Cover Design

Barbara Copper Project

Waste Rock Dump

Prepared for Round Oak Minerals Pty Limited | April 2022

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Prepared for Round Oak Minerals Pty Limited | 22 April 2022

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Table of abbreviations

Common abbreviations used in this report are given in Table 1.

Table 1 Common abbreviations

Abbreviations	Description
AC	Acid consuming
AMD	Acid mine drainage
ANC	Acid neutralising capacity
ANC:MPA	Acid neutralising capacity to maximum potential acidity mass ratio
Ca	Calcium
Ca:Mg	Exchangeable calcium to magnesium ratio
CB	Capillary break
CEC	Cation exchange capacity
Cu	Copper
dS/m	DeciSiemens per metre
DTPA	Diethylenetriaminepentaacetic acid
EA	Environmental authority
EC	Electrical conductivity
ECe	Saturated soil extract electrical conductivity
ESP	Exchangeable sodium percentage
Fe	Iron
ha	Hectares
ISL	Infiltration storage layer
K	Potassium
kg H_2SO_4/t	Kilograms of sulfuric acid per tonne
km	kilometres
kPa	Kilopascals
m	Metres
m bgl	Metres below ground level
m/day	Metres per day
m/s	Metres per second

Abbreviations	**Description**
meq/100g	Milliequivalents per 100 grams
Mg	Magnesium
mg/kg	Milligrams per kilogram
ML	Mining lease
mm	Millimetres
Mn	Manganese
MPA	Maximum potential acidity
NAF	Non-acid forming
NAG	Net acid generation
NAPP	Net acid producing potential
P (Colwell)	Colwell phosphorus
PAF	Potentially acid forming
PAF-LC	Potentially acid forming-low capacity
PMLU	Post mining land use
Project / BCO	Barbara Copper Project
PSD	Particle size distribution
RPL	Reduced permeability layer
SMDD	Standard compaction maximum dry density
SOMC	Standard compaction optimum moisture content
SWCC	Soil water characteristic curve
t/m^3	Tonnes per cubic metre
UC	Uncertain
VWC	Volumetric water content
WRD	Waste rock dump
Zn	Zinc
~	Approximately
°	Degrees

Executive summary

The Barbara Copper Project (the Project) is an open-pit copper mine that resides on mining lease (ML) 90241. The Project is owned and operated by Round Oak Minerals Pty Limited (Round Oak) and administered by the Department of Environment and Science under the environmental authority (EA) EPML02840015.

The Project is a conventional drill and blast / load and haul operation that operated from June 2019 until March 2021 and was placed on care and maintenance in April 2021. Ore was transported by road train to a third-party processing facility. The region in which the Project is located is characterised by low intensity cattle grazing and mineral exploration.

SGM Environmental Pty Limited (SGME) was engaged by Round Oak to prepare a cover design for the Project waste rock dump (WRD) (this Report). The objective is to progressively rehabilitate the WRD to form a final landform that is safe to humans and wildlife, stable, non-polluting and is capable of sustaining an agreed post-mining land use (PMLU).

The majority (89%) of waste rock is non-acid forming (NAF) with a small percentage being potentially acid forming (PAF) or uncertain. All PAF waste rock is stored on a NAF base that was constructed to a minimum thickness of five metres (m). The final landform will include PAF waste rock placed within the central portion of the NAF base to keep the PAF cell at least five meters (m) from the crest of the WRD. An engineered cover system (the cover design) is required to prevent infiltration into the PAF cell, which could potentially generate acidic conditions and mobilise metals and / or metalloids.

A review of the *Global Acid Rock Drainage (GARD) Guide* (INAP 2009) indicates that a store and release cover would be suitable to meet rehabilitation objectives for the Project climate.

The total disturbance of the WRD is approximately 23 hectares (ha). The as-built construction (prior to installing the cover) includes a compacted NAF waste rock cap that sheds water towards the WRD sediment dam and south pit to prevent infiltration into the PAF cell. The final landform design includes:

- batter slopes: 37 degrees (˚) (angle of repose);
- batter height: 10 m;
- bench width: 12 m; and
- average slope: 1 vertical (V):2.5 horizontal (H) (approximately 21.8˚).

SGME completed a conceptual cover design in 2021 for the closure of the WRD (SGME 2021a). The purpose of the conceptual cover design was a cover options analysis that recommended the most suitable covers to progress to column trials (the Trials). The options analysis showed that cover options 3, 4 and 5 were the most suited:

- cover option 4 (Trial 1):
  - a 1.6 m infiltration storage layer (ISL) of coarse waste rock compacted to a bulk density of 1.8 tonnes per cubic metres (t/m^3); and
  - a 0.3 m layer of waste rock above the ISL at a density of 1.6 t/m^3.
- cover option 3 (Trial 2):
  - a 1.6 m ISL of coarse waste rock compacted to a bulk density of 1.8 t/m^3; and
  - a 0.3 m layer of soil above the ISL at a density of 1.6 t/m^3.
- cover option 5 (Trial 3):
  - a 0.5 m reduced permeability layer (RPL) of fine compacted waste rock above the PAF waste rock layer compacted to a bulk density of 2.1 t/m^3;
  - a 1 m ISL of coarse waste rock above the fine compacted waste rock compacted to a bulk density of 1.8 t/m^3; and
  - a 0.3 m layer of fine waste rock above the coarse waste rock layer to a density of 1.6 t/m^3.

The Trials were instrumented with matric suction and volumetric water content (VWC) sensors (sensor pairs) that measure electrical conductivity and how rainfall infiltration and dissolved ions are stored within the cover. Rain gauge tipping buckets were placed under each column to measure seepage.

A numerical model was built in HYDRUS-1D software package (the model) to replicate the cover designs used in the Trials. The model simulates water flow and solute transport in variably saturated media and can be used to predict infiltration, evaporation, transpiration, soil water storage, capillary rise and deep drainage (percolation and / or seepage).

The following information was used as inputs to the model:

- climate data (rainfall, temperature and evaporation);
- soil water characteristic curves derived from the VWC and matric suction sensors; and
- material properties (hydraulic conductivity, particle size distribution and specific gravity).

Modelling has been done without vegetation (to give a conservative assessment) and demonstrates that vegetation is not required to limit seepage.

The model indicates that during periods of normal rainfall or during periods of no rainfall, rainfall will initially infiltrate and then be removed by evapotranspiration with negligible seepage. However, Trial 1 and Trial 3 may have an unacceptable rate of seepage when subject to periods of short duration, heavy rainfall (the wet year).

Trial 1 had an increased capacity to store infiltration in the ISL, but produced more seepage, when compared to Trial 3. Trial 2 has been excluded because there is not enough soil available (Trial 1 and Trial 3 do not require soil). Notwithstanding, Trial 3 is selected as the preferred cover since:

- the coarse nature of waste rock slows runoff water velocity and reduces the potential for erosion; and
- the RPL limits the potential for seepage.

It is recommended that field scale cover trials are done to validate the performance of the preferred cover (Trial 3) to limit seepage into the underlying waste rock.

1.0 Introduction

1.1 The proponent

Barbara Copper (Cu) Project (the Project or BCO) is an open-pit mine that resides on mining lease (ML) 90241. The Project is owned and operated by Round Oak Minerals Pty Limited (Round Oak) and administered by the Department of Environment and Science under the environmental authority (EA) EPML02840015.

1.2 Report scope

SGM Environmental Pty Limited (SGME) was engaged by Round Oak to develop an engineered cover system (the cover) for the Project waste rock dump (WRD) (this Report). The objective is to progressively rehabilitate the WRD to form a final landform that is safe to humans and wildlife, stable, non-polluting and is capable of sustaining an agreed post-mining land use (PMLU). The cover is required to prevent infiltration into the potentially acid forming (PAF) cell, which could potentially generate acidic conditions and mobilise metals and / or metalloids.

This Report has been prepared having regard for the requirements of the *Guideline: Progressive Rehabilitation and Closure Plan (PRC plans)* (the PRC plan guideline) (Table 2).

Table 2 How the PRC plan guideline has been addressed

Requirement	Comment
A cover design is required for the surface treatment of a mine landform or other waste material.	This Report
The cover design must reflect a risk-based approach and take into consideration:	-
• results from geochemical characterisation;	Section 2.1
• type and physical characteristics of material being covered (from the material balance developed for the site);	Appendix A
• site conditions;	Appendix A
• availability of suitable cover materials (both quality and quantity);	Section 3.0 describes cover material quality, material balance was not included in the scope
• criteria for discharge (ie to protect environmental values); and	Not included in scope
• suitable vegetation.	The cover design has been conservatively modelled without vegetation
The cover design should include:	-
• identification and speciation of the objectives of the cover;	Section B.2
• a detailed description of the design including the thickness of each layer;	Section 4.3

Requirement	Comment
• a detailed description of the construction method including any proposed staging of the cover system;	Not included in scope
• a quantitative assessment that identifies the location and quantity of proposed cover material available on-site; and	Not included in scope
• proposed quality assurance / quality control (QA/QC) for the construction of the cover including the timely implementation of corrective actions where deviations from the design are identified.	Not included in scope

1.3 Background

1.3.1 Barbara Copper Project

1.3.1.1 Location and operation

The Project is approximately (~) 67 kilometres (km) northeast of Mount Isa in northern Queensland (Figure 1). It was a conventional drill and blast / load and haul operation that operated from June 2019 until December 2020 and was placed on care and maintenance in April 2021. The surrounding land tenure of the region is typically low intensity cattle grazing and mineral exploration.

The Project includes the following key infrastructure:

- north pit;
- south pit;
- WRD;
- WRD sediment dam;
- run-of-mine (ROM) pad / road train loading area;
- light infrastructure area;
- sewage treatment facility;
- explosive magazine;
- access road, haul roads and tracks; and
- diversion drain.

1.3.2 Waste rock dump

The WRD contains waste from both north and south pits and was conceptually designed as a low-profile structure. PAF waste rock was selectively placed within three stepped cell (the PAF cell) inside the non-acid forming (NAF) WRD boundary to provide protection from rainfall infiltration. During construction, the outside batters were covered with ~ five metres (m) of waste rock to prevent infiltration and erosion.

LEGEND

ML90241

City / town

Scale 1 : 750 000

0 10 20 30 km

SGMenvironmental

Client	Round Oak Minerals Pty Ltd
Project	Waste Rock Dump Closure Plan
Design:	SGM Environmental Pty Ltd 04.03.2022
Scale:	1 : 750,000
CRS:	GDA94 / MGA zone 55
Title	Mine Location
Figure	1

1.3.3 Waste rock dump cover options

1.3.3.1 Assumptions

It is assumed that the following materials could be used:

- BCO waste rock (waste rock):
  - unaltered waste rock (NAF) representative of the majority of the WRD; and
  - for use as the infiltration storage layer (ISL) of the cover.
- BCO NAF (waste rock):
  - crushed waste rock (NAF) with a higher percentage of fines to improve water holding capacity;
  - for use as growth media to supplement the soil deficit; and
  - fine portion (<10 mm) for use as the reduced permeability layer (RPL).
- BCO clay (growth medium):
  - clayey sand taken from haul road bunds; and
  - for use as growth media.

1.3.3.2 Selection of cover options

Selection of cover options was decided following a:

- review of background information that relates to the biophysical environment, the WRD and legislation including the EA; and
- risk assessment and cover options analysis.

A summary of the background information review is presented in Appendix A. The risk assessment and cover options analysis are in Appendix B.

1.3.3.3 The cover options

The outcome of the background information review, risk assessment and cover options analysis were that the following preferred cover options were progressed to cover column trials (the Trials):

- cover option 4 (Trial 1):
  - a 1.6 m ISL of coarse waste rock; and
  - a 0.3 m layer of waste rock above the ISL.
- cover option 3 (Trial 2):
  - a 1.6 m ISL of coarse waste rock; and
  - a 0.3 m layer of soil above the ISL.
- cover option 5 (Trial 3):
  - a 0.5 m RPL of fine compacted waste rock;
  - a 1.0 m ISL of coarse waste rock above the fine compacted waste rock; and
  - a 0.3 m layer of fine waste rock above the coarse waste rock layer.

A schematic representation of the Trials is shown in Figure 2.

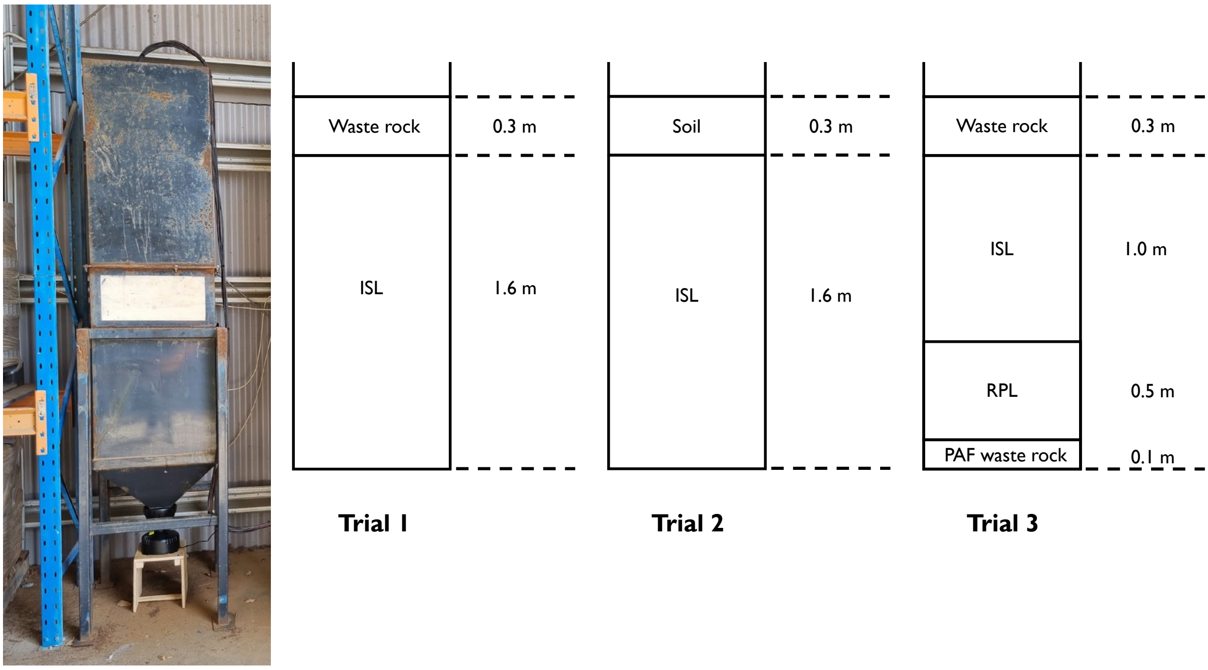


Figure 2 Schematic representation of the Trials

2.0 Method

2.1 Cover material characterisation

2.1.1 Acid mine drainage

The potential for acid mine drainage (AMD) can be assessed by the net acid generation (NAG) test. This involves reaction of the sample with hydrogen peroxide to rapidly oxidise any sulfides. It incorporates both acid generation and neutralising reactions giving a net result of the amount of acid released. A pH after reaction (NAGpH) of above 4.5 generally indicates that the sample is net acid neutralising.

An acid neutralising capacity (ANC) to maximum potential acidity (MPA) mass ratio (ANC:MPA) greater than two is considered to have a negligible to low risk of acid generation and a high factor of safety in terms of potential for AMD; that is a high probability that it will remain neutral (DITR 2007).

The screening criteria used to determine AMD potential is in Table 3 and was taken from *Preventing acid and metalliferous drainage: Leading practice sustainable development program for the mining industry* (DISER & DFAT 2016).

Table 3 AMD screening criteria

Classification	**Net acid producing potential (NAPP)**	**NAGpH**	**Total sulfur**
Units	Kilograms of sulfuric acid per tonne (kg H_2SO_4/t)	pH units	%
PAF	>10	<4.5	-
PAF-low capacity (PAF-LC)	0-10	<4.5	-
NAF	Negative	≥4.5	-
NAF-barren	Negative	≥4.5	<0.05
Acid-consuming (AC)	Less than -100	≥4.5	-
Uncertain (UC)	Positive	≥4.5	-
	Negative	≤4.5	-

2.1.2 Fertility

Soil chemistry results have been compared to soil sufficiency values that are agricultural industry benchmarks sourced from Rayment and Bruce (1984), Baker and Eldershaw (1993), Department of the Environment and Resource Management (DERM) (2011) and Peverill et al. (1999) (Table 4).

Table 4 Sufficiency for common plant nutrition indicators

Constituent	Unit	Sufficiency
pH (1:5)	pH units	6.0-7.5
Saturated soil extract electrical conductivity (ECe)	DeciSiemens per metre (dS/m)	<1.9
Water-soluble chloride	Milligrams per kilogram (mg/kg)	<800
Nitrite and nitrate	mg/kg	>1,500
Colwell phosphorus (P (Colwell))	mg/kg	>10
Total organic carbon	%	>1.2
Exchangeable cations		
Calcium (Ca)	%	60-75
Magnesium (Mg)	%	10-20
Potassium (K)	%	3-8
Exchangeable sodium percentage (ESP)	%	<6
Ca:Mg	-	>2
Cation exchange capacity (CEC)	Milliequivalents per 100 grams (meq/100g)	12-25
Diethylenetriaminepentaacetic acid (DTPA) extractable metals		
Cu	mg/kg	>0.3
Zinc (Zn)	mg/kg	>0.8
Manganese (Mn)	mg/kg	>2
Iron (Fe)	mg/kg	-

2.1.3 Erodibility

Material erodibility was reviewed and assessed using the ESP, electrochemical stability index (ESI) and Emerson aggregate class as indicators of dispersibility.

The ESP measures the proportion of cation exchange sites occupied by sodium (Na). A material is considered sodic when the ESP is greater than 6% and strongly sodic when the ESP is greater than 15%. Sodic materials are prone to disperse when exposed to water (through rain impact and / or runoff).

The structural stability of a material is heavily influenced by a combination of salinity and sodicity. This relationship is described by the ESI which incorporates the dispersive effect of ESP as well as the coagulating effect of elevated EC and is calculated by:

$$ESI = EC\ (1{:}5)\ (dS/m) \,/\, ESP \qquad [EQ1]$$

The Emerson aggregate test measures the stability of the waste rock structure when immersed in water. This test is used to predict dispersive behaviour; with Emerson classes ranging from Class 1 (most dispersible) to Class 8 (least dispersible).

2.1.4 Salinity

The screening criteria used to determine salinity are listed in Table 5 and have been taken from the *Technical Guideline for the Environmental Management of Exploration and Mining in Queensland* (DME 1995).

Table 5 Salinity screening criteria

Classification	EC (1:5)
Very low	<150
Low	150-450
Moderate	450-900
High	900-2,000
Very high	>2,000

2.1.5 Particle size distribution

Three basic parameters can be determined from the particle size distribution (PSD). These are the effective size, D_{10}, which is the particle size in millimetres (mm) through which 10% passes; the uniformity coefficient, (C_u); and the coefficient of curvature (C_c). C_u and C_c are defined by the following relationships:

$$C_u = \frac{D_{60}}{D_{10}} \qquad \text{[EQ2]}$$

$$C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}} \qquad \text{[EQ3]}$$

Where, D_{30} and D_{60} are the diameter corresponding to 30% and 60% finer in grain size distribution respectively.

EQ 2 and EQ 3 may be used to classify a sample in terms of its grading. The higher the value of the C_u, the larger the range of particle sizes in the material. Well graded material will have a:

- C_u greater than four if it is primarily a gravel matrix and six if it is sand; and
- C_c between one to three for both sand and gravel.

2.1.6 Permeability

Greeves et al. (1995) has been used to classify material permeability (Table 6).

Table 6 Classification according to permeability

Degree of permeability	Range of coefficient of permeability k (metres per second (m/s))
Very high	>3.3 x 10^{-5}
High	3.3 x 10^{-5} to 1.7 x 10^{-5}
Moderate	1.7 x 10^{-5} to 5.6 x 10^{-6}

Degree of permeability	Range of coefficient of permeability k (metres per second (m/s))
Low	5.6×10^{-6} to 2.8×10^{-6}
Very low	2.8×10^{-6} to 1.4×10^{-7}
Extremely low	$<1.4 \times 10^{-7}$

2.1.7 Shrink / swell properties

The potential for waste rock to shrink and / or swell is from the Atterberg limit test and PSD. The most useful of the Atterberg limits is the plastic limit. Materials with a high plasticity index tend to be clay, those with medium plasticity index tend to be silt and those with a plasticity index of 0-3 (non-plastic) tend to have little or no silt or clay (Fredlund & Rahardjo 1993) (Table 7).

Table 7 Plasticity index

Plasticity index	Description
0-3	Non-plastic
3-15	Slightly plastic
15-30	Medium plastic
>30	Highly plastic

The shrink / swell potential of waste rock can be assessed using linear shrinkage, which is the percent decrease in the length of a bar of soil when dried in an oven from liquid. The non-critical value for linear shrinkage varied between guidelines but is generally greater than 12%.

2.2 Cover column trials

2.2.1 Sensor calibrations

The following sections describe how the sensors were calibrated prior to installation.

2.2.1.1 Theory

The matric suction sensors consist of a heating and reference wire surrounded by sintered ceramic (the component). The component is porous and when buried in the column trials (the Trials) will wet and dry in response to wetting and drying. The matric suction sensor infers how wet or dry the material is by taking a temperature reading at one second followed by 30 seconds followed by a final measure of the reference wire at 30 seconds. How hot the reference wire becomes is a function of the cover wetness (ie how wet or dry the component is). For example, if the component is wet then it will heat more slowly compared to if the component was dry. Matric suction sensors require calibration so that an empirical relationship between change in temperature (ΔT) and matric suction can be developed for each sensor prior to installation.

Campbell Scientific matric suction sensors are recommended for use for matric suctions ranging from 10-1,000 kilopascals (kPa). These sensors are regularly calibrated for suctions greater than 1,000 kPa (Flint et al. 2002). The calibration functions extend up to 1,000,000 kPa; however, it is unlikely that matric suctions of this order will ever be achieved in the field. The expected range for environmental conditions at the Project is likely to extend from 10 kPa to approximately 100,000 kPa, corresponding to wet and dry seasons respectively.

2.2.1.2 Calibration set-up

The matric suction sensors were calibrated in either soil or waste rock, depending on their depth of burial.

Matric suction sensors were individually calibrated by comparing the measured ΔT of the matric suction sensor to the matric suction of each material. The matric suction was determined by measuring total suction with a dew-point water potential meter and calculating osmotic suction from EC. Matric suction was then calculated by subtracting osmotic suction from total suction.

2.2.2 Design

The preferred cover designs were constructed into three Trials in order to assess the in situ soil water characteristics (Table 8).

Table 8 Trial designs

Layer	**Material**	**Density (t/m^3)**	**Thickness (m)**	**Number of sensor pairs**
Trial 1[1]				
Growth medium	Waste rock	1.6	0.3	3
ISL	Waste rock	1.8	1.6	2
Trial 2[2]				
Growth medium	Soil	1.6	0.3	2
ISL	Waste rock	1.8	1.6	3
Trial 3[3]				
Growth medium	Waste rock	1.6	0.3	2
ISL	Waste rock	1.8	1.0	1
RPL	Fine waste rock (<10 mm)	2.1	0.5	2
PAF	PAF waste rock	2.1	0.1	nil

1. Trial 1 — cover option 4 in SGME (2021a).
2. Trial 2 — cover option 3 in SGME (2021a).
3. Trial 3 — cover option 5 in SGME (2021a).

2.2.3 Construction

Three Trials, one for each cover option, were built to specifications provided by SGME (Table 8). Each Trial is 2 m tall and has a surface area of 0.25 square metres (m^2) (Figure 2).

2.2.3.1 Seepage volume

The Trials include a flume on their base so that seepage can be captured. Rain gauge tipping buckets were placed under the flumes to measure the volume of seepage. The rain gauge tipping buckets sit on-top of a collection reservoir which allows seepage water to be sampled.

2.2.4 Filling

The Trials are made up of layers of growth media (soil or fine waste rock), coarse waste rock and an RPL (Trial 3 only). A 0.1 m layer of clean gravel was placed on the bottom of each Trial to act as a drainage layer (the filter layer). Geofabric was placed on top of the filter layer to prevent clogging by particles migrating into the gravel pore spaces.

- Trial 1:
  - a 1.6 m ISL of coarse waste rock compacted to a bulk density of 1.8 t/m^3; and
  - a 0.3 m layer of waste rock above the ISL at a density of 1.6 t/m^3.
- Trial 2:
  - a 1.6 m ISL of coarse waste rock compacted to a bulk density of 1.8 t/m^3; and
  - a 0.3 m layer of soil above the ISL at a density of 1.6 t/m^3.
- Trial 3:
  - a 0.1 m layer of PAF waste rock compacted to a bulk density of 2.1 t/m^3 in the bottom of the column (not part of the cover), and was used to gauge seepage water quality underneath the PAF cover system;
  - a 0.5 m RPL of fine compacted waste rock above the PAF waste rock layer compacted to a bulk density of 2.1 t/m^3;
  - a 1 m ISL of coarse waste rock above the fine compacted waste rock compacted to a bulk density of 1.8 t/m^3; and
  - a 0.3 m layer of waste rock above the coarse waste rock layer to a density of 1.6 t/m^3.

2.2.5 Instrument depths

The Trials include buried pairs of sensors in the growth media, ISL and RPL. The sensor pairs comprise a buried matric suction sensor and a volumetric water content (VWC) sensor at the depths (metres below ground level (m bgl) given in Table 9.

