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Leading practice store and release cover trials for a tailings storage facility at Century mine

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Abstract

A store and release cover that is designed (the cover) to limit the release of sulphate salts and metals (the potential contamination) from acid forming tailings is site specific; being a function, among other factors, of the borrow materials available, tailings deposition method, and the climatic setting. Three experimental cover trials, each a 75 × 75 m square were developed and constructed on the tailings storage facility at MMG (Minerals and Metals Group) Century mine in the semi-arid Northwest Queensland. The covers rely on the storage of rainfall during the wet season and its release during the dry season through evapotranspiration. Covers typically comprises of a compacted fine-grained reduced permeability layer (RPL) of compacted clay overlain by a significant thickness of loose rock and soil (rock mulch). At the mine there is a paucity of fine-grained material for the RPL, this may be overcome by using mixtures of coarse and fined grained soil and rock (the mixtures). The cover trials have been designed to test three potential RPL mixtures which include minus 10 mm crusher dust conditioned with bentonite, a geo-synthetic clay liner placed between an upper and lower layer of minus 10 mm crusher dust, and minus 10 mm crusher dust conditioned with an extra 15 to 30% fines (passing 0.075 mm). All three cover trials have been enhanced by the addition of a capillary break (CB) layer directly above the tailings. The purpose of the CB is to stop the vertical rise of potential contamination from reaching the top layer of the cover, which is rock mulch. The performance of the cover trials is being monitored by instrumentation, including volumetric water content and matric suction sensors, a weather station capable of estimating evapotranspiration and lysimeters to measure percolation (deep infiltration) through the base of the cover. The instrumentation allows for direct measurement of infiltration into the cover, storage of rainfall and percolation through the base of the cover. The paper describes the cover trials construction, instrumentation and monitoring data from the past two years.

1 Introduction

Minerals and Metals Group (MMG) Century mine is currently in a transition period as it prepares for the end of mining during 2015 before it enters an active closure phase, for approximately five years, where the focus will be on encapsulation and management of mineralised waste.

1.1 Site location

The mine is located at Lawn Hill, 250 km northwest of Mount Isa in the semi-arid Lower Gulf and processes zinc and lead concentrates at Lawn Hill. Zinc and lead concentrate is transferred as a slurry 304 km by an underground pipeline to the port facility at Karumba for shipping to smelters in Australia, Europe and Asia.

1.2 Climate

The average rainfall is 544 mm with a distinct wet and dry season. The wet season extents from November to early April and accounts for 90% of rainfall. Evaporation dominates the climate with a ratio of evaporation and transpiration (evapotranspiration) to rainfall of about 4:1.

Store and release cover systems (covers) are recommended for the long-term management of mineralised wastes in climate regions such as Century (INAP 2009) where evapotranspiration dominates.

2 Background

2.1 Operational TSF

Since commissioning in 1999, approximately 69.5 Mt of tailings has been deposited into the tailings storage facility (TSF). The TSF has been operated as a single point down valley discharge with the main embankment 3 km south of the discharge point. Two decants are located on the main embankment which direct supernatant into the downstream evaporation dam. The expected total tailings beach area at the end of mining will be approximately 360 ha.

2.1.1 TSF closure strategy

One TSF closure strategy, which is being considered at the mine, is the encapsulation of tailings with a cover. The design process for the cover has included an extensive modelling and site material characterisation program, as well as incorporating learnings into the design process from the bulk sample tailings dam (BSTD) study (Defferrard et al. 2014).

2.1.2 TSF chemistry

The earliest tailings studies at Century were of the BSTD tailings produced from the pilot plant in 1996 (EGi 1998). The BSTD was rehabilitated in 1997 by constructing a 2.3 m thick (store and release) cover. In 2013 the BSTD was incorporated into TSF. The removal of the BSTD provided an opportunity to complete an evaluation of the cover system and tailings to inform closure management of the TSF.

The acid rock drainage (ARD) potential or net acid producing potential of the BSTD did not reduce over the 18 years that the facility was operated, closed and rehabilitated. Acid base accounting for tailings samples from the BSTD collected in 2013 indicated that the tailings still had the potential to produce acid (Table 1). Acidity could potentially be produced in the range of 81.68–203.73 kg H_2SO_4/t.

