

Marra Mamba South Waste Rock Dump cover system field trial autopsy, Tom Price Mine, Western Australia

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Abstract

Cover systems are layered materials designed to create an interface between underlying waste rock material and the receiving environment. Two cover system field trials were constructed on the Marra Mamba South (MMS) Waste Rock Dump (WRD) at Tom Price Mine in 2003: Test Plot One (TP1) comprised banded iron formation (BIF) and Test Plot Two (TP2) comprised oxidised Mount McRae Shale (MCS). Both test plots used the moisture 'store-and-release' cover design concept that acts to limit infiltration of atmospheric water, provide a buffer layer reducing the potential for upward migration of salts, and support resilient native vegetation growth. The aim of the field trials was to assess the performance of the constructed cover systems. Okane completed an in situ autopsy of the MCS test plot in 2021, prior to decommissioning of the field trials. The autopsy provided an opportunity to assess the geotechnical and geochemical evolution of the cover system material after 17 years of climate cycling, measure the influence of cover system material type on plant health, determine root distributions through the cover system material, and decommission in situ performance monitoring equipment. Material characterisation of the cover system material included the analysis of fertility, element enrichment and mobility, particle size distribution, and soil water retention. Results were compared to similar works carried out over the 17-year lifespan of the field trials to indicate the degree to which the cover system degraded over time. Vegetation root analysis and tap root tracing indicated the presence of Acacia and Senna species roots within the cover system material (0–2.4 m) and extending to 3 m into the underlying waste rock. Roots of native grass species (Poaceae) were present in the cover system material but were not detected in the underlying waste rock. Material characterisation findings indicate the MCS is a suitable material for cover system design from a stability perspective and to support the establishment of native vegetation cover. Findings on root depth analysis can be used to inform suitable seed mixes to minimise risks related to potentially acid forming WRDs. The autopsy demonstrated minimal degradation of the MCS cover system profile over its 17-year lifespan and indicated that MCS is a suitable material for use in store-and-release cover systems for landforms in the Pilbara.

Keywords: *cover system, store-and-release, cover trial autopsy, rehabilitated cover trials, root depths*

1 Introduction

Tom Price Mine is a Rio Tinto operated open cut iron ore mining operation located near the town of Tom Price, in the Pilbara region of Western Australia (Figure 1). Exposure and removal of waste rock is a derivative of open cut mining operations, where waste rock is commonly stored in waste rock dumps (WRD). Tom Price Mine is in a semi-arid region and, based on the Köppen-Geiger system, is classified as an arid steppe hot site (International Network for Acid Prevention [INAP] 2017), with evaporation greatly exceeding annual total rainfall. A cover system employing the moisture store-and-release concept was implemented for the field trials, owing to the nature of the climate at the site (INAP 2017). The primary design objectives of a store-and-release cover system are as follows: (1) Limit rainwater ingress into the underlying waste rock

material, thereby minimising potential adverse effects on the receiving environmental; (2) provide a buffer layer between the waste rock and ground surface, reducing the potential for upward migration of salts; and (3) provide a layer to support vegetation establishment (INAP 2017).

