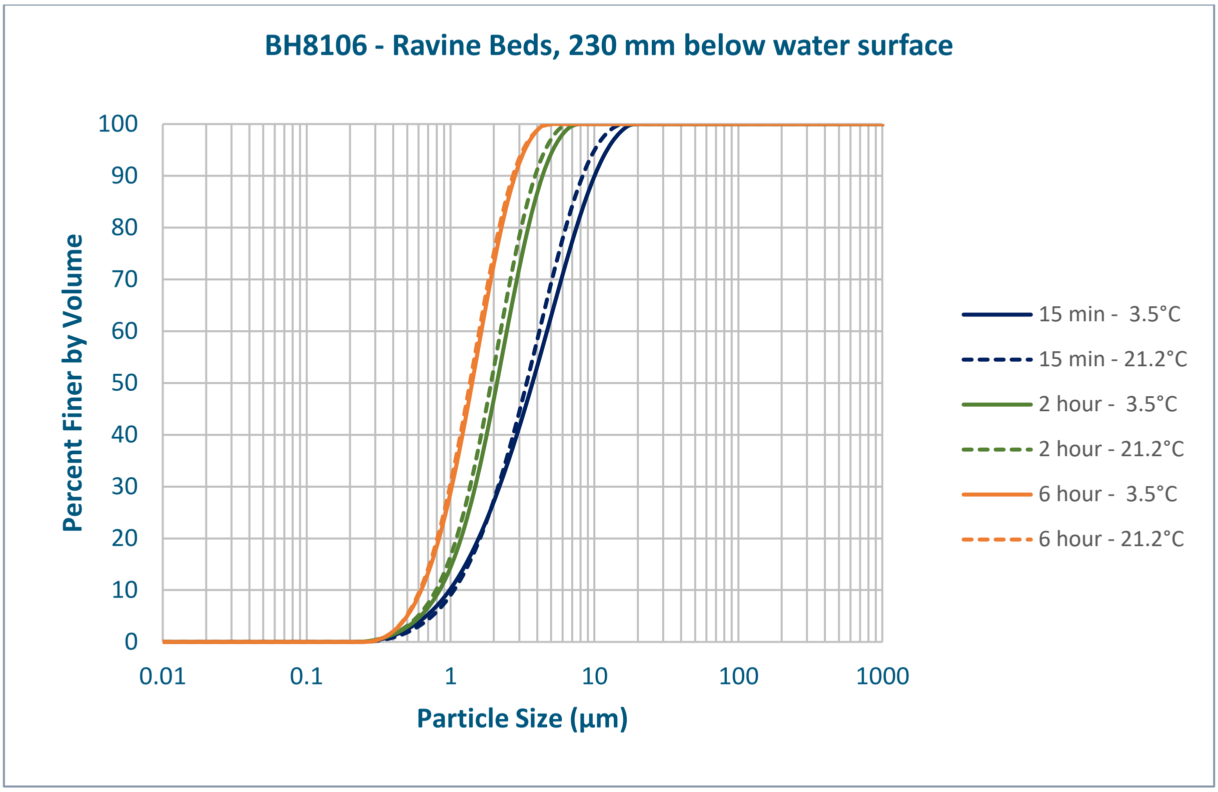
3.3.2 Results and Observations

Air temperature, inside and outside of the refrigerator, and water temperature was recorded every 15 minutes for the duration of the test (6 hours) using Solinist Leveloggers and a Barologger. Room temperature throughout the test varied between 20.2°C and 22.2°C (average 21.6°C). The water temperature in a column maintained at room temperature varied between 20.1 °C and 22.2 °C (average 21.2 °C) while the water temperature in a refrigerated column varied between 3 °C and 4.5 °C (average 3.5 °C).

A comparison of particle size distribution results for the Ravine Beds geological zone (BH8106) at varying temperature is presented in **Graph 6a** and **Graph 6b.** The sub-samples were obtained 15 minutes, 2 hours and 6 hours after addition of crushed rock and at 50 mm and 230 mm below the water surface.



Graph 6a: Refrigerated (3.5 °C) and room temperature (21.2 °C) tests for Ravine Beds geological zone at varying time intervals and 50 mm below water surface.



Graph 6b: Refrigerated (3.5 °C) and room temperature (21.2 °C) tests for Ravine Beds geological zone at varying time intervals and 230 mm below water surface.

3.3.3 Discussion

The results presented in **Graph 6a** and **Graph 6b** indicate that the suspended crushed rock in the columns maintained at a cooler temperature were marginally coarser than the suspended crushed rock in the columns maintained at warmer temperatures at the depths and time intervals sampled. This outcome was expected, because colder water has a higher density and dynamic viscosity which results in higher resistance to settlement of particles, and therefore, coarser sediment is retained in suspension for longer. This phenomenon is described by Stokes Law:

$$w = \frac{2 * (\rho_p - \rho_f) * g * r^2}{9 * \mu}$$

Where w is the settling velocity, ρ_p is the particle density, ρ_f is the fluid density, g is acceleration due to gravity, r is the particle radius and μ is the dynamic viscosity of the fluid. Water at 3.5 °C has a density of roughly 999.9 kg/m^3 and dynamic viscosity of 1.63x10^{-3} Ns/m^2, while water at 21.2 °C has a density of roughly 997.8 kg/m^3 and dynamic viscosity of 0.97x10^{-3} Ns/m^2 (The Engineering Toolbox, 2018). All other terms remain constant, irrespective of temperature. As per Stokes Law, the larger viscosity term combined with higher density of the cold-water results in reduced settling velocity.

In general, however, there is considered to be marginal difference between the particle size distribution and maximum particle size in suspension obtained for the two tests at different temperatures. The temperatures considered for these tests (approximately 3.5 °C and approximately 21.2 °C) encompass the range of temperatures that would be expected within the Talbingo and Tantangara Reservoirs, and as such, temperature is not expected to be a significant consideration for the settling behaviour of crushed rock.

3.4 Length of Fall Pipe in Settlement Test

3.4.1 Overview

The base of the fall pipe in the settlement test was approximately 50 cm below the water surface. In six of the tests, surface turbidity increased from a background level of approximately 2 NTU to more than 10 NTU within approximately six days following commencement of the test. Surface turbidity in two of the tests increased to approximately 5 to 10 NTU and surface turbidity in only one of the tests (Byron Range Group) was within range of natural reservoir turbidity levels (1 to 5 NTU reported by Cardno) at the conclusion of the settlement tests.

Sensitivity tests were undertaken to determine whether a longer fall pipe would result in lower surface turbidity levels. Two settlement columns (2000 mm high) were filled with 50 L of water from Talbingo Reservoir. A fall pipe with an internal diameter of 50 mm was placed in each column. The depth of the fall pipe in each test was:

- Test 10A – base of the fall pipe 165.3 cm below the water surface (7.5 cm above the base of the column); and,
- Test 10B – base of fall pipe 50 cm below the water surface (122.8 cm from the bottom of the column).

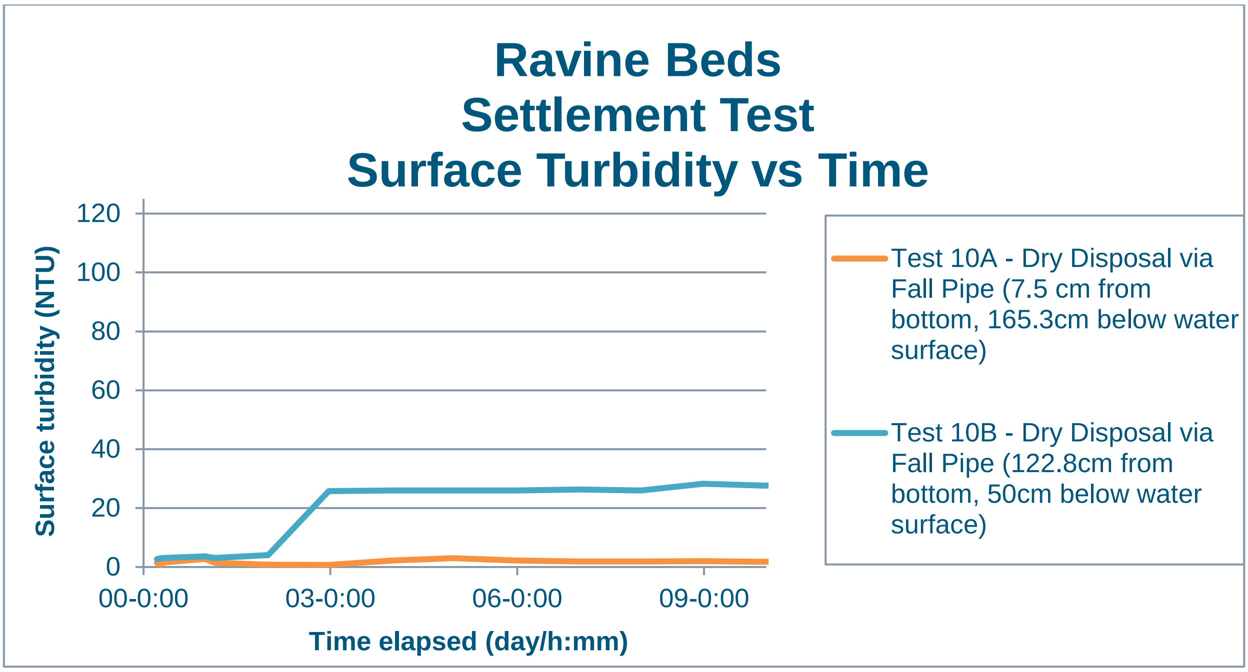
Approximately 40 g of crushed rock from the Ravine Beds (BH8106) geological zone was gently sprinkled into the fall pipes simultaneously. The top of each fall pipe was approximately 75 cm above the water surface. The inside of the fall pipe was rinsed with water from Talbingo Reservoir to ensure that all of the sieved crushed rock entered the column.

The two settlement tests (Tests 10A and 10B) commenced simultaneously on 20th November 2018 at 9:15am. The tests concluded on 30th November 2018, approximately 10 days following commencement.

Surface turbidity in the two columns was measured 25 minutes prior to addition of the sieved crushed rock, with results of 0.9 NTU and 1.8 NTU obtained for Test 10A and 10B respectively.

3.4.2 Results and Observations

Surface turbidity measured at varying time intervals during the 10-day test duration is plotted in **Graph 7** for the two settlement tests. Laboratory log records completed during the settlement tests are provided in **Attachment 1**.



Graph 7: Surface turbidity measured during settlement tests on Ravine Beds with fall pipe of varying length (Tests 10A and 10B).

Significant mixing and diffusion of crushed rock was observed within the fall pipes for Tests 10A and 10B. A turbid plume appeared to descend through the fall pipes at a similar rate over the initial 15-20 seconds (refer **Figure 1**).

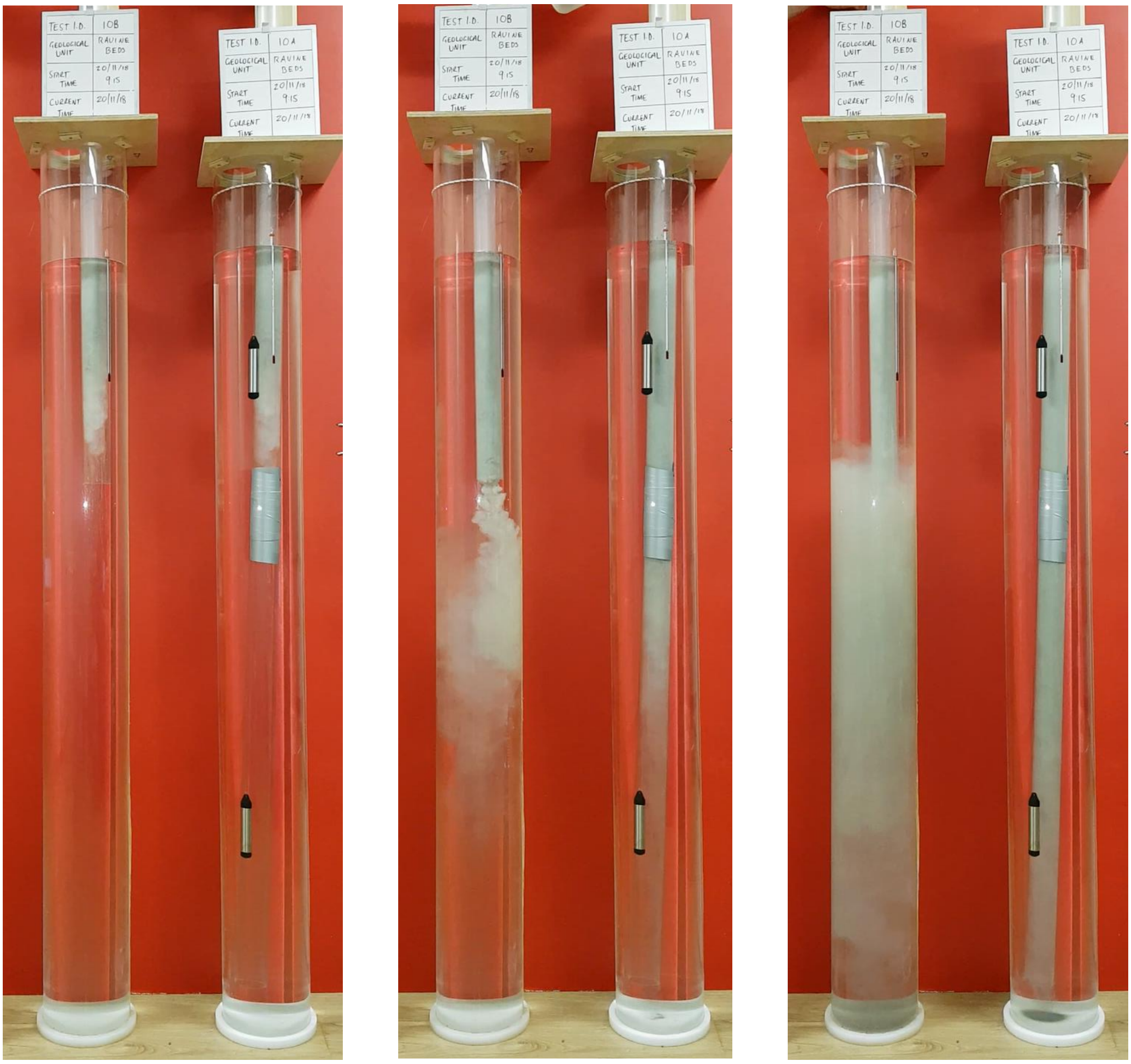


Figure 1: Test 10A (right column in each photograph, fall pipe extended with a splint and grey duct tape) and Test 10B (left column in each photograph) at various time intervals as follows:

- *Left photograph – 15 seconds after placement of crushed rock. Similar settlement velocity in both columns.*
- *Middle photograph – 55 seconds after placement of crushed rock. Crushed rock descended to base of fall pipe in Test 10A. Mixing and diffusion in Test 10B.*
- *Right photograph – 2 minutes after placement of crushed rock. Deposition at base of column in Test 10A. Ongoing mixing and diffusion in Test 10B.*

Clumps of crushed rock fell through the upper portion both fall pipes. However, fine material parted from the clumps during descent and a turbid trail formed through the water column in the wake of the clumps. The clumps generally dissipated before descending to the bottom of the fall pipes.