Table 9 Trial sensor depths

Trial 1		**Trial 2**		**Trial 3**	
Sensor number	Sensor depth (m bgl)	Sensor number	Sensor depth (m bgl)	Sensor number	Sensor depth (m bgl)
1	0.2	6	0.2	11 / B	0.2
2	0.3	7	0.3	12 / C	0.3
3	0.5	8	0.5	13 / D	1.3
4	1.3	9	1.3	14 / E	1.5
5	1.9	10 / A	1.9	15 / F	1.8

1. Light orange = waste rock (crushed), dark orange = soil, light grey = waste rock (ISL), dark grey = waste rock (RPL)

2.2.6 Wetting and drying

The Trials were subjected to 13 artificial rainfall events over five months. The purpose of the artificial rainfall was to allow the Trials to wet up and dry out so that the in situ soil water characteristic curves (SWCCs) and a maximum water balance could be derived:

- 30 mm simulated rainfall on day 1;
- 30 mm simulated rainfall on day 8;

- 30 mm simulated rainfall on day 15;
- 30 mm simulated rainfall on day 22;
- 30 mm simulated rainfall on day 29;
- 30 mm simulated rainfall on day 36;
- 30 mm simulated rainfall on day 43;
- 30 mm simulated rainfall on day 50;
- 50 mm simulated rainfall on day 64;
- 50 mm simulated rainfall on day 78;
- 50 mm simulated rainfall on day 92;
- 50 mm simulated rainfall on day 104;
- 50 mm simulated rainfall on day 118;
- 50 mm simulated rainfall on day 132;

A total of 540 mm of artificial rainfall was applied to each Trial.

2.3 HYDRUS modelling

A one-dimensional (1D) HYDRUS model (the model) was developed and calculates the upward and downward movement of rainfall infiltration and seepage in cover options; it assumes no surface runoff or run on and allows for ponding on the ground surface.

Transpiration from vegetation has been conservatively excluded since data is not available for this parameter (therefore, the model only considers evaporation).

2.3.1 Model dimensions

The model dimensions were developed to replicate the Trials (see Table 8).

2.3.2 Mesh geometry

The model automatic mesh generation and automatic mesh refinement algorithms were used to generate the finite element mesh.

2.3.3 Initial conditions

2.3.3.1 Potential and actual evaporation

The model is at a preliminary stage and is highly sensitive to potential evaporation. Potential evaporation in the model was run at two different rates; 0.0045 and 0.0048 metres per day (m/day), which is the minimum and maximum annual potential calculated from the Trials.

The model calculates actual evaporation using sub-straight matric suction gradients coupled with relative humidity and temperature using the Modified Wilson Limiting Equation (Wilson et al. 1997).

2.3.3.2 Physical characteristics

a Soil water characteristic curves

The model requires SWCCs. The SWCCs show the relationship between VWC and matric suction for each sensor pair in the Trials and have been taken from in situ results.

b Saturated hydraulic conductivity

The saturated hydraulic conductivity values used in the model were:

- growth media — 0.0004 m/day or 5.1 x 10^{-9} m/s;
- ISL — 0.4752 m/day or 5.5 x 10^{-6} m/s; and
- RPL — 0.1296 m/day or 1.5 x 10^{-6} m/s.

c Unsaturated hydraulic conductivity

Hydraulic conductivity is the ability of the soil to transmit rainfall infiltration through the internal pore space and is defined by the rainfall infiltration velocity. The model derives unsaturated hydraulic conductivity curves from the SWCCs and the saturated hydraulic conductivity.

2.3.4 Analysis method

A series of transient analyses were done:

- 150 days of artificial rainfall (from the Trials);
- the average year;
- the wettest year; and
- the driest year.

A dataset of 132 years of rainfall data from 1889 to 2021 was obtained from the Queensland Government SILO climate database (SILO 2021); the datasets are constructed from observed data from the Bureau of Meteorology (BoM).

The annual sequence of daily rainfall corresponding to the average, wettest and driest years were selected from the ranked annual rainfall (the scenarios):

- 2009 was chosen for the wet year;
- 1957 was chosen for the average year; and
- 1926 was chosen for the dry year.

The mean daily values for maximum and minimum temperature, maximum and minimum humidity were obtained from the SILO climate database and used for each scenario.

The rainfall scenarios are given in Table 10.

Table 10 Rainfall for model scenarios

Scenarios	Year	Rainfall (mm)
Wet	2009	1,198.0
Average	1957	463.4
Dry	1926	117.2

3.0 Cover material suitability

Certificates of analysis for the following discussion are given in Appendix C for SGS Australia Pty Ltd (SGS) laboratory and Appendix D for Trilab Pty Ltd (Trilab) laboratory.

3.1 Waste rock

3.1.1 Acid mine drainage

The waste rock samples analysed have a NAGpH above 4.5 and the NAPP is negative indicating that they are not acid generating. Based on the NAPP and NAGpH test results, waste rock is classified as NAF.

ANC ranged from 9.8-32.0 kg H_2SO_4/t and MPA ranged from 1.6-8.4 kg H_2SO_4/t. All waste rock samples analysed have an ANC:MPA greater than two (Table 11). Based on MPA and ANC:MPA, waste rock samples are classified as NAF (low sulfur waste rock with some ANC).

3.1.2 Fertility

Waste rock fertility results are in Table 12:

- pH (1:5) ranged from 9.0-9.5 — waste rock is considered strongly alkaline, which may limit the growth of some plant species sensitive to alkalinity;
- water-soluble chloride is low;
- P (Colwell) is low (<1 mg/kg). P deficiency may therefore limit growth of some plant species (noting that most native plant species are adapted to low P concentrations);
- nitrite and nitrate are low (<15 mg/kg);
- total organic carbon is low (0.30-0.40%), which can indicate poor structural condition, nutrient and water holding capacity;
- CEC is sufficient indicating a capacity to store nutrients;
- ESP is less than 6% indicating that it is not sodic;
- exchangeable K and Mg are low. Exchangeable cation imbalance may limit plant growth; and
- DTPA extractable Zn is low, which is associated with high pH. Micronutrients are unlikely to limit plant growth.

Waste rock has low fertility, strong alkalinity, exchangeable cation imbalances, low nitrite and nitrate, P and total organic carbon when compared to agricultural industry benchmarks.

3.1.3 Erodibility

The structural stability of waste rock is heavily influenced by a combination of EC and ESP. The ESP of waste rock ranges from 1.0-1.1 and is non-sodic.

The Emerson aggregate test measures the instability of the waste rock structure when immersed in water and is used to predict dispersive behaviour. The Emerson aggregate testing was done by Trilab laboratory (Appendix D). The composite waste rock sample was Class 3 indicating that remoulded waste rock (heavily trafficked) at the plastic limit will disperse in water.

3.1.4 Salinity

EC (1:5) was between 120-170 µS/cm (Table 12). Therefore, waste rock is expected to have very low to low salinity.

Table 11 Acid base accounting and NAGpH results

	Units	BCO waste rock 1	BCO waste rock 2	BCO NAF 1	BCO NAF 2	BCO NAF 3
pH (1:5)	pH units	8.9	9.4	9.5	9.4	9.0
EC (1:5)	µS/cm	170	120	140	140	150
Total sulfur	%	0.058	0.052	0.23	0.22	0.27
MPA	kg H_2SO_4/t	1.8	1.6	7.0	6.7	8.4
ANC	kg H_2SO_4/t	9.8	12	28	28	32
ANC:MPA	-	5.4	7.5	4.0	4.2	3.8
NAPP	kg H_2SO_4/t	-8.0	-11	-21	-22	-23
Classification based on NAPP only	-	NAF	NAF	NAF	NAF	NAF
NAGpH 4.5	kg H_2SO_4/t	<0.5	<0.5	<0.5	<0.5	<0.5
NAGpH 7.0	kg H_2SO_4/t	<0.5	<0.5	<0.5	<0.5	<0.5
NAGpH	-	8.6	8.2	9.1	9.3	8.6
Classification based on NAPP and NAGpH	-	NAF	NAF	NAF	NAF	NAF

Table 12 Fertility, erodibility and salinity results

Analyte	Units	Sufficiency	BCO NAF 1	BCO NAF 2	BCO NAF 3	BCO clay 1	BCO clay 2	BCO clay 3
pH (1:5)	pH units	6.0-7.5	**9.5**	**9.4**	**9.0**	**8.8**	**7.1**	**9.1**
EC (1:5)	µS/cm	<1,200	140	140	150	110	**8,700**	**6,500**
Root EC (ECe)[2]	deciSiemens per metre (dS/m)	<2.00	**-**	**-**	**-**	**2.53**	**200.10**	**149.50**
Water-soluble chloride	(mg/kg)	<800	13	16	10	22	**14,000**	**4,600**
P (Colwell)	mg/kg	>10	**<1**	**<1**	**<1**	**7**	25	**7**
Nitrite and nitrate	mg/kg	>15	**11**	**8**	**13**	**3**	210	28
Total organic carbon	%	>1.20	**0.40**	**0.32**	**0.30**	**0.33**	**0.54**	**0.30**
Organic matter	%	-	0.69	0.55	0.52	0.57	0.94	0.52
CEC	milli-equivalent per 100 gram (meq/100 g)	12-25	15	17	16	15	**44**	**47**
ESP	%	<6.0	1.1	1.0	1.1	1.2	**63.7**	**74.8**
Exchangeable K	%	3.0-8.0	**1.7**	**1.7**	**1.7**	**1.9**	**0.9**	**0.7**
Exchangeable Ca	%	60.0-75.0	**94.7**	**94.7**	**94.9**	**89.3**	**24.1**	**22.8**
Exchangeable Mg	%	10.0-20.0	**2.4**	**2.6**	**2.2**	**7.6**	11.4	**1.7**
Ca:Mg	-	>2.0	38.8	36.6	42.2	11.7	2.1	13.3

Analyte	Units	Sufficiency	BCO NAF 1	BCO NAF 2	BCO NAF 3	BCO clay 1	BCO clay 2	BCO clay 3
ESI[3]	-	>0.050	0.127	0.140	0.136	0.092	0.137	0.087
DTPA extractable Cu	mg/kg	>0.3	5.0	5.5	13.0	1.6	3.7	1.7
DTPA extractable Zn	mg/kg	>0.80	**0.26**	**0.47**	**0.26**	**0.35**	0.85	**0.36**
DTPA extractable Mn	mg/kg	>2.0	5.2	4.4	4.9	11.0	53.0	6.1
DTPA extractable Fe	mg/kg	-	35	26	29	20	15	13

1. Bold indicates value did not meet sufficiency target.
2. ECe = EC (1:5) (dS/m) * texture multiplier factor (assumed where unknown) (Hazelton & Murphy 2016)
3. ESI = EC (1:5) (dS/m) / ESP (%).

3.1.5 Physical

3.1.5.1 Particle size distribution

The PSD for waste rock is in Figure 3. Fines (ie silt and clay) make up ~ 3% of the BCO NAF (waste rock) analysed with clay making up less than 1%. Sand makes up ~ 42% while gravel sized particles make up ~ 54%.

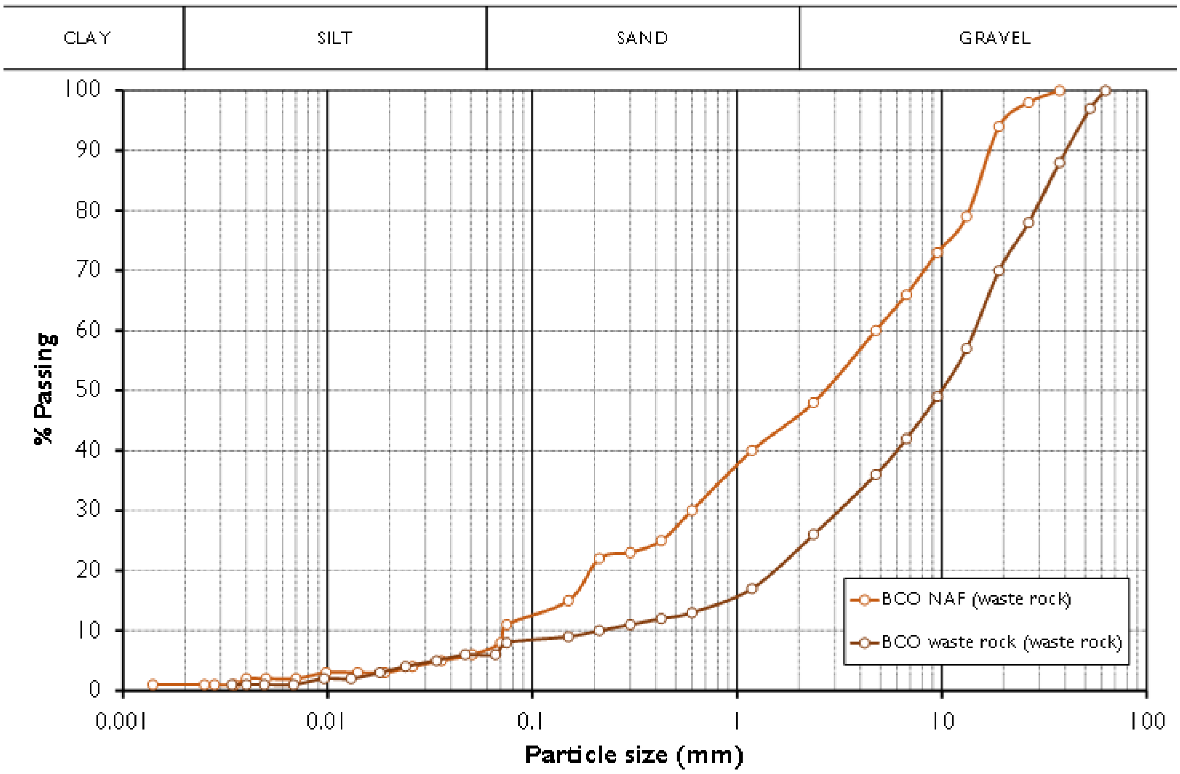


Figure 3 Waste rock PSD

The parameters given in Table 13 may be used to classify waste rock in terms of its grading.

Table 13 Waste rock physical characteristics

D_{10} (mm)	D_{30} (mm)	D_{60} (mm)	C_u	C_c
0.07	0.60	4.75	67.9	1.1

BCO NAF (waste rock) in its current state is well graded. Well-graded materials have a lower propensity for segregation of fine and coarse particles. This will reduce the potential formation of preferential flow paths.

3.1.5.2 Compaction

Standard compaction tests were done on the waste rock to determine the standard compaction maximum dry density (SMDD) and the standard compaction optimum moisture content (SOMC), which was 2.20 t/m^3 and 6.5% respectively for BCO NAF (waste rock). The SMDD and SOMC for the BCO waste rock sample was 2.22 t/m^3 and 7.2% respectively.

3.1.5.3 Permeability

The composite BCO NAF (waste rock) is classified as having a low permeability (at 95% SMDD) (5.5 x 10^{-6} m/s). The composite BCO waste rock is classified as having a very low permeability (at 95% SMDD) (1.5 x 10^{-6} m/s).

3.1.5.4 Shrink / swell properties

BCO NAF is classified as non-plastic (Table 14) and has a linear shrinkage of 0% indicating a negligible potential for shrink-swell behaviour (Appendix D). BCO waste rock is classified as slightly plastic and has a linear shrinkage of 2.0% indicating a limited potential for shrink / swell behaviour.

Table 14 Waste rock plasticity index

	(0-3) **Non-plastic**	**(3-15)** **Slightly plastic**	**(15-30)** **Medium plastic**	**>30** **Highly plastic**
Waste rock	2	-	-	-

3.2 Soil

3.2.1 Fertility

Soil fertility results are in Table 12 (clay 1-3):

- pH (1:5) ranged from slightly (7.1) to strongly (9.1) alkaline, which may limit plant growth for sensitive plant species.
- ECe ranged from slightly (2.53 dS/m) to extremely (200.10 dS/m) saline, which will likely limit plant growth.
- Water-soluble chloride ranged from 22-14,000 and is contributing to salinity.
- P (Colwell) ranged from 7-25 mg/kg. P deficiency will unlikely limit growth of native plant species (most native plant species are adapted to low P concentrations).
- Nitrite and nitrate ranged from low (2.5 mg/kg) to sufficient (15 mg/kg).
- TOC is low (0.30-0.54%), which can indicate poor structural condition and moisture retention as well as nutrient deficiencies.
- CEC is sufficient to very high, indicating a large capacity to store nutrients and a large buffering capacity against acidification.
- ESP ranged from non-sodic (1.2%) to strongly sodic (74.8%) indicating that exchangeable sodium is contributing to salinity.
- Exchangeable Ca, Mg and K are low. Exchangeable cation imbalances may limit plant growth.
- DTPA extractable Zn is low, which is associated with high pH. Micronutrients are unlikely to limit plant growth.

Soil has very low fertility due to strong alkalinity, extreme salinity, nutrient deficiency (P, nitrite and nitrate), exchangeable cation imbalances and low organic matter when compared to agricultural industry benchmarks.

3.2.2 Erodibility

ESP ranged from 1.2-74.8 with a median ESP of 63.7 and is considered strongly sodic.

The ESI ranged from 0.087-0.137 indicating that salinity is high enough to provide some stability through the coagulation of dispersed clay particles.

Soil has an Emerson Class 3, indicating that the remoulded (heavily trafficked) soil will disperse in water.

3.2.3 Salinity

EC (1:5) was between 140-150 µS/cm (Table 12). Therefore, soil is expected to have very low to low salinity.

3.2.4 Physical

3.2.4.1 Particle size distribution

The PSD for soil is in Figure 4. Fines (ie silt and clay) make up ~ 6% with clay making up less than 1%. Sand makes up ~ 40% while gravel sized particles make up ~ 54%.

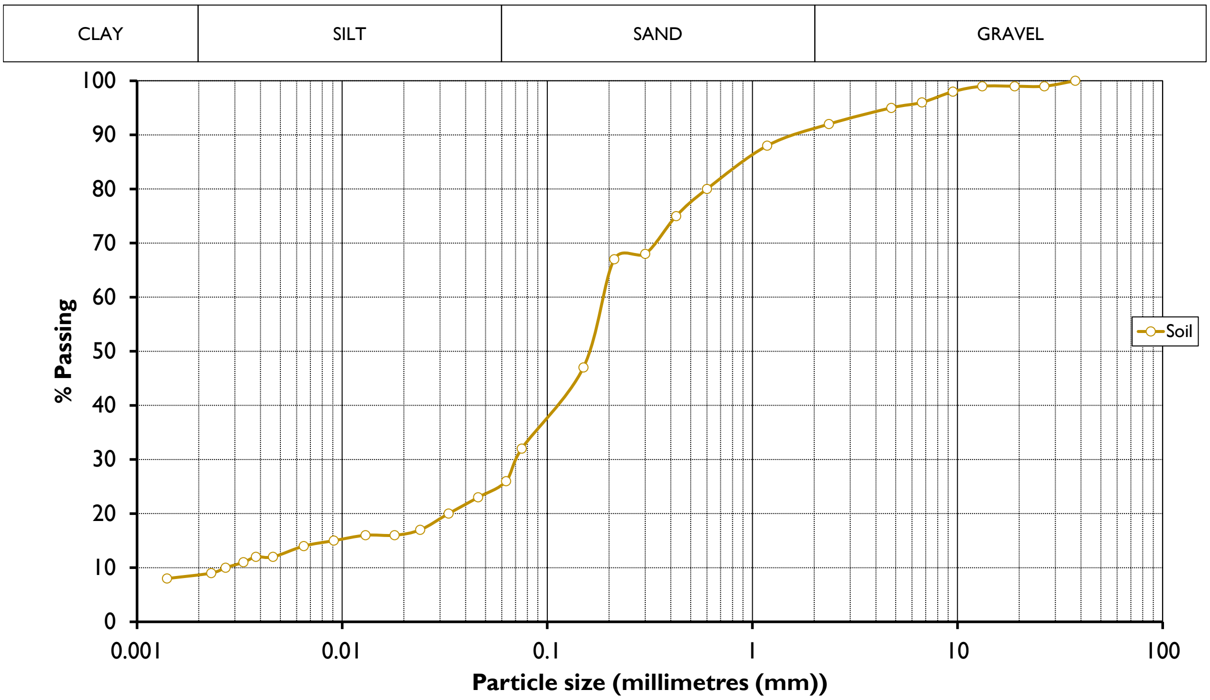


Figure 4 Soil PSD

Soil is well graded (Table 15) and has a lower propensity for segregation of find and coarse particles. This will reduce the potential formation of preferential flow paths.

Table 15 Soil physical characteristics

D_{10} (mm)	D_{30} (mm)	D_{60} (mm)	C_u	C_c
0.0027	0.0700	0.1850	68.5	1.5

3.2.4.2 Compaction

Standard compaction tests were done on the soil to determine the SMDD and SOMC, which was 2.03 t/m^3 and 9.9% respectively.

3.2.4.3 Permeability

Soil is classified as having a low permeability (at 95% SMDD) (Greeves et al. 1995) (5.1 x 10^{-9} m/s).

3.2.4.4 Shrink / swell properties

Soil is classified as slightly plastic (Table 16).

Table 16 Soil plasticity index

	(0-3) Non-plastic	**(3-15) Slightly plastic**	**(15-30) Medium plastic**	**>30 Highly plastic**
Soil	-	4	-	-

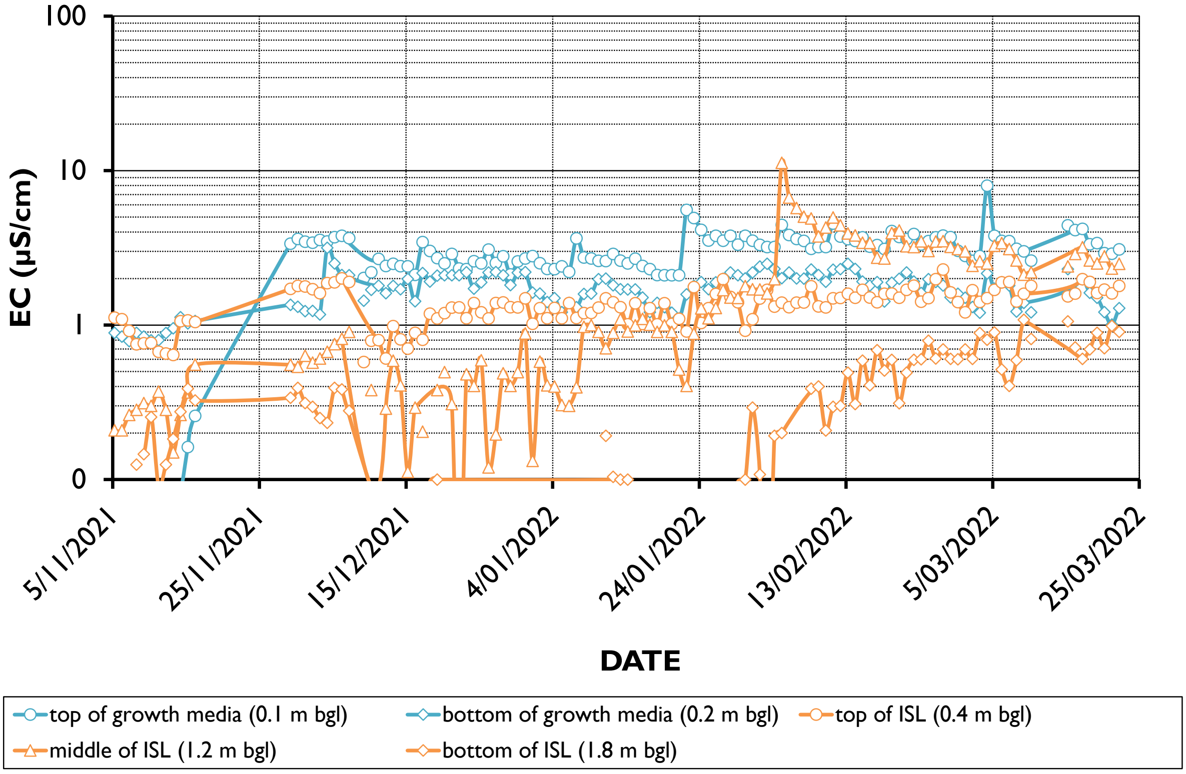
Soil has a linear shrinkage of 2% indicating limited potential for shrink-swell behaviour.

