

Store-and-release cover column trials at Dugald River mine

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Abstract

The MMG Dugald River mine (the Mine) is located approximately (~) 85 km northeast of Mt Isa and 65 km northwest of Cloncurry in northwestern Queensland. The Mine includes an underground operation, a processing area, a 62.5 ha valley fill tailings storage facility (TSF) and two waste rock dumps (WRDs). Mining is done as conventional underground, longhole, open stoping and downhole benching of a massive zinc (Zn) and lead (Pb) deposit hosted within a black slate environment and copper (Cu) mineralisation in the adjacent hanging wall (the deposit). The deposit is estimated to contain ~53 Mt of Zn and Pb and 3.4 Mt of Cu which will be mined over a 28-year mine life, until about 2046.

Waste rock is segregated based on sulphide concentration and temporarily stored in either a potentially acid forming (PAF) or non-acid forming (NAF) WRD. The PAF waste rock is temporarily stored above-ground and will be returned underground as stope fill in the future. NAF waste rock is an asset and will be used for rehabilitation work and other construction projects during operation.

PAF tailings are thickened to a target solids content of 55% before discharge to the TSF or underground mine as stope fill. The PAF tailings require careful rehabilitation to minimise the risk of environmental harm to the receiving environment from acid rock drainage (ARD).

The environmental licence currently prescribes a 2.1 m thick cover on the TSF surface. However, given the early phase of mining and the limited physical and chemical characterisation work completed on potential cover borrow material, MMG developed an innovative and cost-effective way to test several potential cover options that may provide a better environmental outcome than the cover currently prescribed in the environmental licence.

The purpose of this paper is three-fold. Firstly, it describes the desktop cover design process that the Mine used to develop alternative cover options for the TSF that created an opportunity to improve environmental outcomes. Secondly, the paper describes the method and results of large (2.4 m tall) column trials that were used as a cost-effective way to trial four cover options, the result of the desktop cover design. Finally, the paper describes the cover design model that was built from the column trial results and how the model was used to scale up and assess the potential future performance of the alternative covers if they were built on the TSF.

Keywords: cover design, geochemistry, acid rock drainage

1 Introduction and background

1.1 Location and tenure

The Dugald River mine (the Mine) is located approximately (~) 85 km northeast of Mt Isa and 65 km northwest of Cloncurry in northwestern Queensland. It is located within the Mount Isa Mineral Province which is characterised by mineral exploration, mining and pastoral activities. The Mine is located on Roseby

Station pastoral leases (the station), owned by Macmillan Holdings. The station is used for cattle grazing on unimproved pastures.

The Mine tenure includes 40 mining leases (MLs), one mining lease application (MLA) and one mineral development licence (MDL) granted under the *Mineral Resources Act 1989* (Qld) (Government of Queensland 1989) and subsequent *Mines and Energy Legislation Amendment Act 2011* (Qld) (Government of Queensland 2011) (Figure 1).