The dense turbid plume within the fall pipe gradually descended and reached the base of the fall pipe in Test 10B after approximately 20 seconds. The turbid plume diffused throughout the water column, primarily below the base of the fall pipe. After approximately 1 minute and 30 seconds, significant mixing was observed in the middle third of the column, below the fall pipe. After 3 minutes, turbidity was observed in the lower two thirds of the water column, below the base of the fall pipe.

Conversely, in Test 10A, the crushed rock descended to the base of the fall pipe after approximately 55 seconds (refer **Figure 1**). Deposition of crushed rock was observed on the base of the column within approximately 5 seconds of the crushed rock reaching the base of the fall pipe. The deposition of crushed rock at the base of the column accumulated over the following 3 minutes, primarily immediately below the fall pipe with minimal lateral spreading (refer **Figure 1**). Approximately 4 minutes after commencement, turbidity at the base of the water column affected clarity and obscured the view of the deposition of crushed rock and the base of the column.

During the initial stages of both Test 10A and 10B, there was no immediate discernible change in turbidity above the base of the fall pipe, while surface turbidity remained at background levels (refer **Graph 7**).

Surface turbidity in Test 10A remained at less than 3 NTU throughout the duration of the test. The top of the turbid plume (relative to the base of the column) descended from approximately 165.1 cm below the water surface (7.7 cm from the base of the column) to 165.5 cm below the water surface (7.3 cm above the base of the column) over the 10-day test duration.

Conversely, surface turbidity in Test 10B gradually increased during the test. Approximately 2 days after commencement of the test, surface turbidity was 4 NTU. At this point, a relatively rapid increase in surface turbidity was observed. Approximately 3 days after commencement of the test, surface turbidity was 25.8 NTU and a haze was noticeable above the denser turbid plume (below the base of the fall pipe). Surface turbidity remained relatively stable between 26 NTU and 28.3 NTU for the remainder of the test. Photographs taken approximately 3 days and 10 days after commencement of the test are provided in **Figure 2**.

The top of the turbid plume in Test 10B was recorded at approximately 3.2 cm above the base of the fall pipe immediately after placement of crushed rock. The top of the turbid plume was clearly distinguishable for the duration of the test. The top of the plume descended to 58 cm, above the base of the column, approximately 10 days after commencement, which corresponds with a plume settlement rate of 6.8 cm/day.

Figure 2: Test 10A (right column in each photograph) and Test 10B (left column in each photograph) at various time intervals as follows:

- *Left photograph – approximately 3 days after placement of crushed rock; and*
- *Right photograph – approximately 10 days after placement of crushed rock.*

3.4.3 Discussion

The increase in surface turbidity with a short (50 cm deep) fall pipe (Test 10B) was somewhat unexpected, with ongoing settlement and decreasing surface turbidity following initial mixing considered more likely to occur. However, this outcome was consistent with the previous settlement tests simulating placement through a short fall pipe undertaken for Ravine Beds and the remaining eight geological zones.

The longer fall pipe (165 cm, Test 10A) was effective in reducing surface turbidity. Significant deposition was observed at the base of the column, within 5 minutes of commencement of the test. Furthermore, the photograph taken 55 seconds after commencement of the test (refer **Figure 1**) indicated that crushed rock in Test 10A descended quicker than in Test 10B. Crushed rock was observed to diffuse through the entire width of the laboratory settlement column, below the base of the short fall pipe. It is inferred that a loss in fall velocity is encountered below the base of the short fall pipe, due to entrainment of the surrounding ambient (stationery) fluid.

The turbid plume below the base of the fall pipe migrated towards the surface in Test 10B while in Test 10A, the turbid plume did not disperse or migrate towards the surface. It is hypothesised that weak convection currents in Test 10B resulted in the advection of crushed rock. In comparison, confinement and end effects at the base of the column in Test 10A may have reduced the velocity of vertical (and horizontal) currents below the base of the fall pipe.

End effects arise due to the viscosity and incompressibility of water. Boundary resistance (or boundary shear stress) at the base of the column results in a ‘No Slip’ condition where the horizontal and vertical water velocity is zero. Horizontal and vertical water velocities (if present) would increase with distance from the base of the column. The zone over which water velocity increases, from the boundary, is referred to as the boundary layer.

The boundary effect and boundary layer for open channel flow regimes is portrayed in **Figure 3** for various shaped channels. Similar boundary effects and boundary layers would be observed along the walls and at the base of the columns used for the laboratory investigation.

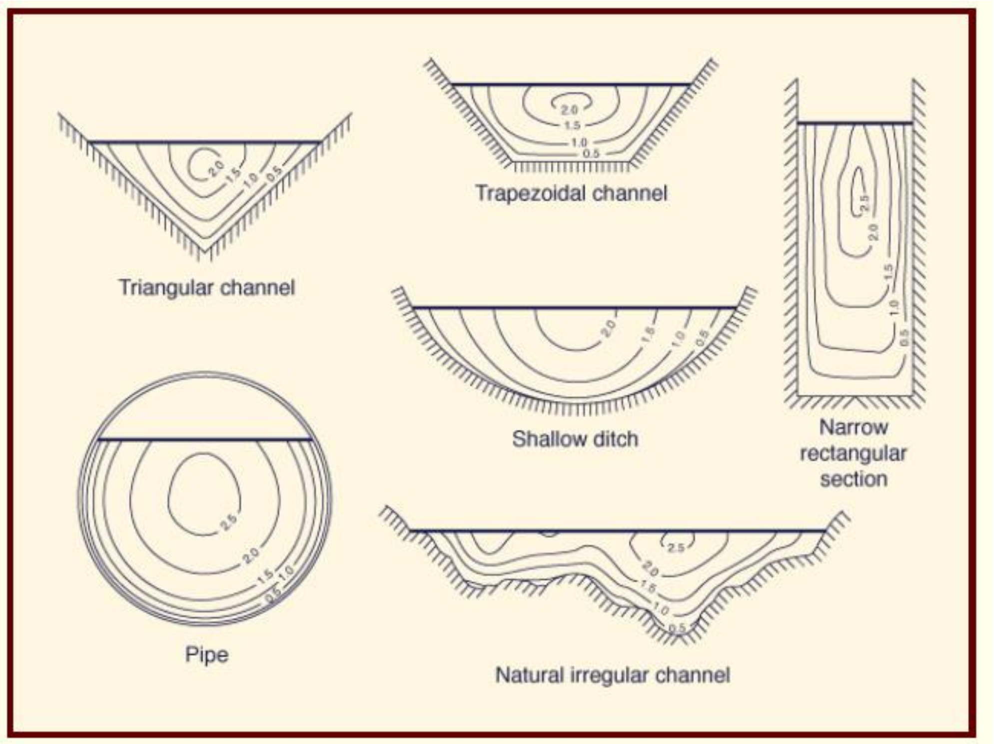


Figure 3: Diagrammatic representation of boundary effect and boundary layer for various open channel sections. The cross sections include isovels that joins regions of equal horizontal water velocity through the channel (San Diego State University, 2018).

3.5 Capping of Column in Settlement Test

3.5.1 Overview

The column tests and settlement tests that simulated surface placement of crushed rock were generally capped for the duration of the tests to prevent foreign matter entering the column. The caps were removed to obtain turbidity measurements. The caps loosely fit on top of the column; there were no rubber seals or screw fittings.

Sensitivity tests were undertaken to determine whether the lid of the settlement columns was having an influence on settlement velocity and surface turbidity. Two settlement columns (2000 mm high) were filled with 50 L of water from Talbingo Reservoir. Crushed rock from the Ravine Beds (BH8106) geological zone was gently sprinkled onto the water surface from a height of approximately 25 cm above the water surface. The following scenarios were investigated:

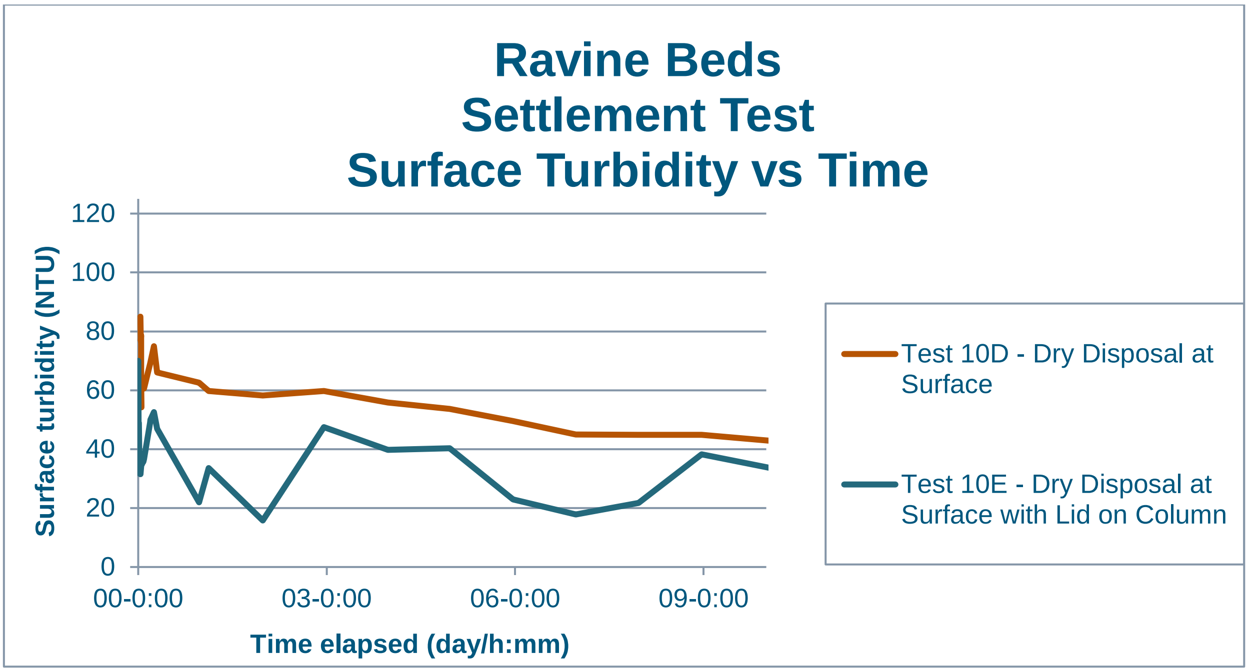
- Test 10D – top of the column remained open for the duration of the test (uncapped); and
- Test 10E – a lid was placed on the column for the duration of the test (capped).

The two settlement tests (Tests 10D and 10E) commenced simultaneously on the 20th November 2018 at 9:45am. The tests concluded on 30th November 2018, approximately 10 days following commencement.

Turbidity in the two columns was measured 55 minutes prior to addition of the sieved crushed rock, with results of 2.7 NTU and 2.0 NTU obtained for Tests 10D and 10E respectively.

3.5.2 Results and Observations

Surface turbidity measured at varying time intervals during the 10-day test duration is plotted in **Graph 8** for the two settlement tests. Laboratory log records completed during the settlement tests are provided in **Attachment 1**.



Graph 8: Surface turbidity measured during the settlement tests on Ravine Beds without and with a lid on the column (Tests 10D and 10E).

The following was observed during placement of the crushed rock:

- Approximately 10-50 seconds after commencement, clumps of crushed rock fell through the upper portion of the column in both Tests. However, fine material parted from the clumps during descent and a turbid trail formed through the water column in the wake of the clumps. The clumps generally dissipated before descending to the bottom of the column.
- Approximately 20 seconds after commencement, crushed rock appeared to fall through the upper portion of both columns with dispersion and mixing approximately 20 cm to 40 cm below the water surface (refer **Figure 4**).
- Approximately 50 seconds after commencement, dispersion and mixing of crushed rock was observed in the upper half of the Test 10D column. A higher fall velocity was observed in Test 10E with turbidity and suspended crushed rock particles observed approximately 20 cm lower in the water column when compared to 10D. Furthermore, the upper approximately 10 cm of Test 10E remained relatively clear whereas turbidity was observed at the surface of the Test 10D column (refer **Figure 4**).
- Approximately 1 minute and 20 seconds after commencement, a gradual change in surface turbidity was observed in the upper approximately 30 cm of the Test 10E column. Relatively similar turbidity was observed throughout the remainder of the column. Conversely, turbidity in the upper layer of the Test 10D column was noticeably higher compared to Test 10E. Relatively even mixing was observed in the upper three quarters of the column and slowly dispersed through the lower portion of the column.
- Approximately 3 minutes after commencement, relatively even mixing throughout both columns was observed. However, a gradual change in surface turbidity remained apparent in the upper approximately 30 cm of the Test 10E column (refer **Figure 5**).

Figure 4: Test 10D (right column of each photograph with no lid on column) and Test 10E (left column of each photograph with lid on column) at various time intervals as follows:

- *Left photograph – 20 seconds after placement of crushed rock.*
- *Middle photograph – 50 seconds after placement of crushed rock.*
- *Right photograph – 1 minute and 20 seconds after placement of crushed rock.*

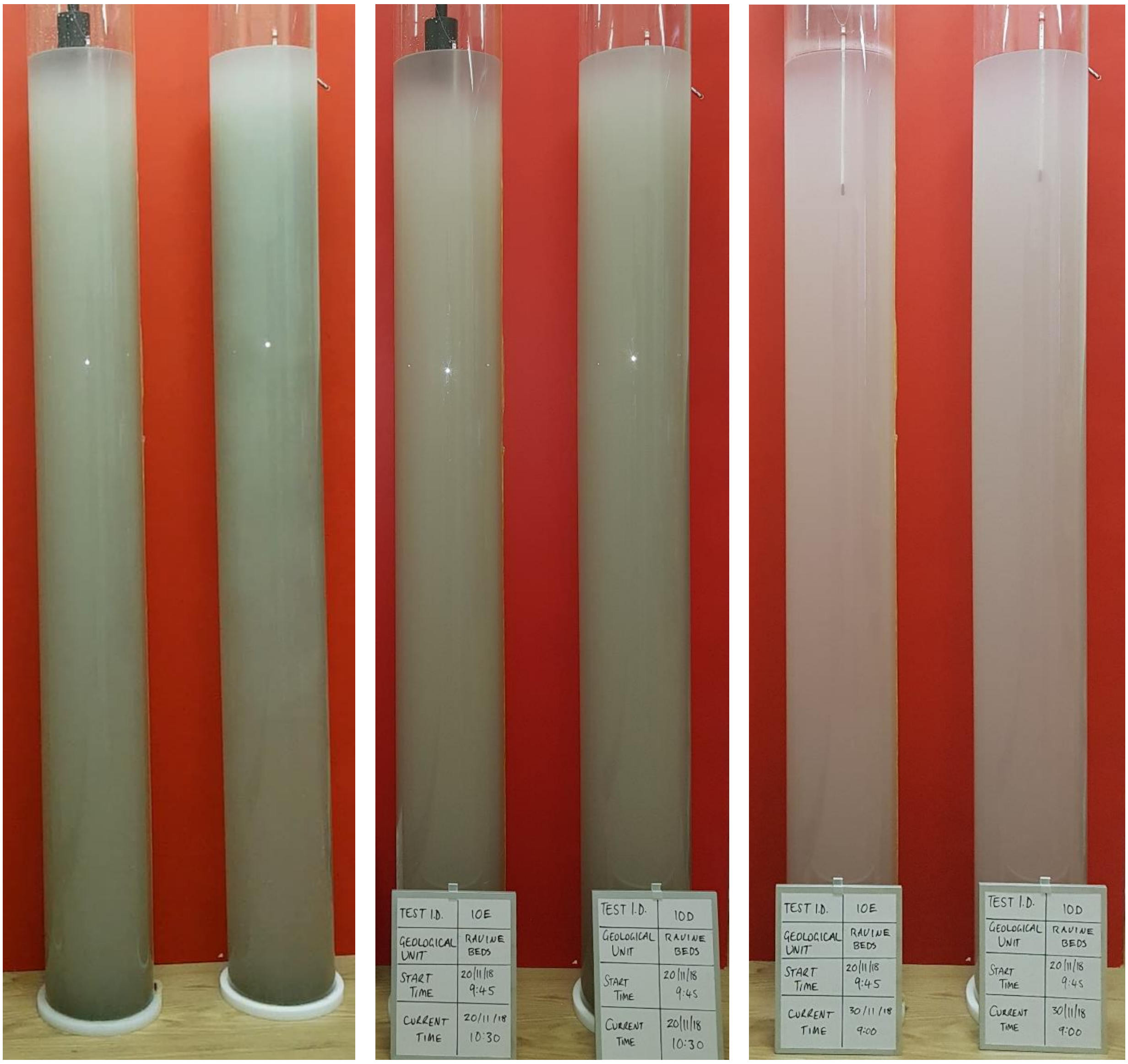


Figure 5: Test 10D (right column of each photograph with no lid on column) and Test 10E (left column of each photograph with lid on column) at various time intervals as follows:

- *Left photograph – 3 minutes after placement of crushed rock.*
- *Middle photograph – 45 minutes after placement of crushed rock.*
- *Right photograph – approximately 10 days after placement of crushed rock.*

Initial surface turbidity in Test 10E was substantially lower than Test 10D. Surface turbidity was 85 NTU and 31.5 NTU in Tests 10D and Test 10E respectively, 50 minutes after commencement of the test (refer **Figure 5**).