4.0 Cover performance

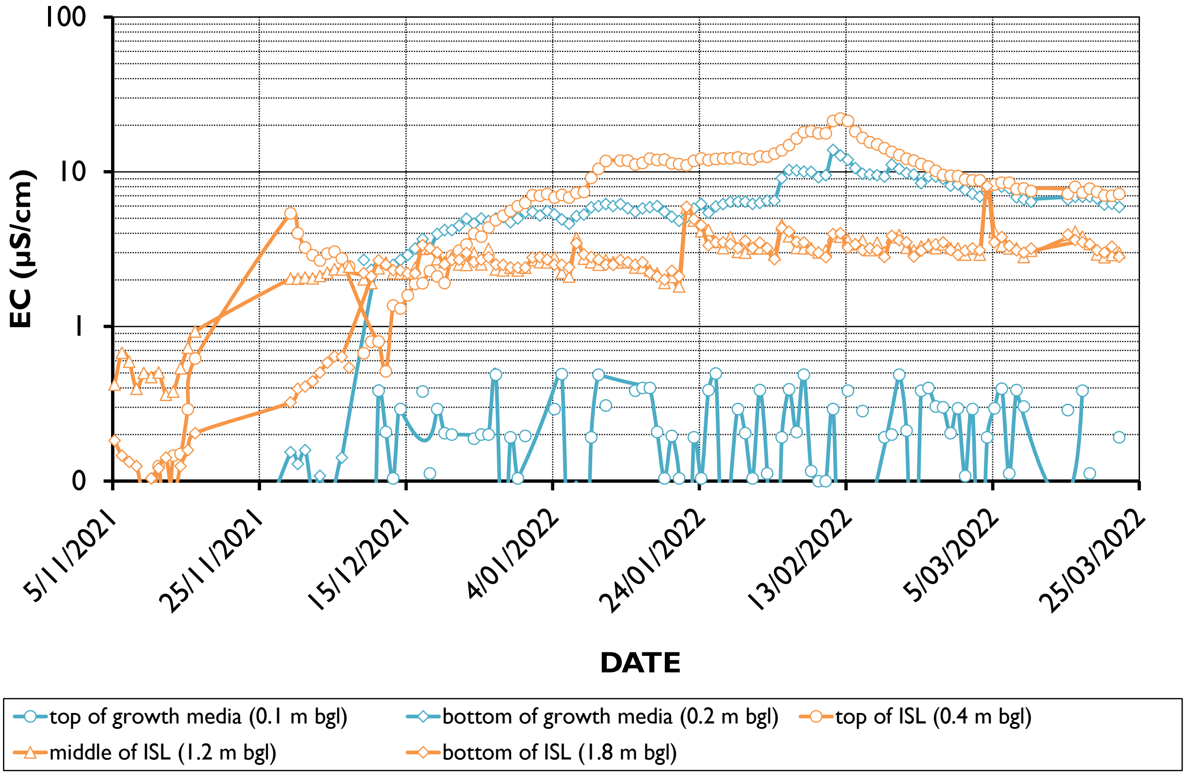
4.1 Cover column trials

4.1.1 Electrical conductivity

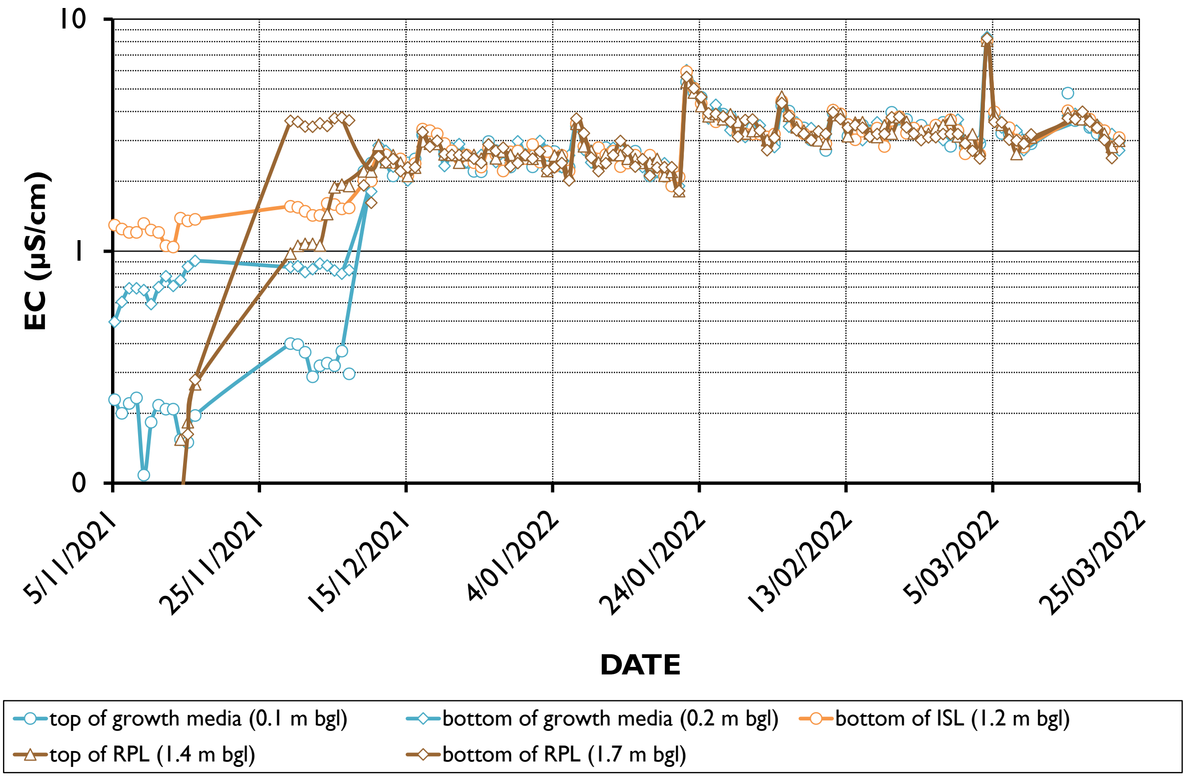
There are no indications that capillary rise is occurring (Figure 5a-Figure 5c). The rises in EC observed in Trial 1 and Trial 2 are from increasing VWC (thereby dissolving existing salts) and are not as a result of capillary rise.



(a)



(b)



(c)

Figure 5 EC of the Trials (a) Trial 1 (b) Trial 2 (c) Trial 3

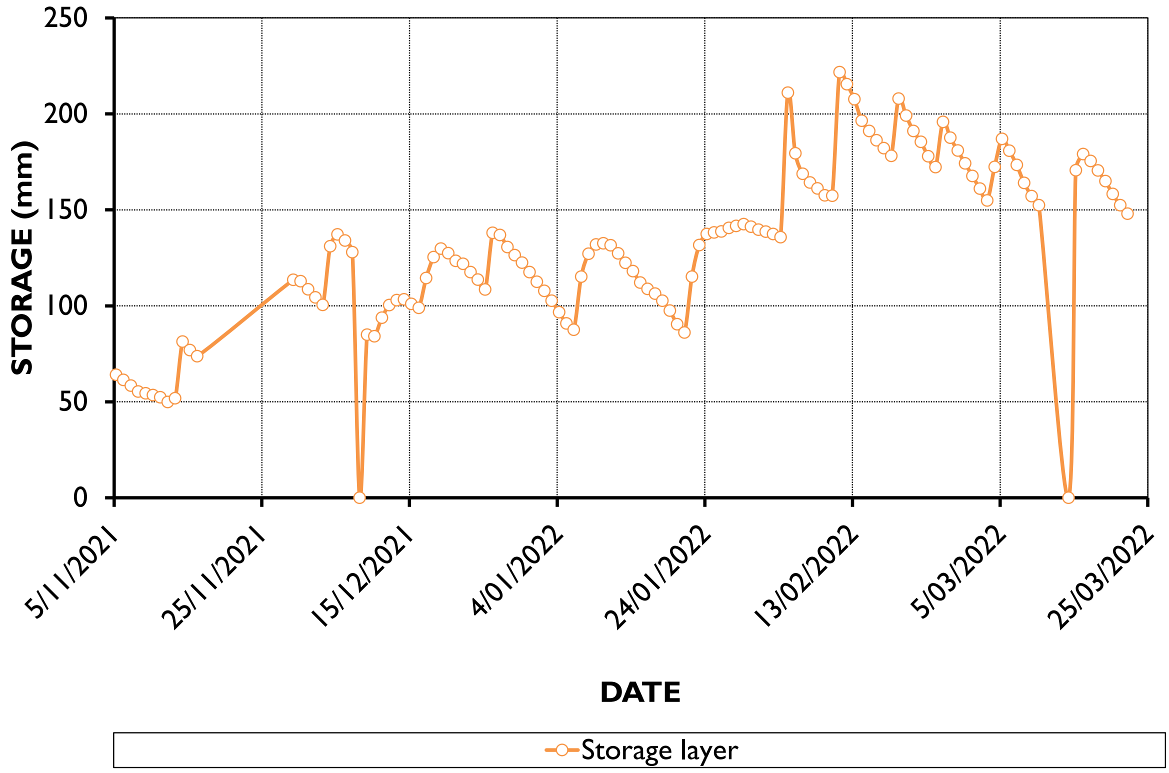
4.1.2 Stored infiltration

Stored infiltration in the Trials was calculated daily by multiplying the change in VWC by depth. The daily incremental change in stored infiltration (ΔSW) balances the infiltration budget daily as either wetting (positive ΔSW) or drying (negative ΔSW). As such, it is proportional to the rate of evaporation. Figure 6 shows the stored infiltration for the Trials:

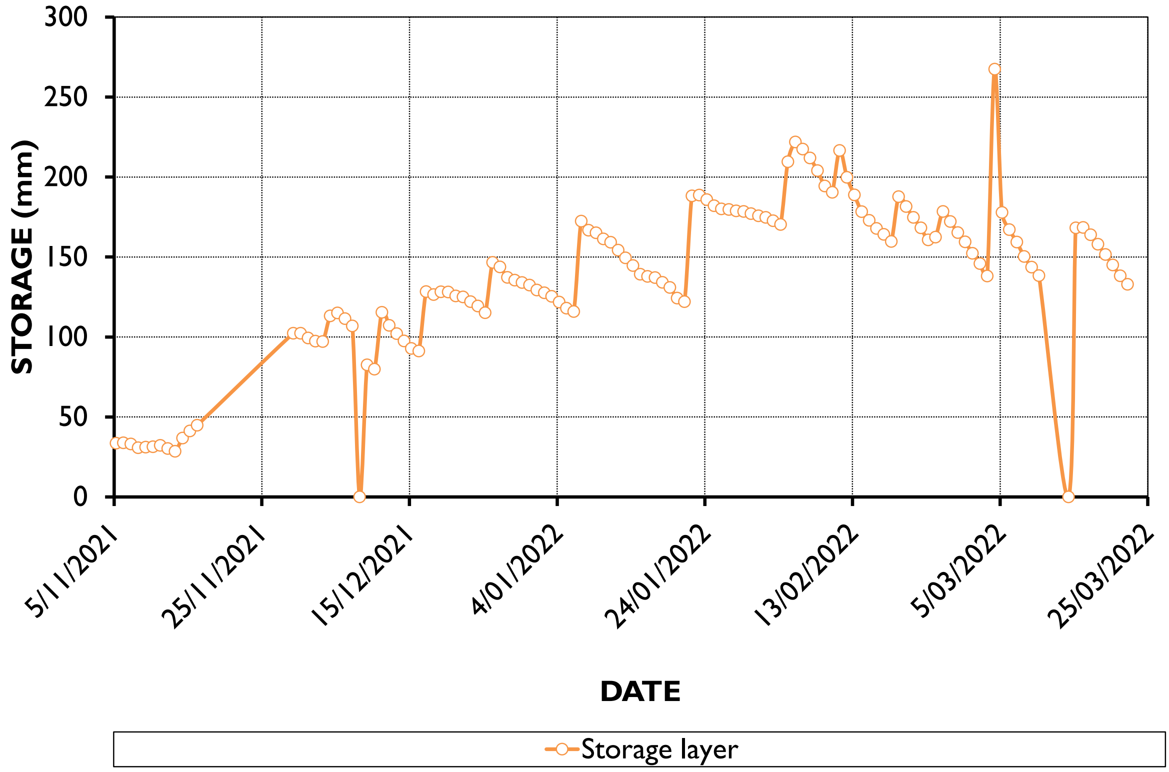
- Figure 6a gives the stored infiltration of Trial 1;
- Figure 6b gives the stored infiltration of Trial 2; and
- Figure 6c gives the stored infiltration of Trial 3.

Of the three Trials, Trial 2 (cover option 3) stored the most infiltration (~170 mm) followed by Trial 1 (cover option 4) (~140 mm) with Trial 3 (cover option 5) storing the least infiltration (~120 mm).

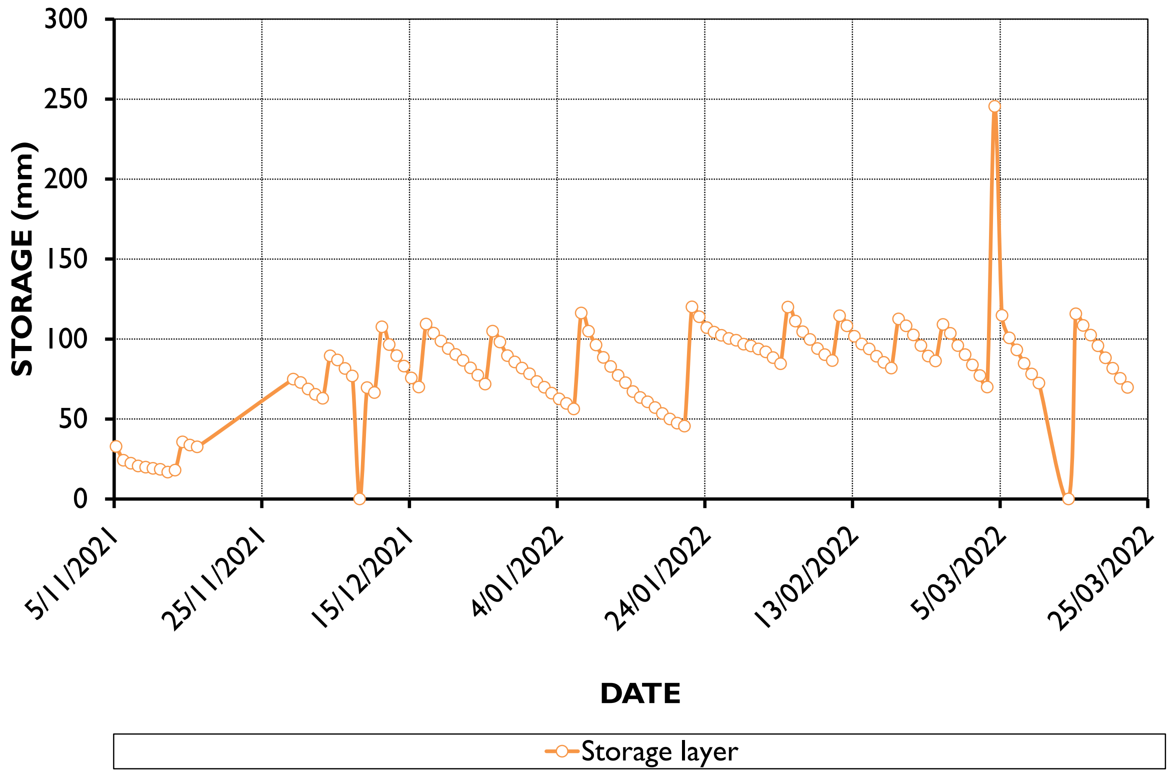
Note that delays in stored infiltration being detected in the Trials (following the watering events) are likely due to bypass flow initially occurring in the macro-pores. This typically occurs faster than the gradual wetting up and flow in the soil and / or waste rock matrix (ie matrix flow). Evaporation of ponded water from the top of the Trials may also be contributing.



(a)



(b)



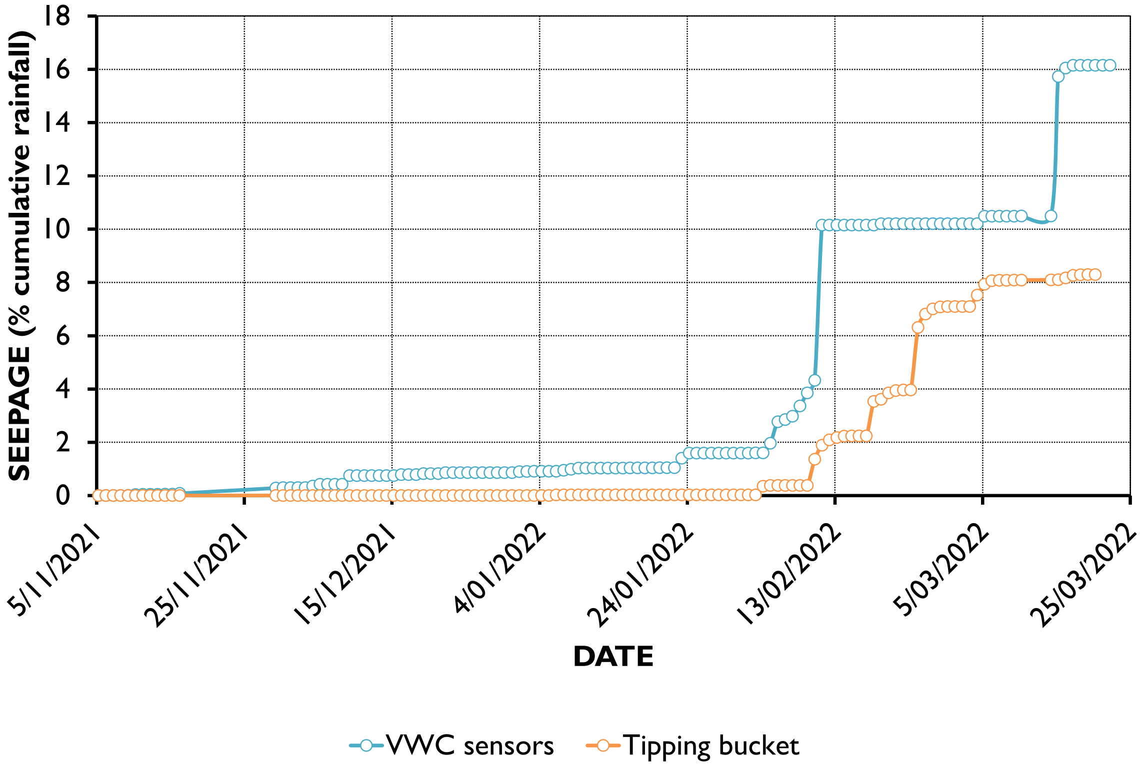
(c)

Figure 6 Stored infiltration in the Trials (a) Trial 1 (b) Trial 2 (c) Trial 3

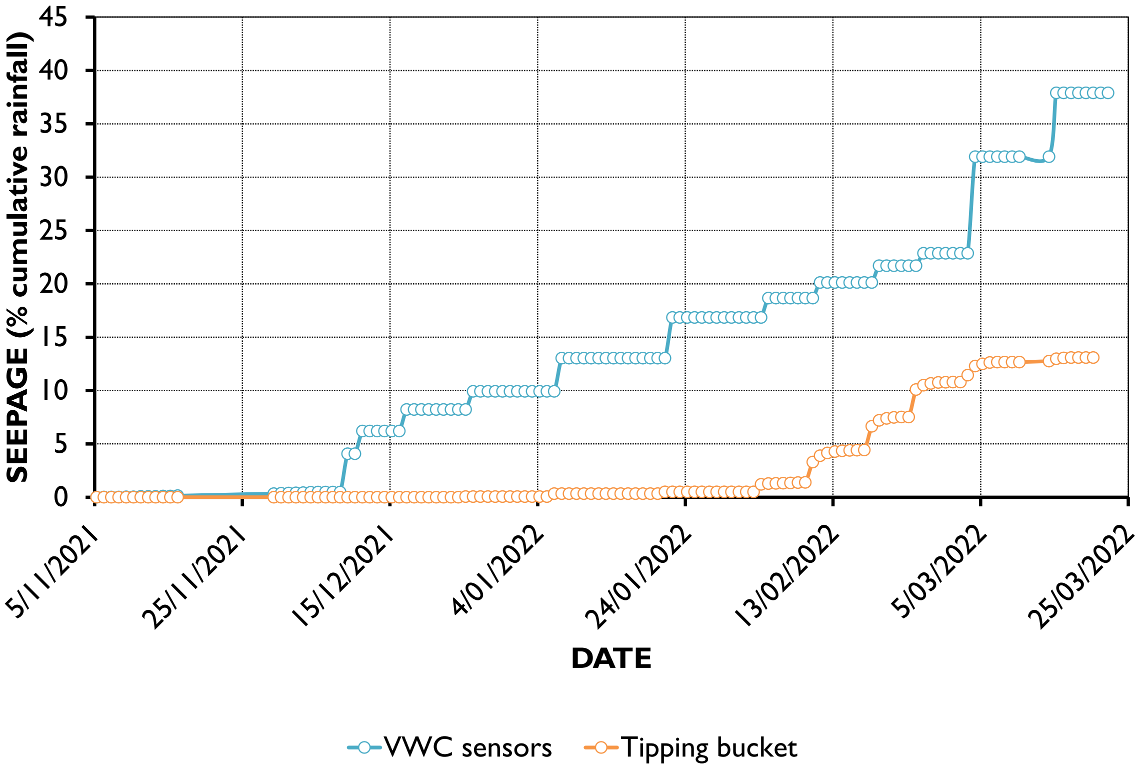
4.1.3 Seepage

Seepage, as a percentage of cumulative rainfall, is given in Figure 7. Seepage is given as both calculated (calculated from the VWC sensors) and measured (the volume removed from each tipping bucket):

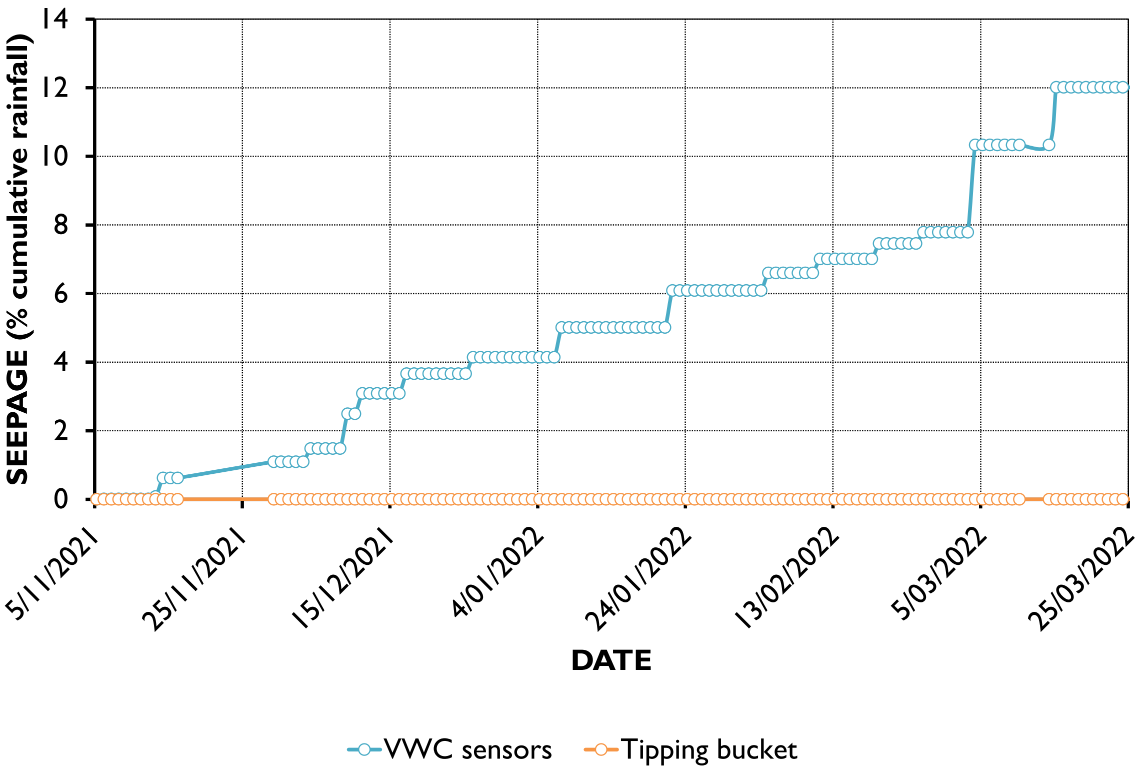
- Trial 1 has recorded about 16% seepage;
- Trial 2 has recorded about 14% seepage; and
- Trial 3 has recorded about 12% seepage.



(a)



(b)



(c)

Figure 7 Seepage of the Trials (a) Trial 1 (b) Trial 2 (c) Trial 3

4.1.4 Water balance

Incorporating stored infiltration, artificial rainfall and seepage allows for the calculation of a water balance for each Trial (Table 17) by solving for evaporation using EQ 4.

Evaporation = artificial rainfall – seepage – stored infiltration [EQ4]

Table 17 Water balance for each Trial

	Flux		
	Units	**mm**	**% of cumulative artificial rainfall**
Trial 1	Stored infiltration	140	26
	Seepage	86.5	16
	Evaporation	313.5	58
Trial 2	Stored infiltration	170	31.5
	Seepage	75.5	14
	Evaporation	294.5	54.5
Trial 3	Stored infiltration	120	22
	Seepage	65	12
	Evaporation	355	66

1. Total artificial rainfall equals 540 mm

4.2 HYDRUS modelling

A model was built to replicate the Trials over time. The model simulates water flow and solute transport in variably saturated media and can be used to predict infiltration, evaporation, transpiration, soil water storage and deep drainage (percolation / seepage).

4.2.1 Soil water characteristic curves

The SWCCs used in the model are given in Appendix E.

4.2.2 Calibration

To make sure that the model was calibrated it was first run for the 150 days of artificial rainfall applied to the Trials (the preliminary run). The preliminary run did not allow for runoff so that it mimicked the Trials and could be calibrated (ie the Trials do not allow for runoff).

4.2.3 Water balance

A comparison of the artificial rainfall water balance from the Trials to the model is given in Table 18.

Table 18 Water balance summary for artificial rainfall

	Trial 1		Trial 2		Trial 3	
	Trial	Model	Trial	Model	Trial	Model
Artificial rainfall (mm)	540	540	540	540	540	540
Stored infiltration (%)	26	32	31.5	10	22	25
Seepage (%)	16	1	14	0	12	0
Evaporation (%)	58	67	54.5	42	66	75
Runoff (%)	-	-	-	-	-	-

The model predicts a lower rate of seepage compared to the Trials. The inconsistency of the results is likely because the model cannot account for macro-pore infiltration (preferential flow) in response to short duration, high intensity rainfall. It is however expected that the effect of macro-pore infiltration would reduce over time as fines migrate within the cover.

4.2.4 Future cover performance

The performance of Trial 1-Trial 3 (modelled for an average, wet and dry year) are in Table 19-Table 21. Note that the future performance models have included runoff since there would be runoff on the actual WRD.

Table 19 Trial 1 model water balance results

	Dry year	Average year	Wet year
Rainfall (mm)	117.2	463.4	1,198.0
Stored infiltration (%)	11	11	8
Seepage (%)	0	2	59
Actual evaporation (%)	88	87	33
Runoff (%)	1	2	8

1. The model has been run with a minimum of 2.5 m of compacted NAF waste rock (the cap) beneath the cover.

Table 20 Trial 2 model water balance results

	Dry year	Average year	Wet year
Rainfall (mm)	117.2	463.4	1,198.0
Stored infiltration (%)	7	5	3
Seepage (%)	0	0	0
Actual evaporation (%)	82	70	70
Runoff (%)	11	25	27

1. The model has been run with a minimum of 2.5 m of compacted NAF waste rock (the cap) beneath the cover.

Table 21 Trial 3 model water balance results

	Dry year	Average year	Wet year
Rainfall (mm)	117.2	463.4	1,198.0
Stored infiltration (%)	6	5	5
Seepage (%)	0	0	36
Actual evaporation (%)	82	70	33
Runoff (%)	12	25	26

1. The model has been run with a minimum of 2.5 m of compacted NAF waste rock (the cap) beneath the cover.

Table 19-Table 21 show that all cover options would likely limit seepage. Trial 1 and Trial 3 have high rates of seepage when subject to periods of short duration, heavy rainfall (wet year).