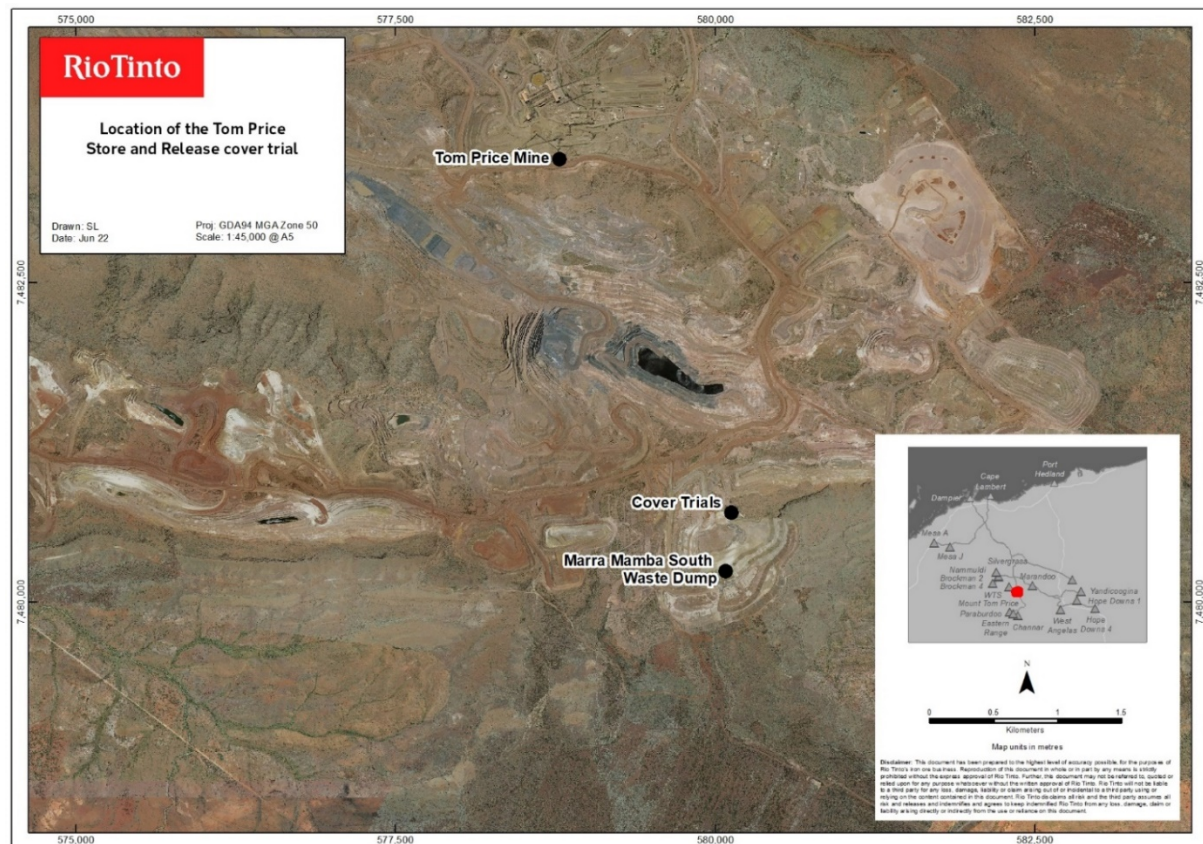


Figure 1 Tom Price Mine, Pilbara region, Western Australia

Two store-and-release type cover system field trials, Test Plot One (TP1) and Test Plot Two (TP2), were constructed at the Marra Mamba South (MMS) WRD in late 2003, topsoiled in September 2004 and seeded in May 2005 with a Tom Price–specific seed mix. TP1 comprised 4 m of banded iron formation (BIF) and TP2 comprised 2.4 m of Mount McRae Shale (MCS). The plots (overlying compacted waste rock) were traffic compacted by the equipment used in construction, plus a vibrating plate compactor used in close proximity to the monitoring equipment. Test plots were instrumented during construction to monitor in situ temperature, matric suction, and volumetric water content. TP2 also contained a radiometer for monitoring net solar radiation, and a tipping bucket rain gauge to monitor rainfall. In July 2021, an in situ autopsy of the cover system trials was completed. The objectives of the autopsy study were to:

- Assess geotechnical/and geochemical evolution of the cover system, including noting evidence of preferential flow paths and bioturbation.
- Assess the influence of material type and fertility of the cover system on observed plant health.
- Decommission and remove performance-monitoring instrumentation.
- Determine root distributions through the cover system material (e.g. root density and depths for plant functional types, including grasses, shrubs, and trees).

For the purpose of this study, plant communities on the test plots were to be categorised and analysed based on three plant functional types: grasses, shrubs, and trees. Using plant functional types reduces the complexity of species diversity in terms of ecological function (Bonan et al. 2002). Plant functional types are a set of species with similar morphology, responses to the environment, and with similar effects on ecosystem functioning (Levin 2013). This manuscript summaries the key findings from the cover system trial

autopsy, providing observations about the cover system material and vegetation establishment over the 17-year life of the trials.

2 Methodology

2.1 Site walkover

During the July 2021 site visit, an initial walkover inspection of the cover system field trials at TP1 and TP2 was carried out. The purpose was to inspect the surface condition of both test plots, noting the degree of vegetation establishment, maturation and health, evidence of erosion, and condition of the above-ground components of the monitoring systems. Okane noted the following observations during the walkover:

- Both TP1 and TP2 cover systems were generally in good condition, with minimal erosion and extensive vegetation coverage (Figure 2). Erosion generally occurred in the form of surface cracking.
- Live vegetation comprised of grasses, shrubs, and trees, none of which appeared stressed. Remnants of former shrubs and trees were also evident on TP1.
- Data acquisition systems (DAS) positioned at the cover system surface were inspected to determine the condition of the fibreglass enclosures, power supply systems, datalogger, wires, and other associated equipment. All visible aspects of the DAS appeared in good condition, with minimal to no damage.



Figure 2 Example of vegetation observed on the cover system trials. (a) TP1; (b) TP2

2.2 Cover trial excavation

An in situ autopsy deconstruction was carried out on TP2 that involved a 3 m stepwise excavation (1 m at a time) of the TP2 test plot by an excavator during the July 2021 site visit. TP1 was not part of the autopsy deconstruction as it was located within 10 m of a slope face and thus was deemed unsafe to operate heavy machinery without risk of slope face collapse. A chosen pathway was excavated through the middle of TP2 (Figure 3), which provided a cross-section of the roots to be exposed from an indicative tree, shrub and grass species, as well as a section of bare ground.

Through the TP2 cross-section, three tree individuals (T1, T2, T3), one shrub individual (S1), one grass individual (G1), and one section of bare ground (B1) were identified. The vegetation has been identified to genus/or species level (where possible): T1, *Acacia* spp.; T2, *Acacia* spp.; T3, *Acacia* spp.; S1, *Senna artemisioides* subsp. *helmsii* (Symon) Randell (Randell 1989); and G1, *Triodia* spp.

Throughout the excavation, Okane followed the tap roots of the three trees and one shrub species until the tap root reached a width of 1 mm or was lost during excavation to a maximum of 3 m. A total of 10 bulk cover

material or waste rock samples (TPM_001 to TPM_010) were collected at various depths along the cross-section of TP2 (Figure 4). Root sub-samples were then taken at various depth intervals along the excavated cross-section.