In Test 10D, surface turbidity gradually decreased to 54.2 NTU, 1 hour and 15 minutes after commencement before gradually increasing to 75 NTU, 6 hours after commencement. For the remainder of the test, surface turbidity gradually decreased and was 43 NTU after approximately 10 days.

The results for Test 10E were substantially different. Surface turbidity increased to 52.6 NTU, 6 hours after commencement. Surface turbidity fluctuated between 15.8 NTU (2 days after commencement) and 47.5 NTU (approximately 3 days after commencement) for the remainder of the test with a trending decrease in surface turbidity. The increase in surface turbidity was somewhat unexpected and a discussion on the reasons for this are provided in **Section 3.5.3**. Approximately 10 days after commencement, surface turbidity was 34 NTU.

Turbidity was noted to gradually increase in the upper 5 cm to 10 cm of the Test 10E column. After the lid of the column was removed for approximately 5 to 10 minutes, to measure surface turbidity, the gradual change in turbidity was less apparent and surface turbidity was visibly higher. In addition, condensation was observed on the inside walls of the column above the water surface. Condensation was less apparent following removal of the column cap.

Water temperature was measured in both columns for the duration of the test using an alcohol thermometer that remained in the column. The water temperature in Test 10D (uncapped column) was consistently 0.2 °C to 1.1 °C (average 0.4) cooler than Test 10E (capped column).

3.5.3 Discussion

The variation in surface turbidity results for Tests 10D and 10E immediately following placement of crushed rock confounds the results. It is hypothesised that the difference in surface turbidity may be due to:

- slight differences in the particle size distribution of the crushed rock samples that were added to the respective column, notwithstanding that the samples were divided using a riffle splitter; or,
- the interaction and clumping of particles during placement whereby clumps of material fall through the water column at a higher velocity.

The difference in initial surface turbidity levels between the two tests highlights the natural variability that occurs when crushed rock is placed in a body of water.

Regardless of the initial surface turbidity, it is apparent that:

1. water temperature in Test 10E, with a lid on the column, was higher; and
2. surface turbidity in Test 10E, with a lid on the column, fluctuated whereas surface turbidity in Test 10D gradually decreased.

The difference in water temperature is hypothesized to be due to evaporation from Test 10D (uncapped). Evaporation is the transition of water from liquid to vapour and it requires the input of thermal energy that is absorbed by the vapour. The same amount of thermal energy is released when water vapour condenses to form liquid droplets, which was observed in Test 10E. Evaporation removes thermal energy from the water column, thereby lowering the temperature of the water, as observed in Test 10D. However, in Test 10E (capped), the vapour could not escape. The vapour condenses, releasing thermal energy which results in warming of the body of water.

It is hypothesised that the process of evaporation and condensation was responsible for the gradual change in turbidity observed up to approximately 10 cm below the water surface in Test 10E. Evaporation is a purifying process and the vapour would not contain suspended crushed rock particles. The condensation in Test 10E would result in purified water precipitating. The precipitate would overlie and mix with the turbid water in the column thereby decreasing surface turbidity.

3.6 Progressive Addition of Crushed Rock in Settlement Test

3.6.1 Overview

The column tests and settlement tests involved one-off ‘bulk’ placements of 40 g of dry crushed rock. A sensitivity test was undertaken to determine whether the progressive addition of crushed rock would influence surface turbidity in a different way to the bulk placements. Two settlement columns (2000 mm high) were filled with 50 L of water from Talbingo Reservoir. Crushed rock was gently sprinkled onto the water surface from a height of approximately 25 cm above the water surface. The following scenarios were investigated:

- Test 10E – 40 g of crushed rock sprinkled on the surface (single ‘bulk’ placement); and
- Test 10F – 5 g of crushed rock sprinkled on the surface, at approximately 9:00am each day for 8 days (40g of crushed rock in total, ongoing ‘progressive’ placement).

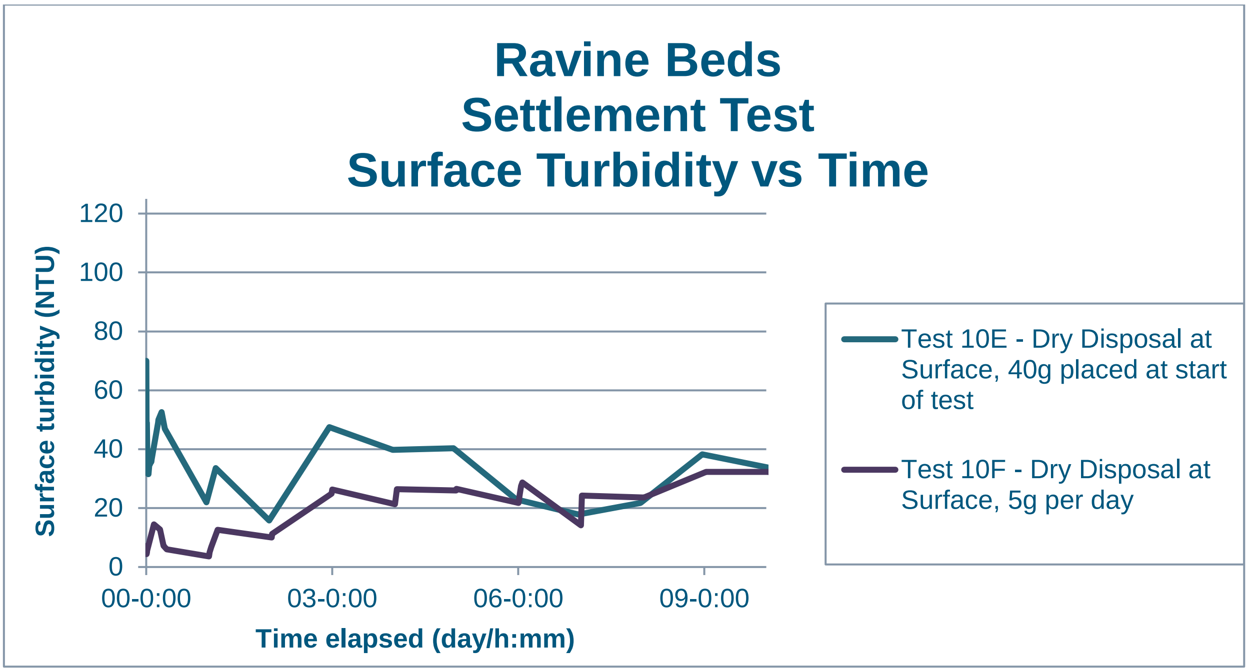
Lids were placed on both columns to prevent foreign material from entering the column.

The two settlement tests (Tests 10E and 10F) commenced on 20th November 2018 at 9:45am and 9:00am respectively. The tests concluded on 30th November 2018, approximately 10 days following commencement.

Turbidity in the two columns was measured prior to addition of the sieved crushed rock, with results of 2.0 NTU and 2.4 NTU obtained for Tests 10E and 10F respectively.

3.6.2 Results and Observations

Surface turbidity measured at varying time intervals during the 10-day test duration is plotted in **Graph 9** for the two settlement tests. Laboratory log records completed during the settlement tests are provided in **Attachment 1**.



Graph 9: Surface turbidity measured during the settlement tests on Ravine Beds comparing mass placement of crushed rock to progressive placement of crushed rock over 8 days.

Observations from Test 10E are discussed in **Section 3.5.2.** Surface turbidity was 31.5 NTU, 50 minutes after commencement of the test. Surface turbidity subsequently reduced to 15.8 NTU (2 days after commencement) and then increased to 47.5 NTU (approximately 3 days after commencement). Over the remaining seven days of the test (days 3 to 10), surface turbidity ranged between around 15 NTU and 40 NTU, with a trending decrease in levels. Approximately 10 days after commencement, surface turbidity was 34 NTU.

The following was observed during initial placement of the crushed rock in Test 10F:

- Approximately 10 to 50 seconds after commencement, clumps of crushed rock fell through the upper portion of the column. However, fine material parted from the clumps during descent and a turbid trail formed through the water column in the wake of the clumps. The clumps generally dissipated before descending to the bottom of the column.
- Approximately 30 seconds after commencement, crushed rock appeared to fall through the upper portion of the column with dispersion and mixing approximately 10 – 40 cm below the water surface.
- Approximately 9 minutes after commencement, a gradual change in surface turbidity was observed in the upper approximately15 cm with turbidity increasing with depth. Peak turbidity in the column appeared to be around 20 cm below the water surface. Turbidity gradually decreased with minimal turbidity observed in the lower approximately 30 cm of the water column.
- Surface turbidity was 5.7 NTU approximately 25 minutes after commencement of the settlement test, and 14.5 NTU approximately 3 hours after commencement of the settlement test.

Settlement and dispersion of crushed rock at each placement interval appeared to be slower in Test 10F compared to Test 10E.

Approximately 24 hours following commencement of Test 10F, immediately prior to the second addition of 5 g of crushed rock, turbidity appeared to gradually increase in the upper approximately15 cm of the water column, with a surface turbidity of 3.6 NTU. Turbidity throughout the remainder of the column appeared to be relatively uniform. During the second placement of crushed rock, similar processes were observed as per the initial placement described above. Clumps of crushed rock fell through the upper water column, a dense plume formed approximately 20 cm to 40 cm below the water surface, and after approximately 9 minutes, turbidity gradually decreased with lower turbidity observed in the bottom approximately 30 cm of the water column. Approximately 50 minutes after addition of the second batch of crushed rock, surface turbidity was 6.8 NTU.

Similar observations were made during each subsequent addition of crushed rock. Surface turbidity generally increased during each placement and throughout the test. However, a dense turbid plume formed around 20 cm to 40 cm below the water surface with lower turbidity near the surface and at the bottom of the column.

Water temperature was measured in both columns for the duration of the test using an alcohol thermometer that remained in the column. The water temperature was generally identical in both columns, as expected.

3.6.3 Discussion

As indicated in **Graph 9**, surface turbidity in both columns was similar after the addition of the 40 g of crushed rock (>8 days following commencement of the settlement tests).

Surface turbidity in Test 10E gradually decreased over time. However, the settlement rate for fine crushed rock, that remains in suspension for more than 24 hours, appears extremely slow with similar surface turbidity observed 1 day after commencement and 10 days after commencement of the settlement test.

Surface turbidity in Test 10F gradually increased as more crushed rock was added to the column. This was a result of the progressive increase in the mass of suspended solids as additional crushed rock was placed into the water column.

From the results of Test 10F it can be concluded that long-term surface turbidity levels do not appear to be influenced by the rate of placement of crushed rock (i.e. surface turbidity was the same in both columns following the placement of an equal mass of crushed rock).

If surface turbidity in Test 10F was lower than 10E at completion of the test, it would be reasonable to infer that placement of crushed rock into a turbid water body (containing suspended crushed rock particles) results in collision between, and agglomeration of, particles leading to increased settlement rates. Conversely, if surface turbidity in Test 10F was higher than 10E at completion of the test, it would be reasonable to infer that placement of crushed rock into a turbid water body (containing suspended crushed rock particles) results in hindered settlement leading to decreased settlement rates in Test 10F or that a portion of the suspended crushed rock in Test 10E settles faster that the rate of progressive placement in Test 10F.

However, as the surface turbidity was similar following the placement of an equal mass of crushed rock in both columns, it suggests that placement of crushed rock into a water body containing suspended crushed rock particles, has minimal influence on the settlement of particles already in suspension and fine crushed rock, following entrainment, remains in suspension for extended periods in the order of several weeks.

3.7 Effect of Temperature Fluctuation in Settlement Test

3.7.1 Overview

The first settlement and column tests undertaken in the laboratory assessed the settling behaviour of the Ravine Beds geological zone (Test 1). These tests were undertaken in the absence of block-out curtains. Unexpected results were obtained including:

- Increase in surface turbidity during Test 1B and Test 1C for crushed rock placed through a fall pipe (crushed rock was dry placed in Test 1B and pre-wetted crushed rock was placed in Test 1C); and,
- Dispersion of fines and collapse of stratified layers in Test 1A and Test 1D. Following further investigations, and noting that the stratified layers were typically identified in approximately the upper10 cm of the column, this observation may have been related to the presence of lids on the columns (refer **Section 3.5**).

It was hypothesised that the advection of fine suspended solids towards the surface following placement through a fall pipe was most likely a result of fluctuations in water temperature leading to the formation of weak convection currents within the column. However, this observation could also be due to the repelling force between anionic clay particles and/or disturbance of the waterbody during measurement of surface turbidity with the Wetlab ECO-NTU sensor.

In an attempt to regulate air and water temperature in the laboratory and to prevent sunlight from shining directly onto the columns, block-out curtains were installed across the windows for Test 2 to Test 9. In addition, water temperature and air temperature was recorded every 15 minutes (in one column) for the duration of the tests using Solinist Leveloggers and a Barologger to enable assessment of temperature variation during testing.

Despite the presence of block-out curtains, similar observations were made for Test 2 to Test 9 with increasing turbidity, above the base of the fall pipe, observed in Test 2B to 5B and Test 7B to 9B. Temperature was monitored at two (2) depths within the water column. The maximum, minimum and average water and air temperature in Test 2 to Test 9 is recorded in **Table 3**.

Table 3: Air and water temperature recorded during the laboratory investigation.