Trials 1 and 2 had higher stored infiltration than Trial 3, which shows that a 1.6 m ISL provides higher stored infiltration than a 1.0 m ISL. While a higher stored infiltration can reduce seepage through evapotranspiration by plants, seepage reduction can be effectively achieved by the inclusion of an engineering control (ie a RPL). Trial 3 limited more seepage than Trial 1 during the wet year, indicating that an RPL would be effective in limiting seepage into the underlying WRD.

Trial 2 includes a soil layer on the surface. While soil contains a higher percentage of fines (ie silt and clay) than the crushed waste rock (which is useful to reduce seepage), it has a high runoff rate during the wet year (~27%) that could lead to an increased potential for soil erosion. However, the coarse nature of waste rock will disrupt runoff velocity and reduce the potential for erosion (Trial 1 and Trial 3 (ie the establishment of vegetation on waste rock is not required to reduce the potential for erosion).

Trial 1-3 were conservatively modelled without vegetation (ie there no reliance upon evapotranspiration to reduce seepage). Therefore, the predicted future performance of Trial 1-3 is not reliant on the establishment of vegetation.

4.2.5 Performance compared to industry examples

Australian literature that relates to cover geometry is typically for mono (ISL only) or duplex (an ISL underlain by an RPL) layer covers:

- Mt Whaleback Mine and Peak Gold Mine exemplify mono layer covers since the cover is an ISL only (Ayres et al. 2003; O'Kane et al. 2000; O'Kane & Walters 2003; Jamson & Rohde 2019) (Figure 8).
- Kidston Mine, Cadia Mine, Century Mine, Endeavour Mine and Mary Kathleen Mine exemplify duplex covers as the covers use a RPL overlain by an ISL (Williams et al. 1997; Durham 2002; Wilson 2000; Rohde & Williams 2009; Rohde et al. 2016; Rohde et al. 2017; Jamson & Rohde 2019; Lottermoser et al. 2003) (Figure 8).

The ratio of evaporation to rainfall (evaporation:rainfall) exceeds two at all of the mines, meaning that a store and release cover is appropriate (Table 22 and Figure 8).

Table 22 Summary of climate for Australian mines with cover trials

Location	Rainfall (mm)	Evaporation (mm)	Evaporation:rainfall
Kidston Mine	700	2,800	4
Mt Whaleback Mine	320	3,000	~ 9
Cadia Mine	900	2,000	~ 2
Century Mine	544	2,700	~ 5
Endeavor Mine	400	1,200	3
Mary Kathleen Mine	420	2,800	~ 6.5

Figure 8 Locations of mines with cover trials

Cover performance is difficult to determine from literature with the reviewer often required to make some assumptions to estimate the performance of the cover (where performance relies on the estimation of seepage percentage from the base of the cover). Some examples of seepage that has been reported in literature include:

- 2.0 m and 4.0 m mono layer cover options from Mt Whaleback Mine;
- 1.5-2.0 m duplex layer cover at Kidston Gold Mine;
- 2.0 m duplex layer cover at Cadia Mine;
- 2.0 m duplex layer cover at Century Mine;
- 0.4-0.8 m duplex layer coves at Endeavor Mine; and
- 1.5 m duplex layer cover at Mary Kathleen Mine.

From Figure 9 it is notable that cover performance monitoring has only been reported for short periods. The performance of the covers, from the estimation of seepage percentage, ranges from near zero for Kidston Mine (duplex layer cover) to nearly 30% for Mt Whaleback Mine (mono layer cover) and Mary Kathleen Mine (duplex layer cover). Century Mine which has the has the most comparable climate to the Mine (Figure 9), has limited seepage to between 1.5-3.6%.

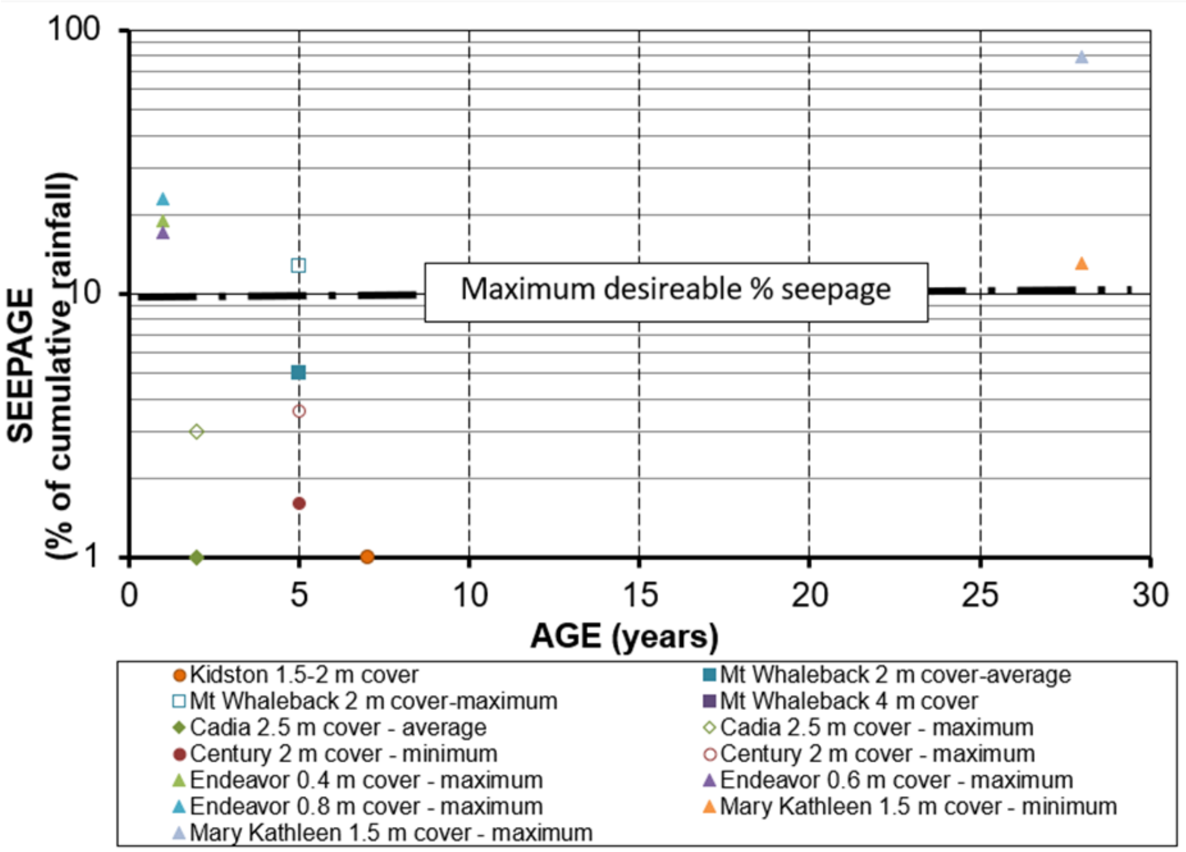


Figure 9 Performance of Australian cover trials

The maximum desirable percentage seepage rate given in Figure 9 (10%) is ~ equivalent to 8.6 x 10^{-4} m/s, being the approximate natural rate of groundwater recharge in semi-arid Australian climates (Cook et al. 2004).

The model shows that Trial 1-3 performs comparably to those in literature and below the maximum desirable seepage rate for dry and average years. However, Trial 1 and Trial 3 would likely perform worse than the maximum desirable seepage rate during short duration, high intensity rainfall events (ie wet year / the worst case).

4.3 Preferred cover design

Trial 2 has been excluded from the selection of the preferred cover design because there are not enough soil resources (stockpiled or undisturbed) (ie Trial 2 is not feasible for construction).

Trial 3 is selected as the preferred cover design since:

- the coarse nature of NAF waste rock slows runoff water velocity and reduces the potential for erosion; and
- the RPL is required to limit the potential for seepage under short intensity high rainfall events.

A cross section of Trial 3 is given in Figure 10.

Cross section	Thickness	Material properties	Material density
	0.3 m	Crushed waste rock	1.6 t/m^3
	1.0 m	Waste rock	1.8 t/m^3
	0.5 m	Fine compacted waste rock (<10 mm)	2.1 t/m^3

Figure 10 Preferred cover design cross section

5.0 Closure strategy

5.1 Rehabilitation objectives

Round Oak aims to rehabilitate the WRD in a manner which is consistent with the EA. Rehabilitation objectives that are applicable to the WRD are as follows (Round Oak 2021):

1. safe for humans and wildlife;
2. non-polluting;
3. stable;
4. able to sustain a PMLU agreed to by the administering authority and any underlying landholders;
5. revegetated with species endemic to the area with no declared pest species; and
6. compliant with all conditions of the EA.

5.2 Completion criteria

Completion criteria for the WRD are in Table 23.

Table 23 WRD completion criteria

Rehabilitation objective	Indicator	Completion criteria
Safe for humans and wildlife	Safety assessment of final landform	Certified by an appropriately qualified person (AQP) to be structurally safe for the PMLU
Non-polluting	Final landform design	Certified by an AQP to have an adequate landform design and construction to prevent the release or seepage of hazardous or contaminated material
	Contamination assessment of final landform	Rehabilitation monitoring shows the final landform is compliant with established and applicable receiving environment limits
Stable	Geotechnical assessment of final landform	Certified by an AQP to be geotechnically stable
Able to sustain the PMLU	Residual risk assessment of final landform	Rehabilitation report assesses any residual risks and ongoing control measures
Compliant with EA conditions	Administering authority sign off	Rehabilitation report is assessed by the administering authority to be compliant

6.0 Conclusions and recommendations

6.1 Cover design

The following covers have been trialled and modelled for this Project:

- Trial 1:
  - a 1.6 m ISL of coarse waste rock; and
  - a 0.3 m layer of waste rock above the ISL.
- Trial 2:
  - a 1.6 m ISL of coarse waste rock; and
  - a 0.3 m layer of soil above the ISL.
- Trial 3:
  - a 0.5 m RPL of fine compacted waste rock;
  - a 1 m ISL of coarse waste rock above the RPL; and
  - a 0.3 m layer of fine waste rock.

Modelling indicated that during periods of normal rainfall or during periods of no rainfall, rainfall will initially infiltrate and then be removed by evapotranspiration with negligible seepage. However, Trial 1 and Trial 3 may have an unacceptable rate of seepage when subject to periods of short duration, heavy rainfall (the wet year or the worst case). Trial 2 has been excluded from the selection of the preferred cover because there not enough soil resources (stockpiled or undisturbed) for rehabilitation and soil has an increased potential for erosion (by mechanical movement) compared to waste rock.

Trial 1 had an increased capacity to store infiltration in the ISL, but produced more seepage, when compared to Trial 3.

Trial 3 (0.3 m of NAF waste rock overlaying a 1.0 m ISL overlaying a 0.5 m RPL) is selected as the preferred cover since:

- the coarse nature of waste rock slows runoff water velocity and reduces the potential for erosion; and
- the RPL is limits the potential for seepage.

Modelling has been done without vegetation (to give a conservative assessment) and demonstrates that vegetation is not required to limit seepage.

6.2 Future studies

Project rehabilitation should be considered as an ongoing Trial, whereby, if research and monitoring identify the potential for improvements in the adopted rehabilitation methods and techniques, these should be incorporated future rehabilitation areas. The PMLUP should be updated when necessary, or when a change in monitoring or rehabilitation methods occur.

6.2.1 Field scale cover trials

It is recommended that a field scale cover trial (field trial) is done to validate the performance of the preferred cover (Trial 3) to limit seepage into the underlying PAF waste rock. The following sections provide a brief description of the methodology proposed for the installation of a field trial.

6.2.1.1 Instrumentation

The cover monitoring system (instruments) could be repurposed from the Trials to reduce the capital cost to establish the field trial.

6.2.1.2 Pre-installation

The instruments should be fitted into an instrument tree before being installed in the field trial. The purpose of the instrument tree is to:

- protect the instruments during their burial so that they provide a long service period before failure; and
- allow an accurate burial depth.

Instrument trees have been used by SGME at a number of notable cover trials including the New Century Mine, Rosebery Mine and the Wallace South Project. An example of the instrument tree is shown in Photo 1.

6.2.1.3 Field Installation

The instrument tree will need to be transported to a proposed field trial cell and stood up vertically. The cover should then be placed by backfilling with an excavator and compacting (where required) using a sheep foot roller and a manual 10 kilogram tamp.

6.2.1.4 Duration

The field scale column trials should be run for several years so that seasonal variation influences on cover performance.

Photo 1 Example of the installation of an instrument tree at Wallace South Project

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Appendix A
Background

A.1 Biophysical environment

A.1.1 Topography

The Project is located on rocky, undulating hills and outcropping, rocky ridgelines in the Leichardt River Basin. The Leichardt River Basin begins to the south of Mount Isa and drains via the Leichardt River to the Gulf of Carpentaria.

The Project contains several drainage lines and ephemeral tributaries that tend to drain north-west down the steeper hills into the Leichardt River.

A.1.2 Hydrology

The Project area is crossed by numerous small, unnamed first- and second-order drainage lines. One larger, third-order watercourse flows through the south-western and north-western sections of the Project. These waterways drain north-west to form an unnamed third-order creek which flows into the Leichhardt River and subsequently north into the Gulf of Carpentaria. The waterways are ephemeral and flow only after heavy rainfall. There are no wetlands within the Project. Lake Julius, a large lacustrine wetland listed on the Directory of Important Wetlands in Australia, is located ~ 17 km downstream.

A.1.3 Hydrogeology

Groundwater levels measured in 2014 ranged from 8.26-25.96 m bgl (nearest to the WRD) (RLA 2014). No shallow aquifers were identified.

A.1.4 Geology

Bedrock geology in the area comprises Proterozoic rocks of the Mount Isa Inlier. Rock types include felsic volcanics (forming the hills), dolerite / amphibolite (in the drainages / valleys) and basalt (forming plateaus). The felsic volcanics are the dominant rock type. The felsic and mafic volcanics dip at 60° towards the northeast and the dolerites are sub-vertical. These three rock types are resistant to weathering and extensive outcrops occur.

The Barbara deposit lies within the Mount Isa Inlier and its weathering profile averages 15 m but can be up to 45 m. Mineralisation is structurally controlled by the Barbara Shear Zone and occurs as a series of sulfide lodes hosted within a package of felsic volcanic rocks intruded by dolerite dykes. Sulfide mineralisation comprises semi-massive pyrrhotite / pyrite with chalcopyrite and chalcopyrite stringer veins. Two phases of mineralisation occur with a low-grade copper-cobalt phase overprinted with a later coarse grained, chalcopyrite-gold-silver phase which forms both hanging wall and footwall zones of higher-grade mineralisation.

The majority of waste is low sulfur rock, primarily high calcium / magnesium basalts and mafics, low calcium / magnesium felsic volcanics, and pedogenic carbonates. Some sulfide rich waste zones occur immediately adjacent to the ore zone, primarily on the footwall. This sulfide rich material can generate AMD if exposed to atmospheric conditions.

A.1.5 Climate

The climate of the Project and surrounding region is classified as hot semi-arid climate (BSh) by Köppen and Geiger. These climates tend to have hot summers and warm to cool winters with minimal rainfall. High variability in rainfall, temperature and evaporation are common.

A.1.5.1 Rainfall, evaporation and temperature

The BoM Mount Isa Aero weather station (29127) is ~ 48 km from the Project (Table 25-Table 27):

- January and February exhibit the highest mean monthly rainfall, averaging 100.4 and 96.7 mm respectively. The driest months of the year are July, August and September averaging less than 10 mm of rainfall. The average annual rainfall for the region is 431.7 mm per year.
- The average annual potential evaporation at the Project is estimated to be 3,032 mm. The evaporation rate varies seasonally, with the highest evaporation rates occurring in the months between October and December. Monthly average evaporation exceeds monthly average rainfall by a factor of at least 2.5.
- The mean annual maximum temperature is 31.9 degrees Celsius (°C) with the hottest months being November through to January (over 36 °C). The mean annual minimum temperature is 17.7°C, with the coolest months being June through to August (below 11°C).

A.1.5.2 Long-term projections

The *Regional Climate Projections Report* provides historical and projected climate information for 2030, 2050 and 2070 (Table 24) based on the SILO climate dataset and the Consistent Climate Scenarios projections data developed by the Queensland Government (Zhang & Carter 2018). The *Regional Climate Projections Report* is based on climate modelling done for the Intergovernmental Panel on Climate Change (IPCC) *Fifth Assessment Report* (AR5).

Table 24 Projected annual climate summary

Climate variable (median annual)	Historical (1960-2010)	Projection (2030)	Projection (2050)	Projection (2070)
Rainfall (mm)	422.4	413.7	406.9	401.2
Evaporation (mm)	3,029.4	3,258.9	3,394.1	3,503.4
Mean temperature (°C)	25.3	26.3	26.9	27.5
Maximum temperature (°C)	32.3	33.4	34.0	34.5
Minimum temperature (°C)	18.1	19.2	19.8	20.4

Based on climate projections, the region can expect lower rainfall, higher evaporation and higher temperatures.

The biennial *State of the Climate* report states that Australia's weather and climate are changing in response to a warming global climate system (CSIRO & BoM 2020), particularly:

- Australia's climate has warmed on average by 1.44 ± 0.24°C since national records began in 1910 leading to an increase in the frequency of extreme heat events;
- more intense short-duration heavy rainfall events; and
- there has been an increase in extreme fire weather and in the length of the fire season across large parts of Australia.

Table 25 Average monthly and annual rainfall

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Mean rainfall (mm)	100.4	96.7	57.5	15.4	13.6	11.6	6.9	3.3	7.9	18.2	31.5	68.8	431.7

Table 26 Average monthly and annual evaporation

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Mean evaporation (mm)	300.7	249.6	268.3	238.1	189.6	154.5	167.1	211.8	263.7	326.0	330.2	332.3	3,031.9

Table 27 Average monthly and annual temperature

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Mean maximum daily temperature (°C)	36.8	35.8	34.3	31.9	27.6	24.7	24.5	27.0	31.0	34.7	36.8	37.3	31.9
Mean minimum daily temperature (°C)	24.0	23.5	22.0	18.7	14.1	10.7	9.3	10.8	14.8	19.1	21.9	23.3	17.7

A.2 The WRD

A.2.1 Design

The WRD is ~ 28 m high from the crest to lowest tow and the maximum disturbance footprint is 23 hectares (ha). Waste rock placement was done by end-dumping / paddock dumping coarse-textured waste rock on the base of the WRD and outer slopes at its angle of repose ~ 1 vertical (V):1.3 horizontal (H) or 37°. Compaction was done by haul truck trafficking with a gradual slope towards the north in the direction of the WRD sediment dam and haul road. Runoff flows to the WRD sediment dam directly downstream of the WRD.

The external batters are 10 m high and stepped inward by 12 m to create an overall batter of ~ 1V: 2.5H. The current landform of the WRD is shown in Figure 11.

PAF waste rock is stored within a managed cell an encapsulated (entirely) by at least 5 m of waste rock.

A.2.2 Stability

A.2.2.1 Geotechnical

The geotechnical stability of the WRD design was assessed by ATC Williams in 2020 (ATCW 2020a). Slope stability was assessed with geotechnical modelling software using the following inputs:

- batter slope: 1V:1.3H;
- batter height: 10 m;
- bench width: 12 m; and
- average batter slope: 1V:2.5H.

Modelling suggests the WRD will have a factor of safety of 1.83.

A.2.2.2 Erosion potential

Rainfall and overland flow simulations were done on cover material (waste rock) collected from the final landform in order to derive calibrated erodibility parameters (SGME 2021). A rainfall simulator was used to study the interrill erosion process and calibrate the interrill erodibility factor and the effective hydraulic conductivity. An overland flow simulator was used to study the rill erosion process and calibrate the rill erodibility factor and critical shear stress.

A hillslope scale erosion model of the WRD was built in the Water Erosion Prediction Project (the WEPP model) and run using desktop data, calibrated erodibility parameters and current landform designs to estimate the potential annual erosion rate for a 100-year period.

The WEPP model showed that the final landform will experience negligible erosion and can be considered stable.

LEGEND

Contour (1 metre)

Scale 1 : 3 000

0 50 100 m

Client	Project
Round Oak Minerals Pty Ltd	Waste Rock Dump Closure Plan

		Title	Figure
Design: SGM Environmental Pty Ltd	04.03.2022	WRD Landform	11
Scale: 1 : 3,000			
CRS: GDA94 / MGA zone 55			

A.2.3 Geochemistry

The geochemical characteristics of the waste rock were assessed by Environmental Geochemistry International Pty Ltd (EGi) in 2014 (EGi 2014), who found that waste rock:

- is predominately NAF (89%) and has low sulfur content;
- largely non-saline;
- is significantly enriched with cobalt, copper and selenium;
- has minor enrichment of some samples with bismuth; and
- in the event of acidic conditions, would likely have increased concentrations of dissolved metals including copper, iron, aluminium, cobalt, manganese, nickel and zinc.

Kinetic leach column testing was done in 2020 (EGI 2020). The characteristics of each tested sample was:

- PAF 1:
  - PAF waste rock with elevated copper (0.79%);
  - high sulfur (2.49%); and
  - some ANC (17 kg H_2SO_4/t) (high sulfur waste rock).
- NAF 1 and NAF 2:
  - waste rock with low copper content (0.02%); and
  - low sulfur (0.05-0.10%, NAF 1 and NAF 2 respectively) (low sulfur waste rock).
- NAF 4:
  - waste rock with high copper content (1.05%);
  - high sulfur (1.32%); and
  - high ANC (75 kg H_2SO_4/t) (high sulfur waste rock).

The first flush leachate was found to be alkaline, low in soluble salts, and contained only trace elements of aluminium, iron and manganese (EGi 2020). Dissolved metals and metalloids were also generally below the limits of analytical detection. Leachate characteristics from each sample for weeks 4-52 was:

- PAF 1:
  - pH remained circum-neutral indicating the sample was in lag phase;
  - sulfate remained relatively low ranging between 155 to 334 milligrams per litre (mg/L) indicating a slow rate of sulfide oxidation;
  - no leaching of iron or copper as a result of slow rates of pyrite and chalcopyrite oxidation; and
  - minor leaching of manganese and aluminium were recorded. Arsenic was below detection limits and only trace concentrations of cobalt, nickel and selenium were present in the leachate.
- NAF 1 and NAF 2:
  - pH of leachate remained alkaline;
  - sulfate concentrations remained very low;
  - calcium was recorded as a major cation in leachate; and
  - there was no indication of significant leaching of copper, cobalt or chromium. NAF 2 had minor leaching of arsenic in the first six months.
- NAF 4:
  - pH of leachate remained slightly alkaline;
  - significant release of sulfate, which is in the moderate range for sulfidic rock;
  - significant release of calcium, which reflects the carbonate minerals within the sample reacting with the acidity generated by sulfide oxidation. Magnesium was also reported suggesting carbonate mineralisation may have been partially dolomitic;
  - the concentration of copper in the leachate was minor; and
  - no significant leaching of iron or manganese or any other element of environmental significance.

A.3 Legal obligations and commitments

A.3.1 General rehabilitation objectives

Mining is a temporary use of land and must be returned to a stable condition. Land is in a stable condition when it is safe and structurally stable, there is no environmental harm being caused by anything on or in the land and the land can sustain a PMLU in accordance with Section 111A of the *Environmental Protection Act 1994* (EP Act).

The aim is to rehabilitate the WRD to a Land Class VIII — Native Ecosystem Services (the PMLU), which is defined as unsuitable land with extreme limitations that prevent its use for the proposed purpose.

A.3.2 Environmental authority

The rehabilitation of the WRD must meet the requirements of EA *Schedule G — Land and Rehabilitation*:

Condition G1:

> *The environmental authority holder must rehabilitate all significantly disturbed land caused by the mining activities in a manner that ensures rehabilitated areas achieve the following rehabilitation objectives:*
>
> *a. Safe for humans and wildlife;*
> *b. Non-polluting;*
> *c. Stable;*
> *d. Able to sustain a post-mining land use agreed to by the administering authority and any underlying landholders;*
> *e. Revegetated with species endemic to the area with no declared pest species; and*
> *f. Compliant with all conditions of this environmental authority.*

Condition G2:

> *Two years from commencement of mining the environmental authority holder must develop and document a Post Mine Land-use Report ('PMLUP') that describes how the rehabilitation objectives in condition G1 will be achieved.*

Condition G3:

> *Rehabilitation must commence progressively in accordance with the Report of Operations.*

A.3.3 Land outcome documents

The WRD design was taken from aerial surveys and the Project's Post *Mining Land Use Plan* (PMLUP) which was developed as per condition G2 of the EA. The PMLUP states that:

> *The total disturbance footprint of the WRD will by approximately 23 ha. The angle of repose of the side batters will be 37 degrees. The natural rill of the batters will create rock armouring / outcropping and potential habitat for the Purple-Necked Rock-Wallaby to assist in achieving the PMLU of Native Ecosystem services.*

Appendix B

Risk assessment and cover options analysis

B.1 Risk assessment

B.1.1 Method

A risk assessment has been done to define the basis of design and guide objectives for the cover. The risk assessment identified potential impacts to the receiving environment associated with the long-term storage of PAF waste rock in the WRD.

The risk assessment was done using a risk assessment approach that has regard for *AS ISO 31000:2018 Risk Management: Guidelines* (the risk standard) (Australian Standard 2018). The risk matrix, which identifies likelihood description and consequence rates, is given in Table 28.