Table 1 Solids acid base accounting for the BSTD tailings after 18 years and TSF tailings within the cover trial cells for reduced permeability layer (RPL) 1, RPL2, and RPL3 after 16 years of operation

Parameter	Unit	BSTD[1] 1995	BSTD[2] 2013	TSF (RPL1)[3] 2014	TSF (RPL2)[3] 2014	TSF (RPL3)[3] 2014
Total S	%S	4.9	7.2	3.94	3.6	3.98
Sulphate-sulphur	%S	0.078	1.5	1.5	0.8	0.8
Sulphide-sulphur	%S	4.8	5.3	2.4	0.8	0.8
Maximum potential acidity	kgH_2SO_4/t	148	163	74.2	84.5	96.7
Acid neutralising potential	kgH_2SO_4/t	15	n/a	8.7	8.9	1.7
Net acid producing potential	kgH_2SO_4/t	133	163	65.6	75.6	95

[1] (EGi 1998). [2] Average of solids base accounting from samples taken at three locations (Rohde 2014). [3] Solids base accounting from three RPL cover cell lysimeter excavation samples at 1 m (Rohde 2013)

Table 1 also presents acid base accounting of samples taken from the TSF during the construction of the cover trials in 2014. The acid base accounting shows that the net acid producing potential of the tailings in the TSF is high (DITR 2007), and that after 16 years of operation the TSF would still be expected to generate acid for several hundred years. The closure strategy needs to mitigate the pathway by which ARD can reach the receiving environment. The potential pathway to the receiving environment is by percolation since this has the potential to flush the ARD oxidation products from the TSF.

2.2 Concept TSF cover trial design options

After reviewing the mine based material characterisation program, five initial cover options were identified and modelled using VADOSE/W (the model), (Table 2).

Table 2 Concept cover trial designs

Cover[1]	Cover type	Number of RPLs	Number of capillary breaks	Total cover thickness (m)	Fatal flaw (y/n)	Comment
Option 1	Multilayer	1	1	3.3	n	Further modelling required to optimise cover thickness
Option 2	Multilayer	1	2	3.6	n	Cover too complex creating constructability issues
Option 3	Mass soil cover	0	0	1.5	y	High O_2 and H_2O flux in and out
Option 4	Mass soil cover	0	0	2.0	y	High O_2 and H_2O flux in and out
Option 5	Multilayer	0	0	2.7	n	Material functionality questioned

[1] (Reid 2012)

Modelling of cover Option 1 performed satisfactorily, however, the cover was considered to be too thick at 3.3 m. Further refinement would be needed with site based characterisation laboratory results and sensitivity analysis to potentially reduce the cover thickness thereby reducing cover construction costs.

Cover Option 2 which incorporated two capillary break (CBs) performed just as satisfactorily as Option 1, but the constructability of the double capillary break was deemed too complex and would most likely result in construction quality assurance issues.

Cover Options 3 and 4 were considered unsuitable due to unacceptably high percolation. It was considered that while the cover options were most cost-effective, they were too thin.

Cover Option 5 incorporated a blocky layer as a CB and performed similarly to Option 1 which had a formal gap graded CB. There were reservations about the modelling outputs for Option 5 because the failed BSTD cover resembled Option 5 both in layer thickness and material type. The BSTD cover failed after 16 years (Defferrard et al. 2014).

Ultimately none of the cover options presented in Table 2 were chosen, however they were important in guiding the next design stage. Section 3 discusses the recommend TSF cover options that were trialled in three 75 × 75 m cells. It should be noted that the three trialled cover options varied the reduced permeability layers (RPL) layer only because this was considered to be the most limiting factor in cover performance because the mine has short supply of suitable natural clay that can be used to construct the RPL (Figure 1).

Figure 1 Perspective image showing cover trials RPL1, RPL2 and RPL3 and the operational TSF in the upper right

3 TSF cover trial designs

The cover trial design had to consider influences of climate, hydrology, human activities, vegetation, fauna/macro fauna (not discussed in this paper), settlement and constructability (INAP 2009).

3.1 Cover attributes

Due to observed learnings and fatal flaws associated with the autopsy of the BSTD, as well as selecting the cover appropriate for the rainfall to evapotranspiration ratio as per the GARD Guide™ (INAP 2009), the following attributes were identified:

- Surface cover has to support local vegetation.
- The final surface should be hummocky in nature to facilitate infiltration and storage of rainfall.
- A RPL to significantly reduce percolation into the tailings mass.
- Oxygen flux into the tailings mass should be reduced with a RPL.
- A running layer for equipment to place the RPL.
- A CB has to be incorporated into the cover to prevent the transport of metals.
- The cover should be not complex in nature to increase constructability and reduce costs.