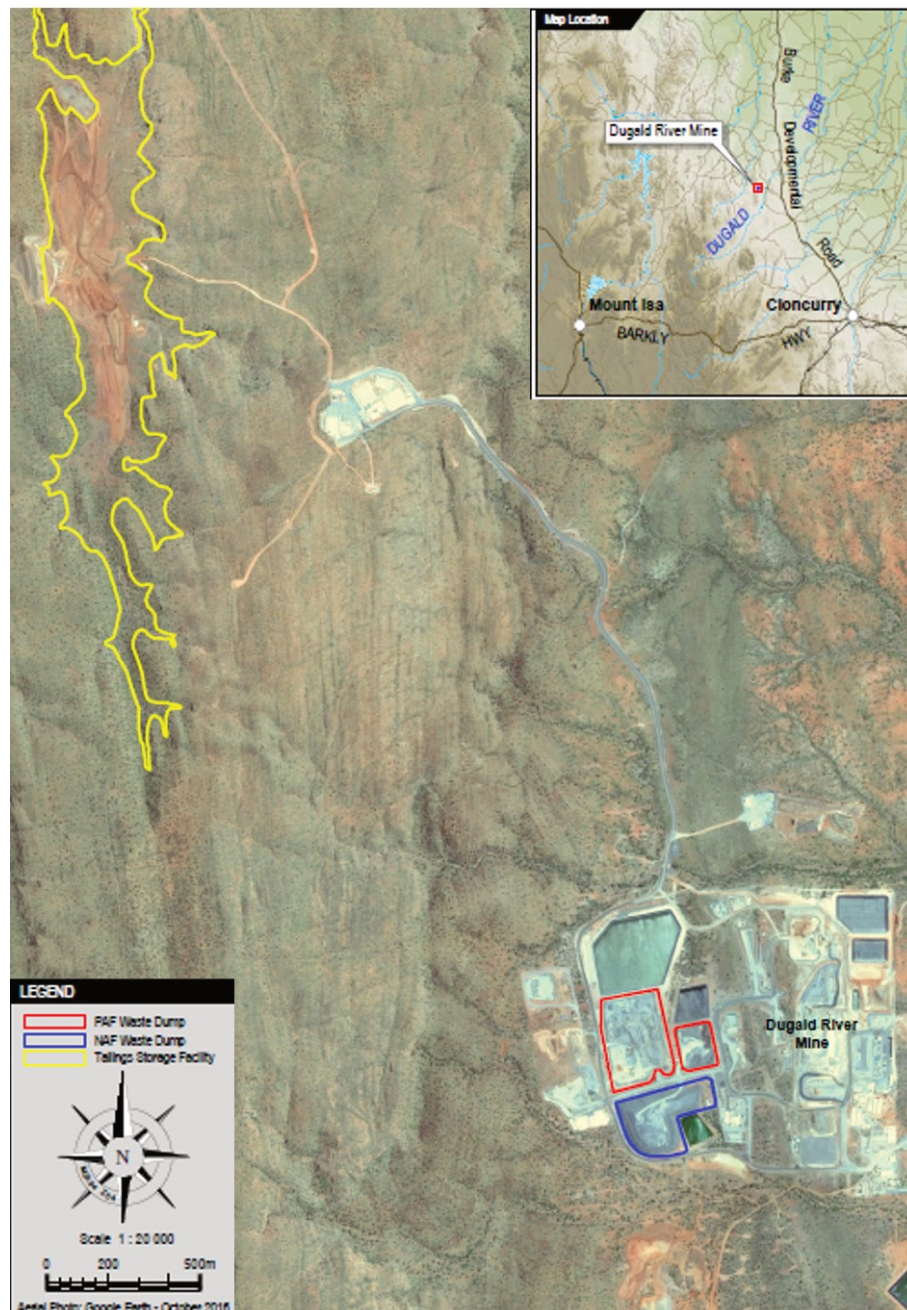


Figure 1 Mine location

1.2 Operational overview

The Mine is an underground zinc (Zn) and lead (Pb) mine accessed by two declines. Ore is mined using conventional longhole open stoping and downhole benching methods. It is trucked to the surface to the run-of-mine (ROM) pad and concentrated through a flotation separation plant. The metal concentrate is stockpiled and transported offsite in sealed trucks. Tailings is transferred to the tailings storage facility (TSF)

(Figure 1) for disposal or combined with cement to paste fill underground voids. Non-ore grade waste rock is generally used as backfill underground; however, where waste rock cannot be directly placed underground, it is classified based on sulphide concentration as non-acid forming (NAF) or potential acid forming (PAF) waste, segregated and transferred to the surface for temporary storage in separate waste rock dumps (Figure 1).

The TSF is a valley fill operation with two discharge locations to the north and south. The target tailings solids content is 55% prior to discharge. The tailings beach grades down towards the centre of the TSF. Tailings supernatant pools occur in the centre of the TSF and are intermittently pumped back to the processing plant for re-use as process water.

1.3 Climate

The mean annual maximum temperature at Cloncurry is 31.2°C, with November to January being the hottest months (>35°C). The mean annual minimum temperature is 18.5°C with June to August being the coolest months (<12°C).

The average annual rainfall for the region is 513 mm. Regionally there is a distinct wet season (between November and April), with very little rain falling in the remaining months of the year. Historical rainfall data shows that January and February exhibit the highest mean monthly rainfall, with both months averaging above 100 mm (149.1 mm and 116.9 mm respectively). These months also experience the rainiest days, with more than seven rain days per month.

The driest months of the year are July and August with mean rainfall under 5 mm, and each averaging less than one day of rain.

The evaporation rate is primarily temperature-driven with the highest mean monthly evaporation (328.6 mm) occurring in December, and the lowest (159.0 mm) in June. Evaporation exceeds rainfall in all months by a factor of three.

2 Method

The TSF is the only above-ground waste storage facility that will require rehabilitation.

2.1 Environmental risk

An environmental risk assessment, having regard for International Organisation for Standardisation (2018) identified the following risks:

1. After discharge, tailings will generate acidic conditions and leach metals i.e. they are PAF and form acid rock drainage (ARD).
2. The tailings will develop a hard pan on the surface and tailings below ~0.5 m will remain fresh and unoxidised indefinitely i.e. the potential timescale for ARD is long.

2.1.1 Controls

The environmental risk assessment identified the following controls to limit the potential for ARD:

1. Limit rainfall infiltration into the tailings to prevent acidic seepage and mobilisation of metals, using compacted, reduced-permeability layers (RPLs), infiltration storage layers (ISLs) and capillary breaks (CBs).
2. Provide an environment favourable to the growth of vegetation (in the ISL) minimising the risk of re-charging unoxidised/partially oxidised tailings and maximising atmospheric loss of rainfall infiltration/storage by evapo-transpiration.

2.1.2 Implementation

Applying the Global Acid Rock Drainage (GARD) Guide (2009) cover criteria suggested a store-and-release cover is the most suitable cover system for the TSF (Figure 2). No alternate cover systems have been assessed.

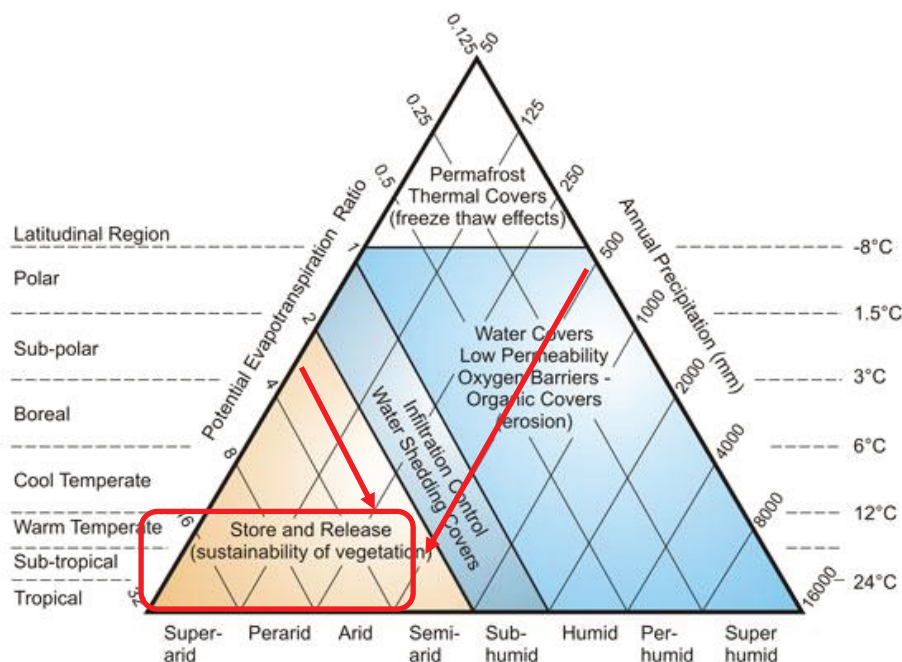


Figure 2 Covers and climate type

A store-and-release cover is constructed to reduce net infiltration by storing rainfall and releasing it via evapo-transpiration. The store-and-release cover may be combined with other engineered controls, for example a reduced-permeability layer and/or a capillary break to further reduce the potential for environmental risk.