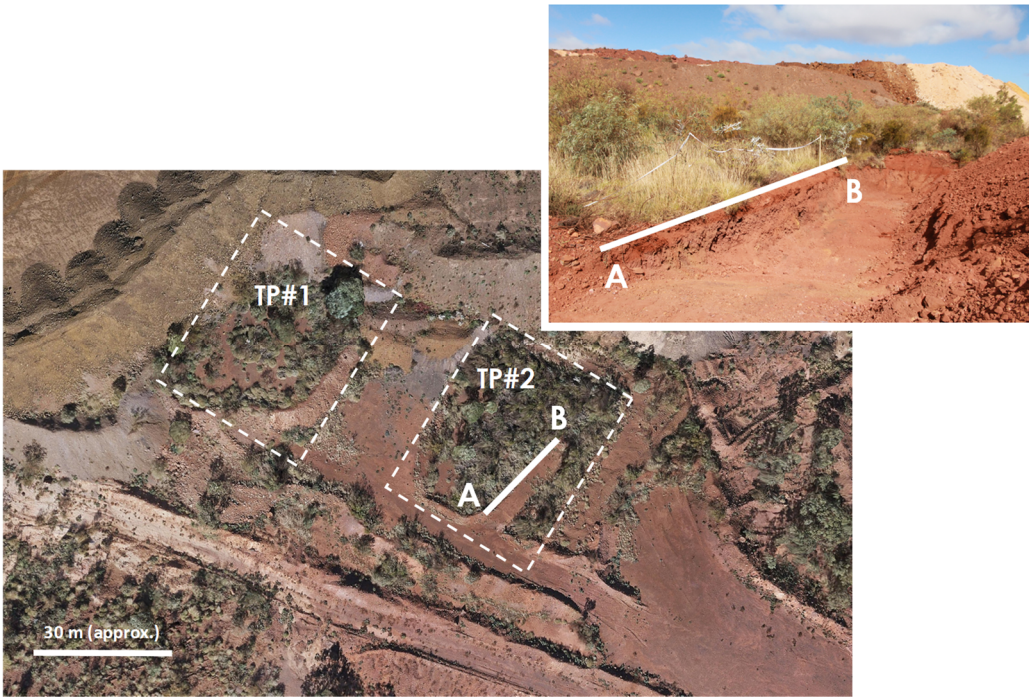


Figure 3 The cross-section excavated into TP2 across the line labelled A to B

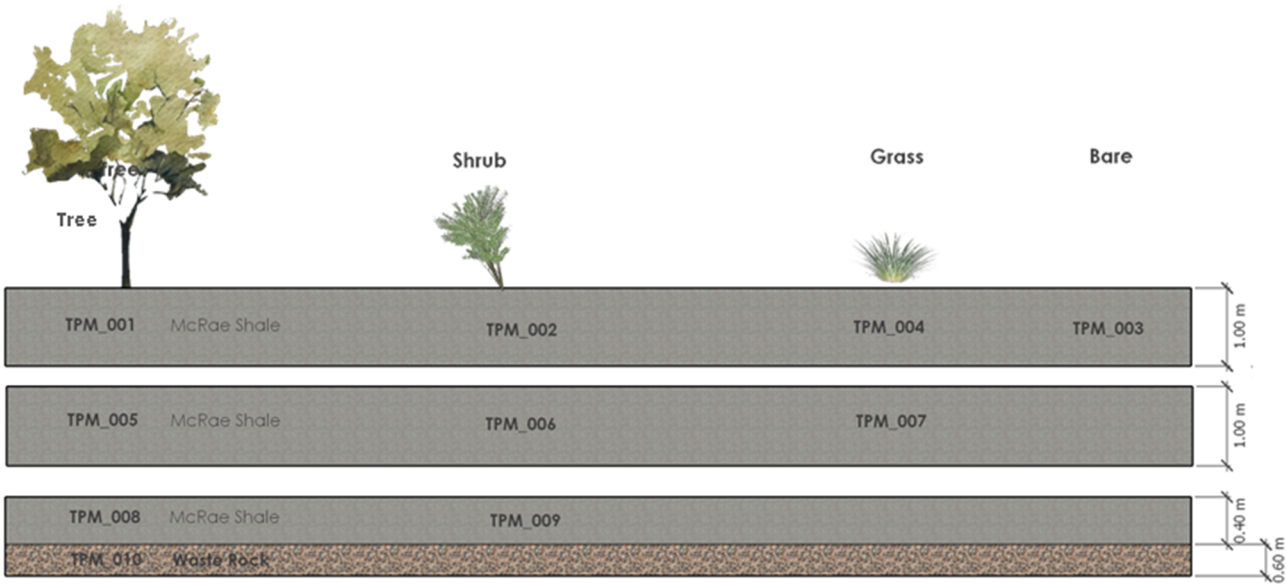


Figure 4 Stepwise excavation details and locations of the nine cover system and one waste rock sample for TP2 (a Mount McRae Shale cover)

3 Results

Samples were dispatched to laboratories in Perth for geochemical and geotechnical analysis, soil water retention curves (SWRC) and plant root environmental DNA (eDNA) by eDNA frontiers at Curtin University. The cover system and waste rock samples taken along the cross-section of TP2 are detailed in Table 1.

Table 1 Autopsy sample identification for nine samples collected from a 2.4 m thick Mount McRae Shale cover and one waste rock sample (TP2) after 17 years

Sample ID	Depth	Material type	Underlying sample area	Grain size	Presence of organic material (visual assessment)
TPM_001	0–1 m	MCS	Tree	Fine-Medium	Yes
TPM_002	0–1 m	MCS	Shrub	Fine-Medium	Yes
TPM_003	0–1 m	MCS	Bare ground	Fine-Medium	Yes
TPM_004	0–1 m	MCS	Grass	Fine-Medium	Yes
TPM_005	1–2 m	MCS	Tree	Medium	Yes
TPM_006	1–2 m	MCS	Shrub	Medium	Yes
TPM_007	1–2 m	MCS	Grass	Medium	Yes
TPM_008	2–2.4 m	MCS	Tree	Medium	Yes
TPM_009	2–2.4 m	MCS	Shrub	Medium	Yes
TPM_010	2.4–3 m	Waste rock	Tree	Medium	Yes

3.1 Geochemistry and material fertility

Material fertility relates to the chemical properties of the materials and their influence on vegetation growth and establishment. If the properties analysed to determine material fertility are either too high or too low in value, depending on the property in question, plant growth can be considerably inhibited. Lab analysis on samples TPM_001 to TPM_004 was carried out to determine material fertility of the TP2 cover system material (Table 2).