Further model sensitivity analysis and cover refinement produced the final cover design which consisted of a cover 2.7 m in thickness including a 0.3 m CB, 0.3 m compacted rock mulch running layer, 0.6 m RPL and a 1.5 m uncompacted rock mulch layer. The CB thickness considered to be of sufficient thickness as it was modelled with rock mulch (including all fines) and it still performed satisfactory. The south east corner of each cover trial (10 × 10 m) was constructed without a CB to ascertain in a future sampling program if a capillary layer is essential (Figure 2). The RPL was the only component that differed between the three trials (Figure 3(a), (b) and (c)). Each of the cover trials are separated by compacted clay embankments (Figure 2).

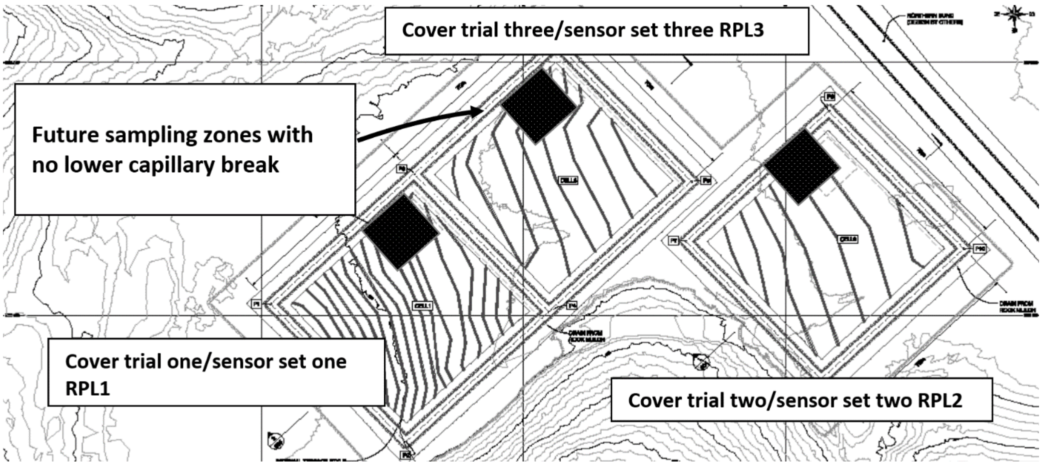


Figure 2 Plan view showing the three cover trials on the partitioned TSF upper beach and the section of the covers free of a CB layer, shown in shaded area

ROCK MULCH	1.5 m	Uncompacted Rock Mulch
REDUCED PERMEABILITY LAYER	0.6 m	-10 mm Cracker Dust Material with Minimum 30% Fines
COMPACTED ROCK MULCH	0.3 m	Compacted Weathered Rock
CAPILLARY BREAK	0.3 m	"+10 mm" Sized Rock Mulch
EXISTING TAILINGS		

(a)

ROCK MULCH	1.5 m	Uncompacted Rock Mulch
REDUCED PERMEABILITY LAYER	0.6 m	-10 mm Cracker Dust Material with Minimum 15% and Maximum 30% Fines plus 10% by dry weight of Bentonite
COMPACTED ROCK MULCH	0.3 m	Compacted Weathered Rock
CAPILLARY BREAK	0.3 m	"+10 mm" Sized Rock Mulch
EXISTING TAILINGS		

(b)

ROCK MULCH	1.5 m	Uncompacted Rock Mulch
RPL GCL IN CENTRE	0.3 m	-10 mm Cracker Dust Material with Maximum 20% Fines, with an imported GCL.
RPL	0.3 m	
COMPACTED ROCK MULCH	0.3 m	Compacted Weathered Rock
CAPILLARY BREAK	0.3 m	"+10 mm" Sized Rock Mulch
EXISTING TAILINGS		

(c)

Figure 3 (a) RPL1 minus 10 mm with minimum 30% fines passing 0.075 mm sieve; (b) RPL2 minus 10 mm with 15–30% fines passing 0.075 mm sieve and 10% by dry weight of bentonite; and, (c) RPL3 minus 10 mm with maximum 20% fines passing 0.075 mm sieve and a sandwiched geosynthetic clay liner (GCL)

3.2 Material characterisation

3.2.1 Reduced permeability layer

Suitable clays for the construction of RPL are a limited resource within the mining lease, however, natural clay deposits do exist in Gregory and Korong land systems, as identified by Dames and Moore (1994). Within these land systems the natural clay deposits are between approximately 0.4 and 1.6 m thick. The required volume of RPL mixture to construct a sealing layer over the 360 ha TSF would be approximately 2.2 M m^3. This would equate to a disturbance borrow area of approximately 180 ha, which could potentially create another closure liability as it would be challenging to restore it back to its former land system.