Potential store-and-release cover materials could include soil (topsoil and subsoil either co-mixed or stockpiled separately), growth media (co-mixed soil, rock and vegetation mulch) and NAF waste rock.

2.2 Store-and-release column trials

The low rainfall environment was seen as a limiting factor to achieving a timely response from potential cover trials. Regional experience (Rohde et al. 2016) indicated that several years of data would be required to capture a representative window of how the covers would respond to seasonal changes. Space availability on the TSF to construct the trials was also a limiting factor. In order to achieve interim data for cover performance, it was decided that the cover trials would be constructed as large columns. This approach allowed flexibility to decide the frequency and quantity of rainfall, providing greater capacity to develop a maximum water balance for each column trial (cover option) quickly. Noting that the columns do alter the environmental conditions (i.e. evaporation); however, this variable can be interrogated during modelling.

2.2.1 The cover options

The cover options that were tested are as follows (Figure 3, Table 1):

1. The approved cover option described in the Mine's Environmental Impact Statement (the EIS cover option).
2. A high-risk cover option (double CB) having regard for the Department of Environment and Science definition (<https://environment.des.qld.gov.au/assets/documents/regulation/rs-ca-mining-erc-calculator.xlsm>).

3. A high-risk cover option with an ISL that was half as thick as the EIS and high-risk cover options.
4. A monofill ISL cover without a CB or RPL.



Figure 3 The cover options; Far left = Environmental Impact Statement cover; Second from left = high-risk cover; Second from the right = high-risk cover with half ISL; Far right = monofill cover

Table 1 Layer thicknesses

Description	Units	Environmental Impact Statement cover	High-risk cover	High-risk cover with half ISL	Monofill cover
Topsoil	m	0.20	0.20	0.20	0.20
ISL	m	1.00	1.00	0.50	0.50
RPL	m	0.50	0.50	0.50	0.00
CB	m	0.40	0.60 ¹	0.60 ¹	0.00
Total cover thickness	m	2.10	2.30	1.80	0.70

1. The complete thickness of the CB layer, is split 0.3 m above and below the RPL.

2.2.2 Instrumentation

The column trials include pairs of matric suction and volumetric water content sensors (VWC) buried in each of the topsoil, ISL, CB, RPL and tailings layers (Figure 4). A rain gauge tipping bucket is included under the column trials to measure seepage.

EIS cover		High-risk cover		High-risk cover with half ISL		Monofill cover	
Sensor number	Burial depth	Sensor number	Burial depth	Sensor number	Burial depth	Sensor number	Burial depth
1-1	0.3 m	1-6	0.7 m	2-1	0.5 m	2-6	0.3 m
1-2	1.2 m	1-7	1.5 m	2-2	1 m	2-7	0.5 m
1-3	1.4 m	1-8	1.7 m	2-3	1.2 m	2-8	0.7 m
1-4	1.7 m	1-9	2 m	2-4	1.5 m	2-9	0.9 m
2-10	2 m	1-10	2.2 m	2-5	1.7 m	1-5	1 m

Notes: Yellow-brown = topsoil, red-brown = ISL, blue = RPL, orange = CB, grey = tailings

Figure 4 Depth of burial of paired matric suction and volumetric water content sensors

The sensor burial depths were arranged so that there was replicate data from the various store-and-release cover materials across all of the column trials. The buried sensor arrangement provided redundancy, in case of damage during installation, and allows the data from all of the column trials to be aggregated in the future to assess other cover options (if needed).

The matric suction sensors are recommended for use for suctions ranging from 10 to 1,000 kPa. The sensors have been calibrated for suctions greater than 1,000 kPa having regard for the technique used by Flint et al. (2002). The calibration functions presented extended up to 1,000,000 kPa (Figure 5); however, it is unlikely that matric suctions of this order will ever be achieved in the column trials.

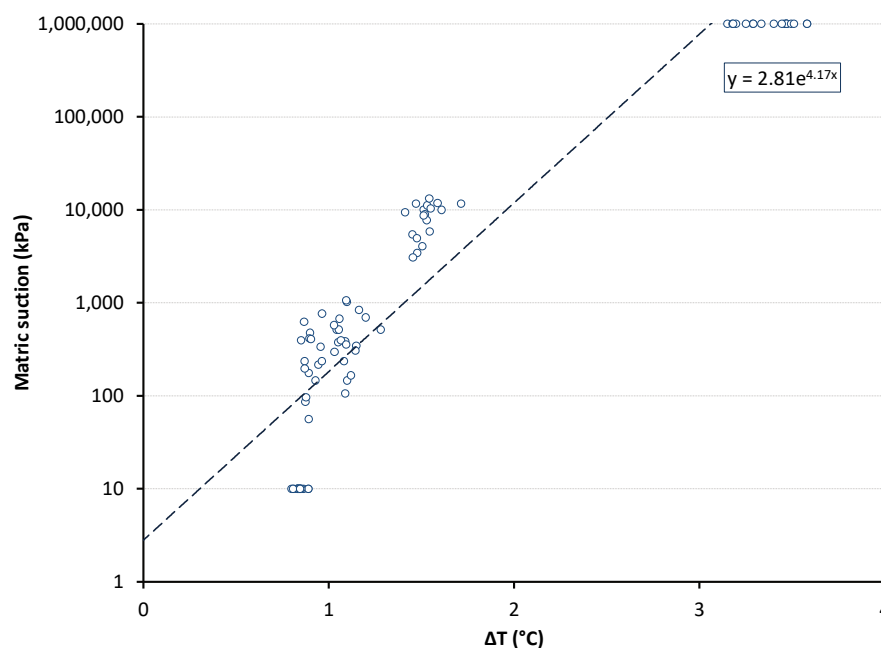


Figure 5 General calibration function for matric suction sensors

2.2.3 Wetting and drying events

The column trials were subjected to artificial rainfall events. The purpose of the artificial rainfall was to allow them to wet up and dry out so that soil water characteristic curves (SWCCs) and a maximum water balance could be developed for each cover option.