Risk evaluation will inform decisions about what risks need to be managed and prioritised for risk treatment; that is, the need for a:

- compacted shedding layer;
- ISL;
- RPL; and / or
- a capillary break (CB).

Table 28 Likelihood table and risk matrix

		Consequence					
Likelihood	**Description**	**1**	**2**	**3**	**4**	**5**	**6**
Almost certain (A)	Likely to occur multiple times a year	High	High	Very High	Very High	Very High	Very High
Likely (B)	Might occur once a year	Medium	High	High	Very High	Very High	Very High
Possible (C)	Might occur multiple times during the Project operation	Low	Medium	High	High	Very High	Very High
Unlikely (D)	Might occur once during the Project operation	Low	Low	Medium	High	High	Very High
Rare (E)	Unlikely to occur during the Project operation	Low	Low	Low	Medium	High	High

B.1.2 Results and discussion

The risk assessment, grouped as key review areas is given in Table 29. The risk assessment informs cover requirements in Section B.2.

Table 29 Risk assessment

Area	Risk / threat (aspect)	Cause / source	Pathway	Receptor	Impact	Consequence	Likelihood	Risk level	Rationale
Geochemical	AMD	• Sulfide oxidation with or without associated neutralisation reactions	• Infiltration • Seepage • Runoff	• Surface water • Groundwater • Dependent ecosystems	• Poor seepage water quality • Poor water quality in surface water and groundwater • Surface salts from evaporation of near surface infiltration	5	E	Very High	Geochemical testing indicates that there would be significant increases in the concentrations of dissolved metals (copper, iron, aluminium, cobalt, manganese, nickel and zinc) in the seepage in the event of acidic conditions
	Poor quality seepage	• Heavy rainfall events • Lack of water mixing • Poor water management • Constituents of concern in the waste rock	• Infiltration • Seepage	• Surface water • Groundwater • Dependent ecosystems	• Poor seepage water quality • Release of heavy metals and / or salts from PAF waste rock by leaching • Poor water quality in surface water and groundwater • Surface salts from evaporation of near surface infiltration	5	E	Very High	As above
Erodibility	Wind erosion	• Drying of rehabilitated WRD • Storm event (high winds)	• Wind	• Surface water • Vegetation • Dependent ecosystems	• Poor visual amenity • Spreading of potential contaminants from the waste rock on and off the ML • Smothering of vegetation	3	D	High	Winds within the area can be variable and are influenced by the location of high-pressure cell and storm fronts that may move over the Project
	Water erosion	• Run on • Access to land by cattle	• Runoff • Infiltration • Seepage	• Surface water • Groundwater • Dependent ecosystems	• Excessive downstream sedimentation • Increased seepage of poor-quality water • Unsafe and unsustainable landform	5	E	Very High	Hard-panning of surface layer as oxidation takes place
Surface water	Water logging	• Head of water within the WRD causing a groundwater mound, with seepage at the toe • Poor infiltration • Storm event	• Capillary rise	• Vegetation	• Death of vegetation • Capillary rise of salts	5	D	High	Monthly rainfall rarely exceeded evaporation
Groundwater	Reduced water quality	• Seeping of constituents from PAF waste rock into groundwater	• Infiltration • Seepage	• Groundwater • Dependent ecosystems	• Prevention of beneficial groundwater use	5	E	Very High	Potential impact to groundwater
Vegetation	Poor establishment of vegetation	• Insufficient seed supply for rehabilitation • Insufficient growth medium with limited plant available water, nutrient deficiency and / or chemical toxicity • Excessive erosion • Lack of evidence of ability to grow appropriate species in available subtract • Climatic uncertainty (extreme variability)	-	-	• Poor visual amenity • Unstable landform with increased erosion rates • Increased seepage of poor water quality	3	E	High	PAF waste rock cell is unlikely to be favourable for plant growth

B.2 Cover requirements

Based on the outcomes of the risk assessment, the cover design objectives are as follows:

- limit rainfall infiltration into the WRD to prevent seepage and mobilisation of oxidation products from PAF waste rock that may form AMD impacting on surface water and / or groundwater; and
- provide long term geotechnical and erosional stability.

The cover design will achieve these objectives through:

- being simple and easy to construct;
- limiting the potential for seepage into the WRD (for semi-arid Australian environments, seepage should be less than 10% of cumulative rainfall or 8.64×10^{-4} m/day; and
- including an engineered RPL or a CB layer to limit seepage (if required).

The cover design objectives and attributes are consistent with the PRC plan guideline which requires:

- land to be returned to a condition similar to the pre-existing condition or to an agreed PMLU;
- land to be returned to a stable condition that is not compromised by surface instability and erosion and is safe;
- that the final landform is geochemically stable to the extent that it does not impact surface water and / or groundwater quality;
- the PMLU has regard for the land use in the surrounding region; and
- land to be able to sustain the PMLU.

B.3 International Network for Acid Prevention's Global Acid Rock Drainage guide cover assessment

The International Network for Acid Prevention's *Global Acid Rock Drainage (GARD) Guide* (the GARD Guide) provides general guidance on appropriate cover types for climates ranging from arid to high rainfall and tropical to polar climates (INAP 2009).

Applying the GARD Guide cover criteria to the climate of the Project suggests a store and release cover is the most suitable cover type for the WRD (Figure 12). Store and release covers perform best in wet / dry climates with high potential evaporation equal to two- or three-times rainfall. No alternative cover types have been assessed for application at the Project.

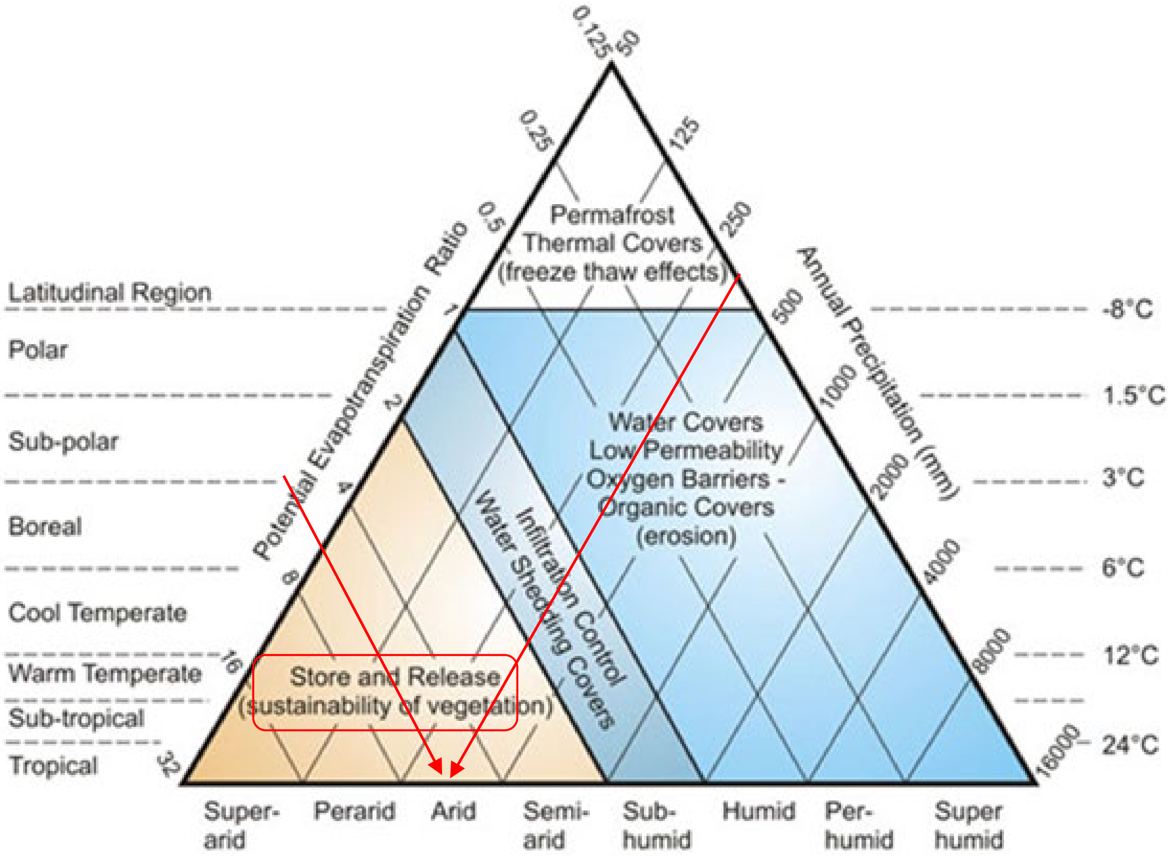

Figure 12 Cover and climate types (INAP 2009)

A store and release cover can be thought of as a 'natural analogue' that mimics an undisturbed soil profile and can reduce net infiltration by storing water during periods of high rainfall and releasing it as evapotranspiration in dry periods. A store and release cover may be combined with other engineering controls, for example an RPL and / or CB layer to further limit the movement of water and contaminants and reduce the potential for environmental harm after closure.

Where there is potential for the upward movement (capillary rise) of dissolved constituents into the store and release cover, a CB layer may be required. This is very similar to a C horizon in an undisturbed soil profile. The store and release cover design therefore follows a typical engineering safety hierarchy of controls. Rainfall infiltration cannot be removed from design (as it cannot be eliminated); it is naturally occurring event and cannot be substituted. The ISL (soil or waste rock), therefore isolates rainfall infiltration by engineered design with an RPL or CB layer only required if the potential for capillary rise is identified.

B.4 Wallace South Project

Wallace South Project, owned by Round Oak, is located ~ 100 km south-east of the Project and ~ 30 km south-east of Cloncurry on ML100077. ATC Williams Pty Ltd (ATCW) did a cover system review using vadose zone (infiltration) modelling to estimate infiltration rates into the WRD (ATCW 2020c). The cover system modelled included:

- a 2.0 m compacted cover soil layer;
- a 0.5 m waste rock layer above the compacted soil layer; and
- a 0.2-0.3 m topsoil layer above the waste rock layer.

ATCW (2020c) found, based on material characterisation and cover system modelling, that the cover would minimise rainfall infiltrating into the waste rock with the majority of incidental rainfall lost through evaporation and runoff. The cover model suggests that low rates of seepage could occur from the base for a short duration following significant rainfall events (ATCW 2020c).

B.5 Cover options analysis

B.5.1 Method

The options assessment in Table 30 was done to identify potential advantages and disadvantages associated with each cover option and recommend cover options to progress to the Trials.

Cover options were designed based on environmental factors (climate), material properties, PMLU and cover requirements. These cover options aim to explore the effects of different ISL thicknesses and the presence / absence of CB and RPL layers.

The cover options were ranked based on the following criteria:

- plant available water capacity;
- infiltration potential;
- root penetration depth;
- water storage potential;
- capillary rise potential; and
- cost.

B.5.2 Results

The options analysis in Table 30 shows that the most suitable covers are:

- Cover option 3, which includes:
  - 1.6 m ISL comprised of compacted waste rock; and
  - 0.3 m soil layer above the ISL.
- Cover option 4, which includes:
  - 1.6 m ISL comprised of compacted waste rock; and
  - 0.3 m soil layer comprised of loose waste rock above the ISL.
- Cover option 5, which includes:
  - 0.5 m RPL comprised of fine (<10 mm) compacted waste rock ;
  - 1.0 m ISL layer comprised of compacted waste rock above the RPL; and
  - 0.3 m soil layer comprised of loose waste rock above the ISL.

The above three cover options were recommended to progress to the Trials (SGME 2021). Cover option 6 also performed favourably, but was excluded due to the high cost associated with an engineered CB layer not being reasonable or practicable for the Project.

Table 30 Cover options analysis

		Cover option 1	Cover option 2	Cover option 3	Cover option 4	Cover option 5	Cover option 6
Description		Direct seeding	Cover design for the Wallace Project WRD	Soil as growth medium	waste rock as growth medium	Cover option 4 with a RPL and a smaller ISL	Cover option 4 with a CB
Layer	Units						
Soil	m	-	0.2-0.3	0.3	0.3 (loose waste rock)	0.3 (loose waste rock)	0.3 (loose waste rock)
ISL	m	-	0.5	1.6	1.6	1.0	1.6
RPL	m	-	2.0	-	-	0.5	-
CB	m	-	-	-	-	-	0.6
Total	m	-	2.7-2.8	1.9	1.9	1.8	2.5
Advantages		Lowest cost	Restriction to seepage Increased plant available water capacity	Restriction to seepage Increased plant available water capacity	Restriction to seepage	Restriction to seepage	Restriction to seepage Restriction to capillary rise
Disadvantages		Decreased infiltration storage No restriction to capillary rise No restriction to seepage Unlikely to be suitable for plant growth	Decreased infiltration storage High cost Insufficient stockpiled soil Evapotranspiration may not effectively be removed below ~ 0.8 m bgl No restriction to capillary rise	High cost Insufficient stockpiled soil No restriction to capillary rise	No restriction to capillary rise	Decreased infiltration storage Evapotranspiration may not effectively be removed below ~1.3 m bgl No restriction to capillary rise	High cost

	Cover option 1	Cover option 2	Cover option 3	Cover option 4	Cover option 5	Cover option 6
Report available water capacity	5	4	2	3	4	3
Report growth	5	2	2	3	3	3
Seepage potential	5	2	4	4	3	4
Water storage potential	5	4	2	2	3	2
Capillary rise potential	5	4	4	4	4	1
Cost	1	5	5	1	4	5
Material availability	1	5	5	1	4	5
Ranking points	**27**	**26**	**24**	**18**	**25**	**23**
Overall ranking	**6**	**5**	**3**	**1**	**4**	**2**

Appendix C
SGS laboratory results

ANALYTICAL REPORT

Accreditation No. 2562

CLIENT DETAILS		LABORATORY DETAILS	
Contact	Julie Byrd	Manager	Anthony Nilsson
Client	ROUND OAK MINERALS PTY LIMITED	Laboratory	SGS Cairns Environmental
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Facsimile	61 7 38356207	Facsimile	+61 07 4035 5122
Email	Julie.Byrd@roundoakmin.com.au	Email	AU.Environmental.Cairns@sgs.com
Project	**21B002**	SGS Reference	**CE153058 R1**
Order Number	(Not specified)	Date Received	02 Jun 2021
Samples	8	Date Reported	19 Jul 2021

COMMENTS

Accredited for compliance with ISO/IEC 17025 - Testing. NATA accredited laboratory 2562(3146/19038)

This report cancels and supersedes the report No.CE153058_R0. dated 30/06/2021 issued by SGS Environment, Health and Safety due to addition of Nitrogen results.

SIGNATORIES

Alyson BERGAMO
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Mitsuko BALDWIN
Metals Team Leader

Parameter	Units	LOR	CE153058.001 Soil BCO waste rock 1	CE153058.002 Soil BCO waste rock 2	CE153058.003 Soil BCO clay 1	CE153058.004 Soil BCO clay 2
Moisture Content Method: AN002 Tested: 3/6/2021						
% Moisture	%w/w	0.5	<0.5	<0.5	6.8	4.9
pH in soil (1:5) Method: AN101 Tested: 10/6/2021						
pH	pH Units	-	8.9	9.4	8.8	7.1
pH (CaCl2)*	pH Units	-	8.5	8.8	8.3	7.3
Conductivity and TDS by Calculation - Soil Method: AN106 Tested: 10/6/2021						
Conductivity of Extract (1:5 dry sample basis)	µS/cm	1	170	120	110	8700
Total Dissolved Solids (by calculation)	mg/kg	5	510	350	330	26000
Chloride (water extractable) Method: AN274 Tested: 11/6/2021						
Chloride (water extractable 1:5)	mg/kg	5	50	22	22	14000
Colwell Phosphorus Method: AN015 Tested: 9/6/2021						
Colwell Phosphorus	mg/kg	1	1	1	7	25
Nitrate Nitrogen and Nitrite Nitrogen (NOx) by Auto Analyser in Soil Method: AN248 Tested: 17/6/2021						
Nitrate/Nitrite Nitrogen, NOx as N	mg/kg	0.05	3.5	1.2	2.5	210

Parameter	Units	LOR	CE153058.001 Soil BCO waste rock 1	CE153058.002 Soil BCO waste rock 2	CE153058.003 Soil BCO clay 1	CE153058.004 Soil BCO clay 2
Soil - Nitrogen by Leco Method: -AN205 Tested: 19/7/2021						
Nitrogen	mg/kg	150	<150	<150	<150	330
Total Organic Carbon by Heanes Oxidation Method: AN273 Tested: 9/6/2021						
Total Organic Carbon	%w/w	0.05	0.17	0.19	0.33	0.54
Organic Matter	%w/w	0.1	0.29	0.33	0.57	0.94
Exchangeable Cations and Cation Exchange Capacity (CEC/ESP/SAR) Method: AN122 Tested: 16/6/2021						
Exchangeable Sodium, Na	mg/kg	2	96	76	42	6400
Exchangeable Sodium, Na	cmol (+)/kg	0.01	0.42	0.33	0.18	28
Exchangeable Sodium Percentage*	%	0.1	6.0	4.2	1.2	63.7
Exchangeable Potassium, K	mg/kg	2	84	82	110	160
Exchangeable Potassium, K	cmol (+)/kg	0.01	0.21	0.21	0.29	0.41
Exchangeable Potassium Percentage*	%	0.1	3.1	2.6	1.9	0.9
Exchangeable Calcium Percentage*	%	0.1	81.1	86.2	89.3	24.1
Exchangeable Calcium, Ca	cmol (+)/kg	0.01	5.6	6.9	14	11
	mg/kg	2	1100	1400	2700	2100
Exchangeable Magnesium, Mg	mg/kg	2	83	68	140	610
Exchangeable Magnesium, Mg	cmol (+)/kg	0.02	0.68	0.56	1.2	5.0
Exchangeable Magnesium Percentage*	%	0.1	9.9	7.0	7.6	11.4
Cation Exchange Capacity	cmol (+)/kg	0.02	6.9	8.0	15	44
Sodium Adsorption Ratio*	No unit	0.1	0.2	0.2	<0.1	10.0
Exchangeable Calcium/Exchangeable Magnesium Ratio*	No unit	0.1	8.2	12.3	11.7	2.1
Exchangeable Magnesium/Exchangeable Potassium	No unit	0.1	3.2	2.6	4.1	12.2
Soil - Aluminium (KCL Extraction) Method: AN046 Tested: 21/6/2021						
Exchangeable Aluminium*	mg/kg	1	-	-	-	-
Exchangeable Aluminium*	cmol (+)/kg	0.01	-	-	-	-
DTPA Extractable Metals in Soil Method: AN025/AN320 Tested: 15/6/2021						
Copper, Cu	mg/kg	0.05	54	24	1.6	3.7
Zinc, Zn	mg/kg	0.05	1.0	0.60	0.35	0.85
Manganese, Mn	mg/kg	0.5	7.5	9.8	11	53
Iron, Fe	mg/kg	0.5	14	21	20	15
HCl Extractable S, Ca and Mg in Soil ICP OES Method: AN014 Tested: 24/6/2021						
Acid Soluble Sulfur (SHCl)	%w/w	0.005	0.006	<0.005	-	-

Parameter	Units	LOR	Sample Number: CE153058.001 Sample Matrix: Soil Sample Name: BCO waste rock 1	CE153058.002 Soil BCO waste rock 2	CE153058.003 Soil BCO clay 1	CE153058.004 Soil BCO clay 2

Acid Neutralising Capacity or Neutralisation Potential(ANC/NP) Method: AN212 Tested: 22/6/2021

Parameter	Units	LOR	CE153058.001	CE153058.002	CE153058.003	CE153058.004
ANC as % $CaCO_3$	% CaCO3	0.05	**1.0**	**1.3**	-	-
ANC as % $CaMg(CO_3)2$	%w/w	0.05	**1.1**	**1.4**	-	-
Acid Neutralisation Capacity/Neutralisation Potential	kg CaCO3/T	0.5	**10**	**13**	-	-
Acid Neutralisation Capacity/Neutralisation Potential kg	kg H2SO4/T	0.5	**9.8**	**12**	-	-

Net Acid Generation Potential (NAGP) Method: AN215 Tested: 24/6/2021

Parameter	Units	LOR	CE153058.001	CE153058.002	CE153058.003	CE153058.004
Net Acid Production Potential (Tot S and ANC only)	kg H2SO4/T	-400	**-8.0**	**-11**	-	-
Maximum Potential Acidity (MPA)	kg H2SO4/T	0.2	**1.8**	**1.6**	-	-

Single Addition Net Acid Generation (NAG) Method: AN216 Tested: 24/6/2021

Parameter	Units	LOR	CE153058.001	CE153058.002	CE153058.003	CE153058.004
ECox (NAG Conductivity)	µS/cm	1	**81**	**110**	-	-
pHox (NAG pH)	No unit	-	**8.6**	**8.2**	-	-
NAG as kg H_2SO_4/tonne to pH 4.5	kg H2SO4/T	0.5	<0.5	<0.5	-	-
NAG as kg H_2SO_4/tonne to pH 7	kg H2SO4/T	0.5	<0.5	<0.5	-	-
NAG as kg CaCO3/tonne to pH 4.5	kg CaCO3/T	0.5	<0.5	<0.5	-	-
NAG as kg CaCO3/tonne to pH 7	kg CaCO3/T	0.5	<0.5	<0.5	-	-

Total Sulfur Method: AN012/AN320 Tested: 24/6/2021

Parameter	Units	LOR	CE153058.001	CE153058.002	CE153058.003	CE153058.004
Total Sulfur	%w/w	0.005	**0.058**	**0.052**	-	-

Parameter	Units	LOR	Sample Number: CE153058.005 Sample Matrix: Soil Sample Name: BCO clay 3	CE153058.006 Soil BCO NAF 1	CE153058.007 Soil BCO NAF 2	CE153058.008 Soil BCO NAF 3
Moisture Content Method: AN002 Tested: 3/6/2021						
% Moisture	%w/w	0.5	4.1	<0.5	<0.5	<0.5
pH in soil (1:5) Method: AN101 Tested: 10/6/2021						
pH	pH Units	-	9.1	9.5	9.4	9.0
pH (CaCl2)*	pH Units	-	8.7	8.4	8.3	8.4
Conductivity and TDS by Calculation - Soil Method: AN106 Tested: 10/6/2021						
Conductivity of Extract (1:5 dry sample basis)	µS/cm	1	6500	140	140	150
Total Dissolved Solids (by calculation)	mg/kg	5	20000	420	430	460
Chloride (water extractable) Method: AN274 Tested: 11/6/2021						
Chloride (water extractable 1:5)	mg/kg	5	4600	13	16	10
Colwell Phosphorus Method: AN015 Tested: 9/6/2021						
Colwell Phosphorus	mg/kg	1	7	<1	<1	<1
Nitrate Nitrogen and Nitrite Nitrogen (NOx) by Auto Analyser in Soil Method: AN248 Tested: 17/6/2021						
Nitrate/Nitrite Nitrogen, NOx as N	mg/kg	0.05	28	11	7.7	13

Parameter	Units	LOR	Sample Number: CE153058.005 Sample Matrix: Soil Sample Name: BCO clay 3	CE153058.006 Soil BCO NAF 1	CE153058.007 Soil BCO NAF 2	CE153058.008 Soil BCO NAF 3

Soil - Nitrogen by Leco Method: -AN205 Tested: 19/7/2021

Nitrogen	mg/kg	150	<150	<150	<150	<150

Total Organic Carbon by Heanes Oxidation Method: AN273 Tested: 9/6/2021

Total Organic Carbon	%w/w	0.05	0.30	0.40	0.32	0.30
Organic Matter	%w/w	0.1	0.52	0.69	0.55	0.52

Exchangeable Cations and Cation Exchange Capacity (CEC/ESP/SAR) Method: AN122 Tested: 16/6/2021

Exchangeable Sodium, Na	mg/kg	2	8100	39	38	41
Exchangeable Sodium, Na	cmol (+)/kg	0.01	35	0.17	0.16	0.18
Exchangeable Sodium Percentage*	%	0.1	74.8	1.1	1.0	1.1
Exchangeable Potassium, K	mg/kg	2	120	110	110	100
Exchangeable Potassium, K	cmol (+)/kg	0.01	0.31	0.27	0.28	0.27
Exchangeable Potassium Percentage*	%	0.1	0.7	1.7	1.7	1.7
Exchangeable Calcium Percentage*	%	0.1	22.8	94.7	94.7	94.9
Exchangeable Calcium, Ca	cmol (+)/kg	0.01	11	15	16	15
	mg/kg	2	2100	2900	3100	3000
Exchangeable Magnesium, Mg	mg/kg	2	98	46	52	43
Exchangeable Magnesium, Mg	cmol (+)/kg	0.02	0.80	0.38	0.43	0.35
Exchangeable Magnesium Percentage*	%	0.1	1.7	2.4	2.6	2.2
Cation Exchange Capacity	cmol (+)/kg	0.02	47	15	17	16
Sodium Adsorption Ratio*	No unit	0.1	14.6	<0.1	<0.1	<0.1
Exchangeable Calcium/Exchangeable Magnesium Ratio*	No unit	0.1	13.3	38.8	36.6	42.2
Exchangeable Magnesium/Exchangeable Potassium	No unit	0.1	2.6	1.4	1.5	1.3

Soil - Aluminium (KCL Extraction) Method: AN046 Tested: 21/6/2021

Exchangeable Aluminium*	mg/kg	1	-	-	-	-
Exchangeable Aluminium*	cmol (+)/kg	0.01	-	-	-	-

DTPA Extractable Metals in Soil Method: AN025/AN320 Tested: 15/6/2021

Copper, Cu	mg/kg	0.05	1.7	5.0	5.5	13
Zinc, Zn	mg/kg	0.05	0.36	0.26	0.47	0.26
Manganese, Mn	mg/kg	0.5	6.1	5.2	4.4	4.9
Iron, Fe	mg/kg	0.5	13	35	26	29

HCl Extractable S, Ca and Mg in Soil ICP OES Method: AN014 Tested: 24/6/2021

Acid Soluble Sulfur (SHCl)	%w/w	0.005	-	0.039	0.032	0.018

Parameter	Units	LOR	CE153058.005 Soil BCO clay 3	CE153058.006 Soil BCO NAF 1	CE153058.007 Soil BCO NAF 2	CE153058.008 Soil BCO NAF 3

Acid Neutralising Capacity or Neutralisation Potential(ANC/NP) Method: AN212 Tested: 23/6/2021

Parameter	Units	LOR	CE153058.005	CE153058.006	CE153058.007	CE153058.008
ANC as % $CaCO_3$	% CaCO3	0.05	-	2.9	2.9	3.3
ANC as % $CaMg(CO_3)2$	%w/w	0.05	-	3.1	3.1	3.5
Acid Neutralisation Capacity/Neutralisation Potential	kg CaCO3/T	0.5	-	29	29	33
Acid Neutralisation Capacity/Neutralisation Potential kg	kg H2SO4/T	0.5	-	28	28	32

Net Acid Generation Potential (NAGP) Method: AN215 Tested: 24/6/2021

Parameter	Units	LOR	CE153058.005	CE153058.006	CE153058.007	CE153058.008
Net Acid Production Potential (Tot S and ANC only)	kg H2SO4/T	-400	-	-21	-22	-23
Maximum Potential Acidity (MPA)	kg H2SO4/T	0.2	-	7.0	6.7	8.4

Single Addition Net Acid Generation (NAG) Method: AN216 Tested: 24/6/2021

Parameter	Units	LOR	CE153058.005	CE153058.006	CE153058.007	CE153058.008
ECox (NAG Conductivity)	µS/cm	1	-	160	180	200
pHox (NAG pH)	No unit	-	-	9.1	9.3	8.6
NAG as kg H_2SO_4/tonne to pH 4.5	kg H2SO4/T	0.5	-	<0.5	<0.5	<0.5
NAG as kg H_2SO_4/tonne to pH 7	kg H2SO4/T	0.5	-	<0.5	<0.5	<0.5
NAG as kg CaCO3/tonne to pH 4.5	kg CaCO3/T	0.5	-	<0.5	<0.5	<0.5
NAG as kg CaCO3/tonne to pH 7	kg CaCO3/T	0.5	-	<0.5	<0.5	<0.5

Total Sulfur Method: AN012/AN320 Tested: 24/6/2021

Parameter	Units	LOR	CE153058.005	CE153058.006	CE153058.007	CE153058.008
Total Sulfur	%w/w	0.005	-	0.23	0.22	0.27

MB blank results are compared to the Limit of Reporting
LCS and MS spike recoveries are measured as the percentage of analyte recovered from the sample compared the the amount of analyte spiked into the sample.
DUP and MSD relative percent differences are measured against their original counterpart samples according to the formula : *the absolute difference of the two results divided by the average of the two results as a percentage.* Where the DUP RPD is 'NA' , the results are less than the LOR and thus the RPD is not applicable.