Large reserves of non-acid forming (NAF) dolomite mine waste was ruled out for manufacturing the RPL due to the large haul distance (11 km) to the TSF, as well as the risk of saturated permeability (K_{sat}) degradation through calcium and magnesium exchange with bentonite products within RPL2 and RPL3 (Buckley et al. 2010).

To achieve the cover attribute of constructability the RPL mixture was sourced from natural ridge material from the adjacent Termite ranges (siltstone, sandstone and shale) to produce -10 mm mixture. The average field K_{sat} for this material with 30% fines passing 0.075 mm was 2.0×10^{-9} m/s, which is comparable to natural clay deposits. The disturbance footprint for this material would be less than 25% of the disturbance footprint associated with wining natural available clay.

3.2.2 Capillary break materials

The CB layer mixture (+10 -30 mm) was the by-product from manufacturing the RPL mixture (Section 3.1.1).

3.2.3 Rock mulch

The rock mulch was sourced from natural ridge material (siltstone, sandstone and shale) from the adjacent Termite ranges.

3.3 Construction

Construction of the three cover trials was completed over a four month period using sixteen pieces of equipment listed in Table 3. The cover trials were constructed directly on the upper beach of the operational TSF approximately 300 m from the tailings outfall (Figure 3(b)). This was made possible by constructing a northern embankment and installing a new tailings outfall down gradient of the northern embankment and the cover trials. This created a safe, stable area away from the operational TSF which would ensure that the cover trials was not compromised by operational activities and that long-term data could be collected (Figure 2).

Table 3 Equipment required for preparing, constructing and manufacturing mixtures for the trial cover cells

Equipment	Required for
1 × 14 tonne grader[1]	Grading of tailings beach to create graded foundation
1 × D8 dozer[1]	Strip borrow areas and level cover layers in cells to design
1 × 30 tonne excavator	Load crushing plant with borrow mixture
1 × 85 tonne excavator	Excavate borrow pits for cell embankments
3 × 40 tonne artic dump trucks	Haul borrow and manufactured cover mixture
1 × 40 tonne water cart	Moisture conditioning cell embankments, RPL1 and RPL2
1 × pad foot roller	Compaction of cell embankments, RPL1 and RPL2
1 × smooth drum roller	Compaction of cell embankments and RPL1 and RPL2
1 × 20 tonne excavator[1]	Form cell embankments to design
1 × 65 tonne excavator	Excavate and mix borrow pit mixture for cell embankments
1 × 30 tonne excavator	Load dump trucks with manufactured mater
1 × cone crusher	Manufacture RPL and CB mixture
1 × jaw crusher	Manufacture RPL and CB mixture
1 × 20 × 7 screen	Manufacture RPL and CB mixture
1 × pug mill	Moisture condition RPL1 and 2 and mix bentonite for RPL2
1 × 20 tonne loader	Load pug mill with -10 mm and bentonite

[1] GPS grade control system fitted

The first stage of the trial construction was to prepare the tailings beach over which the cover trial was to be constructed. This was achieved using a grader to fill in the tailings erosion gullies and create a consistent 1% grade (Figure 4(a)).

(a) (b) (c) (d)

Figure 4 (a) Tailings beach preparation; (b) embankment construction; (c) CB placement; and, (d) RPL compaction

Next the trial cell embankment foundation keys were excavated 0.3 m into the tailings using an excavator while at the same time the lysimeters were installed into the tailings 0.1 m below the tailings.

The cell embankments were raised with approximately 0.2 m compacted lifts with moisture conditioned material borrowed from an identified clay deposit from the adjacent Termite ranges (Figure 4(b)).

Both RPL (-10 mm) and CB (+10 -30 mm) mixtures were manufactured using a crushing and screening plant from material obtained from the adjacent Termite range with dozers and excavators.

The CB was placed in a 0.3 m thick layer over the tailings using an excavator fitted with a GPS grade control system to ensure quality control requirements were achieved (Figure 4(c)).

Next, a 0.3 m thick rock mulch layer was placed and compacted over the lower CB layer. The RPL was then constructed in 0.2 m compacted lifts with moisture conditioning achieved with the pug mill and falling head tests conducted on each lift. The average in situ saturated K_{sat} for RPL1 and RPL2 was 2.0×10^{-9}m/s and 8×10^{-9}m/s respectively (Figure 4(d)).