The artificial rainfall events were separated by a seven-day period of drying.

3 Results

The column trial water balances are made up of: artificial rainfall; stored infiltration which was calculated from the VWC sensors; seepage which was calculated from the rain gauge tipping buckets underneath the column trials and evaporation which was the difference between the sum of artificial rainfall and stored infiltration minus seepage.

3.1 Artificial rainfall

The column trials were subjected to a maximum of 11 artificial rainfall events over five months however, only two of the columns received all rainfall events. The total artificial rainfall applied was up to 910 mm on column trial 1 and 2 (EIS and high-risk covers), column 3 (High-risk cover with half ISL) had 710 mm of rainfall from ten artificial events and column 4 (monofill cover) received 510 mm from nine artificial rainfall events (Figure 6).

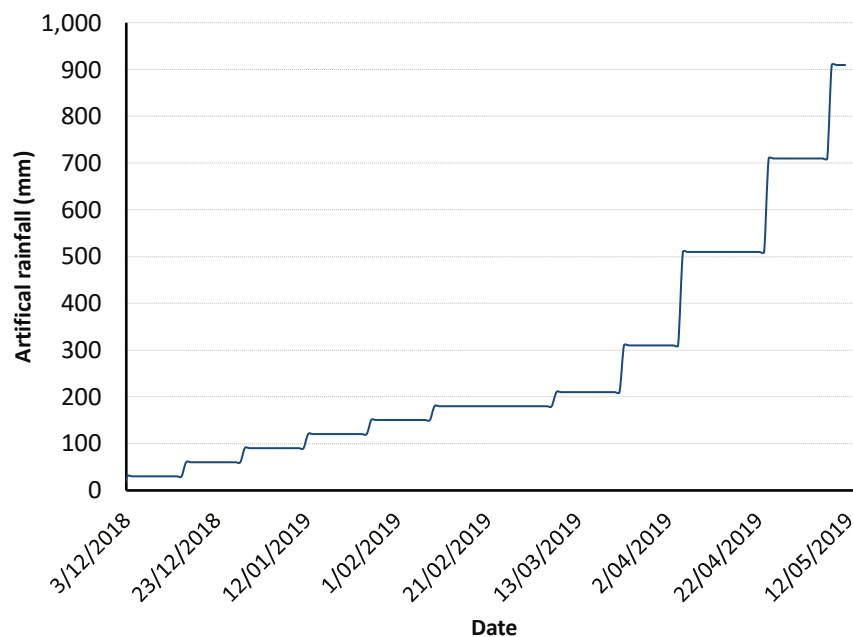


Figure 6 Cumulative artificial rainfall

3.2 Stored infiltration

Stored infiltration in the columns was calculated daily by multiplying the change in VWC in each layer, by the depth of that layer. The daily incremental change in stored infiltration (ΔSW) balances the infiltration budget daily as either wetting (+ve ΔSW) or drying (-ve ΔSW). As such, it reflects a balance between the rate of addition and the rate of evaporation and seepage (Figure 7).

Of the four cover options, the EIS cover stored the most total infiltration (~ 79 mm) followed by the high-risk cover (~ 68 mm) and the high-risk cover with half ISL (~52 mm). The monofill cover stored the least infiltration (~ 31 mm).

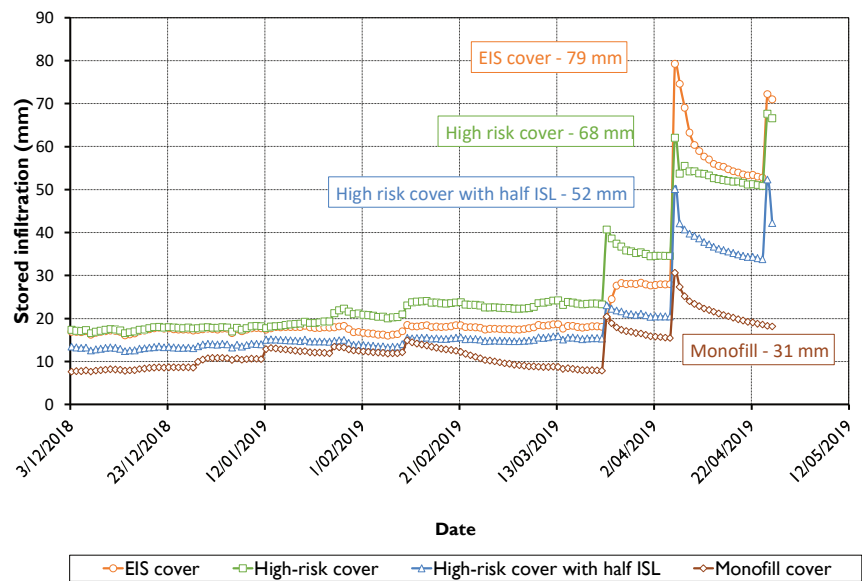


Figure 7 Stored infiltration

3.3 Seepage

Of the four cover options, the EIS cover had the highest seepage (~3 mm) followed by the high-risk cover with half ISL (~2 mm) and the high-risk cover and monofill cover (~1 mm) (Figure 8).