Table 2 Material fertility analysis results of four material samples taken from TP2 deconstruction. Further characteristics of these four material samples can be found in Table 1 and Table 3

Analysis	Unit	Sample ID			
		TPM_001 (tree)	TPM_002 (shrub)	TPM_003 (bare)	TPM_004 (grass)
pH 1:5	pH Unit	5.4	5.1	5.0	5.3
EC 1:5	µS/cm	14	18	17	160
Moisture content	%	3.5	2.4	2.6	2.5
Exchangeable Ca	meq/100 g	0.8	<0.1	0.1	0.8
Exchangeable Mg	meq/100 g	0.4	0.2	0.2	0.7
Exchangeable K	meq/100 g	<0.1	<0.1	<0.1	<0.1
Exchangeable Na	meq/100 g	<0.1	<0.1	<0.1	0.6
Ca/Mg ratio	Calc.	2.0	0.5	0.5	1.1
Cation exchange capacity (CEC)	meq/100 g	1.2	0.3	0.4	2.2
Exchangeable sodium percentage (ESP)	%	1.2	4.4	5.7	25.6

Analysis	Unit	Sample ID			
		TPM_001 (tree)	TPM_002 (shrub)	TPM_003 (bare)	TPM_004 (grass)
Bicarbonate extractable K (Colwell)	mg/kg	<100	<100	<100	<100
KCL-40 extractable sulfur	mg/kg	28	38	42	93
DTPA extractable Cu	mg/kg	<1.0	<1.0	<1.0	<1.0
DTPA extractable Fe	mg/kg	27.8	18.1	18.0	14.0
DTPA extractable Mn	mg/kg	4.08	<1.0	<1.0	2.79
DTPA extractable Zn	mg/kg	1.56	<1.0	<1.0	<1.0
Boron	mg/kg	<5	<5	<5	<5
Mercury (Total rec.)	mg/kg	0.02	<0.01	<0.01	0.01
Fluoride	mg/kg	70	<40	<40	70
Nitrate as N (Sol)	mg/kg	<0.1	<0.1	<0.1	<0.1
Nitrate + nitrate as N (Sol)	mg/kg	0.4	<0.1	<0.1	<0.1
Total nitrogen as N	mg/kg	150	<20	20	130
Total phosphorous as P	mg/kg	495	725	663	550
Bicarbonate ext. P (Colwell)	mg/kg	12	16	14	11

Results indicate sample material to be strongly acidic to very strongly acidic, ranging from pH 5.0 to 5.4, as classified in Hazelton & Murphy (2016). Samples tested are considered non-saline, with ECs below 200 $\mu\text{S}/\text{cm}$. All four samples were dry, with moisture contents ranging from 2.4% to 3.5%.

Soil structure and stability can be assessed by geochemical investigation measuring exchangeable cations (Ca^{2+} , Mg^{2+} , K^{+} and Na^{+}), cation exchange capacity (CEC; the sum of exchangeable cations), exchangeable sodium percentage (ESP) and sodium adsorption ratio. The CEC of the samples is very low, with a maximum of 2.2 meq/100 g, typical of sandy or gravelly soils with low clay content. Soils with CEC <3 are often low in fertility and susceptible to soil acidification (Hazelton & Murphy 2016). Exchangeable Ca and Mg were below suggested quantities in soil, with Ca deficiencies in soils with exchangeable Ca <0.5 meq/100 g (NSW Agriculture 2002). Symptoms of Ca deficiency are stubby, weakly branched and discoloured roots, similar to symptoms of Al toxicity (NSW Agriculture 2002). However, features of Ca deficiency in the vegetation were not observed in the field. Sandy and acid soils that have been strongly leached often have very low levels of exchange Ca and Mg, and plant growth may be limited as a result. Exchangeable K (K on the surface of clay and organic colloids) is also very low, as well as Colwell K (extractable K in a soil solution; i.e. water soluble), both being below detection limits. The uptake of K by plants is almost entirely from K in soil solution and is displaced in acid soils. With Na detection at moderate levels in only one sample (grass), and below detection for the remaining samples, samples can be classified generally as non-sodic. Results showed the sample taken from below the grass is slightly higher with Na and S. Conclusions from these results need to be made with caution, given the small sample size.

Total nitrogen and nitrate-N (plant-available N) are low, with nitrate-N below detection in three samples (TPM_002, TPM_003 and TPM_004). Total phosphorus was within an expected range for soils, but the available P for plant uptake (Colwell P) is at low levels, with reduced levels of availability due to the low pH of the soil. Available S (KCL-40 extractable S) is within range, and above critical values, for most plants.

Extractable metals, Cu, Zn and Mn, were at low levels and often below detection limits, suggesting trace element deficiencies in the soil.

3.2 Geotechnical characterisation

Lab analysis was carried out on samples TPM_001 to TPM_010 for geotechnical characterisation, including Emerson dispersion classification, particle size distribution testing, and Atterberg limit tests.

3.2.1 *Emerson dispersion classification*

Emerson tests are used to classify the behaviour of soil aggregates, when immersed, on the coherence in water. Once aggregates are immersed in water, an osmotic stress arises between the negatively charged particles. The stress increases gradually as the soluble salts present in the aggregates diffuse. The increase may be sufficient to cause dispersion. Soils are divided into seven classes based on their dispersion and slaking behaviour. Class 1 disperses completely, Class 2 partially. Classes 3–6 do not disperse initially but may do so upon remoulding and may also exhibit flocculation or slaking behaviour. Class 7 involves no slaking or dispersion but swelling instead, typical of organic matter.

All samples (TPM-001 to TPM_010) from the TP2 autopsy were placed in Class 6. This indicates the sampled material will not disperse unless under specific conditions, for example, through rework and movement, which may be encountered during rehabilitation works.

3.2.2 *Particle size distribution*

The particle distribution (PSD) curve indicates the relative proportions of the different particle sizes that make up the material on a mass basis. The standard size fraction, based on the unified soil classification system, includes:

- Cobble and gravel: >4.75 mm.
- Sand: 0.075–4.75 mm.
- Silt: 0.005–0.075 mm.
- Clay: <0.005 mm.