Test	Depth of probe below water surface (cm)	Water Temperature			Difference in Water Temperature Between Lower and Upper Monitoring Location			Air Temperature		
		Minimum (°C)	Maximum (°C)	Average (°C)	Minimum (°C)	Maximum (°C)	Average (°C)	Minimum (°C)	Maximum (°C)	Average (°C)
Test 2B simultaneous to Test 3	21.6	15	19.5	17.76	0	0.8	0.35	14.45	21.98	18.07
	129.1	14.7	19.2	17.41						
Test 4B simultaneous to Test 5	25.3	16.2	22.5	18.67	0.1	0.9	0.34	15.89	24.5	19.03
	126.8	16.1	21.9	18.32						
Test 6B simultaneous to Test 7	29.8	19.8	25.1	21.41	0.2	0.9	0.4	19.47	27.52	21.84
	133.8	19.6	24.2	21.02						
Test 9B simultaneous to Test 8	30.4	20	24.3	21.46	0	0.6	0.24	19.81	25.14	21.68
	120.4	19.9	24.2	21.22						
Test 10A (during operation of Air Conditioning)	34	20.1	22.6	21.43	0	0.5	0.21	19.77	23.18	21.6
	134.5	19.9	22.4	21.22						
Test 10A (post operation of Air Conditioning)	34	20.1	25.1	23.63	0.1	0.9	0.4	20.25	27.47	24.1
	134.5	19.9	24.6	23.22						

Test 10 was then undertaken to determine whether maintaining a consistent air temperature (and water temperature) would affect settlement rates and/or surface turbidity following placement of crushed rock through a short fall pipe. The following tests were then repeated for the Ravine Beds geological zone:

- Test 1A (dry placement on the surface) - repeated in Test 10E; and,
- Test 1B (dry placement through a fall pipe, 50 cm below the water surface) - repeated in Test 10B.

The duplicate testing on Ravine Beds (Test 10) was undertaken with automatic temperature control on an air-conditioning unit at the laboratory set at 23 °C. This temperature was selected as it was the approximate mean air temperature. Block-out curtains were maintained across the windows as per Test 2 to Test 9. The air conditioning unit was turned off after approximately 10 days.

The two duplicate settlement tests (Tests 10B and 10E) commenced simultaneously on 20th November 2018 at 9:15am and 9:45am respectively. The tests concluded on 30th November 2018, approximately 10 days following commencement. The test columns were retained for an additional 12 days, without air-conditioning to regulate air temperature. This was to assess whether there was a notable reduction in temperature fluctuation with the air conditioning operating and to assess variations in surface turbidity with and without regulation of the air temperature.

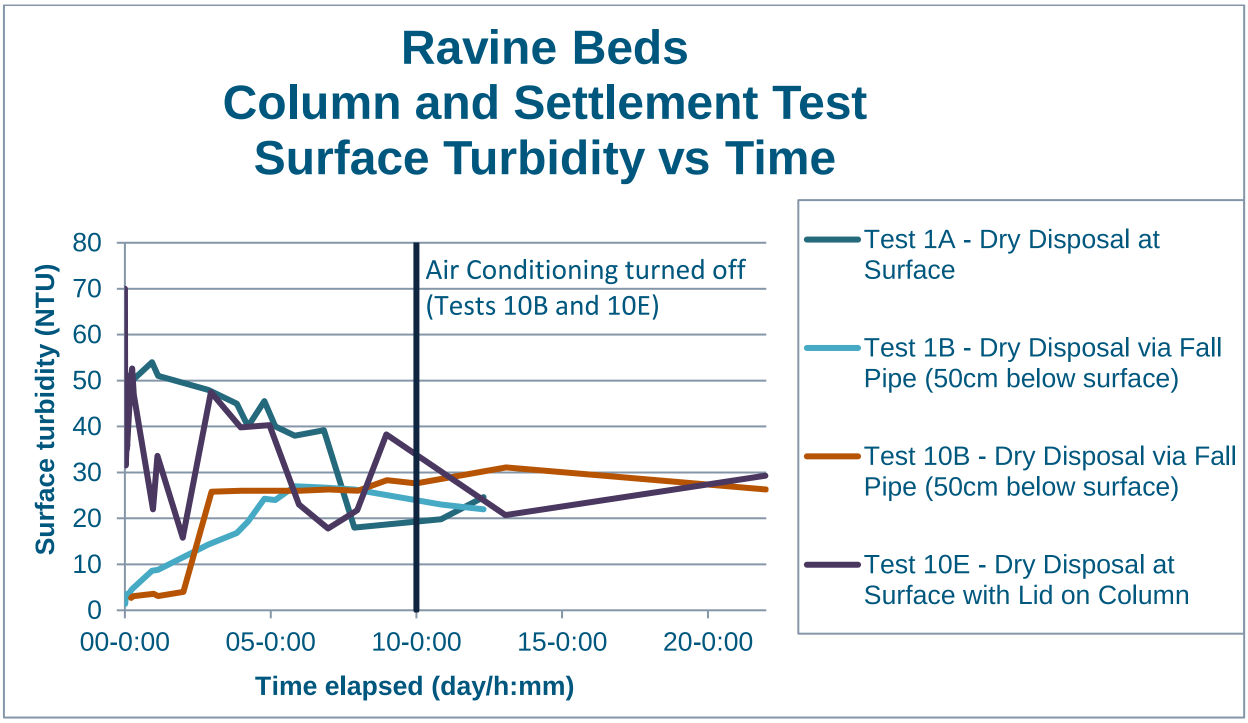
Surface turbidity in the two columns was measured 25 minutes prior to addition of the sieved crushed rock, with results of 1.8 NTU and 2.0 NTU recorded for Tests 10B and 10E respectively.

Air temperature and water temperature was recorded every 15 minutes during Test 10A (crushed rock placement through a long fall pipe) using a Barologger and Solinist Leveloggers. Water temperature was monitored at two depths, 34 cm and 134.5 cm below the water surface. Test 10A commenced simultaneous to Test 10B. Test 10A was undertaken in the same room and within approximately 2-m of Test 10B and Test 10E. It is assumed that water temperature in Test 10A is representative of water temperature in Test 10B and Test 10E. The maximum, minimum and average water and air temperature in Test 10A is recorded in **Table 3**.

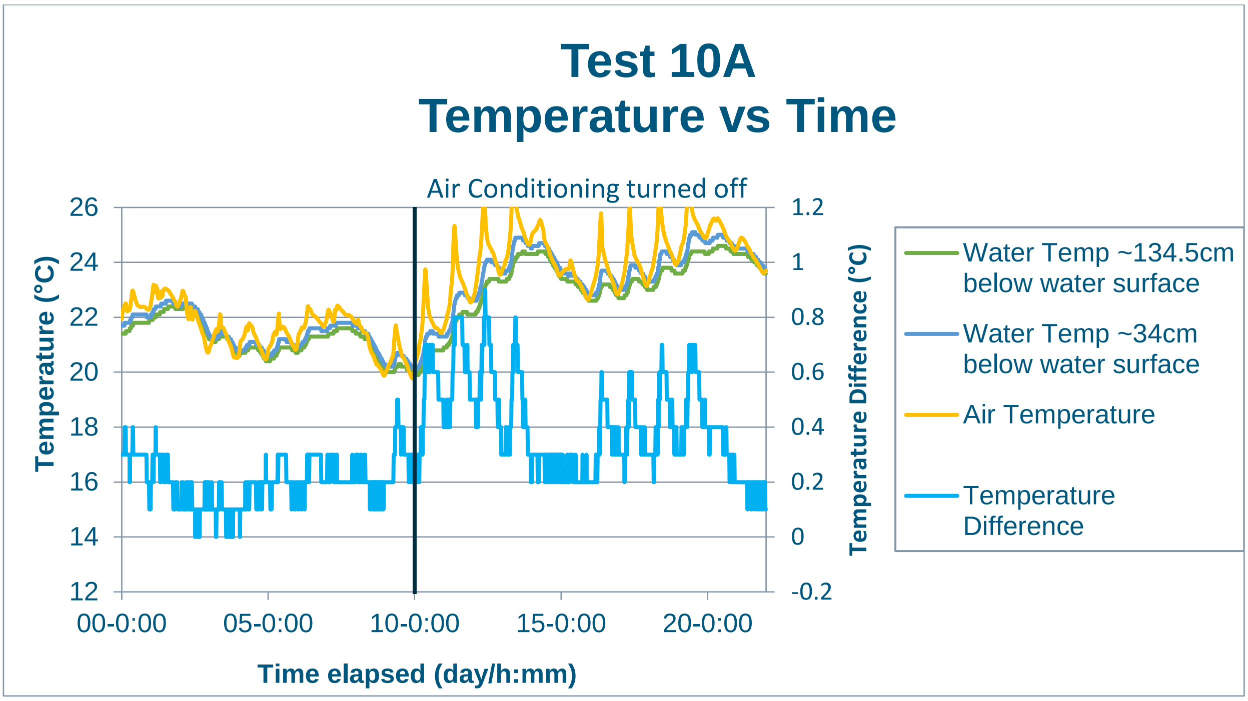
It is noted that the original test for the Ravine Beds geological zone (Test 1) was conducted on rock crushed using a hammer drill while the duplicate test (Test 10) was conducted on rock crushed with a ring mill.

3.7.2 Results and Observations

Surface turbidity measured at varying time intervals during the 22-day test duration is plotted in **Graph 10** for the two duplicate settlement tests alongside settlement test results for Test 1 (Ravine Beds). Laboratory log records completed during the duplicate settlement tests are provided in **Attachment 1**. Air and water temperature recorded every 15 minutes in Test 10A are presented in **Graph 11**. A summary of air and water temperature in Test 10A is provided in **Table 3**.



Graph 10: Surface turbidity measured during the initial (Test 1A and 1B) and duplicate (Test 10B and 10E) settlement tests on Ravine Beds. Air conditioning turned off, 10 days after commencement of Test 10B and 10E.



Graph 11: Air and water temperature in Test 10A (simultaneous to Test 10B).

Observations from Test 10B and Test 10E are discussed in **Section 3.4.2** and **Section 3.5.2** respectively.

From **Table 3** and **Graph 11**, it is apparent that water temperature was warmer at higher elevations in the water column. Without air conditioning, the water temperature in Test 2 to Test 9 was consistently 0 °C to 0.9 °C warmer at the upper monitoring location, while the average temperature differential between the monitoring depths varied between 0.24 °C (Test 9) and 0.4 °C (Test 6).

The temperature differential in Test 10A (with air conditioning operating) was less apparent. The water temperature was consistently 0 °C to 0.5 °C warmer at the upper monitoring location, while the average temperature differential between the monitoring depths was 0.21 °C. After the air conditioner was turned off, approximately 10 days after commencement of Test 10A, the temperature differential was similar to Test 2 to Test 9; water temperature was consistently 0.1 °C to 0.9 °C warmer at the upper monitoring location while the average temperature differential between the monitoring depths was 0.4 °C.

From **Graph 10**, it is apparent that surface turbidity in Test 10E (duplicate surface placement) fluctuated more than Test 1A (initial surface placement). However, 5 days after placement of crushed rock, surface turbidity was approximately 40 NTU for both Test 1A and Test 10E, whereas 10 days after placement of crushed rock, surface turbidity was approximately 20 NTU for Test 1A and 34 NTU for Test 10E. Given the fluctuation in surface turbidity, similar settlement characteristics were observed.

Surface turbidity in Test 1B (initial fall pipe placement) and Test 10B (duplicate fall pipe placement) was similar throughout the duration of the respective tests. Surface turbidity increased to around 25 NTU after 3 to 5 days and remained relatively constant for the remainder of the tests. However, surface turbidity in Test 1B increased gradually whereas surface turbidity in Test 10B increased rapidly between 2 and 3 days after commencement of the test. The increase in surface turbidity during Test 10B corresponded with a decrease in water temperature of 1.3 °C over 17 hours. The difference in water temperature between the upper and lower monitoring location during this period was 0 °C to 0.2 °C, which is less than the average temperature differential of 0.21 °C.

3.7.3 Discussion

Automatic air conditioning in the laboratory combined with block out-curtains implemented for Test 10 was effective in regulating air and water temperature compared to Test 2 to Test 9, which were not undertaken under temperature control. Despite the reduced fluctuation in air temperature, the water temperature in the Test 10A column varied by approximately 2.5 °C during the 10-day test period. Water temperature varies in response to air temperature.

An increase in surface turbidity was observed during Test 10B (short fall pipe) despite the reduced temperature variation. However, the increase in surface turbidity corresponded with a period of decreasing water temperature and minimal temperature variation between the temperature monitoring locations in the column.

Warmer water near the top of the column would have a lower density and would therefore be buoyant compared to the cooler water lower in the column. This is referred to as a thermocline and reduces the potential for mixing of horizontal layers within a body of water. However, during a period of cooling, the temperature variation between the upper and lower monitoring locations in Test 10A was minimal (0 to 0.2 °C) and the water density throughout the column would generally be consistent. The similarity in water temperature and density throughout the column would be less likely to suppress mixing and/or the formation of convection currents. Therefore, minor variations in water temperature would be sufficient to form weak convection currents in the column.

Convection currents usually occur during a heating phase where warmer water, with a lower density, rises to cooler areas in the column and cooler water, with a higher density, sinks to take the place of the warmer water. However, they can also occur during a cooling phase, where cool water sinks to warmer areas of the column and warm water is displaced, to take the place of cool water. Convection currents during a cooling phase could lead to the advection of fine suspended solids towards the surface.

Turbidity and temperature graphs for Test 2 to Test 9 are provided in **Attachment 2**. It has been hypothesized that an increase in surface turbidity was associated with convection currents established during a period of warming, which correspond to high temperature differentials between water temperature monitoring locations in the column. It was inferred that heat was transferred from the air to the column and from the column to the adjacent water near the wall of the column through the process of conduction. The temperature differential across the column would lead to the formation of convection currents. This hypothesis could also explain why the water at the top of the column would be warmer than water at lower depths.

However, based on the observations from Test 10 and a review of surface turbidity and temperature plots for the remaining tests in **Attachment 2**, it appears that a period of cooling, resulting in similar water temperatures throughout the column, often corresponds with an increase in surface turbidity.

Based on the results and observations for Test 10, it is apparent that the measures to regulate air temperature were insufficient to prevent advection of fine suspended crushed rock particles towards the surface. Despite the fluctuations and irregularities in settlement behaviour, the settlement test appears to be repeatable and reliable. This is despite different methods adopted for crushing of rock in Test 1 and Test 10.

4 Conclusion

This report documents various QA tests that were conducted to validate the experimental laboratory methodology used to assess the settling performance of different geological zones that are proposed for subaqueous placement as part of Snowy 2.0.

The findings of this report are that the equipment and methodology used in the critical particle size analysis produces consistent and repeatable results of crushed rock settling characteristics and behaviour.

The settlement tests are sensitive to:

1. The depth of placement, with deeper placement resulting in lower surface turbidity levels;
2. The presence of lids placed on the column, with evaporation and condensation appearing to have an influence on surface turbidity; and
3. Temperature fluctuations, where a variation in water temperature was observed to result in an increase in surface turbidity. The increase in surface turbidity is hypothesized to be a result of convection currents.

The temperature of the water has a predictable influence on settlement behaviour. This is explained by Stokes Law and is due to an increase in density and dynamic viscosity of cooler water (and vice versa for warmer water). The effect of overall water temperature is measurable but not significant to the outcome of the laboratory investigation.

Surface turbidity in the laboratory investigation appears to be sensitive to the way in which crushed rock is placed as this influences fall velocity through the upper portion of the water column and clumping of crushed rock. This was particularly evident in Tests 10D and 10E. Surface turbidity in the laboratory investigation does not appear to be sensitive to the rate of placement of crushed rock. Following placement of the same mass of crushed rock, surface turbidity appeared to be similar.