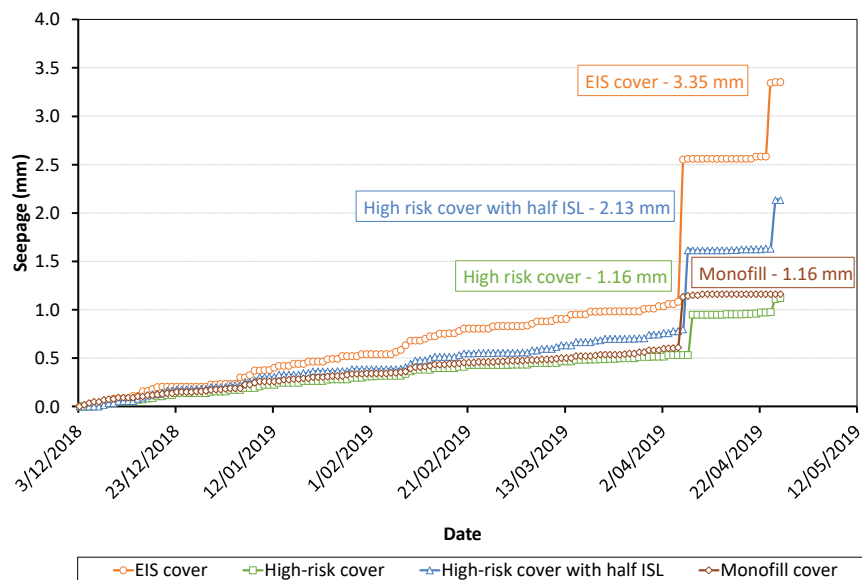


Figure 8 Seepage

3.4 Water balance

The water balance for the cover options is given in Table 2, noting that it is assumed that 100% of rainfall will initially infiltrate. The following section describes how the seepage calculation was verified using modelling.

Table 2 Water balance

Water balance element	Environmental Impact Statement cover	High-risk cover	High-risk cover with half ISL	Monofill cover
Units	mm (%)	mm (%)	mm (%)	mm (%)
Rainfall	910	910	710	510
Stored infiltration	79 (8.71)	68 (7.43)	52 (7.37)	31 (6)
Seepage	3 (0.37)	1 (0.12)	2 (0.3)	1 (0.23)
Evapo-transpiration	~827 (90.92)	~841 (92.45)	~656 (92.33)	~478 (93.77)

4 Vadose modelling

The following sections describes how seepage was predicted using Vadose/w (the model) (Geoslope 2012).

The model was developed in one dimension and calculates the upward and downward movement of rainfall infiltration and seepage; it assumes no surface runoff or run on and allows ponding at the surface.

Transpiration from vegetation has been conservatively excluded since data is not available for this parameter i.e. the model only considers evaporation.

4.1 Model dimensions and mesh geometry

The models were developed to replicate the column trials (Figures 3 and 9). The model automatic mesh generation and automatic mesh refinement algorithms were used to generate the finite element mesh.

4.2 Initial conditions

4.2.1 Evaporation

Potential evaporation in the model was kept as a constant at 0.0035 m/day. The potential evaporation rate is the average for the column trials.

4.2.2 Physical characterisation

4.2.2.1 Soil water characteristic curves

The model requires SWCCs. A SWCC for each layer was derived from the relationship between VWC and matric suction for each depth where the sensors are placed in the cover (the in situ results). The in situ SWCCs for the ISL, RPL, topsoil and CB were fitted to the in situ results using the Fredlund & Xing (1994) method (Figure 10).