The PSD can be used to classify textural classes and can be used as an indicator of erosion, water-holding capacity, or material suitability for a low permeability layer. Fine soils such as clays or silts will hold more water and generally have a lower hydraulic conductivity, while coarser materials will tend to erode less. Furthermore, PSD curves may be used as a guide for material consistency, and if a major part of the curve is steep, then the soil has a size distribution extending over a limited range, with most particles being approximately the same size. However, if the soil exhibits a flat section or plateau, then the soil is considered gap graded and a large percentage of it is larger and smaller particles with less intermediate particles in between.

Results from the PSD testing are shown in Table 3. The PSD curve is shown in Figure 5. The proportion of oversized fractions (>100 mm) was factored separately, as the oversize fraction was removed in the field and not sent for analysis.

Table 3 Particle size distribution results for samples collected from a Mount McRae Shale cover after 17 years (TP2)

Sample ID	Particle density (t/m ³)	Moisture content (%)	% >100 mm	Coarse (>4.75 mm) (%)	Sand (4.75–0.075 mm) (%)
TPM_001	2.65	3.4	5%	66%	34%
TPM_002	2.75	2.4	5%	46%	54%
TPM_003	2.76	2.5	5%	55%	45%
TPM_004	2.6	2.4	5%	57%	43%
TPM_005	2.88	2.0	3%	61%	39%
TPM_006	2.76	1.9	3%	47%	53%
TPM_007	2.80	2.1	3%	67%	33%
TPM_008	2.54	2.7	3%	63%	37%
TPM_009	2.69	2.5	3%	57%	43%
TPM_010	2.90	2.6	3%	54%	56%

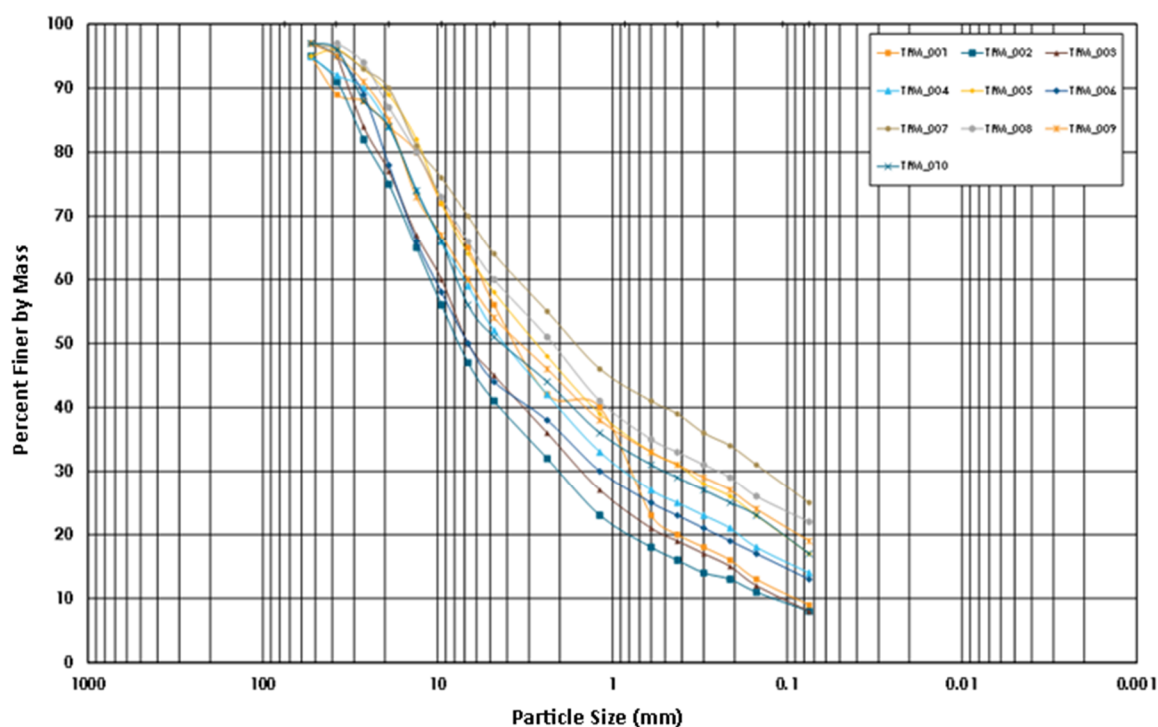


Figure 5 Particle size distribution curves for each of the 10 material samples taken from TP2. Characteristics of the 10 samples can be found in Table 1 and Table 3

The PSD curves developed for the 10 material samples indicate all samples can be classified as silty gravel with all material passing through the 53 mm sieve.

3.2.3 Atterberg limits

The physical behaviour of soil changes with increasing moisture content. To describe how the properties of soils change with moisture content, such as becoming more plastic or cohesionless, critical moisture limits

have been defined using the Atterberg limits. Atterberg limits are used primarily in classifying fine-grained cohesive soil materials and to test the limits of these various soil states. These limits include the plastic limit (PL), where the soil is no longer brittle and cracks, but instead begins to mould easily and display plastic behaviour, and the liquid limit (LL), where soil no longer displays plastic behaviour but instead flows like a liquid. The plasticity index (PI) is the difference between LL and PL and defines the range of water content over which the material is plastic.

Figure 6 shows the PI and LL for each test pit sample as developed from Atterberg limit tests. The characteristics of various fine-textured materials, such as clay content and mineralogy, can be determined through the relationship between the LL and PI. The plot of LL-PI can be used to identify clay mineralogy of a sample. Montmorillonites are highly active clay minerals and plot above the A-Line near the U-Line. Illites plot directly above the A-Line and are less active than montmorillonites; kaolinites plot below the A-Line and are relatively inactive. Active clay minerals provide additional water storage capacity as a bound water volume. TP2 samples plot above the A-Line and below the U-Line with medium plastic organic clays, indicating moderately active clays.