5 References

The Engineering Toolbox (2018). *Water – Dynamics and Kinematic Viscosity Calculator*. Accessed 29/11/2018: https://www.engineeringtoolbox.com/water-dynamic-kinematic-viscosity-d_596.html

Royal HaskoningDHV (Haskoning, 2018), *Settlement characteristics of fine crushed rock, Laboratory Assessment Factual Report*.

San Diego State University (2018). *Calculation of velocity distribution coefficients α and β in open-channel flow*. Accessed 29/11/2018: http://ponce.sdsu.edu/onlinevelocitycoefficients.php

Attachment 1 – Sensitivity of Parameters Laboratory Log Records

Test ID	10A		
Geological Unit	Ravine Beds		
Description	Test 10A - Dry Disposal via Fall Pipe (7.5 cm from bottom, 165.3cm below water surface)		
Start Date/Time	20-11-18 9:15		
Water volume	50 L		
Water surface level in column	172.8	cm	
Mass sediment added	40 g	(sieved to <250 um)	
Test Location	Geochemical Assessments Workshop, Roseville NSW		
Test Officers	Pat Lawless, Rick Plain		
Depth of Temperature Probes	142cm	39cm	Old Probe at Bottom

Observations

Date/Time	Time since start	Turbidity (NTU)	Measurement Location (cm)	Measurement Depth (cm)	Comments	Temperature (°C)
20-11-18 8:50	25 minutes prior	0.9	169.4	3.4	Background turbidity measured 25 minutes before test start	22.3
20-11-18 9:55	00-0:40		169.4	3.4	Top of turbid plume at 8cm.	
20-11-18 11:45	00-2:30		169.4	3.4	Top of turbid plume at 8cm. Plume within fall pipe visibly more turbid than corresponding plume in 10B	22.4
20-11-18 12:00	00-2:45	1.2	169.4	3.4		
20-11-18 13:30	00-4:15		169.4	3.4	Top of turbid plume at 7.7cm. Plume within fall pipe visibly more turbid than corresponding plume in 10B	22.4
20-11-18 14:25	00-5:10	1.4	169.4	3.4		
20-11-18 15:45	00-6:30	0.7	169.4	3.4	Top of turbid plume at 7.7cm.	22.45
20-11-18 17:00	00-7:45	1.6	169.4	3.4	Top of turbid plume at 7.7cm.	22.5
21-11-18 9:00	00-23:45	2.8	169.4	3.4	Top of turbid plume at 7.7cm.	22.6
21-11-18 12:40	01-3:25	1.4	169.4	3.4	Top of turbid plume at 7.7cm.	23
22-11-18 9:20	02-0:05	0.8	169.4	3.4	Top of turbid plume at 7.6cm.	23
23-11-18 8:40	02-23:25	0.7	169.4	3.4	Top of turbid plume at 7.4cm.	22
24-11-18 9:10	03-23:55	2.2	169.4	3.4	Top of turbid plume at 7.4cm.	21.25
25-11-18 8:45	04-23:30	3	169.4	3.4	Top of turbid plume at 7.4cm.	21.1
26-11-18 9:00	05-23:45	2.2	169.4	3.4	Top of turbid plume at 7.4cm.	21.4
27-11-18 9:00	06-23:45	1.9	169.4	3.4	Top of turbid plume at 7.4cm.	22
28-11-18 9:00	07-23:45	1.9	169.4	3.4	Top of turbid plume at 7.4cm.	22.2
29-11-18 9:00	08-23:45	2	169.4	3.4	Top of turbid plume at 7.3cm.	20.9
30-11-18 9:00	09-23:45	1.8	169.4	3.4	Top of turbid plume at 7.4cm.	20.5
03-12-18 11:00	13-1:45	1.7	169.4	3.4	Top of turbid plume at 7.3cm.	24.3
12-12-18 9:00	21-23:45	2.2	169.4	3.4	Top of turbid plume at 7.3cm. Plume less turbid than previous.	24.5

Test ID	10B	
Geological Unit	Ravine Beds	
Description	Test 10B - Dry Disposal via Fall Pipe (122.8cm from bottom, 50cm below water surface)	
Start Date/Time	20-11-18 9:15	
Water volume	50 L	
Water surface level in column	172.8	cm
Mass sediment added	40 g	(sieved to <250 um)
Test Location	Geochemical Assessments Workshop, Roseville NSW	
Test Officers	Pat Lawless, Rick Plain	

Observations

Date/Time	Time since start	Turbidity (NTU)	Measurement Location (cm)	Measurement Depth (cm)	Comments	Temperature (°C)
20-11-18 8:50	25 minutes prior	1.8	169.4	3.4	Background turbidity measured 25 minutes before test start	
20-11-18 9:55	00-0:40		168.4	4.4	Top of turbid plume at 126cm.	
20-11-18 11:45	00-2:30		169.4	3.4	Top of turbid plume at 126cm.	22.4
20-11-18 12:00	00-2:45	2.4	169.4	3.4	Top of turbid plume at 126cm.	
20-11-18 13:30	00-4:15		169.4	3.4	Top of turbid plume at 125cm.	22.4
20-11-18 14:25	00-5:10	2.7	169.4	3.4		
20-11-18 15:45	00-6:30	3	169.4	3.4	Top of turbid plume at 124.5cm.	22.4
20-11-18 17:00	00-7:45	3.1	169.4	3.4	Top of turbid plume at 123.5cm.	22.5
21-11-18 9:00	00-23:45	3.6	169.4	3.4	Top of turbid plume at 122.7cm.	22.5
21-11-18 12:40	01-3:25	3.1	169.4	3.4	Top of turbid plume at 122.5cm.	22.9
22-11-18 9:20	02-0:05	4	169.4	3.4	Top of turbid plume at 123.5cm.	23
23-11-18 8:40	02-23:25	25.8	169.4	3.4	Top of turbid plume at 87cm. Visibly turbid above.	22
24-11-18 9:10	03-23:55	26	169.4	3.4	Top of turbid plume at 83cm. Visibly turbid above.	21.25
25-11-18 8:45	04-23:30	26	169.4	3.4	Top of turbid plume at 78.5cm. Visibly turbid above.	21.2
26-11-18 9:00	05-23:45	26	169.4	3.4	Top of turbid plume at 75cm. Visibly turbid above.	21.4
27-11-18 9:00	06-23:45	26.3	169.4	3.4	Top of turbid plume at 68cm. Visibly turbid above.	22
28-11-18 9:00	07-23:45	26	169.4	3.4	Top of turbid plume at 66cm. Visibly turbid above.	22.2
29-11-18 9:00	08-23:45	28.3	169.4	3.4	Top of turbid plume at 66cm. Visibly turbid above.	20.9
30-11-18 9:00	09-23:45	27.6	169.4	3.4	Top of turbid plume at 58cm. Visibly turbid above.	20.5
03-12-18 11:00	13-1:45	31.1	169.4	3.4	Turbidity homogenous throughout.	24.3
12-12-18 9:00	21-23:45	26.3	169.4	3.4	Turbidity homogenous throughout.	24.5

Test ID	10D	
Geological Unit	Ravine Beds	
Description	Test 10D - Dry Disposal at Surface, without lid on column	
Start Date/Time	20-11-18 9:45	
Water volume	50 L	
Water surface level in column	172.8	cm
Mass sediment added	40 g	(sieved to <250 um)
Test Location	Geochemical Assessments Workshop, Roseville NSW	
Test Officers	Pat Lawless, Rick Plain	

Observations

Date/Time	Time since start	Turbidity (NTU)	Measurement Location (cm)	Measurement Depth (cm)	Comments	Temperature (°C)
20-11-18 8:50	55 minutes prior	2.7	169.4	3.4	Background turbidity measured 55 minutes before test start	
20-11-18 10:35	00-0:50	85	169.4	3.4	Probe entered water at 10:35, high turbidity ~85 NTU, possibly related to agitation of column	
20-11-18 10:43	00-0:58	76.7	169.4	3.4		
20-11-18 10:50	00-1:05	78.7	169.4	3.4	Turbidity not settling, probe left in place for 10 mins.	
20-11-18 10:55	00-1:10	63	169.4	3.4	Probe removed, rinsed with fresh water, re-inserted. Turbidity lower.	
20-11-18 10:58	00-1:13	54.9	169.4	3.4	Turbidity steadily falling	
20-11-18 11:02	00-1:17	54.2	169.4	3.4	Seems to have stabilised. Probe removed to take corresponding reading in 10E.	
20-11-18 11:45	00-2:00		169.4	3.4	Surface sample taken (50mm below surface) via pipette for Mastersizer analysis	
20-11-18 12:00	00-2:15	60.6	169.4	3.4		
20-11-18 14:20	00-4:35	69	169.4	3.4		Cannot see thermometer
20-11-18 15:45	00-6:00	75	169.4	3.4	Log file "10D_6hr_181120" started.	
20-11-18 16:58	00-7:13	66.1	169.4	3.4	Log file "10D_6hr_181120" stopped.	
21-11-18 9:00	00-23:15	62.6	169.4	3.4		22.5
21-11-18 12:40	01-2:55	59.8	169.4	3.4		
22-11-18 9:20	01-23:35	58.2	169.4	3.4		22.8
23-11-18 8:40	02-22:55	59.8	169.4	3.4		21.8
24-11-18 9:10	03-23:25	55.8	169.4	3.4		21
25-11-18 8:45	04-23:00	53.7	169.4	3.4		20.9
26-11-18 9:00	05-23:15	49.5	169.4	3.4		21.1
27-11-18 9:00	06-23:15	45	169.4	3.4		21.7
28-11-18 9:00	07-23:15	44.9	169.4	3.4		22
29-11-18 9:00	08-23:15	44.9	169.4	3.4		20.6
30-11-18 9:00	09-23:15	43	169.4	3.4		20.4
03-12-18 11:00	13-1:15	37.4	169.4	3.4		23.9
12-12-18 9:00	21-23:15	29.7	169.4	3.4		24.1

Test ID	10E	
Geological Unit	Ravine Beds	
Description	Test 10E - Dry Disposal at Surface, lid on column	
Start Date/Time	20-11-18 9:45	
Water volume	50 L	
Water surface level in column	172.8	cm
Mass sediment added	40 g	(sieved to <250 um)
Test Location	Geochemical Assessments Workshop, Roseville NSW	
Test Officers	Pat Lawless, Rick Plain	

Observations

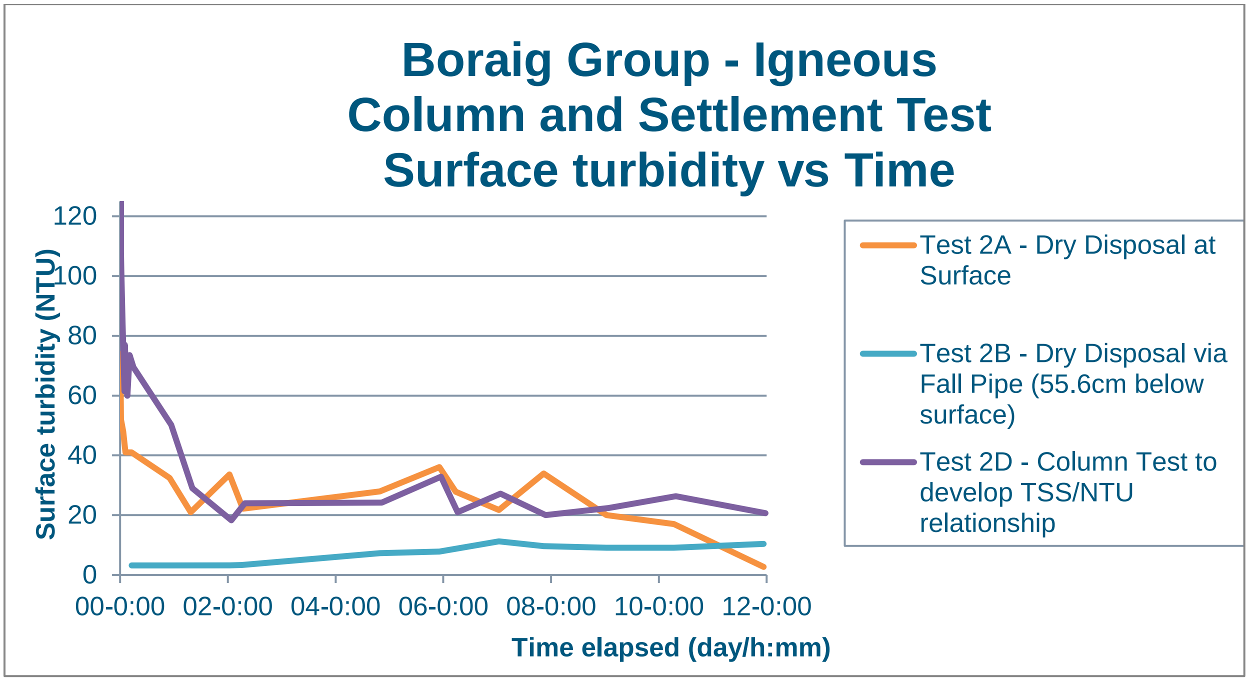
Date/Time	Time since start	Turbidity (NTU)	Measurement Location (cm)	Measurement Depth (cm)	Comments	Temperature (°C)
20-11-18 8:45	55 minutes prior	2	169.4	3.4	Background turbidity measured 55 minutes before test start	
20-11-18 9:48	00-0:03	70	169.4	3.4		
20-11-18 9:55	00-0:10	49	169.4	3.4		
20-11-18 10:00	00-0:15	48.9	169.4	3.4		
20-11-18 10:10	00-0:25	40.3	169.4	3.4		
20-11-18 10:28	00-0:43	31.5	169.4	3.4		
20-11-18 10:35	00-0:50	31.5	169.4	3.4	Log file "10E_Start_181120" stopped to take measurement in other columns	
20-11-18 11:09	00-1:24	36.5	169.4	3.4	Log file "10E_2_181120" started. Re-inserting probe has elevated turbidity. However, significantly lower than adjacent column 10D (54 NTU at 11:02)	
20-11-18 11:15	00-1:30	35	169.4	3.4		
20-11-18 11:34	00-1:49	35.8	169.4	3.4		
20-11-18 11:45	00-2:00	35.8	169.4	3.4	Surface sample taken (50mm below surface) via pipette for Mastersizer analysis	
20-11-18 11:55	00-2:10	36.6	169.4	3.4	Log file "10E_2_181120" stopped after removal of the probe.	
20-11-18 14:20	00-4:35	49	169.4	3.4		22
20-11-18 14:28	00-4:43	50	169.4	3.4	Log file "10E_3_181120" started.	
20-11-18 15:45	00-6:00	52.6	169.4	3.4	Log file "10E_3_181120" stopped.	22.1
20-11-18 17:00	00-7:15	47	169.4	3.4		22.1
21-11-18 9:00	00-23:15	22	169.4	3.4		22.5
21-11-18 12:40	01-2:55	33.6	169.4	3.4		22.8
22-11-18 9:20	01-23:35	15.8	169.4	3.4		23
23-11-18 8:40	02-22:55	47.5	169.4	3.4		22.1
24-11-18 9:10	03-23:25	39.8	169.4	3.4		21.4
25-11-18 8:45	04-23:00	40.3	169.4	3.4		21.1
26-11-18 9:00	05-23:15	23	169.4	3.4	Stratification 167.5cm.	21.5
27-11-18 9:00	06-23:15	17.8	169.4	3.4	Gradual change near the surface to approximately 161cm. Turbidity reading takes a while to stabilise. Gradual change near surface diminishes over time following removal of the lid.	22
28-11-18 9:00	07-23:15	21.8	169.4	3.4	Gradual change near the surface to approximately 162cm. Turbidity reading takes a while to stabilise. Diminished following removal of the lid.	22.25
29-11-18 9:00	08-23:15	38.3	169.4	3.4	Condensation at top of column.	21
30-11-18 9:00	09-23:15	34	169.4	3.4	Condensation at top of column.	21.5
03-12-18 11:00	13-1:15	20.7	169.4	3.4	Condensation at top of column.	24.3
12-12-18 9:00	21-23:15	29.3	169.4	3.4	Condensation at top of column.	24.6