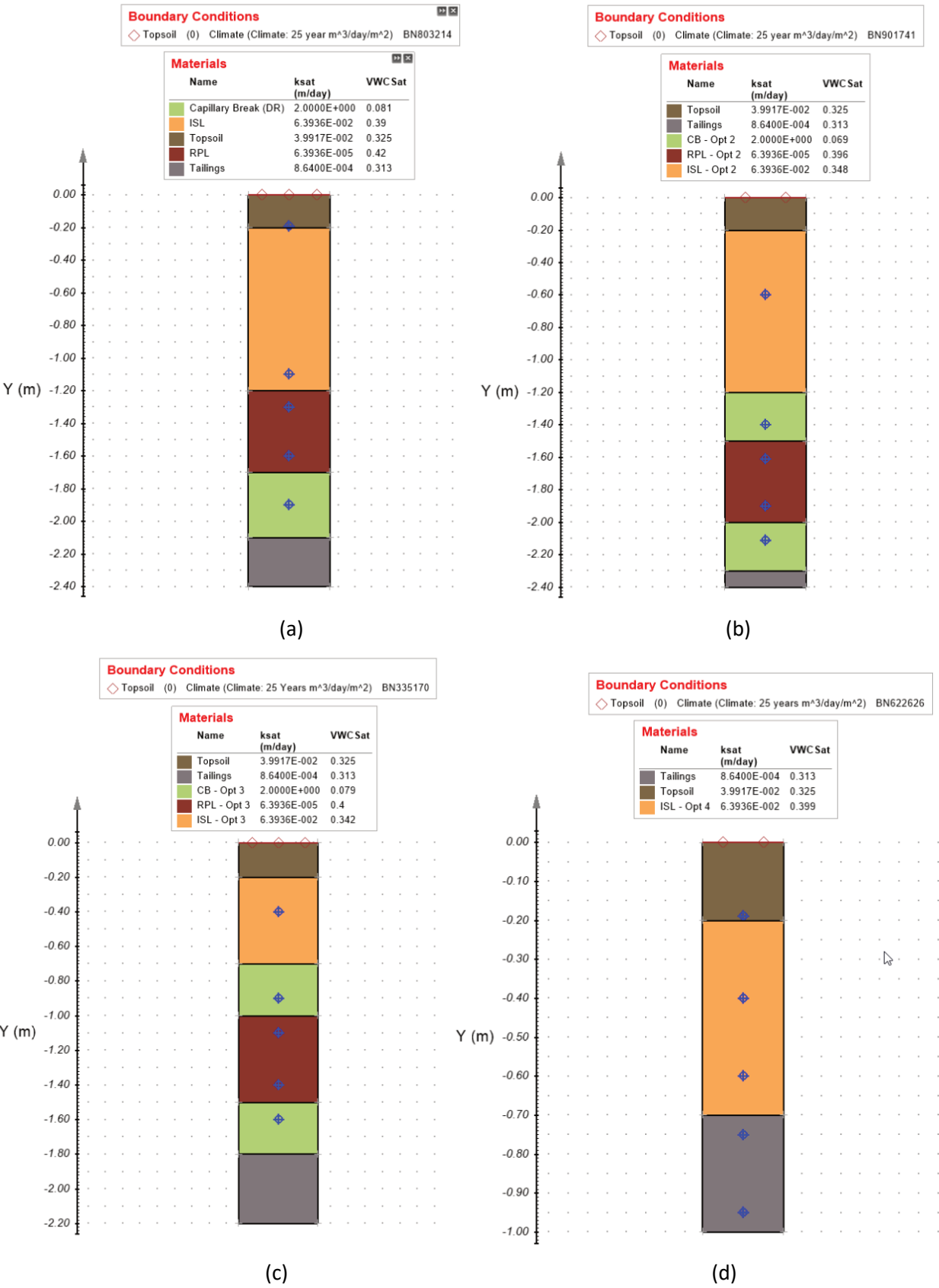


Figure 9 Model dimensions; (a) Environmental Impact Statement cover; (b) High-risk cover; (c) High-risk cover with half ISL; (d) Monofill cover

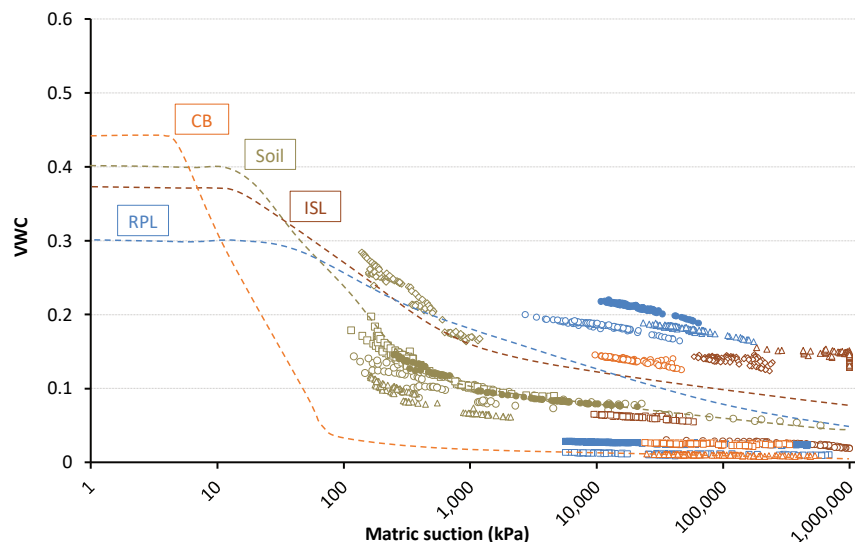


Figure 10 Soil water characteristic curves

4.2.2.2 Saturated and unsaturated hydraulic conductivity

The saturated hydraulic conductivity of the topsoil, ISL, RPL, CB and tailings were derived from a 2018 characterisation programme carried out by the Mine (taken from the same stockpiles as the column material):

1. Topsoil – 0.04 m/day or 4.62×10^{-7} m/s.
2. ISL – 0.063 m/day or 7.4×10^{-7} m/s.
3. RPL – 0.000063 m/day or 7.4×10^{-10} m/s.
4. CB – 2 m/day or 2.31×10^{-5} m/s.

The model derives unsaturated hydraulic conductivity curves from the SWCCs and the saturated hydraulic conductivity.

4.2.2.3 Transient analysis

The model was run for the artificial rain events given in Figure 6. The model results compared to the column trial VWC results are given in Figures 11 to 14. The model generally matched the observed VWC results from the column trials. Noting that (Table 3):

1. Stored infiltration was substantially lower in the model – the difference being approximately equal to greater predicted seepage (in the model compared to the observed data).
2. The RPL consistently returned a higher VWC model prediction which may be influencing the seepage result.

The semi-calibrated model suggests that the monofill cover (0.7 m thick) returns a similar result to the high-risk cover based on the predicted seepage. And that both covers perform better than the EIS cover and high-risk cover with half ISL. It is thought that the poorer performance (increased seepage) of the EIS cover and high-risk cover with half ISL is a result of rainfall infiltration moving beyond the effective depth that it can be removed by evapo-transpiration:

1. In the case of the EIS cover the velocity of vertical migration of rainfall infiltration is greater than evapo-transpiration as a result of the cover thickness.
2. In the case of the high-risk cover with half ISL the CB layers create a capillary break which prevents rainfall infiltration being removed by evapo-transpiration – effectively halving the cover thickness.