RPL3 was constructed by placing a 0.3 m thick layer of minus 10 mm mixture with a maximum of 20% fines and rolled flat with a smooth drum roller. The RPL mixture was not moisture conditioned and compacted as this trial cell was designed to trial the performance of the geosynthetic clay liner (GCL). Furthermore, the site water contains high cations levels which could have a detrimental effect on the K_{sat} through cation exchange. It was proposed to allow for hydration from incident rainfall. The GCL was rolled out over the entire cell and glued together with a bentonite powder. To complete RPL3 another 0.3 m thick layer of minus 10 mm screened mixture was placed over the GCL to bring the RPL up to a 0.6 m thickness.

To manage the lateral movement of water along the 1% grade of the RPL, a continuous length of 100 mm agricultural drainage pipe (fitted with a filter sock) was installed in a trench excavated through the cell embankments to enable free drainage outside of the cover trial.

Rock mulch was then loosely placed to a nominal thickness of 1.5 m over the RPL's to finish the surface with a hummocky profile.

Finally the hummocky surface was seeding with a tree shrub and grass mix that was representative of the surrounding vegetation.

3.4 Instrumentation

3.4.1 Weather station

The cover trial monitoring program includes an automated weather station that measures:

- Daily rainfall.
- Maximum wind gust and average wind speed.
- Maximum and minimum air temperature.
- Maximum and minimum relative humidity.
- Solar radiation.

The listed parameters are used to calculate the potential evapotranspiration rate using the Penman-Monteith method (Campbell Scientific Inc. 2000).

3.4.2 Cover trial sensors

Each of the three cover trials were instrumented with a preassembled instrument tree that contained two sensor types (Table 4):

- Volumetric water content (VWC) sensors using time domain reflectometer (TDR).
- Matric suction (ψ) sensors.

Each of the cover system layers contained both a matric suction and volumetric water content sensor. The tailing only contained a matric suction sensor.

Table 4 Cover trial sensors and cover layers definitions

Cover trial one	Sensor type	Mixture	Cover trial two	Sensor type	Mixture	Cover trial three	Sensor type	Mixture
1-1	ψ, VWC	NRM[1]	2-1	ψ, VWC	NRM[1]	3-1	ψ, VWC	NRM[1]
1-2	ψ, VWC	NRM[1]	2-2	ψ, VWC	NRM[1]	3-2	ψ, VWC	NRM[1]
1-3	ψ, VWC	NRM[1]	2-3	ψ, VWC	NRM[1]	3-3	ψ, VWC	NRM[1]
1-4	ψ, VWC	RPL1[2]	2-4	ψ, VWC	RPL2[3]	3-4	ψ, VWC	RPL3[4]
1-5	ψ, VWC	RPL1[2]	2-5	ψ, VWC	RPL2[3]	3-5	ψ, VWC	RPL3[4]
1-6	ψ, VWC	NRM[1]	2-6	ψ, VWC	NRM[1]	3-6	ψ, VWC	NRM[1]
1-7	ψ, VWC	+10–30 mm	2-7	ψ, VWC	+10 -30 mm	3-7	ψ, VWC	+10–30 mm
1-8	ψ only	Tailings[5]	2-8	ψ only	Tailings[5]	3-8	ψ only	Tailings[5]

[1] Locally excavated raw weathered rock mixture (siltstone, sandstone and shale) won from the ridgeline around the TSF. [2] Clayey sand/gravel. -10 mm mixture with minimum 15% fines and maximum 30% fines (passing 0.075 mm). [3] Clayey sand/gravel.-10 mm mixture with minimum 30% fines (passing 0.075 mm) with 10% by dry weight of powdered bentonite. [4] Clayey sand/gravel.-10 mm mixture with 20% fines (passing 0.075 mm) and GCL. [5] Century tailings sample

3.4.3 Lysimeters

The lysimeters were custom-made with reinforced 10 mm HDPE to provide structural strength that can withstand a potentially low pH environment. The conical drain point of the lysimeter was recessed 500 mm from the base to allow for considerably easier installation of the lysimeter sump, because it exited on the side wall (Figure 1(a)). The internal diameter of the lysimeter was 2 m and the vertical height to the drain point was 1.95 m.

A filter was installed in the base of the lysimeter consisting of a 0.5 m layer of washed river gravelly sand overlaying a sheet of 3 mm geofabric. The sand filter and geofabric were installed to prevent the clogging of the sump from silt and clay sized particles migrating from the tailings.

A one-dimensional model was set-up in VADOSE/W to determine if the fabricated lysimeters wall height performed correctly so as not to create capillarity. Capillarity could make percolation preferentially move away from the lysimeters and result in lysimeter measurements that did not reflect the actual percolation. VADOSE/W modelling was also undertaken to confirm that the sand filter design did not form a CB with the overlying tailings. The estimated soil water characteristic curve of the tailings and the filter sand showed that the air entry value (AEV) of the tailings was ~8 kPa and filter sand water entry value (WEV) of the filter sand was ~5 kPa. Therefore it is unlikely that the filter sand will act as a CB layer as the tailings AEV and the filter WEV are approximately equal (Rohde 2013).