Test ID	10F	
Geological Unit	Ravine Beds	
Description	Test 10F - Dry Disposal at Surface, 5g per day	
Start Date/Time	20-11-18 9:00	
Water volume	50 L	
Water surface level in column	172.8	cm
Mass sediment added	5 g per day for 8 days	(sieved to <250 um)
Test Location	Geochemical Assessments Workshop, Roseville NSW	
Test Officers	Pat Lawless, Rick Plain	

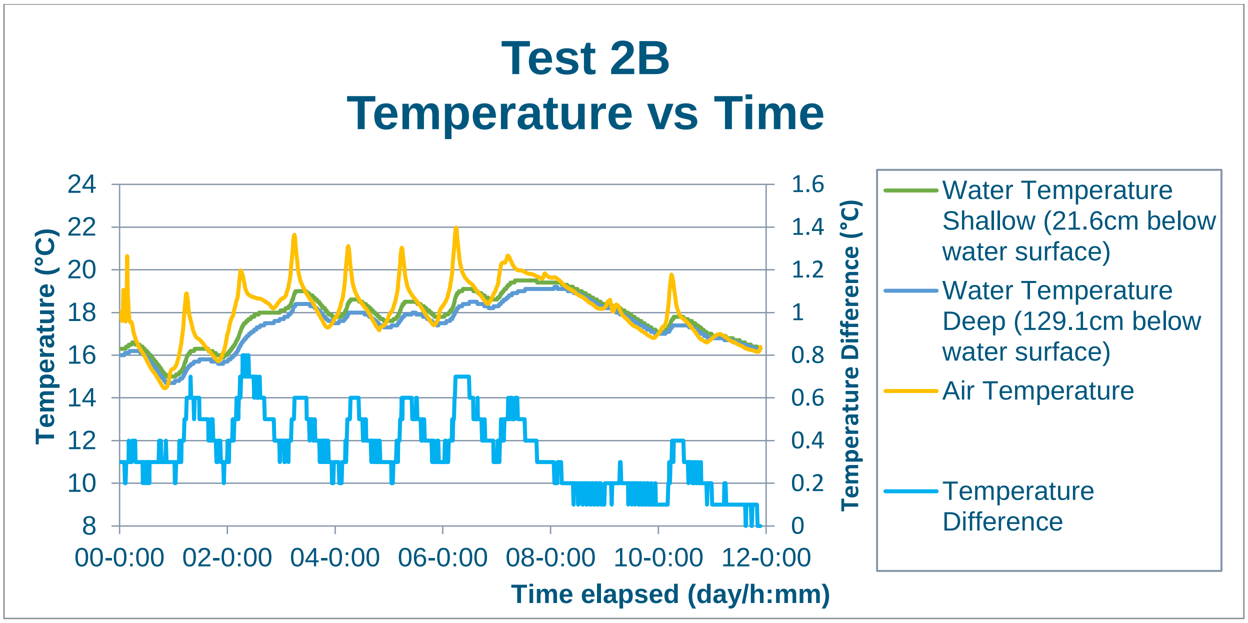
Observations

Date/Time	Time since start	Turbidity (NTU)	Measurement Location (cm)	Measurement Depth (cm)	Comments	Temperature (°C)
20-11-18 8:45	15 minutes prior	2.4	169.4	3.4	Background turbidity measured 15 minutes before test start	
20-11-18 9:02	00-0:02	7.1	169.4	3.4		
20-11-18 9:05	00-0:05	6.2	169.4	3.4		
20-11-18 9:08	00-0:08	4.4	169.4	3.4		
20-11-18 9:25	00-0:25	5.7	169.4	3.4		
20-11-18 11:58	00-2:58	14.5	169.4	3.4		22
20-11-18 14:20	00-5:20	12.7	169.4	3.4		22
20-11-18 15:45	00-6:45	7.2	169.4	3.4		
20-11-18 17:00	00-8:00	6	169.4	3.4		22.2
21-11-18 9:20	01-0:20	3.6	169.4	3.4	Log file "10F_1_181121" started.	22.5
21-11-18 9:30	01-0:30	5	169.4	3.4		
21-11-18 10:08	01-1:08	6.8	169.4	3.4	Log file "10F_1_181121" stopped.	
21-11-18 12:40	01-3:40	12.6	169.4	3.4		22.6
22-11-18 9:32	02-0:32	10	169.4	3.4	Log file "10F_1_181122" started.	22.9
22-11-18 9:42	02-0:42	11.2	169.4	3.4	Log file "10F_1_181122" stopped.	
23-11-18 8:47	02-23:47	24.9	169.4	3.4	Log file "10F_1_181123" started.	21.8
23-11-18 8:57	02-23:57	26.3	169.4	3.4	Log file "10F_1_181123" stopped.	
24-11-18 9:14	04-0:14	21.3	169.4	3.4	Log file "10F_1_181124" started.	21.3
24-11-18 10:00	04-1:00	26.4	169.4	3.4	Log file "10F_1_181124" stopped.	
25-11-18 8:56	04-23:56	26	169.4	3.4	Log file "10F_1_181125" started.	21.25
25-11-18 9:02	05-0:02	26.5	169.4	3.4	Log file "10F_1_181125" stopped.	
26-11-18 9:09	06-0:09	21.7	169.4	3.4	Stratification 169cm. Log file "10F_1_181126" started.	21.4
26-11-18 9:34	06-0:34	24.8	169.4	3.4		
26-11-18 10:08	06-1:08	27.5	169.4	3.4		
26-11-18 10:38	06-1:38	28.7	169.4	3.4	Log file "10F_1_181126" stopped.	
27-11-18 9:15	07-0:15	14.1	169.4	3.4	Log file "10F_1_181127" started.	22
27-11-18 9:40	07-0:40	24.3	169.4	3.4		
28-11-18 9:40	08-0:40	23.6	169.4	3.4	Gradual change near the surface. Diminished following removal of the lid. Turbidity reading takes a while to stabilise.	22.1
29-11-18 9:40	09-0:40	32.3	169.4	3.4	Condensation at top of column.	21
30-11-18 9:40	10-0:40	32.3	169.4	3.4	Condensation at top of column.	21.5
03-12-18 11:00	13-2:00	19.2	169.4	3.4	Condensation at top of column.	24.1
12-12-18 9:00	22-0:00	28.5	169.4	3.4	Condensation at top of column.	24.5

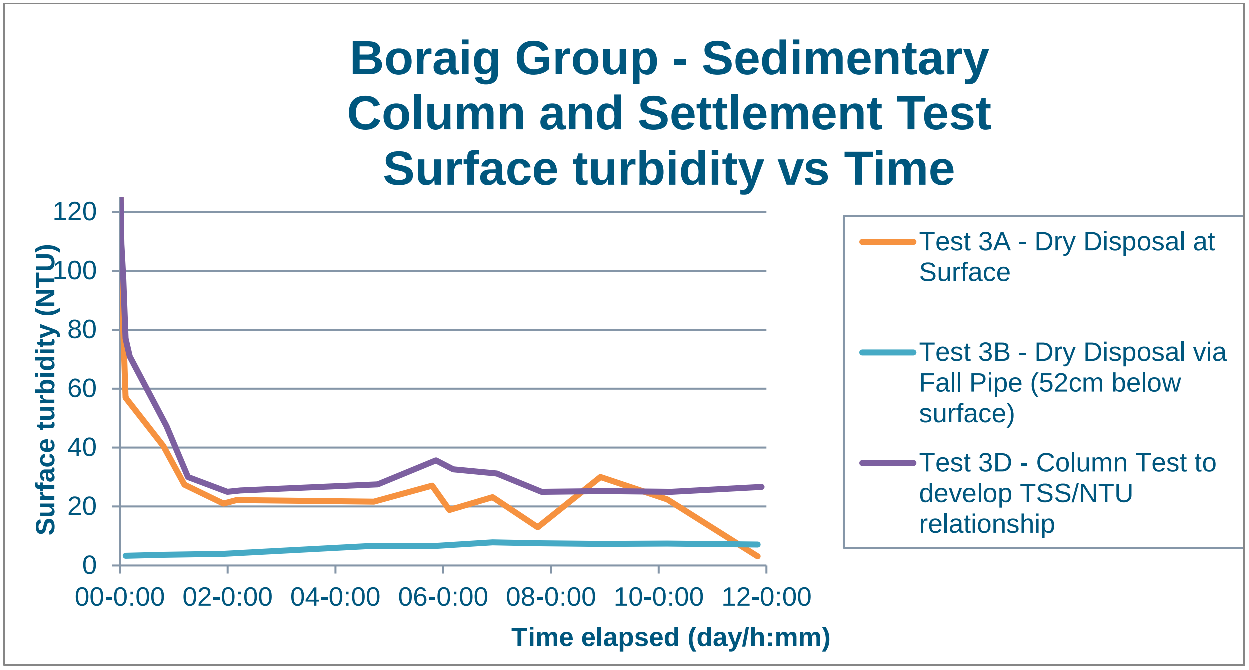
Attachment 2 – Turbidity and Temperature Graphs



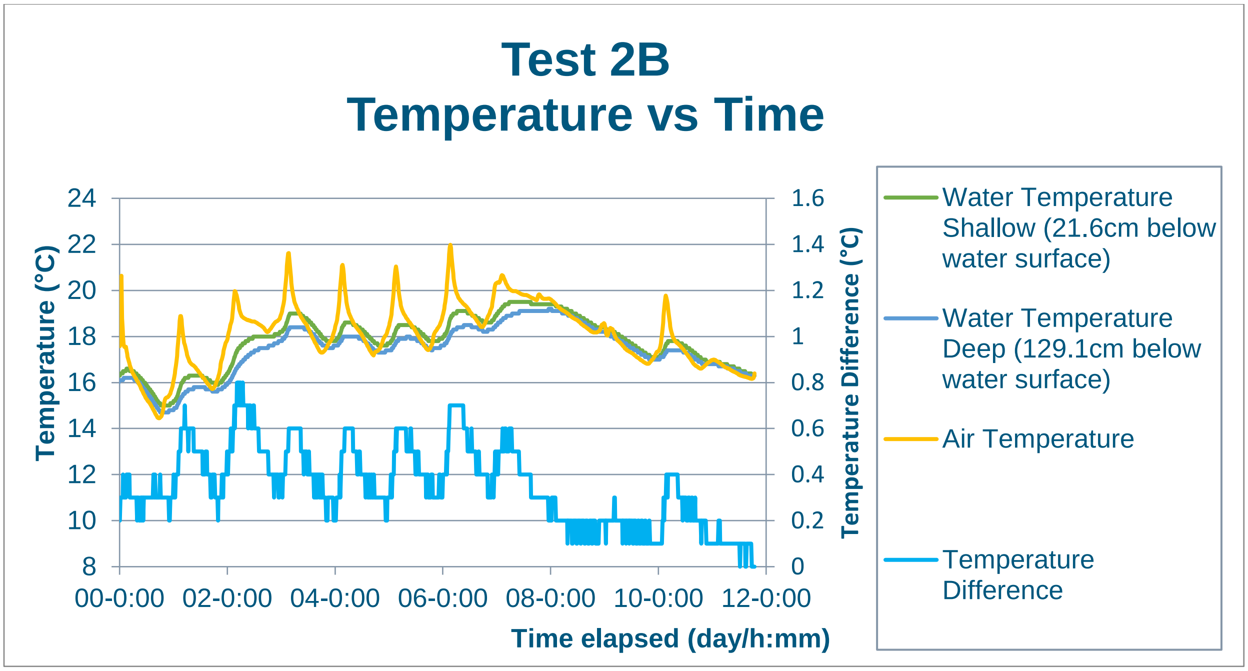
Graph 1: Surface turbidity measured during the settlement and column tests – Boraig Group igneous crushed rock (Tests 2A, 2B and 2D).



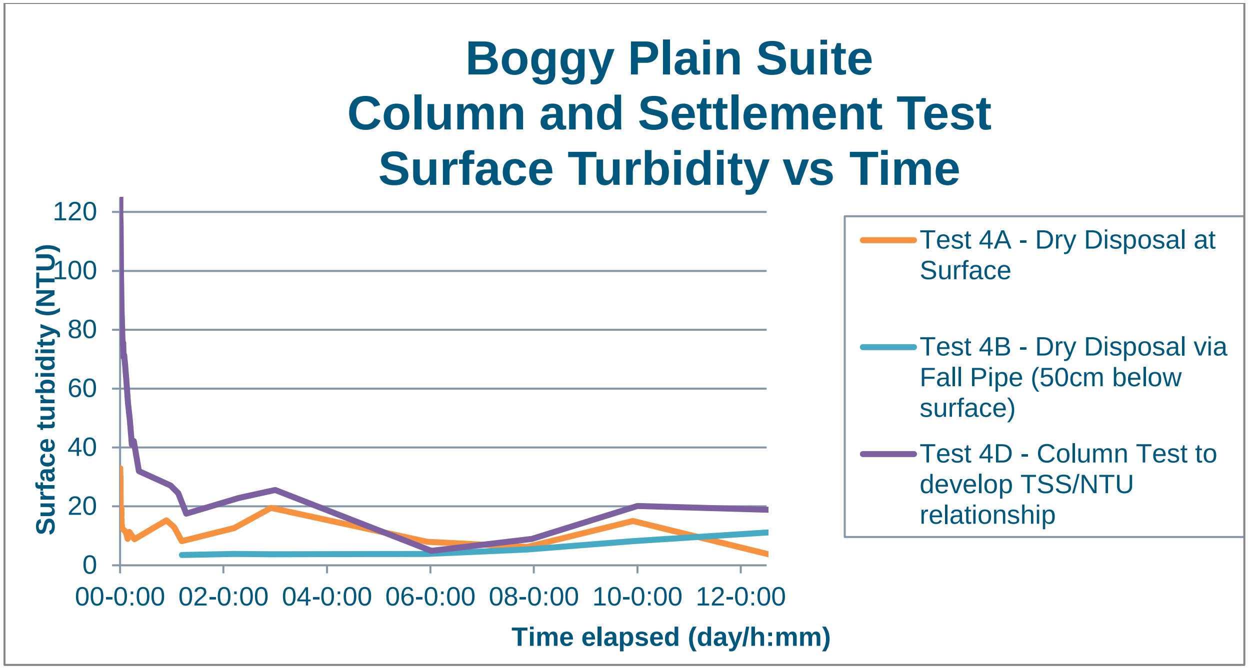
Graph 2: Air and water temperature in Test 2B. Elapsed time relative to commencement of Test 2A and 2B.