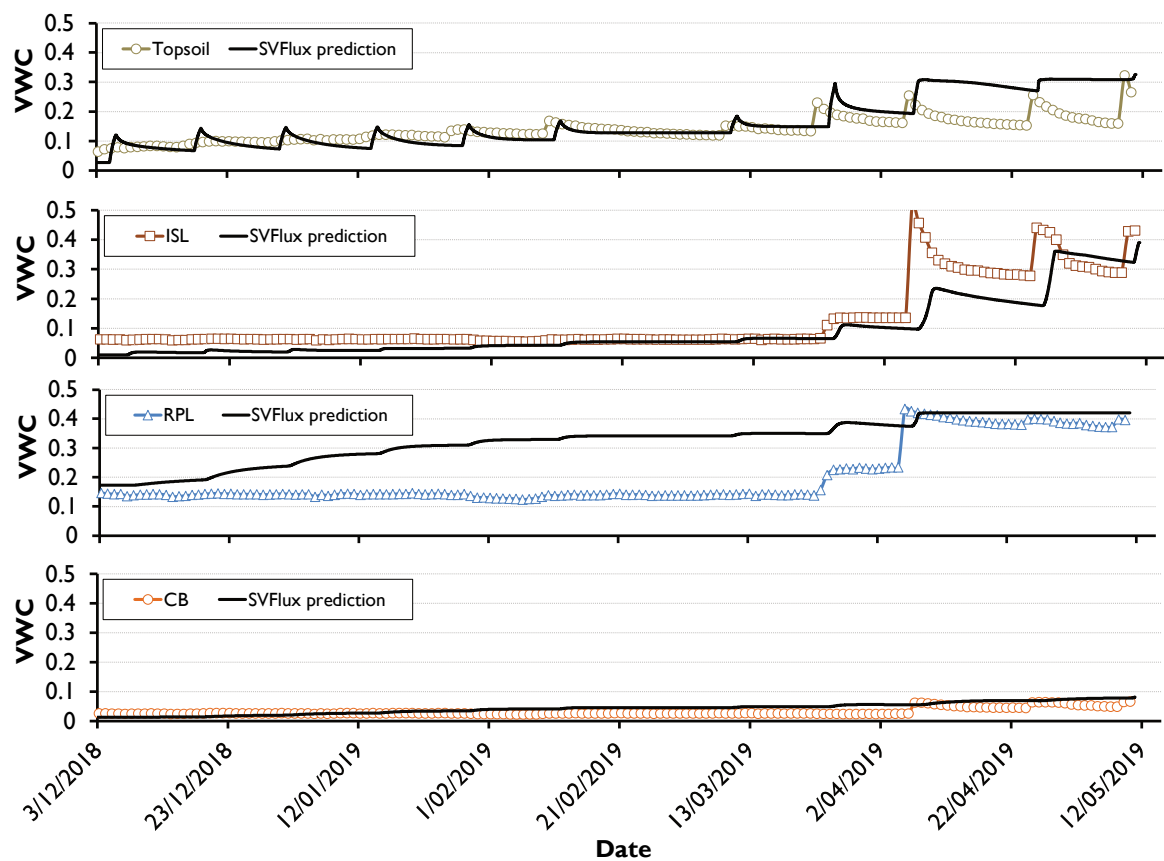


Figure 11 Environmental Impact Statement cover column trial volumetric water content sensors (VWC) compared to SVFlux prediction

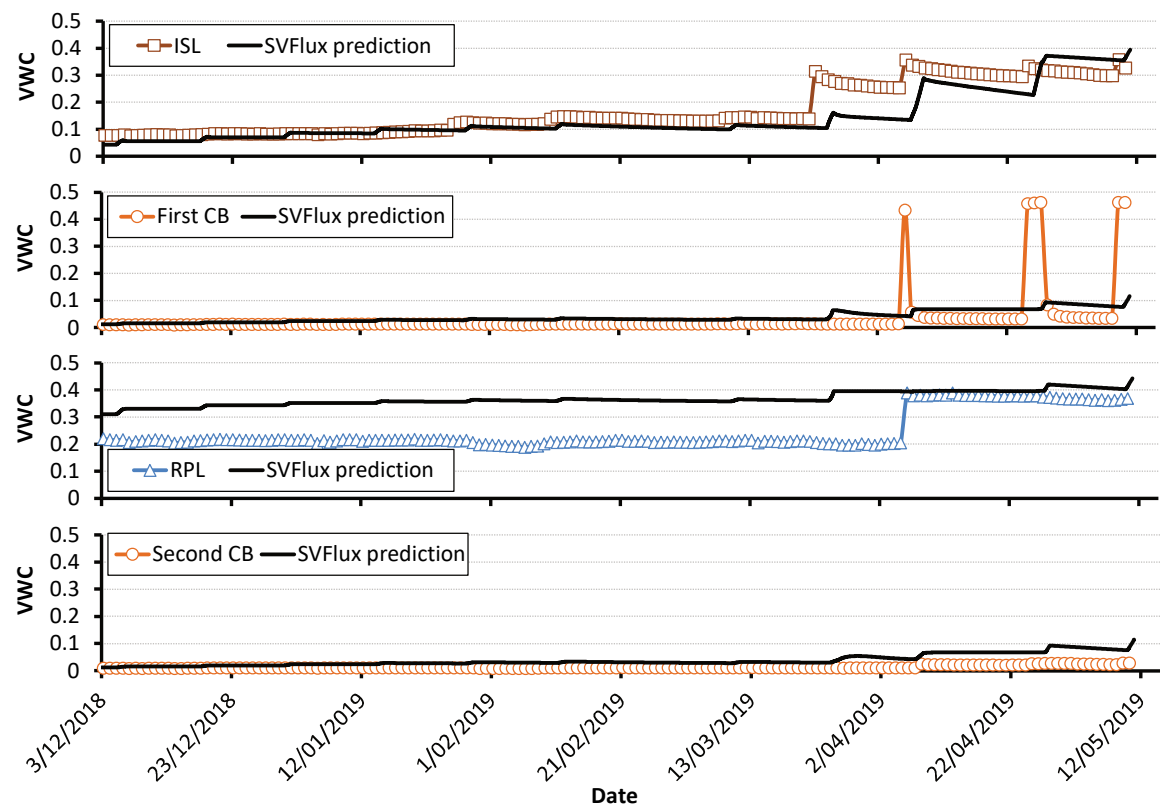


Figure 12 High-risk cover column trial volumetric water content sensors (VWC) compared to SVFlux prediction