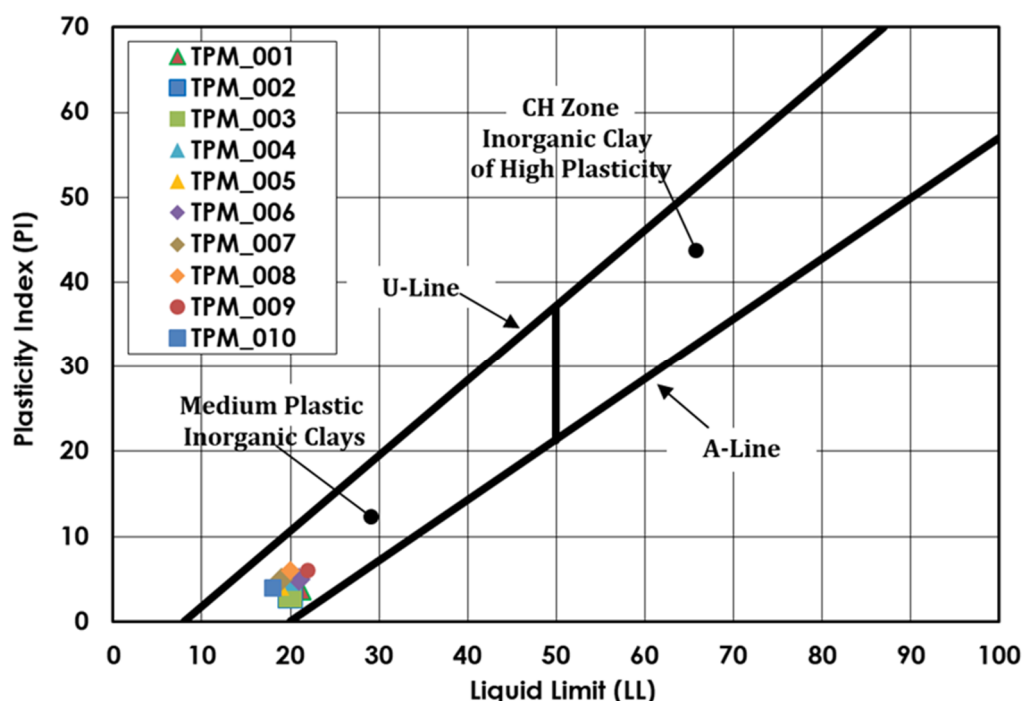


Figure 6 The plasticity index (PI) and liquid limit (LL) for each of the 10 material samples taken from TP2, as developed from Atterberg limit tests. Characteristics of the 10 samples can be found in Table 1 and Table 3

3.3 Soil water retention curve

The SWRC is a continuous function relating to energy and the state of water in a soil sample. It describes the water content of a material as a function of soil suction or negative pore-water pressure. SWRC testing was carried out on samples TPM_001 to TPM_004. Results are shown in Figure 7, where the curve relates matric suction with volumetric water content under material-specific conditions. Note the results for both TPM-002 and TPM-003 samples are very similar and graphically indistinguishable at this scale. The SWRC labelled TPM-002 could be inferred as TPM-003. Samples from TP2 are compared to data collected from McRae Shale samples as part of initial performance monitoring planning and pre-cover system trials.

Samples from TP2 all show similar trends and are similar to that of the pre-trial McRae Shale curve. At the start of each test, the materials were in equilibrium with free water at atmospheric pressure and the matric suction was zero. No outflow was observed initially until enough suction was applied for pores to release

entrapped water. The point at which water is displaced by air from larger pore spaces is referred to as air-entry suction. This is generally small for well-aggregated soils, which is the case here, compared to that of fine-grained soils (Hillel 1982). Increasing the matric suction results in the progressive removal of water from smaller pores. The coarse-grained aggregate nature of the test plot soils results in water being able to move freely, even under suction conditions.

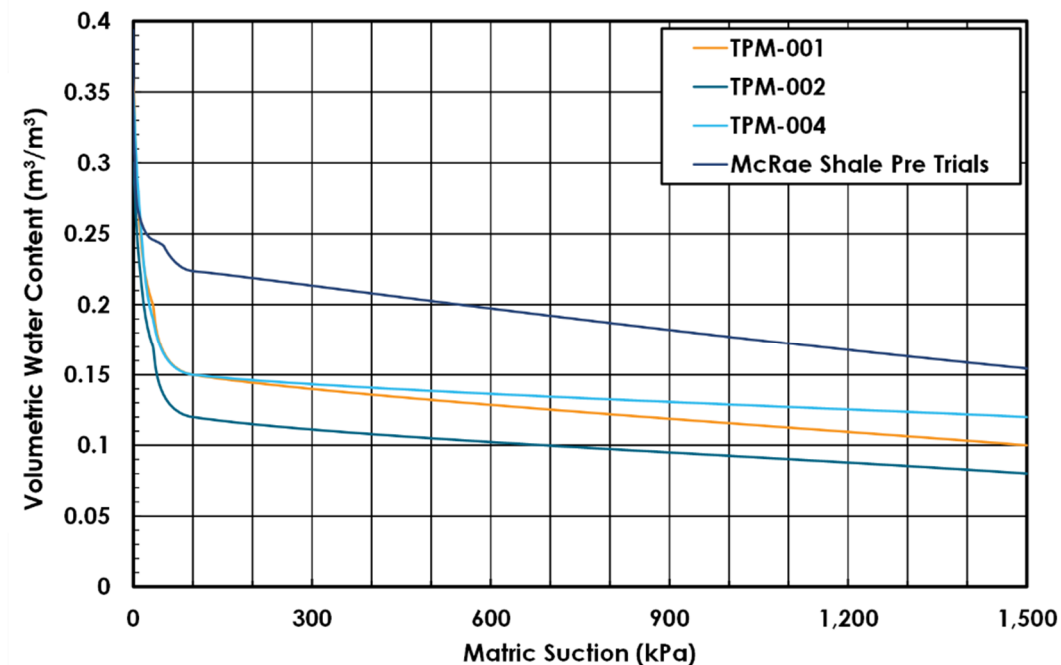


Figure 7 Soil water retention curve carried out on four material samples taken from TP2. Results for both are very similar, and at this scale are homogenous. The four samples are compared to data collected from McRae Shale pre-cover system trials. Characteristics of the four material samples can be found in Table 1 and Table 3