Acid Neutralising Capacity or Neutralisation Potential(ANC/NP) Method: ME-(AU)-[ENV]AN212

Parameter	QC Reference	Units	LOR	DUP %RPD	LCS %Recovery
Acid Neutralisation Capacity/Neutralisation Potential	LB091324	kg CaCO3/T	0.5	0 - 6%	NA
Acid Neutralisation Capacity/Neutralisation Potential kg H_2SO_4/t	LB091324	kg H2SO4/T	0.5	0 - 6%	NA

Chloride (water extractable) Method: ME-(AU)-[ENV]AN274

Parameter	QC Reference	Units	LOR	MB	DUP %RPD	LCS %Recovery
Chloride (water extractable 1:5)	LB090985	mg/kg	5	<5	0 - 1%	103 - 104%

Colwell Phosphorus Method: ME-(AU)-[ENV]AN015

Parameter	QC Reference	Units	LOR	MB	DUP %RPD	LCS %Recovery
Colwell Phosphorus	LB090930	mg/kg	1	<1	0 - 2%	96%

DTPA Extractable Metals in Soil Method: ME-(AU)-[ENV]AN025/AN320

Parameter	QC Reference	Units	LOR	MB	DUP %RPD	LCS %Recovery
Copper, Cu	LB091082	mg/kg	0.05	<0.05	2%	105%
Zinc, Zn	LB091082	mg/kg	0.05	<0.05	8%	111%
Manganese, Mn	LB091082	mg/kg	0.5	<0.5	1%	117%
Iron, Fe	LB091082	mg/kg	0.5	<0.5	0%	97%

Exchangeable Cations and Cation Exchange Capacity (CEC/ESP/SAR) Method: ME-(AU)-[ENV]AN122

Parameter	QC Reference	Units	LOR	MB	DUP %RPD	LCS %Recovery
Exchangeable Sodium, Na	LB091147	mg/kg	2		2%	97%
Exchangeable Sodium, Na	LB091147	cmol (+)/kg	0.01	<0.01	2%	NA
Exchangeable Potassium, K	LB091147	mg/kg	2		2%	96%
Exchangeable Potassium, K	LB091147	cmol (+)/kg	0.01	<0.01	2%	NA
Exchangeable Calcium, Ca	LB091147	cmol (+)/kg	0.01	<0.01	2%	NA
		mg/kg	2		2%	100%
Exchangeable Magnesium, Mg	LB091147	mg/kg	2		1%	99%
Exchangeable Magnesium, Mg	LB091147	cmol (+)/kg	0.02	<0.02	1%	NA
Cation Exchange Capacity	LB091147	cmol (+)/kg	0.02	<0.02	2%	NA

MB blank results are compared to the Limit of Reporting
LCS and MS spike recoveries are measured as the percentage of analyte recovered from the sample compared the the amount of analyte spiked into the sample.
DUP and MSD relative percent differences are measured against their original counterpart samples according to the formula : *the absolute difference of the two results divided by the average of the two results as a percentage.* Where the DUP RPD is 'NA' , the results are less than the LOR and thus the RPD is not applicable.

Nitrate Nitrogen and Nitrite Nitrogen (NOx) by Auto Analyser in Soil Method: ME-(AU)-[ENV]AN248

Parameter	QC Reference	Units	LOR	MB	DUP %RPD	LCS %Recovery
Nitrate/Nitrite Nitrogen, NOx as N	LB091190	mg/kg	0.05	<0.05	1%	104%

Single Addition Net Acid Generation (NAG) Method: ME-(AU)-[ENV]AN216

Parameter	QC Reference	Units	LOR	MB	DUP %RPD	LCS %Recovery
ECox (NAG Conductivity)	LB091406	µS/cm	1	40	0 - 14%	97%
pHox (NAG pH)	LB091406	No unit	-	5.4	2 - 3%	92%
NAG as kg H_2SO_4/tonne to pH 4.5	LB091406	kg H2SO4/T	0.5	<0.5	0%	110%
NAG as kg H_2SO_4/tonne to pH 7	LB091406	kg H2SO4/T	0.5	<0.5	0 - 2%	106%
NAG as kg CaCO3/tonne to pH 4.5	LB091406	kg CaCO3/T	0.5	<0.5	0%	110%
NAG as kg CaCO3/tonne to pH 7	LB091406	kg CaCO3/T	0.5	<0.5	0 - 2%	106%

Soil - Nitrogen by Leco Method: ME-(AU)-[ENV]-AN205

Parameter	QC Reference	Units	LOR	MB
Nitrogen	LB092126	mg/kg	150	<150

Total Organic Carbon by Heanes Oxidation Method: ME-(AU)-[ENV]AN273

Parameter	QC Reference	Units	LOR	MB	DUP %RPD	LCS %Recovery	MS %Recovery
Total Organic Carbon	LB090902	%w/w	0.05	<0.05	0%	99%	98%
Organic Matter	LB090902	%w/w	0.1		0%		

METHOD	METHODOLOGY SUMMARY
AN002	The test is carried out by drying (at either 40°C or 105°C) a known mass of sample in a weighed evaporating basin. After fully dry the sample is re-weighed. Samples such as sludge and sediment having high percentages of moisture will take some time in a drying oven for complete removal of water.
AN002/AN320/AN321	Soil sample is extracted in deionised water (1:2 or 1:5) and metals analysed by ICP OES, method AN320/AN321, with results reported on the dried sample basis.
AN012/AN320	Dried prepared soil is digested by oxidation with nitric acid and bromine followed by analysis of the digest by ICP OES.
AN014	This method is for the determination of soluble sulfate (SO4-S) by extraction with hydrochloric acid. Sulphides should not react and would normally be expelled. Sulfur is determined by ICP.
AN015	Soil sample is extracted in an end over end roller in 0.5 N sodium bicarbonate at pH 8.5 with the supernatant liquor analysed for Phosphorous. Orthophosphate anion (PO43-) is reacted with ammonium molybdate and potassium antimony tartrate in sulfuric acid solution. The resulting phospho-molybdate complex is reduced, using ascorbic acid, to an intense blue coloured complex Molybdenum Blue. The absorbance of this complex is measured at 880 nm by Discrete Analyser, and compared with calibration standards to obtain the concentration of orthophosphate in the sample. Based on Rayment & Higginson 9B1.
AN025/AN320	A chelating agent is used to complex metal ions in solution. The extracted elements are determined byICP OES.
AN101	pH in Soil Sludge Sediment and Water: pH is measured electrometrically using a combination electrode and is calibrated against 3 buffers purchased commercially. For soils, sediments and sludges, an extract with water (or 0.01M CaCl2) is made at a ratio of 1:5 and the pH determined and reported on the extract. Reference APHA 4500-H+.
AN103	pH in Soil Sludge Sediment and Water: pH is measured electrometrically using a combination electrode (glass plus reference electrode) and is calibrated against 3 buffers purchased commercially. For soils, an extract with water is made at a ratio of 1:5 and the pH determined and reported on the extract. Reference APHA 4500-H+.
AN106	Conductivity and TDS by Calculation: Conductivity is measured by meter with temperature compensation and is calibrated against a standard solution of potassium chloride. Conductivity is generally reported as µmhos/cm or µS/cm @ 25°C. For soils, an extract of as received sample with water is made at a ratio of 1:5 and the EC determined and reported on the extract, or calculated back to the as-received sample. Salinity can be estimated from conductivity using a conversion factor, which for natural waters, is in the range 0.55 to 0.75. Reference APHA 2510 B.
AN122	Exchangeable Cations, CEC and ESP: Soil sample is extracted in 1M Ammonium Acetate at pH=7 (or 1M Ammonium Chloride at pH=7) with cations (Na, K, Ca & Mg) then determined by ICP OES/ICP MS and reported as Exchangeable Cations. For saline soils, these results can be corrected for water soluble cations and reported as Exchangeable cations in meq/100g or soil can be pre-treated (aqueous ethanol/aqueous glycerol) prior to extraction. Cation Exchange Capacity (CEC) is the sum of the exchangeable cations in meq/100g.

METHOD	METHODOLOGY SUMMARY
AN122	The Exchangeable Sodium Percentage (ESP) is calculated as the exchangeable sodium divided by the CEC (all in meq/100g) times 100. ESP can be used to categorise the sodicity of the soil as below: ESP < 6% non-sodic ESP 6-15% sodic ESP >15% strongly sodic Method is referenced to Rayment and Lyons, 2011, sections 15D3 and 15N1.-
AN-205	Nitrogen in soil by Induction furnace, IR detection.
AN212	Samples are initially evaluated to determine the strength of reagents needed using a `'fizz ' test. Samples are then subjected to an excess of hydrochloric acid followed by alkaline back titration to pH 7. Results are expressed in kg H2SO4/tonne or Kg CaCO3/tonne after correction for moisture content if applicable.
AN215	This is purely a calculation based on results obtained from Total Sulphur , Sulfate Method, and Acid Neutralisation Capacity Method (ME-AU-ENV-AN212). The negative value included as the LOR allows negative NAPP data to be reported in the LIMS, it is not the numerical LOR which would theoretically be 1kg H2SO4/tonne. The range of results is theoretically -980 to 1640kg H2SO4/ Tonne.
AN216	Pulverised sub-sample of a waste rock or an as received sample of filter cake, soil or sludge is subjected to an oxidising digest with 15% hydrogen peroxide adjusted to pH 4.5. The pH and EC of the NAG suspension is recorded at various stages in the digest. The acid produced (if any) is titrated using standardised NaOH to pH 7.0. NAG results are reported to 0.5 kg H2SO4/tonne.
AN248	Nitrate / Nitrite in extract by Auto Analyser: In an acidic medium, nitrate is reduced quantitatively to nitrite by cadmium metal. This nitrite plus any original nitrite is determined as an intense red-pink azo dye at 540 nm following diazotisation with sulphanilamide and subsequent coupling with N-(1-naphthyl) ethylenediamine dihydrochloride. Reference APHA 4500-NO3- F.
AN273	The sample is digested in Dichromate / Sulfuric Acid to oxidise the organic carbon. The determination is completed colourimetrically by Aquakem Discrete Analyser at 600 nm. Based on Rayment & Higginson 6B1.
AN274	Chloride by Aquakem DA following 1:5 or 1:2 DI water extraction: Chloride reacts with mercuric thiocyanate forming a mercuric chloride complex. In the presence of ferric iron, highly coloured ferric thiocyanate is formed which is proportional to the chloride concentration. Results reported on dry sample basis. Reference APHA 4500Cl-
SOL061	Soil sample is extrcated 1:10 in 1MKCl with aluminium determined by ICP OES.

FOOTNOTES

IS	Insufficient sample for analysis.	LOR	Limit of Reporting
LNR	Sample listed, but not received.	↑↓	Raised or Lowered Limit of Reporting
*	NATA accreditation does not cover the performance of this service.	QFH	QC result is above the upper tolerance
		QFL	QC result is below the lower tolerance
**	Indicative data, theoretical holding time exceeded.	-	The sample was not analysed for this analyte
***	Indicates that both * and ** apply.	NVL	Not Validated

Unless it is reported that sampling has been performed by SGS, the samples have been analysed as received.
Solid samples expressed on a dry weight basis.

Where "Total" analyte groups are reported (for example, Total PAHs, Total OC Pesticides) the total will be calculated as the sum of the individual analytes, with those analytes that are reported as <LOR being assumed to be zero. The summed (Total) limit of reporting is calcuated by summing the individual analyte LORs and dividing by two. For example, where 16 individual analytes are being summed and each has an LOR of 0.1 mg/kg, the "Totals" LOR will be 1.6 / 2 (0.8 mg/kg). Where only 2 analytes are being summed, the " Total" LOR will be the sum of those two LORs.

Some totals may not appear to add up because the total is rounded after adding up the raw values.

If reported, measurement uncertainty follow the ± sign after the analytical result and is expressed as the expanded uncertainty calculated using a coverage factor of 2, providing a level of confidence of approximately 95%, unless stated otherwise in the comments section of this report.

Results reported for samples tested under test methods with codes starting with ARS-SOP, radionuclide or gross radioactivity concentrations are expressed in becquerel (Bq) per unit of mass or volume or per wipe as stated on the report. Becquerel is the SI unit for activity and equals one nuclear transformation per second.
Note that in terms of units of radioactivity:

a. 1 Bq is equivalent to 27 pCi
b. 37 MBq is equivalent to 1 mCi

For results reported for samples tested under test methods with codes starting with ARS-SOP, less than (<) values indicate the detection limit for each radionuclide or parameter for the measurement system used. The respective detection limits have been calculated in accordance with ISO 11929.

The QC and MU criteria are subject to internal review according to the SGS QAQC plan and may be provided on request or alternatively can be found here: www.sgs.com.au/en-gb/environment-health-and-safety.

Appendix D
Trilab laboratory results

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ATTERBERG LIMITS TEST REPORT

Test Methods: AS 1289 2.1.1, 3.2.1, 3.3.1, 3.4.1

Client	SGM Environmental	**Report No.**	21060163-AL
		Workorder No.	0008705
Address	37 Mt View Crescent Narangba QLD 4504	**Report Date**	30/06/2021
Project	21B002 - BCM (column trials)		

Sample No.	21060163	21060164	21060165			
Liquid Limit Determination	AS 1289.3.1.2	AS 1289.3.1.2	AS 1289.3.1.2			
Test Date	21/06/2021	21/06/2021	21/06/2021			
Client ID	1.) BCO NAF	2.) BCO Clay	3.) Waste Rock			
Depth (m)	Not Supplied	Not Supplied	Not Supplied			
Liquid Limit (%)	16	20	20			
Plastic Limit (%)	14	16	17			
Plasticity Index (%)	2	4	3			
Linear Shrinkage (%)	0.0	2.0 *	0.0			
Moisture Content (%)	0.3	5.2	0.1			

Sample No.						
Liquid Limit Determination						
Test Date						
Client ID						
Depth (m)						
Liquid Limit (%)						
Plastic Limit (%)						
Plasticity Index (%)						
Linear Shrinkage (%)						
Moisture Content (%)						

NOTES/REMARKS: The samples were tested oven dried, dry sieved and in a 125-250mm mould.

Sample/s supplied by the client * Cracking occurred + Curling occurred

Accredited for compliance with ISO/IEC 17025 - Testing.
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Tested at Trilab Brisbane Laboratory

Authorised Signatory

C. Park

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PERMEABILITY BY CONSTANT HEAD TEST REPORT

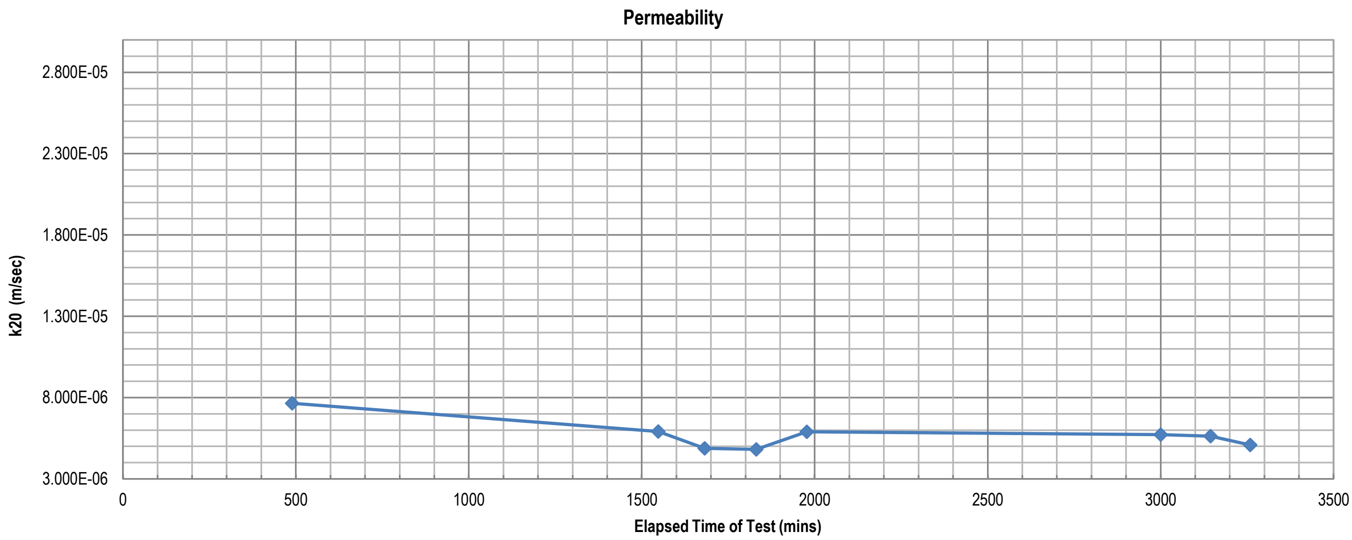
Test Method AS 1289 6.7.1, 5.1.1

Client	SGM Environmental	**Report No.**	21060163-CHP
		Workorder No.	0008705
Address	37 Mt View Crescent Narangba QLD 4504	**Test Date**	15/6/21-24/6/21
		Report Date	24/06/2021
Project	21B002 - BCM (column trials)		
Client ID	1.) BCO NAF	**Depth (m)**	Not Supplied
Description	Silty Sandy GRAVEL - brown	**Sample Type**	Remoulded Soil Specimen

RESULTS OF TESTING

Compaction Method	**AS1289.5.1.1 - Standard Compaction**		
Maximum Dry Density (t/m^3)	**2.20**	Hydraulic Gradient	**0.6**
Optimum Moisture Content (%)	**6.5**	Surcharge (kPa)	**3.7**
Placement Moisture Content (%)	**6.5**	Head Pressure Applied (kPa)	**0.69**
Moisture Ratio (%)	**99.3**	Water Type	**Deaerated**
Placement Wet Density (t/m^3)	**2.23**	Percentage Material Retained/Sieve Size (mm)	**6 % / 19 mm**
Density Ratio (%)	**95.1**	Sample Height and Diameter (mm)	**116.6 / 152.36 mm**

PERMEABILITY $k_{(20)} = 5.5 \times 10^{-06}$ **(m/sec)**



Remarks: The above specimen was remoulded at 95% Standard Dry Density and at Optimum Moisture Content as advised by the client

Sample/s supplied by client

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EMERSON CLASS NUMBER TEST REPORT

Test Method: AS 1289 3.8.1

Client	SGM Environmental	**Report No.**	21060163-EM
		Workorder No.	8705
Address	37 Mt View Crescent Narangba QLD 4504	**Test Date**	25/06/2021
		Report Date	30/06/2021
Project	21B002 - BCM (column trials)		

Sample No.	21060163	21060164	21060165	-	-	-	-
Client ID	1.) BCO NAF	2.) BCO Clay	3.) Waste Rock	-	-	-	-
Depth (m)	Not Supplied	Not Supplied	Not Supplied	-	-	-	-
Description	Silty Sandy GRAVEL - brown	Clayey SAND - brown	Silty Sandy GRAVEL - grey / brown	-	-	-	-
Emerson Class Number	**3**	**3**	**3**	**-**	**-**	**-**	**-**

Sample No.	-	-	-	-	-	-	-
Client ID	-	-	-	-	-	-	-
Depth (m)	-	-	-	-	-	-	-
Description	-	-	-	-	-	-	-
Emerson Class Number	**-**	**-**	**-**	**-**	**-**	**-**	**-**

Sample No.	-	-	-	-	-	-	-
Client ID	-	-	-	-	-	-	-
Depth (m)	-	-	-	-	-	-	-
Description	-	-	-	-	-	-	-
Emerson Class Number	**-**	**-**	**-**	**-**	**-**	**-**	**-**

NOTES/REMARKS:

Sample/s supplied by the client Tested with Distilled water at 21.8°C

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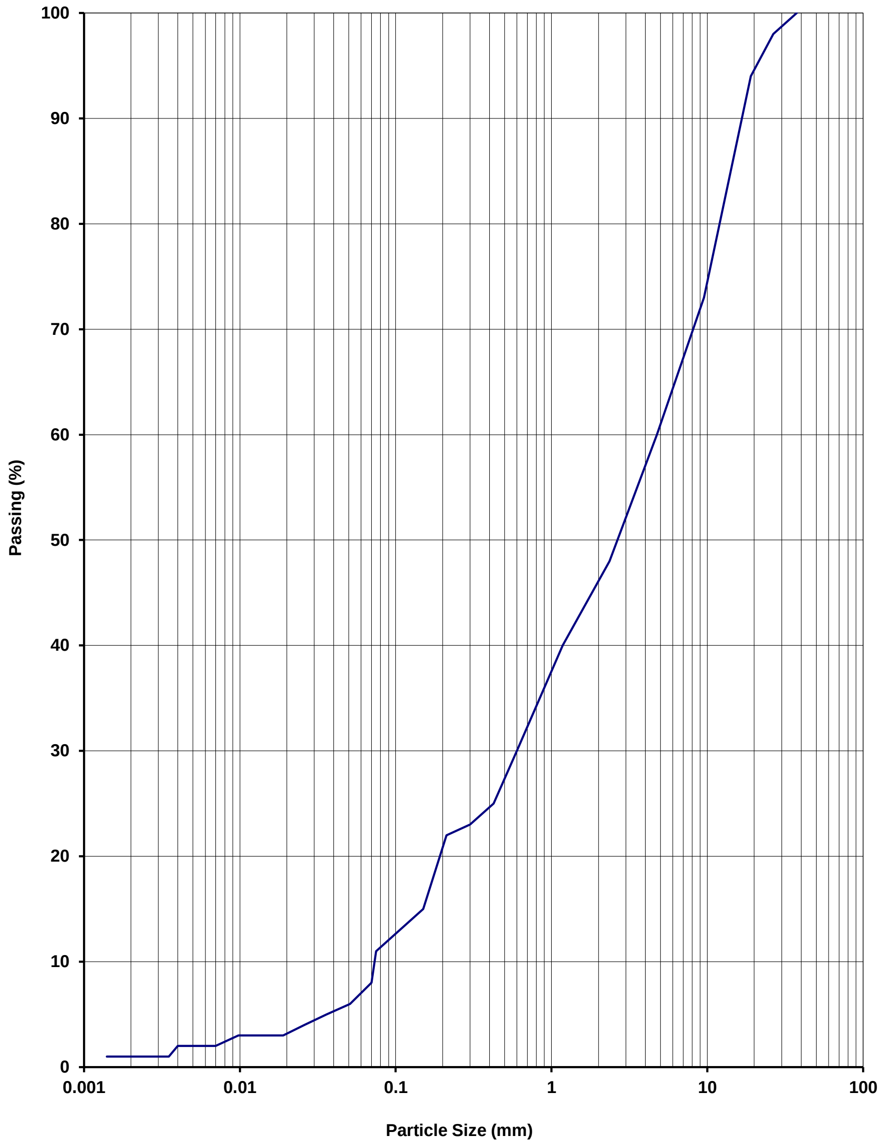
PARTICLE SIZE DISTRIBUTION TEST REPORT