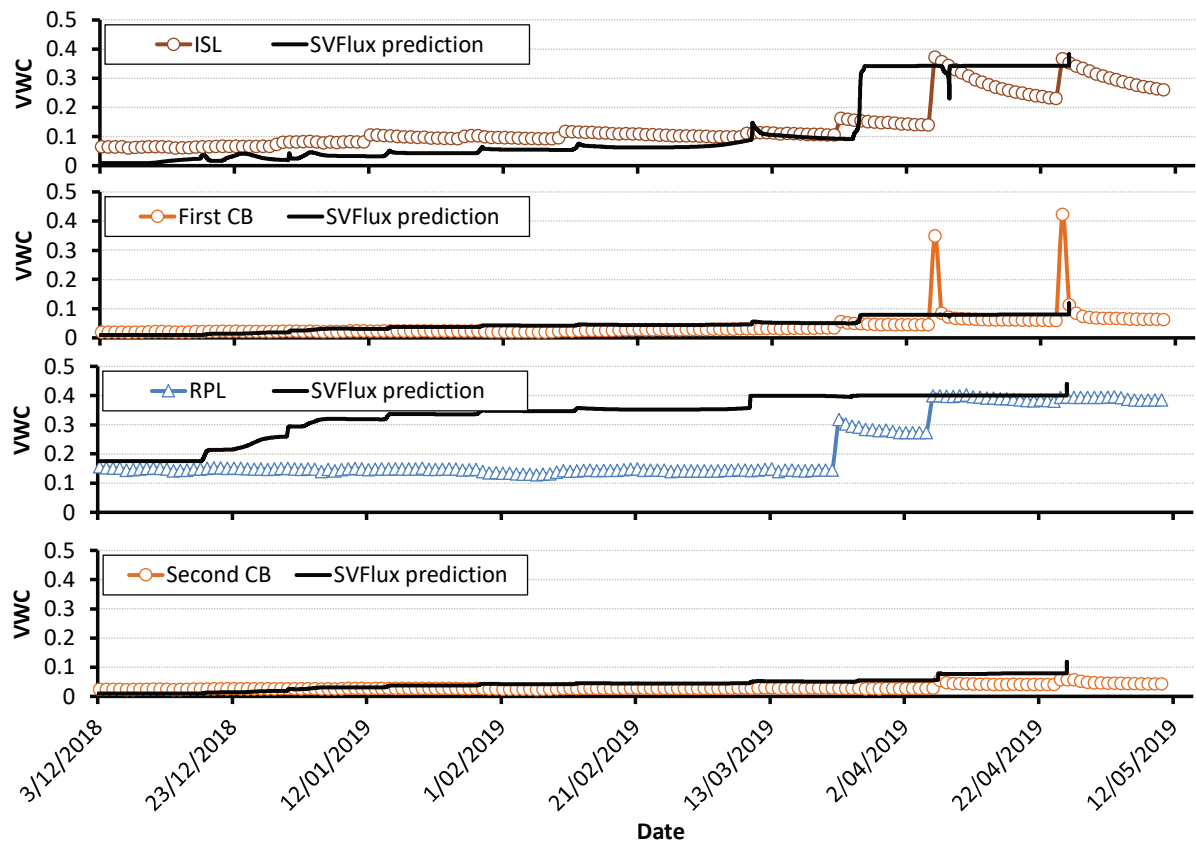


Figure 13 High-risk cover with half ISL column trial volumetric water content sensors (VWC) compared to SVFlux prediction

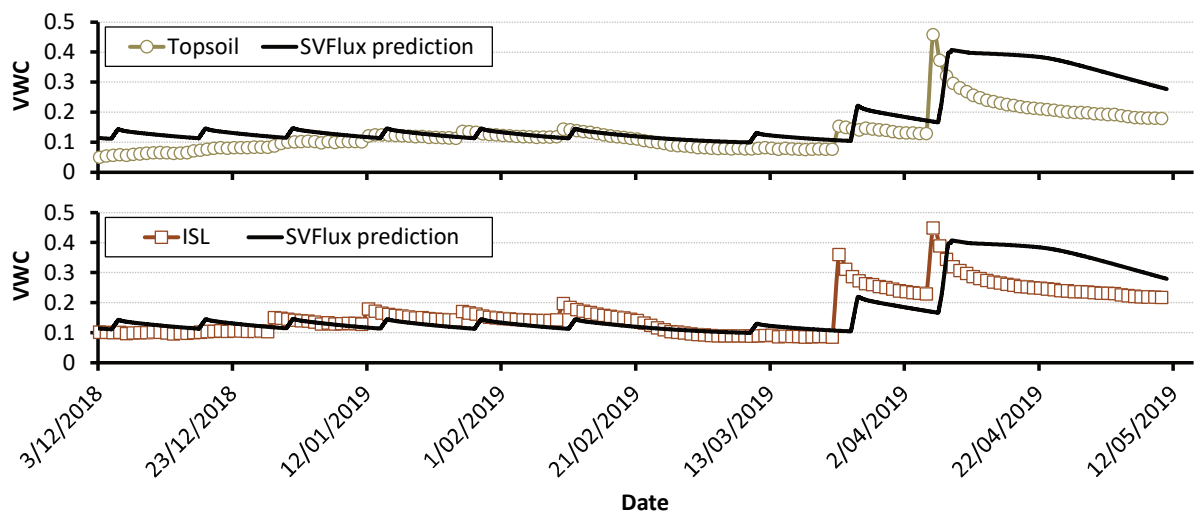


Figure 14 Monofill cover column trial volumetric water content sensors (VWC) compared to SVFlux prediction

Table 3 Comparison of column trial and SVFlux water balances

	EIS cover		High-risk cover		High-risk cover with half ISL		Monofill cover	
	Column	Model	Column	Model	Column	Model	Column	Model
Rainfall (mm)	910	910	910	910	710	710	510	510
Stored infiltration (%)	8.71	5.10	7.43	5.90	7.37	2.6	6	3.9
Seepage (%)	0.37	8.00	0.12	3.40	0.3	12.9	0.23	4.6
Evapo-transpiration (%)	90.92	86.90	92.45	90.70	92.33	84.50	93.77	91.5

5 Conclusion

This study has demonstrated a technique to develop cover performance data that can be used to develop a semi-calibrated model to predict the future performance of cover options for a TSF. It is advantageous to a desktop assessment because it gives model parameters that are like those that might be experienced in a large field trial. Whilst large field trials are necessary to confirm future performance, this technique overcomes some of the constraints that often prevent large field trials from being successful i.e. constraints on available space and long lead times before meaningful data is produced.

The outcome of this study is that at this stage the high-risk cover is likely the preferred option (based on the column data and modelling) because it best balances cover thickness with potential evapo-transpiration. Further work is required to confirm the performance of the RPL, substantiate the potential for capillary rise, investigate alternative options for the ISL material i.e. topsoil/growth medium versus NAF waste rock and the influence of vegetation on cover performance.

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