An excavated pit was dug at the centre point of each of the three cover trial cells to accommodate the dimensions of the lysimeter so that the top of the lysimeter rested 0.1 m below the 1% graded tailings beach.

The assembly of lysimeter sump and riser pipe was next and was built using high strength PVC glue. The sump and riser were connected to the lysimeter and secured to the lysimeter using tape to prevent damage when being lowered into place (Figure 5(a)).

(a) (b) (c) (d)

Figure 5 (a) Placement of lysimeter and sump beneath tailings; (b) backfilling of filter sand in base of lysimeter; (c) internal compacted tailing backfill; and (d) external compacted tailing backfill

The invert level of the pit was confirmed as per design using the GPS grade control system before the lysimeter was lowered into place with an excavator. The tailings around the sump were backfilled by hand (Figure 5(a)).

The excavated pit surrounding the lysimeter was backfilled to a depth of one meter and compacted using whacker-packers (Figure 5(d)).

The lysimeter was backfilled to a depth of 0.5 m using washed filter sand (Figure 5(b)). The internal area of the lysimeter was backfilled to a depth of one meter and compacted using a whacker-packer (Figure 5(c)).

The lysimeter internal area and excavation surrounding the lysimeter was backfilled in unison to ensure that there was no deformation of the lysimeter wall. The final surface was compacted by trafficking with a loader to reinstate the tailing surface.

The lysimeters require manual purging so that seepage through the cover trials can be measured. The lysimeters are purged by in situ pumps driven by a 12 volt battery from the surface.

4 Results

Cumulative rainfall for the monitoring period was 734 mm with 555.3 and 179 mm falling in 2014 and 2015 wet seasons, respectively. Therefore, the trials experienced an average wet season in 2014 and a drier than average 2015 wet season with only 32% of the annual rainfall average.

4.1 Seepage

The seepage collected in the lysimeter sump for RPL1 in 2014 was 0.2 L which is (0.06 mm) of rainfall or 1.37E–04% of cumulative rainfall for that year. Dissolved metal concentrations of zinc (Zn), cadmium (Cd) and manganese (Mn) were detected in the lysimeter sump seepage water chemistry. Cadmium was below the level of detection and concentrations of Zn and Mn were 0.009 and 6.147 mg/L, respectively (Table 5). No seepage was detected in the 2015 wet season.

Table 5 Lysimeter sump data for 2014 and 2015

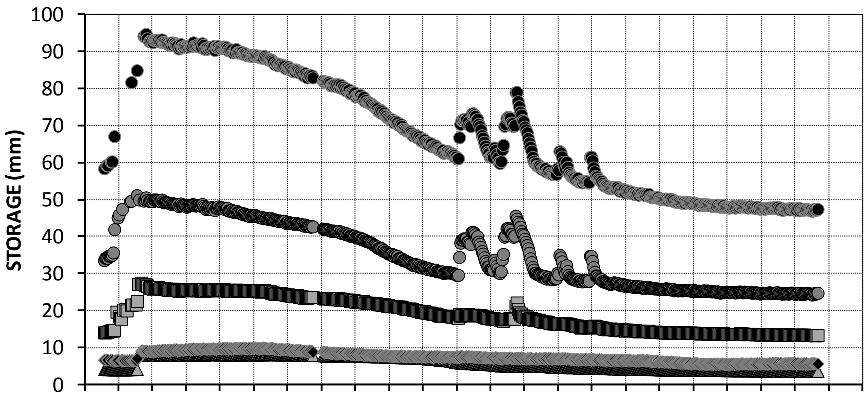
2014	Volume (L)	Electrical conductivity (mS/cm)	pH	Dissolved Zn (mg/L)	Dissolved Cd (mg/L)	Dissolved Mn (mg/L)
RPL1	0.2	0.625	7.35	0.009	<0.0005	6.147
RPL2	n/a	n/a	n/a	n/a	n/a	n/a
RPL3	1.2	5.12	6.03	815	0.009	<0.001

Seepage within the RPL2 lysimeter was not detected after both wet seasons (Table 5). RPL3 experienced 1.2 L of seepage following the 2014 wet season, which equates to 0.38 mm of rainfall or 8.20E-04% of cumulative rainfall. Lysimeter sump seepage from RPL3 had dissolved metal concentrations of the order of 815mg/L Zn and 0.009 mg/L Cd. Manganese was below the level of detection (Table 5). No seepage was detected during the 2015 wet season.