3.4 Vegetation assessment

3.4.1 Vegetation observations

During the site visit to carry out the autopsy on the cover system trials, TP1 and TP2 were observed for vegetation cover. TP1 contained vegetation that covered approximately 50% of the surface area. Seventeen living individual trees and 32 living individual shrubs were counted. TP2 contained vegetation that covered approximately 80% of the surface area. Seventy-six living individual trees and 29 living individual shrubs were counted. It was observed that TP1 had more bare ground than TP2. Fewer trees were observed at TP1; however, on average, these were taller than those found at TP2. Higher mortality of both trees and shrubs was observed at TP1 compared to TP2.

3.4.2 Root depth analysis

During the autopsy of TP2, root depth analysis was carried out. Focal plants included three individual trees (*Acacia* spp.), one shrub (*Senna artemisioides* subsp. *helmsii*), and one cluster of grass (*Triodia* spp.) (Figure 8). Tap roots of the trees and shrub were traced down the cross-section excavation of TP2 until the root reached 1 mm diameter or reached a maximum excavation depth of 3 m. Root depths were observed as follows:

- Tree 1 – tap root reached 1.7 m.
- Tree 2 – tap root reached 2.75 m.

- Tree 3 – tap root reached 1.5 m.
- Shrub 1 – tap root reached 3.0 m.

The lateral roots of the *Acacias* and *Senna* individuals were all within the top 30 cm of the cover material. The roots of the grass *Triodia* spp. were harder to follow, as they were finer and could not be defined by a central tap root. Roots could be seen growing around larger-sized cover material, potentially creating preferential pathways for moisture to follow through the cover profile, which could contribute to locally higher water content.

3.4.3 Root eDNA analysis

To gain full understanding of the root distributions through the cover and waste material, eDNA analysis was carried out on root material found in three samples collected at depth (TPM_008 and TPM_009 from the MCS cover and TPM_010 from the underlying waste rock; see Table 1) during the autopsy deconstruction. Results from the eDNA analysis observed four taxa in the root samples, of which two were identified as *Acacia*, one as *Senna*, and one as an equal match between four genera. All species matches were at 100% similarity. As *Acacia* and *Senna* species are often hard to distinguish to species levels, all possible matches for the four taxa are shown in Table 4. It is important to note that the samples listed could contain one, some, or all of the taxon indicated in the lists provided.

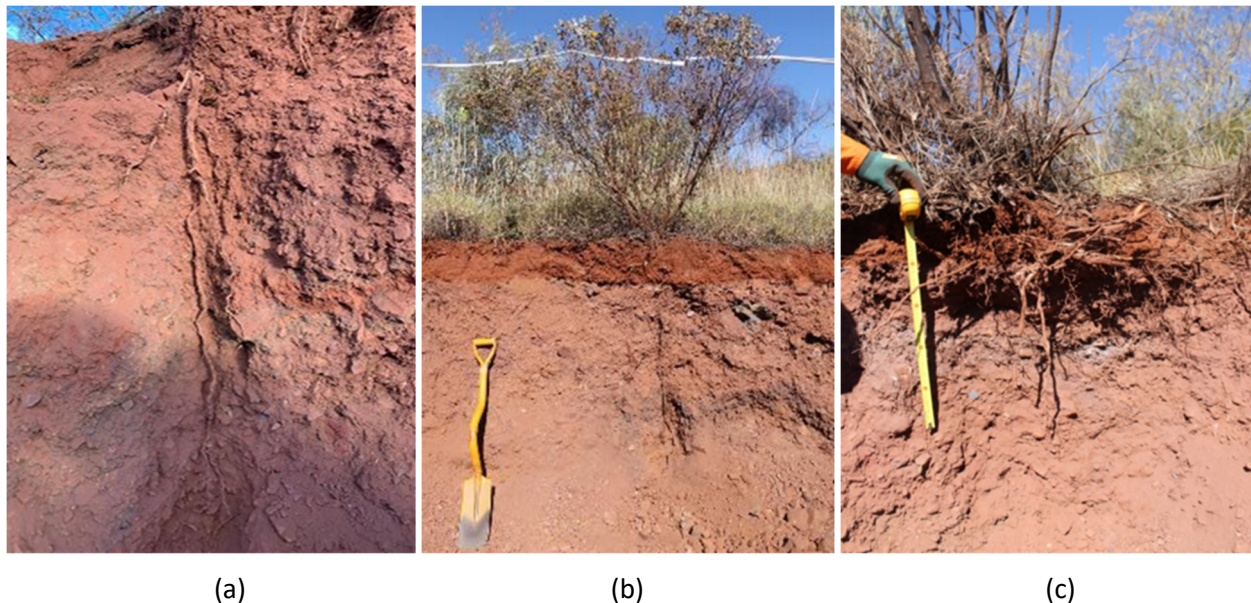


Figure 8 (a) Tree 1 (*Acacia*) tap root at 1–2 m depth; (b) Shrub 1 (*Senna*) tap root visible below the above-ground foliage (yellow spade measures 1 m high); (c) Tree 2 (*Acacia*) cluster of lateral secondary roots off the main tap root to around 30 cm depth.