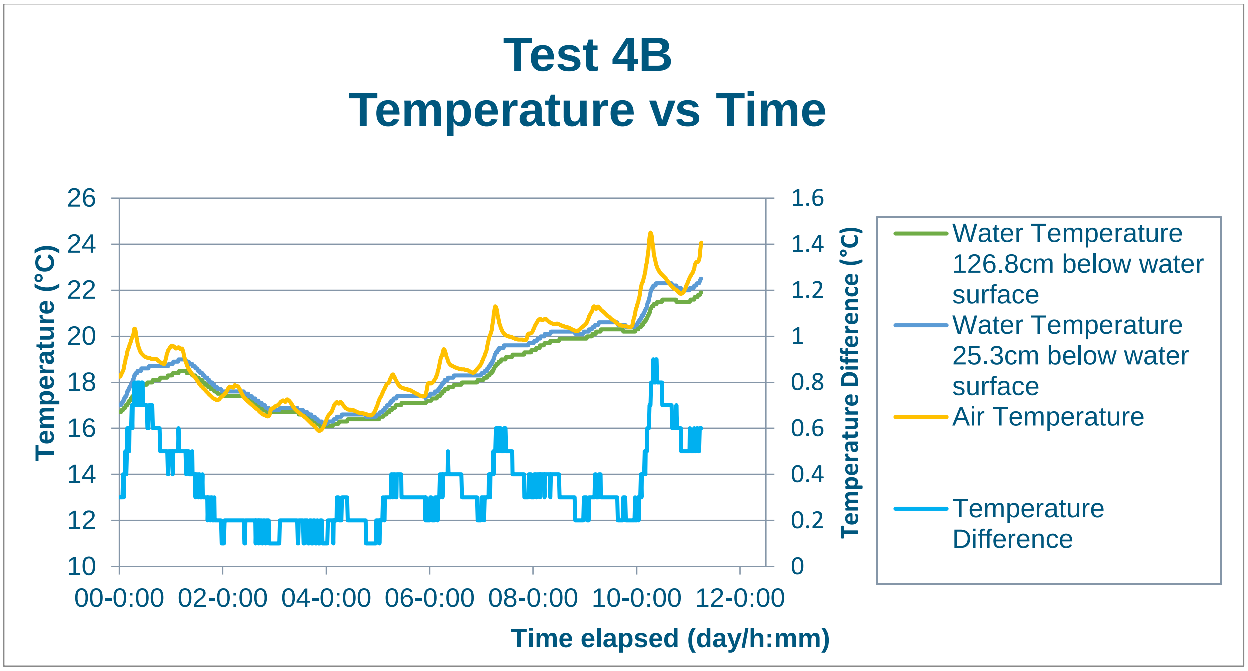
Graph 3: Surface turbidity measured during the settlement and column tests – Boraig Group sedimentary crushed rock (Tests 3A, 3B and 3D).



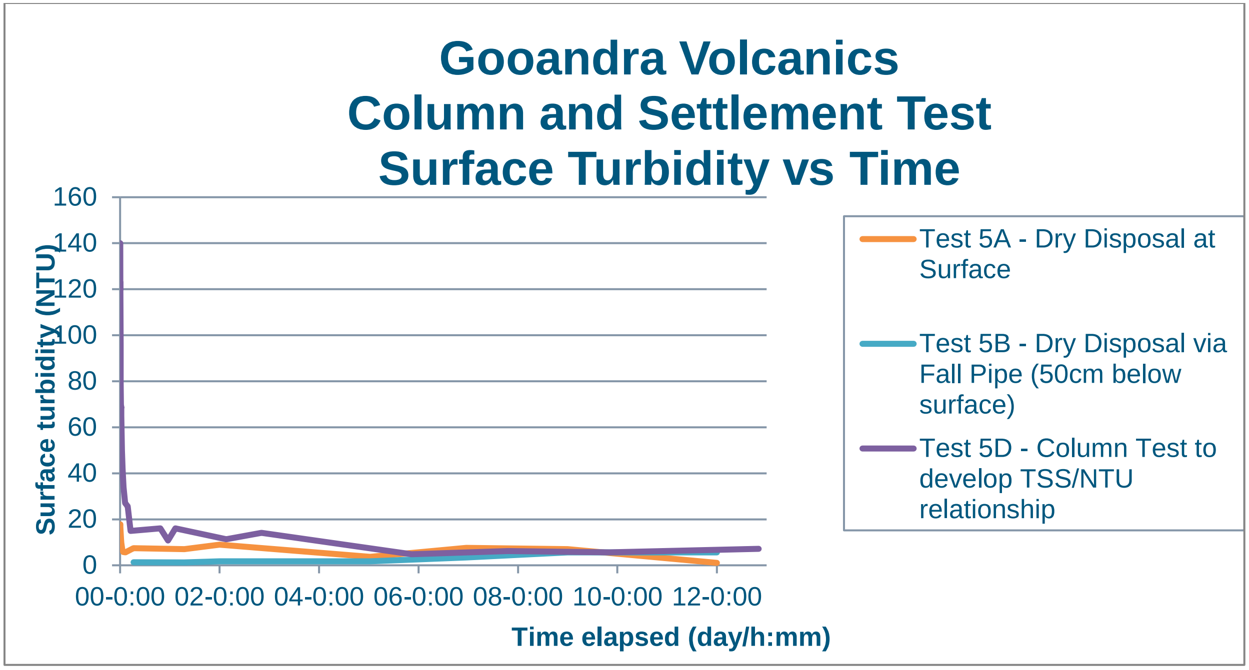
Graph 4: Air and water temperature in Test 2B. Elapsed time relative to commencement of Test 3A and 3B.



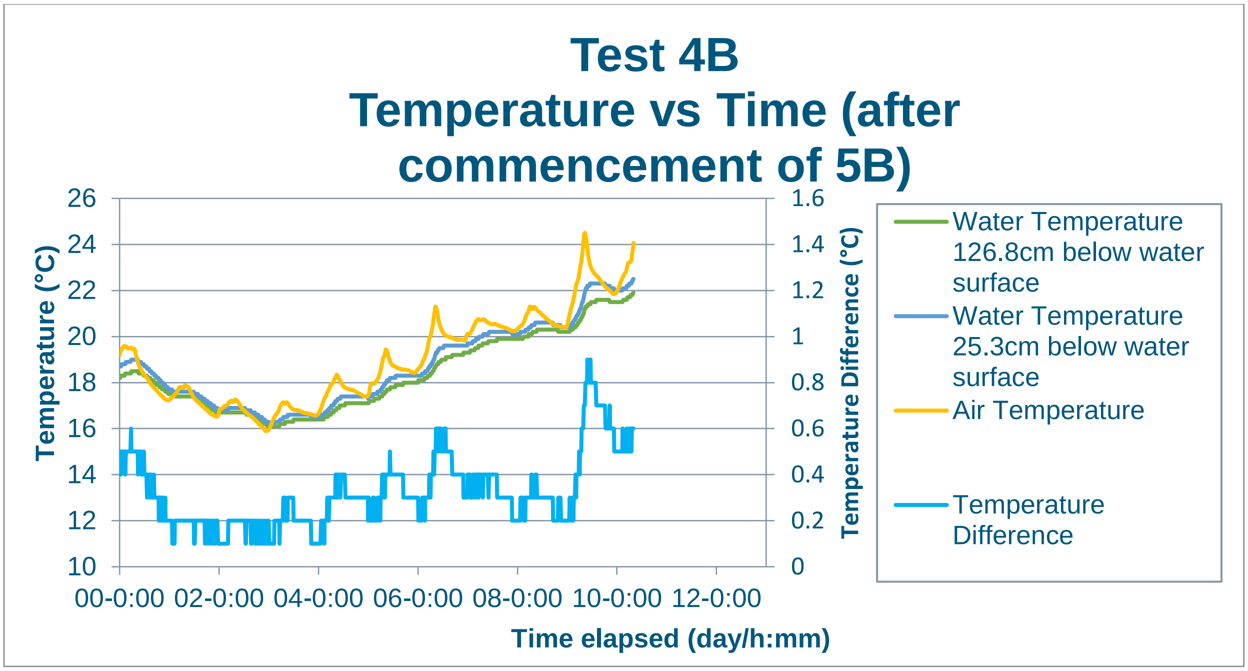
Graph 5: Surface turbidity measured during the settlement and column tests – Boggy Plain Suite (Tests 4A, 4B and 4D).



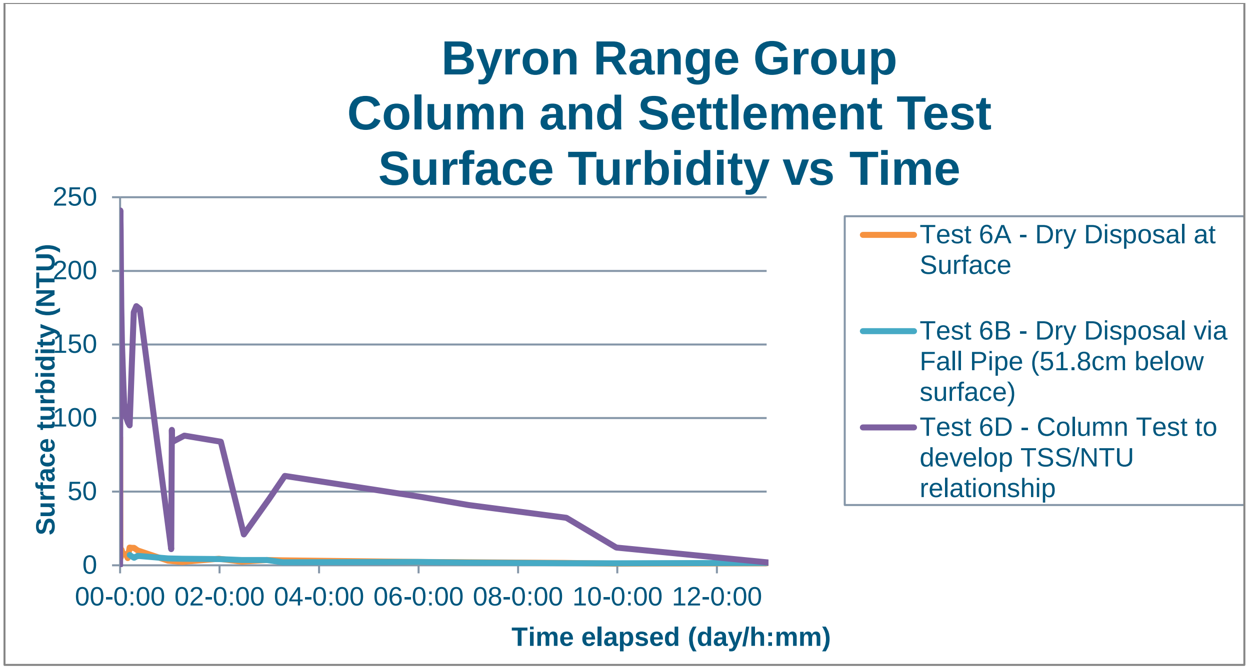
Graph 6: Air and water temperature in Test 4B. Elapsed time relative to commencement of Test 4A and 4B.



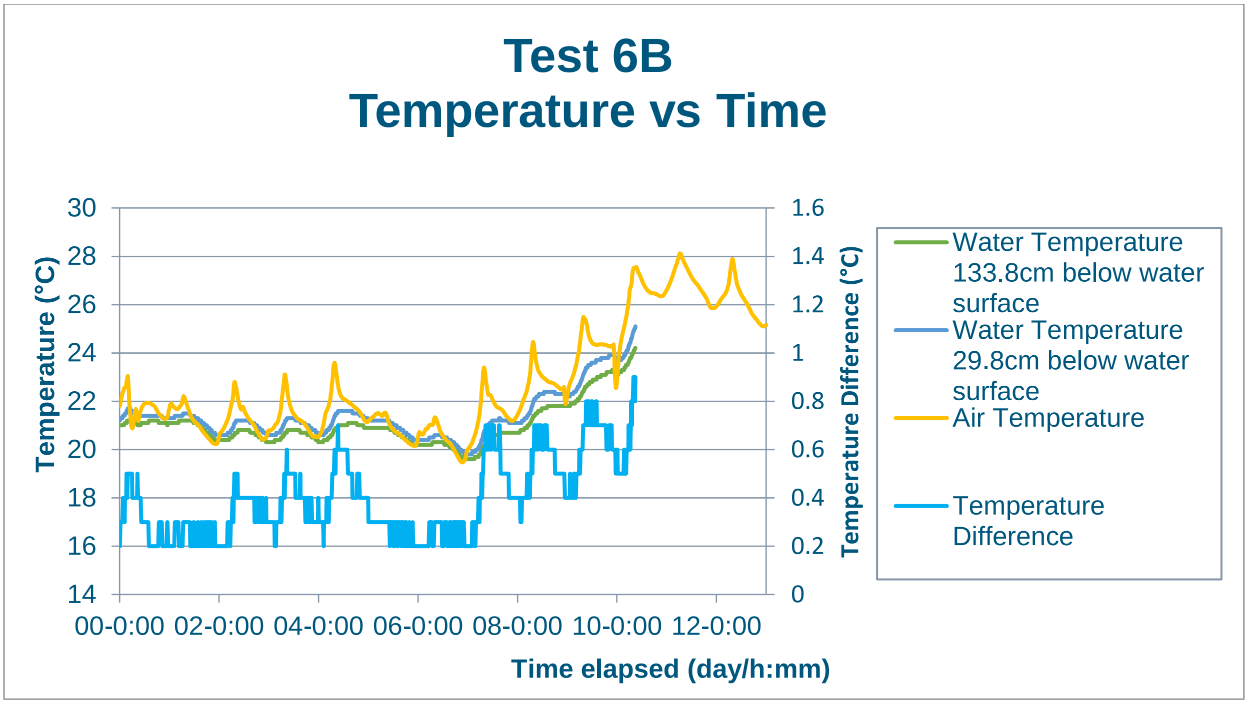
Graph 7: Surface turbidity measured during the settlement and column tests – Gooandra Volcanics (Tests 5A, 5B and 5D).



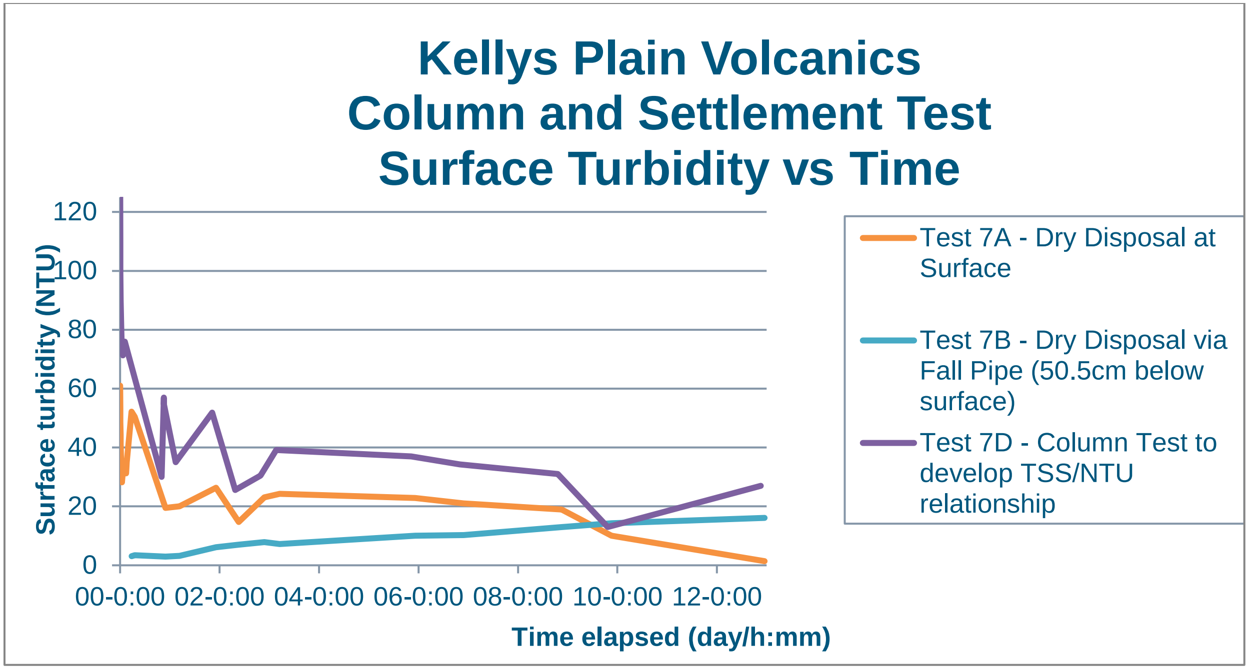
Graph 8: Air and water temperature in Test 4B. Elapsed time relative to commencement of Test 5A and 5B.