5 Discussion

5.1 Seepage

The seepage through the cover can be determined through a basic water balance using the storage in (mm) versus time data (Figure 6). It is assumed that storage which makes it into the CB layer will enter the tailings as deep percolation (seepage), therefore RPL1, RPL2 and RPL3 have a 6, 6 and 8 mm seepage respectively (Figure 6). This seepage expressed as a percentage of cumulative rainfall to date for RPL1, RPL2 and RPL3 is 0.82, 0.82 and 1% respectively. These inferred seepages are expected to be higher than the actual lysimeter seepage (Table 5) as there is a storage component within the tailings and the seepage data is derived from the VWC sensor in the CB.



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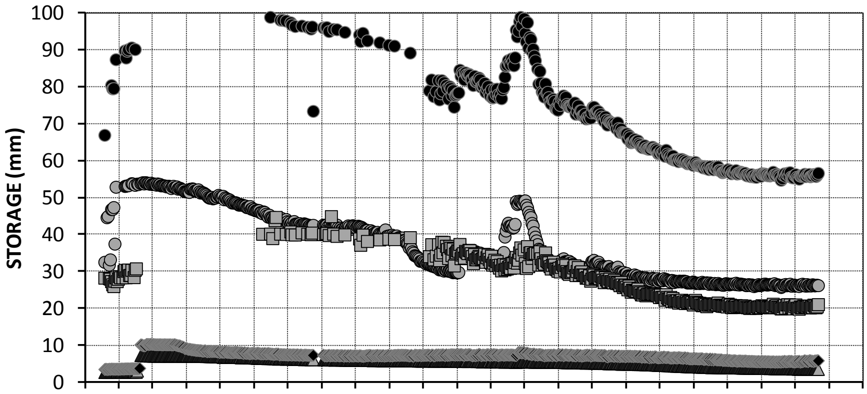

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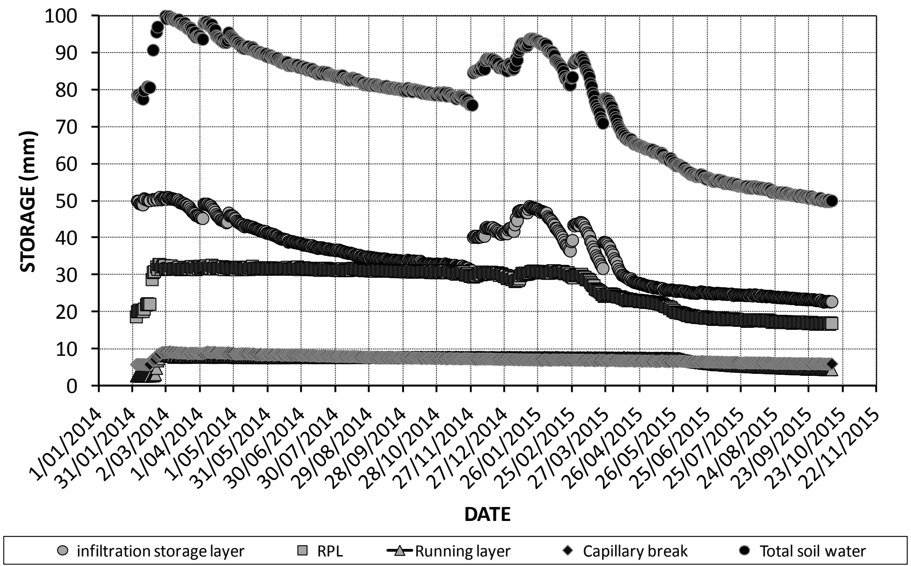


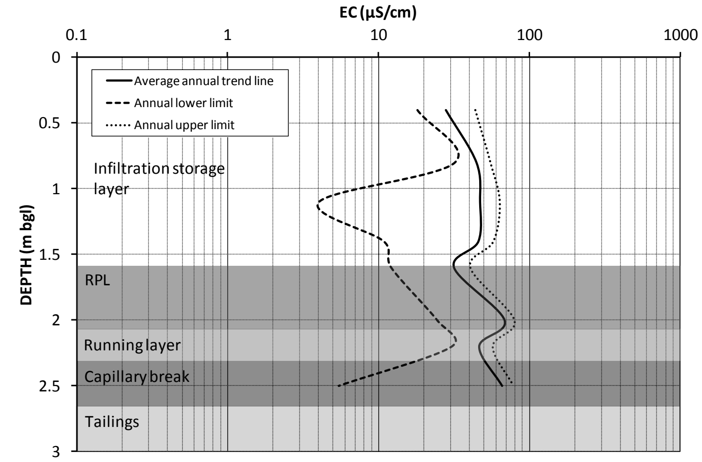
(c)