Test Method: AS 1289 3.6.3, 3.5.1 & 2.1.1

Client	SGM Environmental	**Report No.**	21060163-G
		Workorder No.	0008705
Address	37 Mt View Crescent Narangba QLD 4504	**Test Date**	18/6/21-24/6/21
		Report Date	24/6/2021
Project	21B002 - BCM (column trials)		
Client ID	1.) BCO NAF	**Depth (m)**	Not Supplied

Sieve Size (mm)	Passing %
150.0	
75.0	
63.0	
53.0	
37.5	100
26.5	98
19.0	94
13.2	79
9.5	73
6.7	66
4.75	60
2.36	48
1.18	40
0.600	30
0.425	25
0.300	23
0.212	22
0.150	15
0.075	11
0.07	8
0.051	6
0.036	5
0.026	4
0.019	3
0.014	3
0.0098	3
0.007	2
0.005	2
0.004	2
0.0035	1
0.0028	1
0.0025	1
0.0014	1



NOTES/REMARKS: -

Moisture Content 0.3% -2.36mm Soil Particle Density(t/m^3) 2.68

Sample/s supplied by the client

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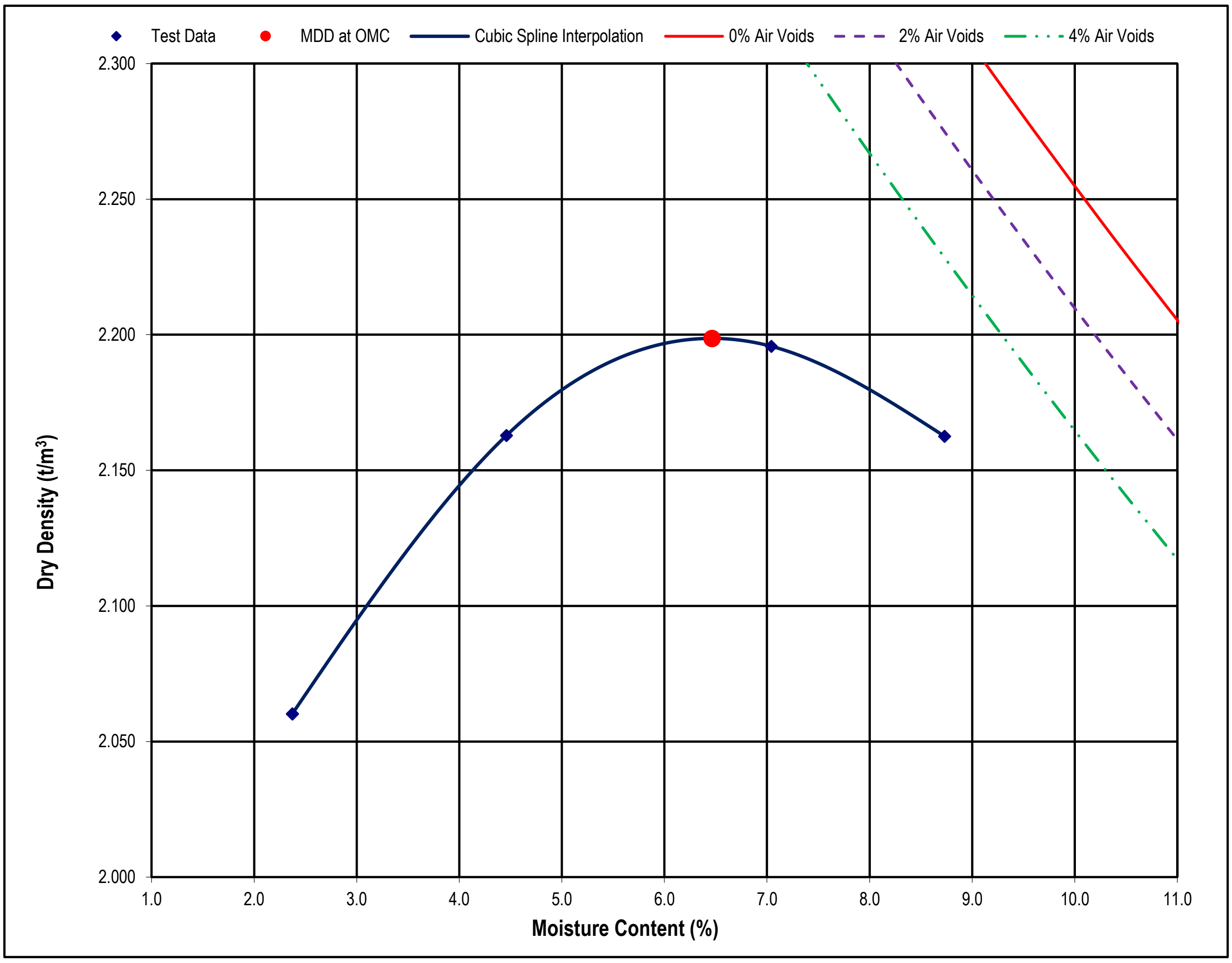
MOISTURE/DENSITY RELATIONSHIP TEST REPORT

Test Method: AS 1289 5.1.1 (Standard) & AS 1289.2.1.1

Client	SGM Environmental	**Report No.**	21060163-MDD
		Workorder No.	0008705
Address	37 Mt View Crescent Narangba QLD 4504	**Test Date**	14/06/2021
		Report Date	24/06/2021
Project	21B002 - BCM (column trials)		
Client ID	1.) BCO NAF	**Depth (m)**	Not Supplied



Maximum Dry Density (t/m^3)	2.20	**Optimum Moisture Content (%)**	6.5
Moisture Content (%)	0.3	**Percentage of Oversize/Sieve Size (mm)**	6 / 19

NOTES/REMARKS:

Sample/s supplied by the client

% Voids based on assumed SG of 2.91

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PERMEABILITY BY FALLING HEAD TEST REPORT

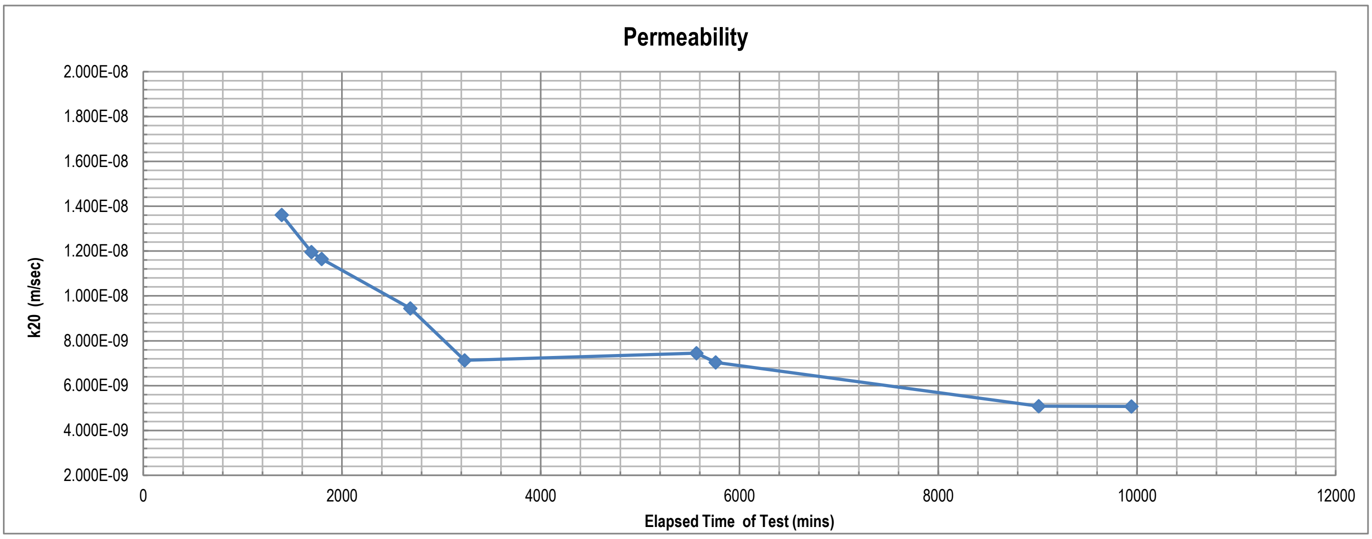
Test Method AS 1289 6.7.2, 5.1.1

Client	SGM Environmental	**Report No.**	21060164-FHPT
		Workorder No.	0008705
Address	37 Mt View Crescent Narangba QLD 4504	**Test Date**	16/6/21-24/6/21
		Report Date	24/06/2021
Project	21B002 - BCM (column trials)		
Client ID	2.) BCO Clay	**Depth (m)**	Not Supplied
Description	Clayey SAND - brown	**Sample Type**	Remoulded Soil Specimen

RESULTS OF TESTING

Compaction Method	**AS1289.5.1.1 - Standard Compaction**		
Maximum Dry Density (t/m^3)	**2.03**	Hydraulic Gradient	**9.5**
Optimum Moisture Content (%)	**9.9**	Surcharge (kPa)	**3.6**
Placement Moisture Content (%)	**9.9**	Head Pressure Applied (kPa)	**10.79**
Moisture Ratio (%)	**100.3**	Water Type	**Deaerated**
Placement Wet Density (t/m^3)	**2.12**	Percentage Material Retained/Sieve Size (mm)	**1 % /19 mm**
Density Ratio (%)	**94.9**	Sample Height and Diameter (mm)	**116.1 / 152.51 mm**

PERMEABILITY $k_{(20)} = 5.1 \times 10^{-09}$ **(m/sec)**



Remarks: The above specimen was remoulded at 95% Standard Dry Density and at Optimum Moisture Content as advised by the client

Sample/s supplied by client

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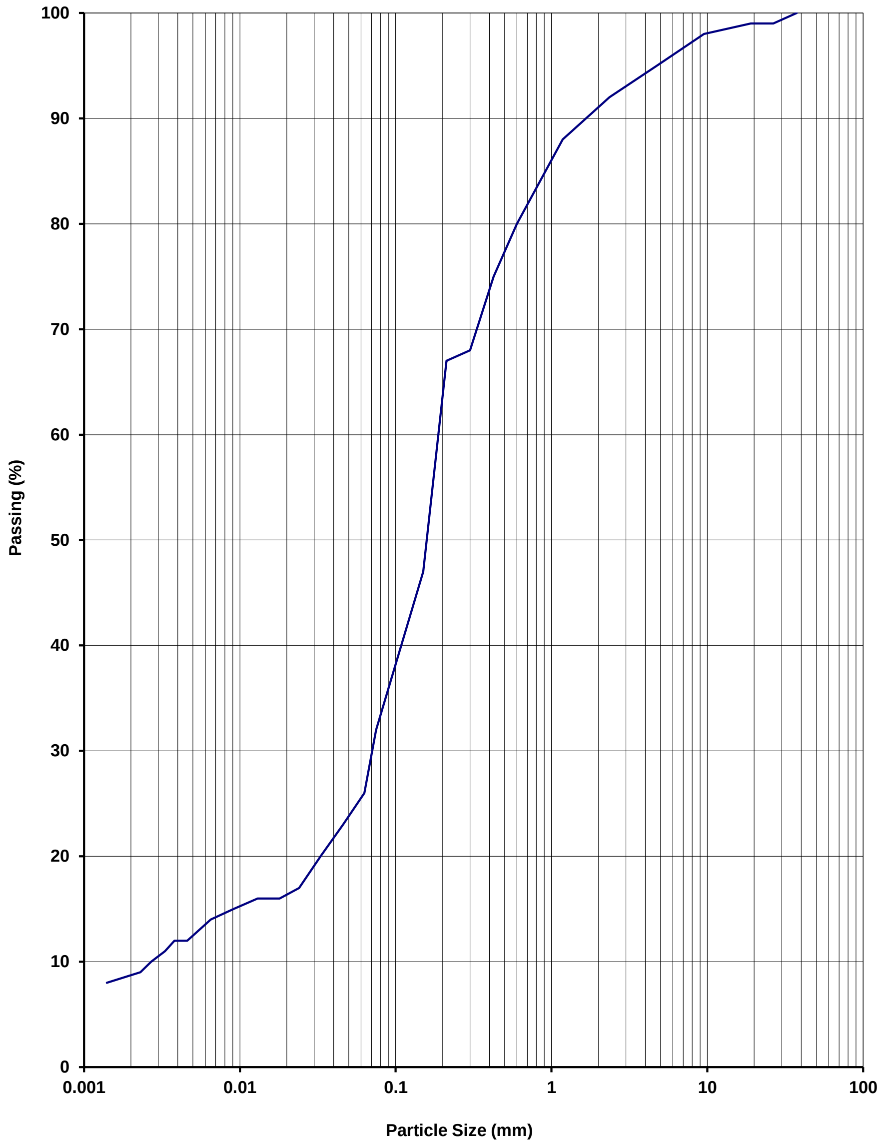
PARTICLE SIZE DISTRIBUTION TEST REPORT

Test Method: AS 1289 3.6.3, 3.5.1 & 2.1.1

Client	SGM Environmental	**Report No.**	21060164-G
		Workorder No.	0008705
Address	37 Mt View Crescent Narangba QLD 4504	**Test Date**	18/6/21-24/6/21
		Report Date	24/6/2021
Project	21B002 - BCM (column trials)		
Client ID	2.) BCO Clay	**Depth (m)**	Not Supplied

Sieve Size (mm)	Passing %
150.0	
75.0	
63.0	
53.0	
37.5	100
26.5	99
19.0	99
13.2	99
9.5	98
6.7	96
4.75	95
2.36	92
1.18	88
0.600	80
0.425	75
0.300	68
0.212	67
0.150	47
0.075	32
0.063	26
0.046	23
0.033	20
0.024	17
0.018	16
0.013	16
0.0091	15
0.0065	14
0.0046	12
0.0038	12
0.0033	11
0.0027	10
0.0023	9
0.0014	8



NOTES/REMARKS: -

Moisture Content 5.2% -2.36mm Soil Particle Density(t/m^3) 2.72

Sample/s supplied by the client

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Tested at Trilab Brisbane Laboratory

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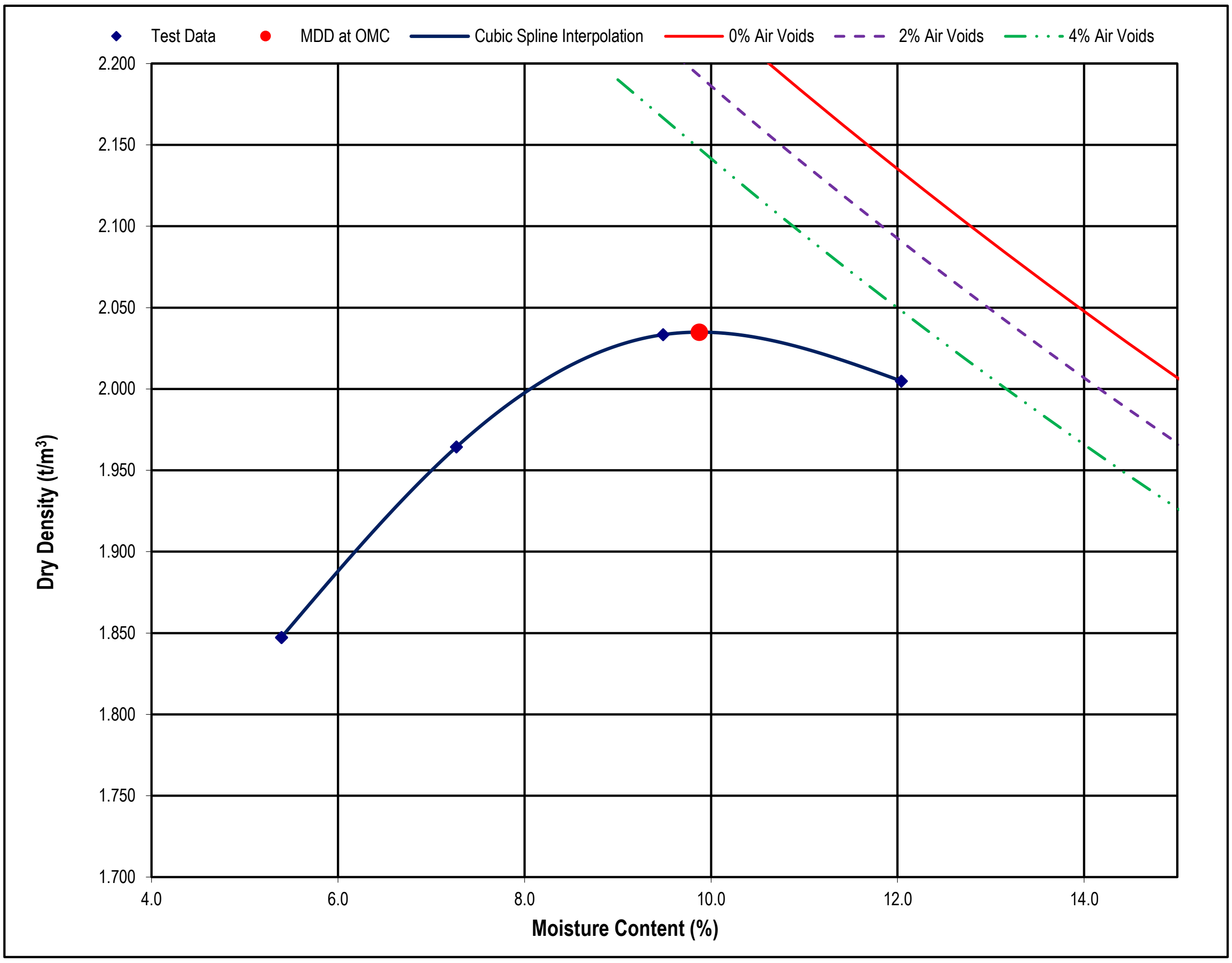
MOISTURE/DENSITY RELATIONSHIP TEST REPORT

Test Method: AS 1289 5.1.1 (Standard) & AS 1289.2.1.1

Client	SGM Environmental	**Report No.**	21060164-MDD
		Workorder No.	0008705
Address	37 Mt View Crescent Narangba QLD 4504	**Test Date**	14/06/2021
		Report Date	24/06/2021
Project	21B002 - BCM (column trials)		
Client ID	2.) BCO Clay	**Depth (m)**	Not Supplied



Maximum Dry Density (t/m³)	2.03	**Optimum Moisture Content (%)**	9.9
Moisture Content (%)	5.2	**Percentage of Oversize/Sieve Size (mm)**	1 / 19

NOTES/REMARKS:

Sample/s supplied by the client % Voids based on assumed SG of 2.87

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PERMEABILITY BY CONSTANT HEAD TEST REPORT

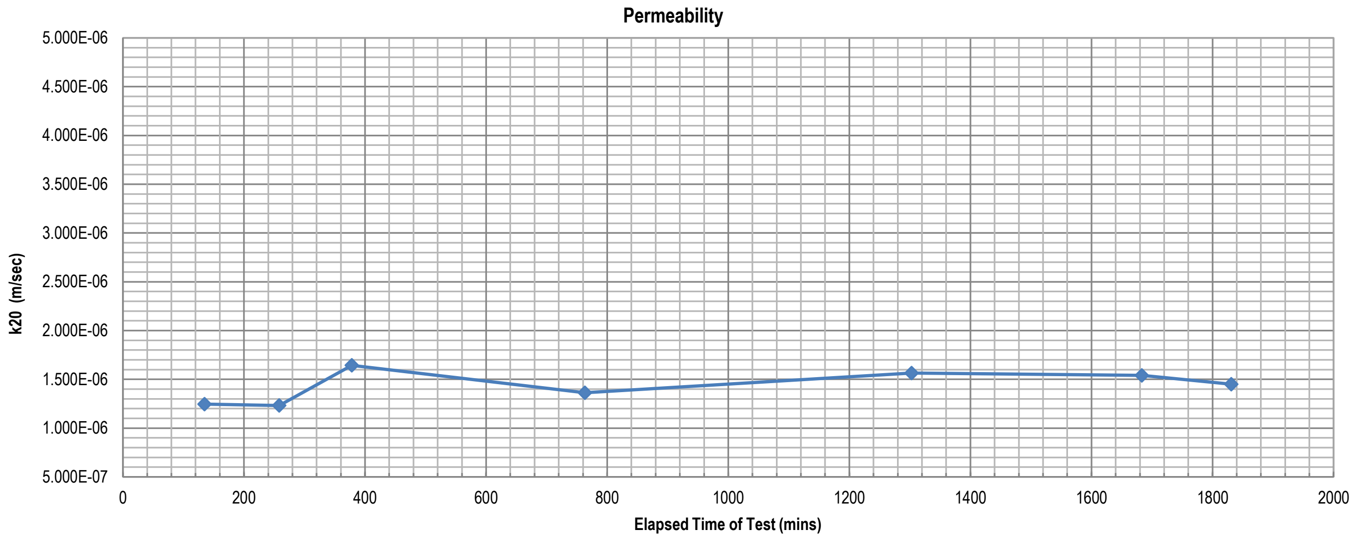
Test Method AS 1289 6.7.1, 5.1.1

Client	SGM Environmental	**Report No.**	21060165-CHP
		Workorder No.	0008705
Address	37 Mt View Crescent Narangba QLD 4504	**Test Date**	15/6/21-22/6/21
		Report Date	22/06/2021
Project	21B002 - BCM (column trials)		
Client ID	3.) Waste Rock	**Depth (m)**	Not Supplied
Description	Silty Sandy GRAVEL - grey / brown	**Sample Type**	Remoulded Soil Specimen

RESULTS OF TESTING

Compaction Method	**AS1289.5.1.1 - Standard Compaction**		
Maximum Dry Density (t/m^3)	**2.22**	Hydraulic Gradient	**0.9**
Optimum Moisture Content (%)	**7.2**	Surcharge (kPa)	**3.7**
Placement Moisture Content (%)	**7.2**	Head Pressure Applied (kPa)	**1.08**
Moisture Ratio (%)	**99.6**	Water Type	**Deaerated**
Placement Wet Density (t/m^3)	**2.26**	Percentage Material Retained/Sieve Size (mm)	**30 % / 19 mm**
Density Ratio (%)	**95.1**	Sample Height and Diameter (mm)	**115.88 / 152.38 mm**

PERMEABILITY $k_{(20)} =$ **1.5×10^{-06} (m/sec)**



Remarks: The above specimen was remoulded at 95% Standard Dry Density and at Optimum Moisture Content as advised by the client

Sample/s supplied by client

Authorised Signatory

C. Park

Trilab
Soil Rock Calibration

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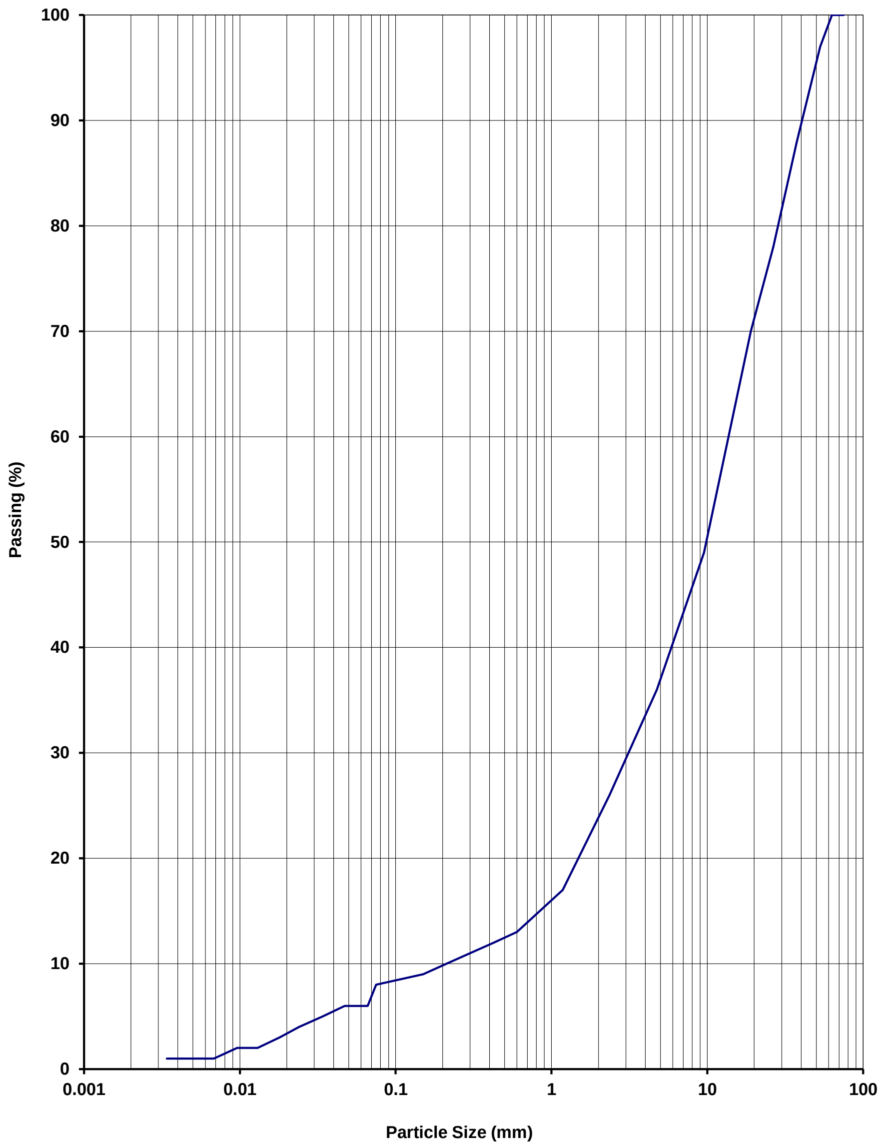
PARTICLE SIZE DISTRIBUTION TEST REPORT

Test Method: AS 1289 3.6.3, 3.5.1 & 2.1.1

Client	SGM Environmental	**Report No.**	21060165-G
		Workorder No.	0008705
Address	37 Mt View Crescent Narangba QLD 4504	**Test Date**	18/6/21-24/6/21
		Report Date	24/6/2021
Project	21B002 - BCM (column trials)		
Client ID	3.) Waste Rock	**Depth (m)**	Not Supplied

Sieve Size (mm)	Passing %
150.0	
75.0	
63.0	100
53.0	97
37.5	88
26.5	78
19.0	70
13.2	57
9.5	49
6.7	42
4.75	36
2.36	26
1.18	17
0.600	13
0.425	12
0.300	11
0.212	10
0.150	9
0.075	8
0.066	6
0.047	6
0.034	5
0.024	4
0.018	3
0.013	2
0.0096	2
0.0068	1
0.0049	1
0.004	1
0.0034	1
0.0028	0
0.0024	0
0.0014	0



NOTES/REMARKS: -

Moisture Content 0.1%   -2.36mm Soil Particle Density(t/m^3) 2.74

Sample/s supplied by the client

Accredited for compliance with ISO/IEC 17025 - Testing.
The results of the tests, calibrations, and/or measurements included in this document are traceable to Australian/National Standards.