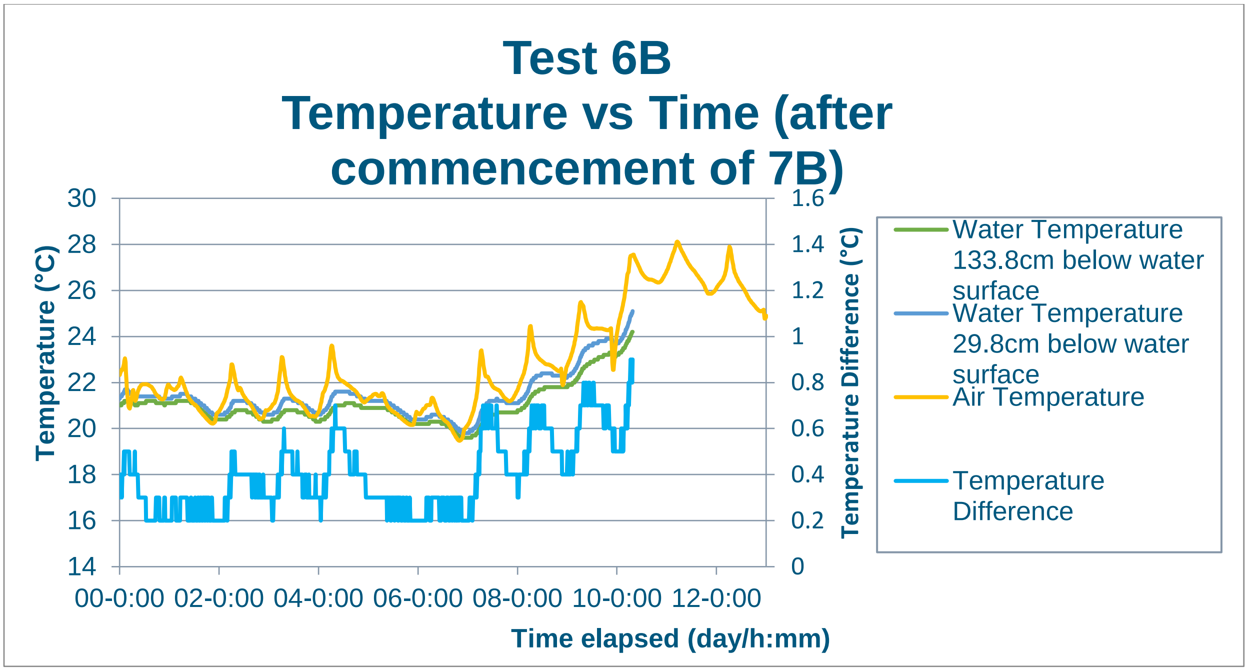
Graph 9: Surface turbidity measured during the settlement and column tests – Byron Range Group (Tests 6A, 6B and 6D).



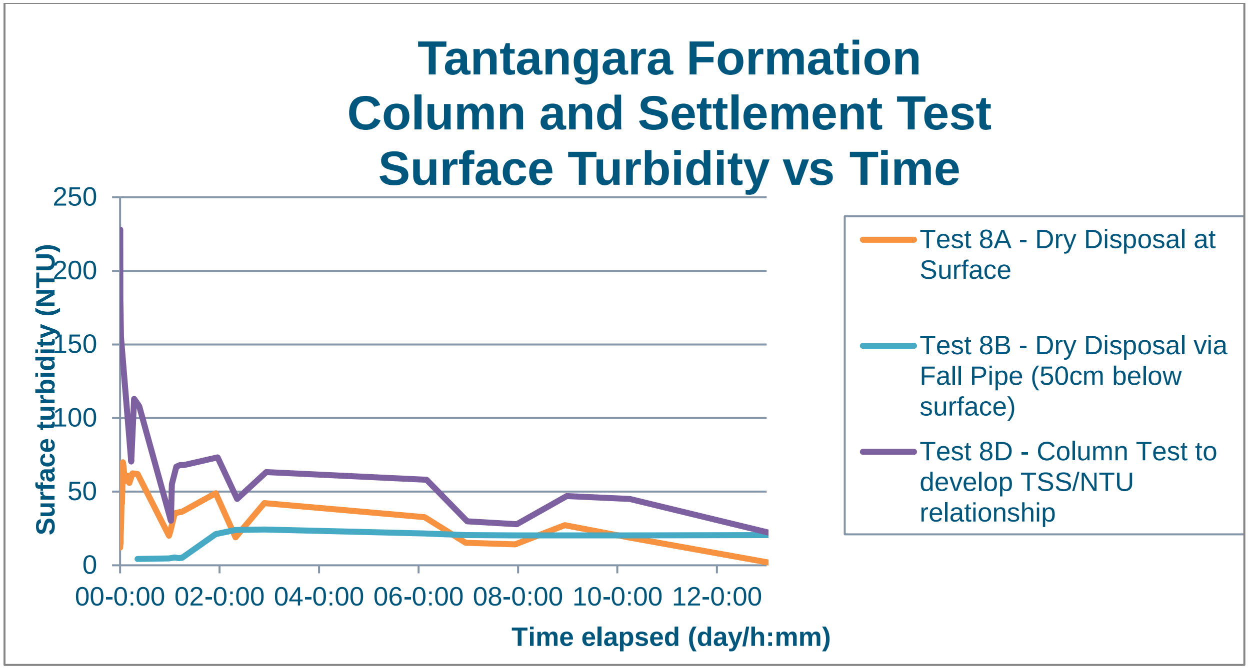
Graph 10: Air and water temperature in Test 6B. Elapsed time relative to commencement of 6A and 6B.



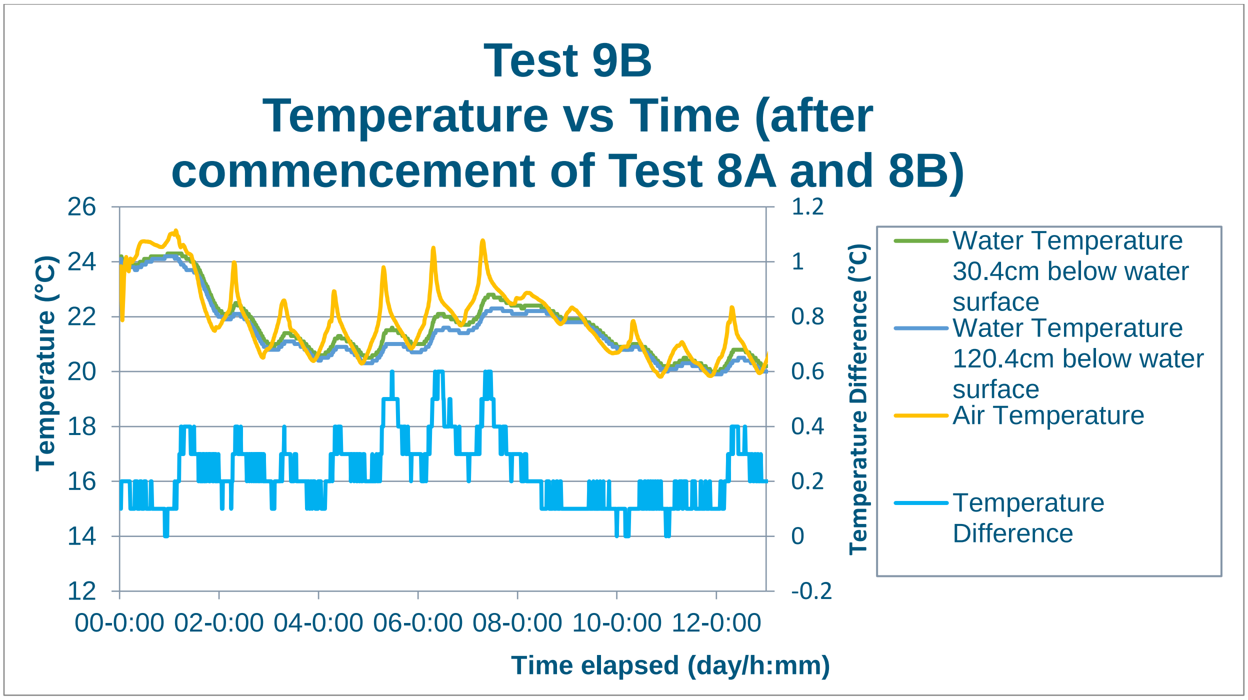
Graph 11: Surface turbidity measured during the settlement and column tests – Kelly Plains Volcanics crushed rock (Tests 7A, 7B and 7D).



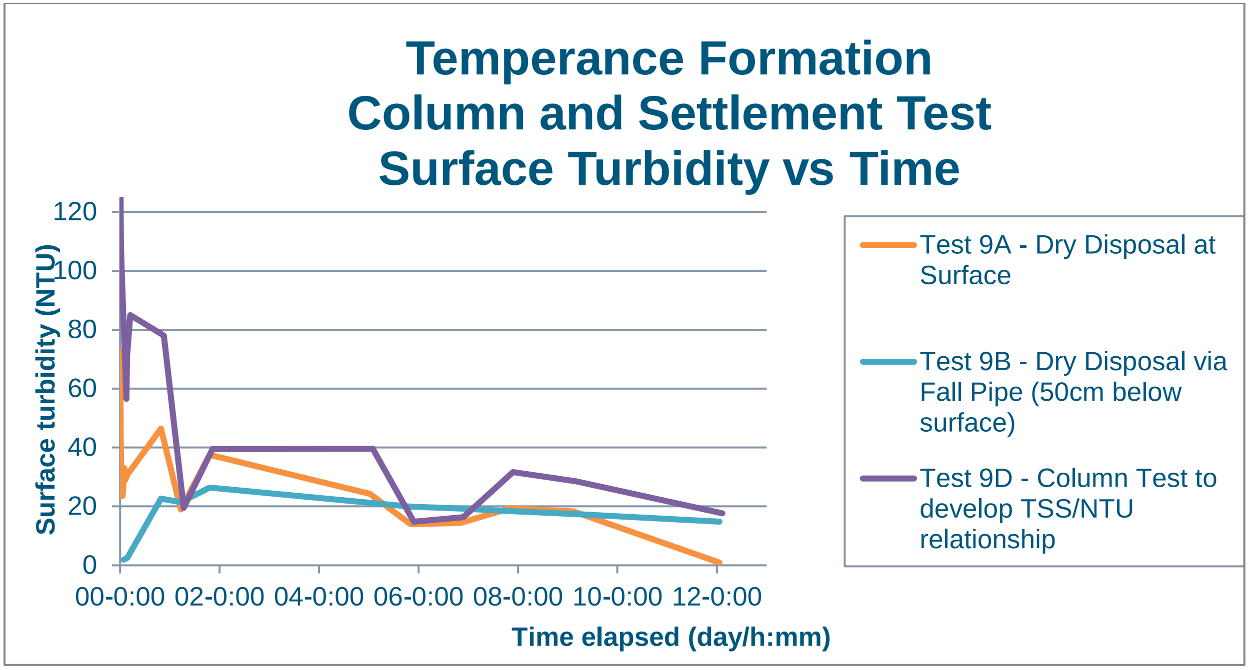
Graph 12: Air and water temperature in Test 6B. Elapsed time relative to commencement of Test 7A and 7B



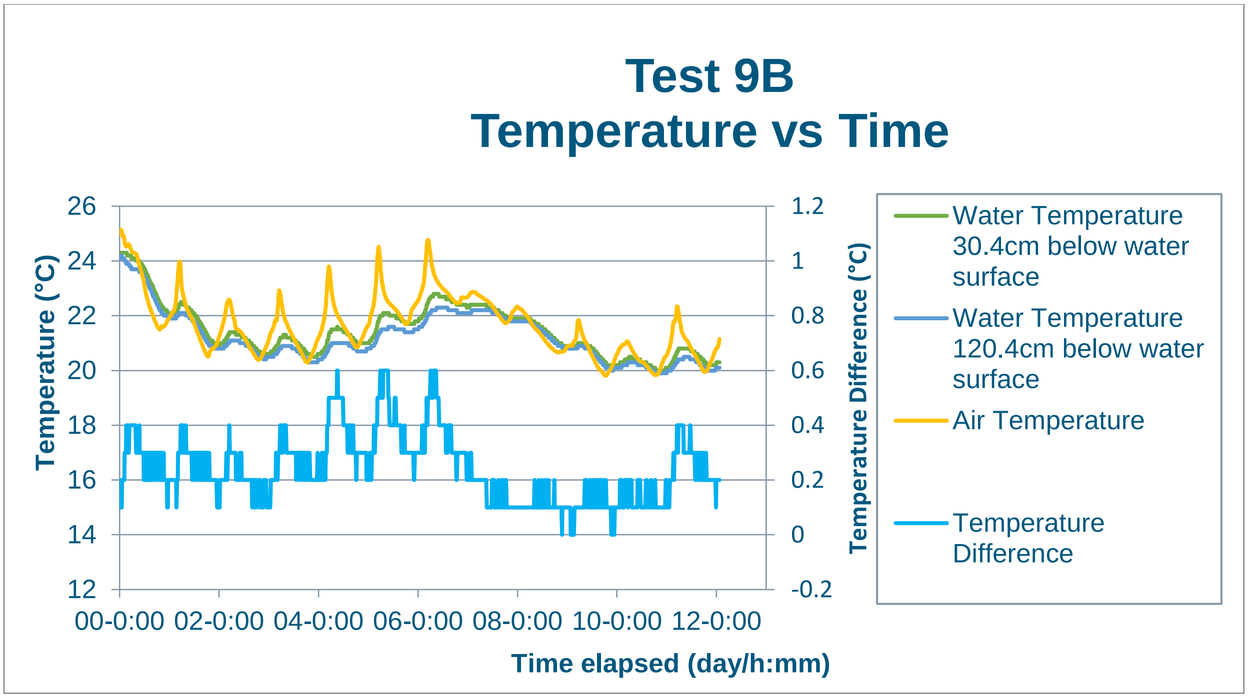
Graph 13: Surface turbidity measured during the settlement and column tests – Tantangara Formation (Tests 8A, 8B and 8D).



Graph 14: Air and water temperature in Test 9B. Elapsed time relative to commencement of Tests 8A and 8B



Graph 15: Surface turbidity measured during the settlement and column tests – Temperance Formation (Tests 9A, 9B and 9D).



Graph 16: Air and water temperature in Test 9B. Elapsed time relative to commencement of Test 9A and 9B.