Figure 6 (a) RPL1 storage curve versus time; (b) RPL2 storage curve versus time; and (c) RPL3 storage curve versus time

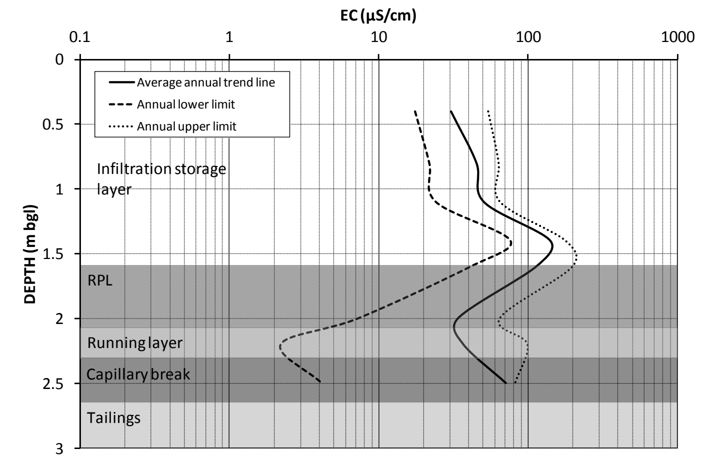
Lysimeter sump water analysis from RPL3 which was testing the performance of the GCL, revealed dissolved zinc (815 mg/L) and cadmium (0.009 mg/L) indicating that deep percolation and seepage is occurring through the cover and into the tailings. The GCL could potentially be going through a sealing/bedding process in as it was installed without moisture conditioning due to risk of cation exchange with the bentonite.

5.2 Electrical conductivity

The electrical conductivity (EC) versus depth profile for each of the cover trials reveal that the CB is functioning as designed, as all trend lines are showing a decrease in EC from the tailings to the surface of the cover (Figure 7). The highest EC was captured in RPL2 which could potentially be attributed to the addition of bentonite that includes cations of sodium, calcium and magnesium.



(a)



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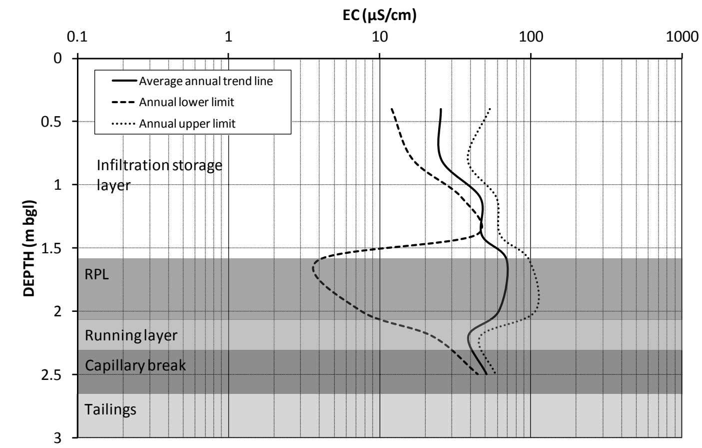

(c)

Figure 7 (a) EC versus depth profile for cover trial 1 (RPL1); (b) EC versus depth profile for cover trial 2 (RPL2); and (c) EC versus depth profile for cover trial 3 (RPL3)

6 Conclusion

MMG Century mine has designed, instrumented and constructed large scale TSF cover trials through a robust process that accounts for climate, hydrology, human activities, vegetation, settlement and constructability.

Cover trials RPL1 and RPL2 to date have performed the best with seepage of 0.82% of cumulative rainfall, however, RPL3 with seepage of 1% is still considered to be very good with the industry minimum standard of ≤10% (Defferrard et al. 2015).

Cover trial RPL3 should continue to improve as the GCL hydrates with incident rainfall allowing for long-term GCL performance to be studied.

Ongoing long-term lysimeter monitoring and seepage multi element analysis will provide valuable cover performance data.

Long-term monitoring of EC with depth profile will provide valuable insight into the performance of the CB and the cover design as a whole.

The cover trials have experienced one average and a lower than average wet season (32% of average annual rainfall) since constructed so the performance of the three covers will need to experience a number of average to above average wet seasons to understand the true cover performances in response to future wetting and drying cycles.

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