Tested at Trilab Brisbane Laboratory

Authorised Signatory

C. Park

NATA ACCREDITED FOR TECHNICAL COMPETENCE

Laboratory No. 9926

Trilab
Soil Rock Calibration

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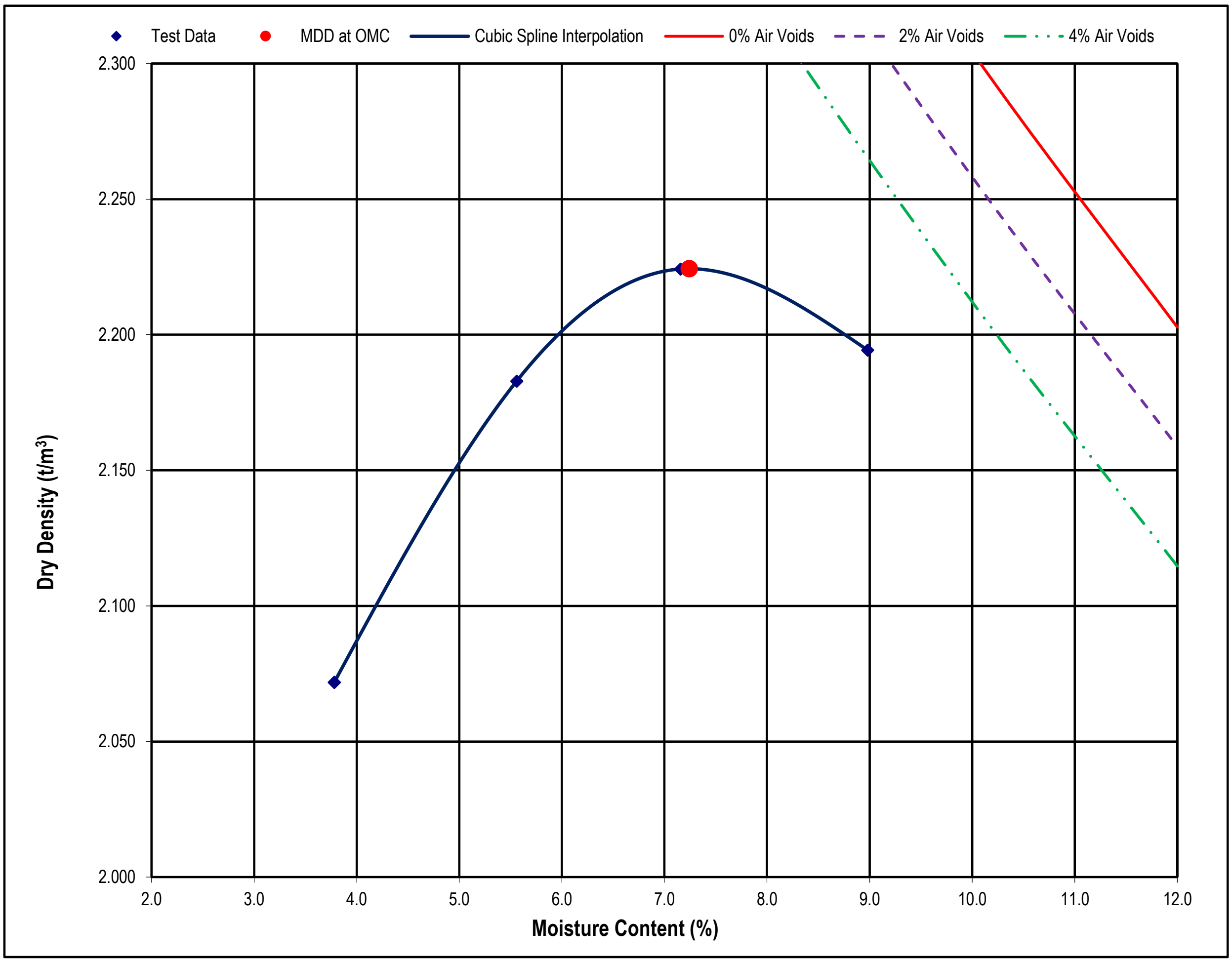
MOISTURE/DENSITY RELATIONSHIP TEST REPORT

Test Method: AS 1289 5.1.1 (Standard) & AS 1289.2.1.1

Client	SGM Environmental	**Report No.**	21060165-MDD
		Workorder No.	0008705
Address	37 Mt View Crescent Narangba QLD 4504	**Test Date**	14/06/2021
		Report Date	24/06/2021
Project	21B002 - BCM (column trials)		
Client ID	3.) Waste Rock	**Depth (m)**	Not Supplied



Maximum Dry Density (t/m^3)	2.22	**Optimum Moisture Content (%)**	7.2
Moisture Content (%)	0.1	**Percentage of Oversize/Sieve Size (mm)**	30 / 19

NOTES/REMARKS:

Sample/s supplied by the client

% Voids based on assumed SG of 2.99

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C. Park

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Laboratory No. 9926

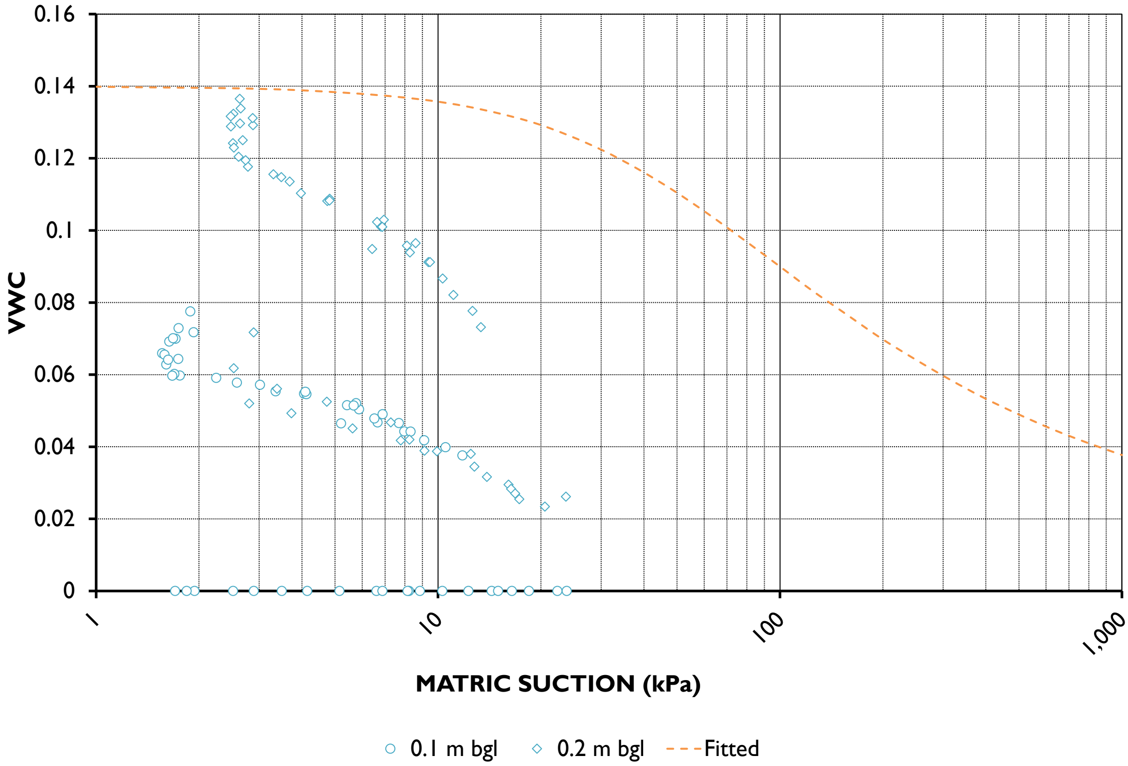
Appendix E

In situ soil water characteristic curves

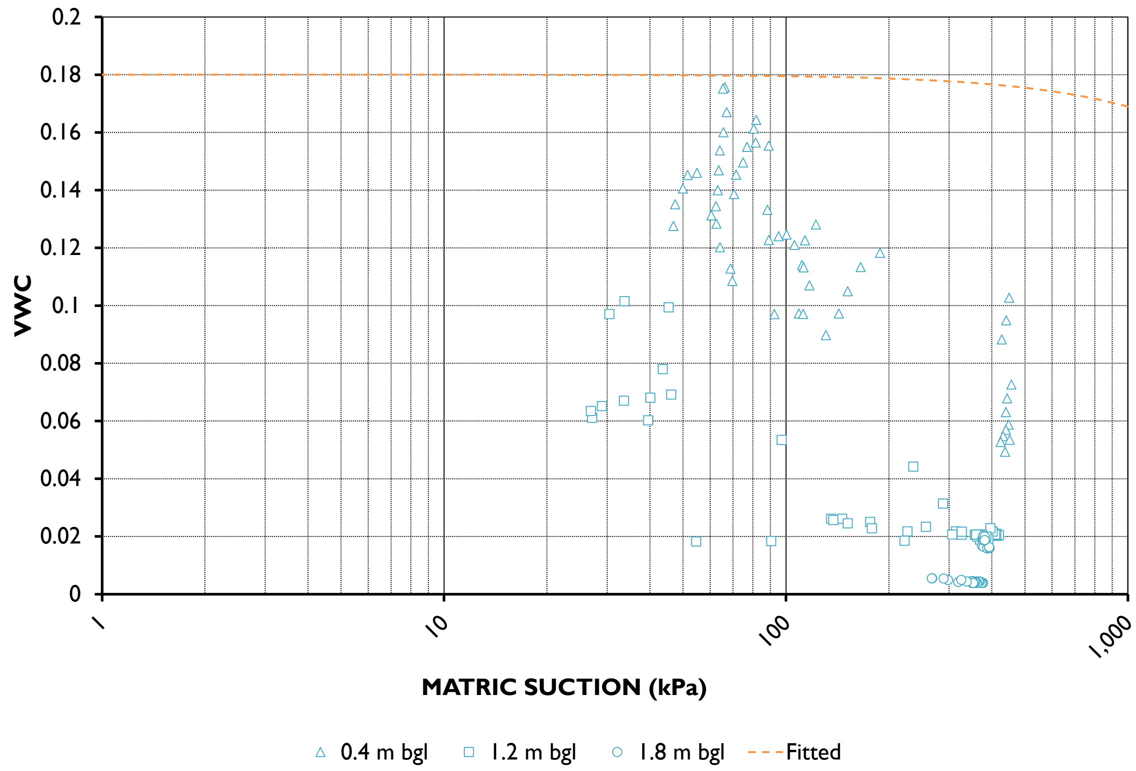
E.1 Soil water characteristic curves

A SWCC for each layer was fitted to the Trial results using the Fredlund and Xing (1994) method (Figure 13-Figure 15):

- Figure 13a-Figure 13 b gives the observed and fitted SWCCs for Trial 1;
- Figure 14a-Figure 14 b gives the observed and fitted SWCCs for Trial 2; and
- Figure 15a-Figure 15 c gives the observed and fitted SWCCs for Trial 3.

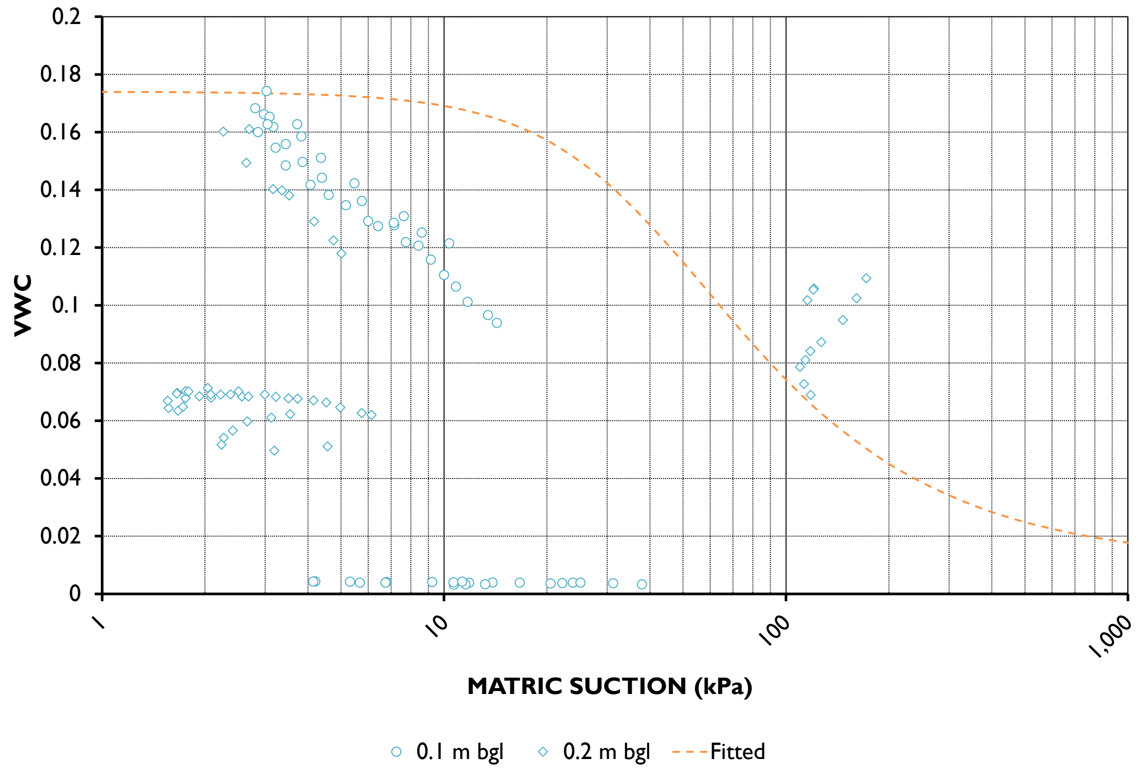


(a)

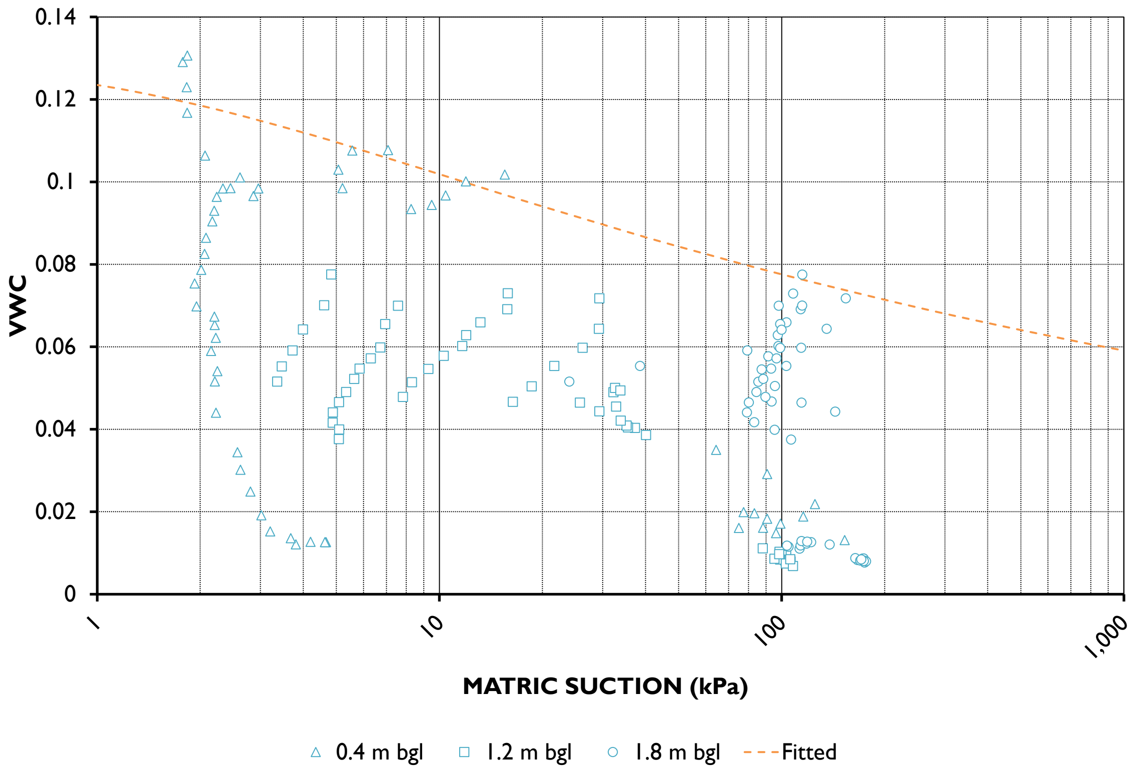


(b)

Figure 13 Trial 1 SWCCs (a) growth media (b) ISL

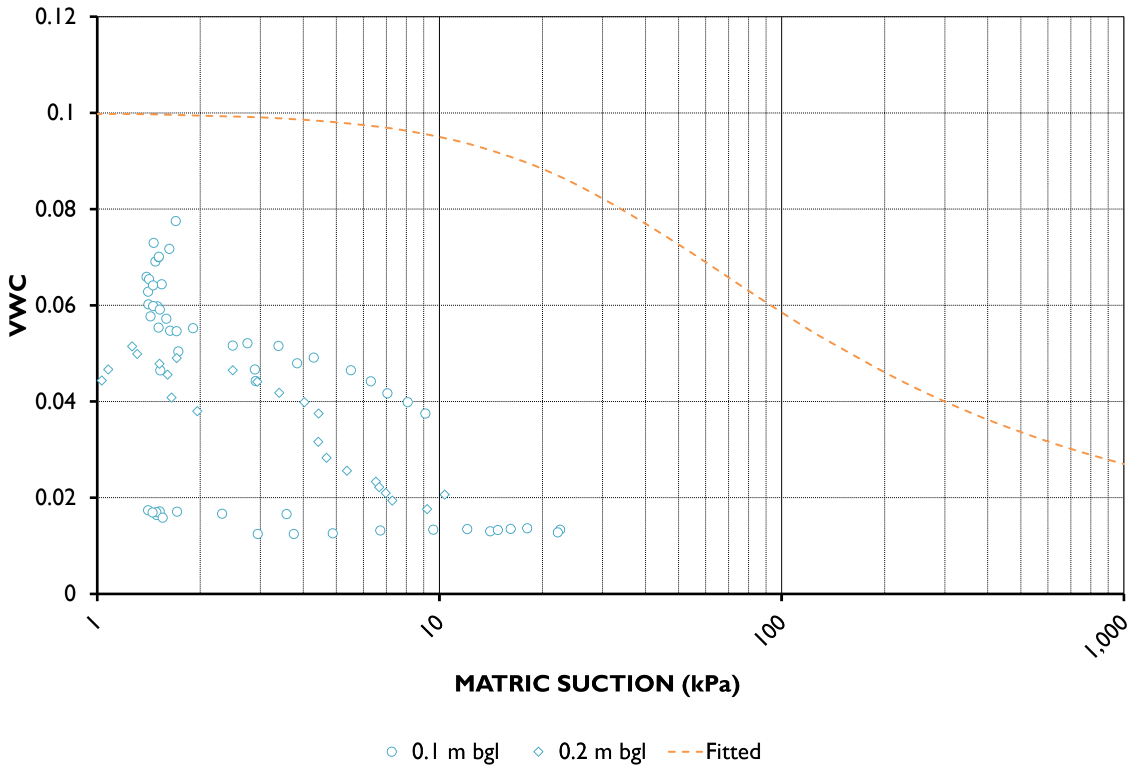


(a)

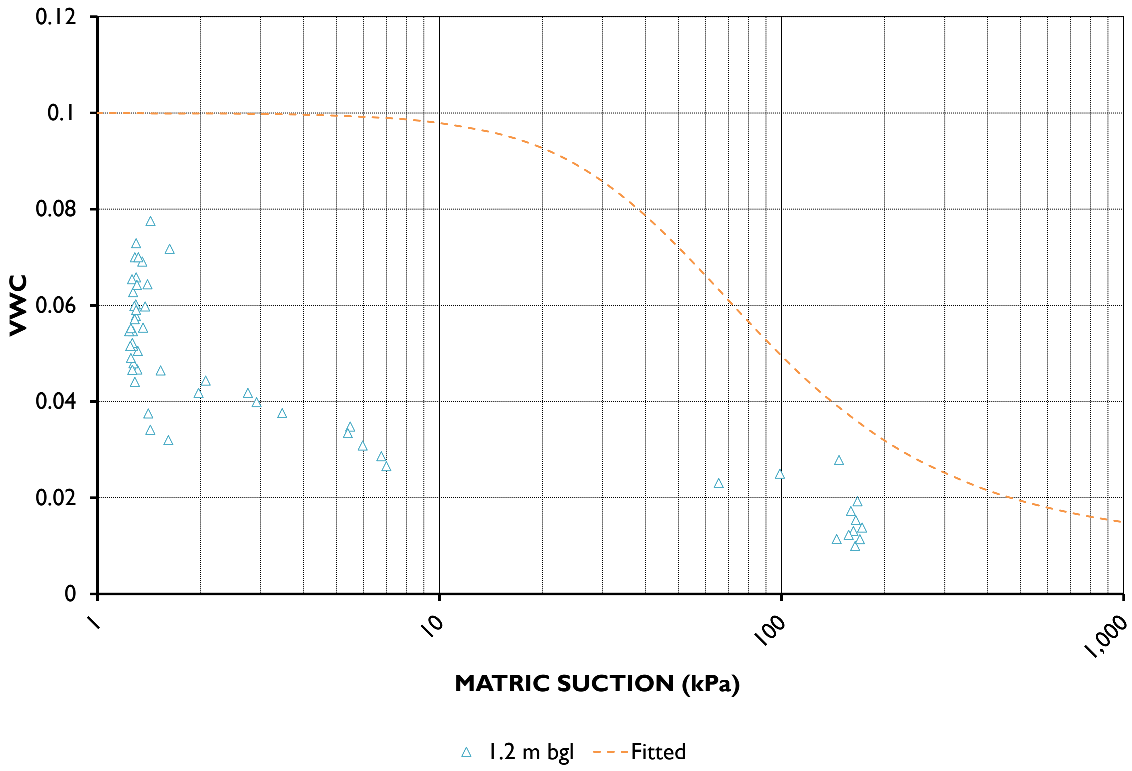


(b)

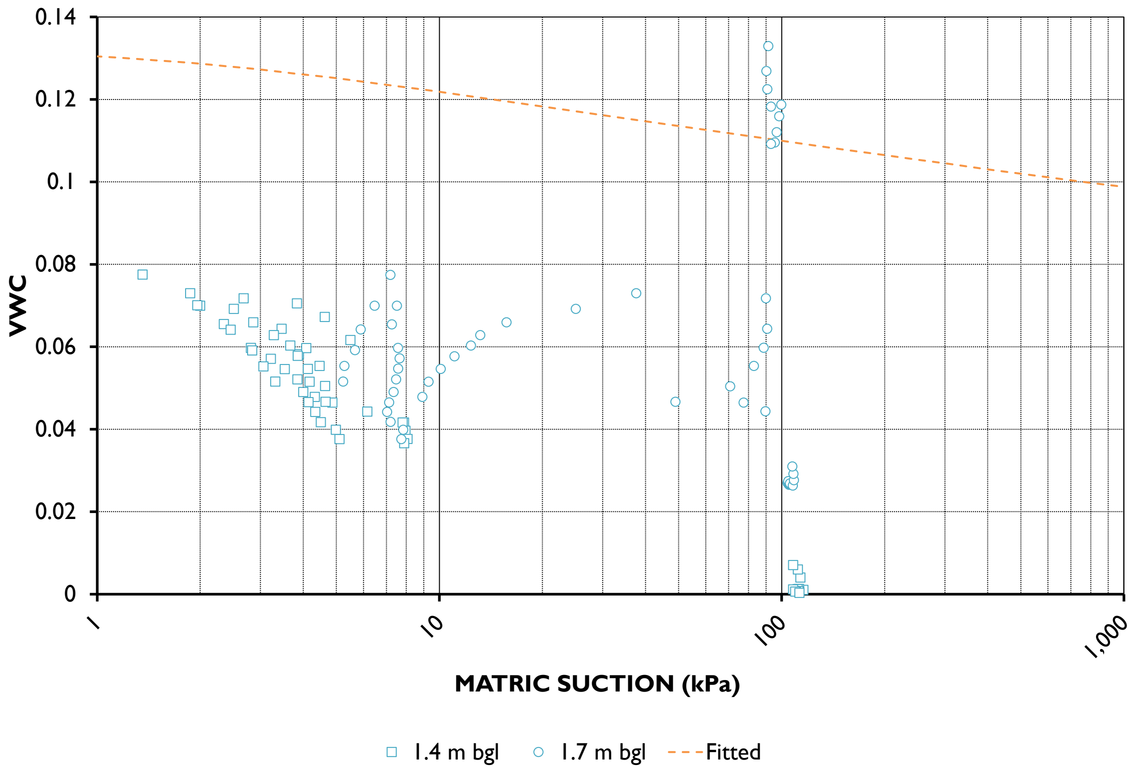
Figure 14 Trial 2 SWCCs (a) growth media (b) ISL



(a)



(b)



(c)

Figure 15 Trial 3 SWCCs (a) growth media (b) ISL (c) RPL

SGMenvironmental

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