Table 4 Results from eDNA analysis. Taxa within the class Magnoliopsida in three sieved root samples from TP2. Exact location of where each sample came from during the TP2 deconstruction can be found in Figure 4. Presence of the possible species roots in each material sample present is indicated by * symbol. All species listed were at 100% similarity and thus cannot be distinguished further. Bold text indicates the species was part of the initial cover system seeding and subsequently observed during monitoring

Order	Family	Genus	Species	TPM_008	TPM_009	TPM_010
Fabales	Fabaceae	<i>Acacia</i>	<i>Acacia ligulata</i>			
			<i>Acacia elachantha</i>			
			<i>Acacia effusa</i>			
			<i>Acacia cowleana</i>			
			<i>Acacia colei</i> var. <i>colei</i>	*	*	*
			<i>Acacia paraneura</i>			
			<i>Acacia monticola</i>			
			<i>Acacia citrinoviridis</i>			
			<i>Acacia bivenosa</i>			
			<i>Acacia ampliceps</i>			
Fabales	Fabaceae	<i>Acacia</i>	<i>Acacia aneura</i>			
			<i>Acacia</i> sp. XZ-2019			
			<i>Acacia sclerosperma</i>			
			<i>Acacia aptaneura</i>			
			<i>Acacia bromilowiana</i>	*	*	*
			<i>Acacia ayersiana</i>			
			<i>Acacia hamersleyensis</i>			
			<i>Acacia tumida</i> var. <i>pilbarensis</i>			
			<i>Acacia atkinsiana</i>			
			<i>Acacia sphaerostachya</i>			
Fabales	Fabaceae	<i>Senna</i>	<i>Senna artemisioides</i> subsp. <i>petiolaris</i>			
			<i>Senna</i> aff. <i>hamersleyensis</i> XZ-2019			
			<i>Senna ferraria</i>	*	*	
			<i>Senna glutinosa</i> subsp. <i>luerssenii</i>			
			<i>Senna</i> sp. <i>karijini</i>			
			<i>Senna hamersleyensis</i>			
			<i>Senna artemisioides</i> subsp. <i>oligophylla</i>			

Order	Family	Genus	Species	TPM_008	TPM_009	TPM_010
Poales	Poaceae	–	<i>Panicum austaliense</i>			
			<i>Panicum decompositum</i>			
			<i>Panicum effusum</i>			
			<i>Triodia vanleeuwenii</i>	*	*	
			<i>Triodia brizoides</i>			
			<i>Triodia</i> sp. R4			
			<i>Triodia epactia</i>			
			<i>Eulalia aurea</i>			
			<i>Chrysopogon benthamianus</i>			

4 Cover system trial findings and discussion

4.1 Material properties

As part of the preparatory works for the cover trial construction, a preliminary material characterisation program was carried out in 2002. The intent was to develop a more comprehensive understanding of the materials in which the instrumentation would be installed and provide a medium against which instrumentation could be calibrated.

A comparison between the results of previous material characterisation against the current assessment suggests that minimal evolution has occurred for the physical and geochemical properties of the MCS cover material over the 17 years.

Laboratory analysis of physical parameters combined with observations made during the autopsy suggests the cover system is geotechnically stable and has not encountered significant erosion or material dispersion. The cover profile at TP2 atop the waste rock is considered suitable from a geotechnical stability perspective.

4.2 Material fertility and vegetation

Fertility analysis was compared against vegetation and root establishment during the autopsy. While the cover material from TP2 is considered nutrient poor, vegetation in the form of grasses, shrubs, and trees had matured extensively across both TP1 and TP2. Roots typically did not extend deeper than 2.5 m except for isolated areas where roots were observed to penetrate into the underlying waste rock. Vegetation density in TP2 was higher than TP1, with a total of 105 trees and shrubs in TP1 but only 49 trees and shrubs in TP2. *Acacia* spp. roots grow to a depth of at least 3.0 m through the MCS cover material and into the waste rock material (as seen by observation to 2.75 m and found in the eDNA waste rock samples). *Senna* spp. roots grow to a depth of at least 3.0 m through the MCS cover material and into the waste rock material (as seen by observation to 3.0 m and found in the eDNA samples through the cover material). The monocotyledonous grasses, Poaceae, identified in the eDNA analysis were found to grow roots to a depth of at least 2.4 m.

It should be noted that the waste rock underlying the field trials is non-acid forming (NAF). Should the material have been potentially acid forming (PAF), there is potential that the roots may not have extended to the same depths. Generally, shallow-rooted species should be selected for the final cover system to minimise the likelihood for plant roots to penetrate into the underlying waste material and help prevent contaminants entering the food chain through consumption of leaves by local fauna, such as cattle and kangaroos. However, unless there are severe times of drought, kangaroos and livestock are more likely to

feed on the shallower rooting grass species (Dawson & Ellis 1994). The eDNA analysis gives an indication of the potential plant species to be avoided in regard to root depth extents.

Moisture contents for the four samples collected from TP2 ranged from 2.4% to 3.5%; hence, are all considered dry, as would be expected in the Pilbara, particularly during the dry season. This, in addition to the SWRC described in Section 4.4, can provide an indication of plant-available moisture within the material. Observations of vegetation at TP2 suggest the vegetation growing on the cover systems had limited stress and were generally healthy.

5 Conclusion

Monitoring after 17 years at the MMS field cover trials has provided valuable information with respect to the overall performance of the two test plots under various climatic conditions. An autopsy was carried out at one of the test plots composed of MCS (i.e. trial TP2), and results of field observations and the autopsy of TP2 are summarised as follows:

- TP2 (2.4 m thick MCS cover) contained more vegetation cover than observed at TP1 (4 m thick BIF cover). However, trees at TP1 were taller on average. A higher mortality rate of vegetation was observed at TP1 compared to TP2.
- Results of the material characterisation performed on TP2 sample material supported observations made during the autopsy, indicating the MCS cover profile is geotechnically and geochemically stable and can support a variety of vegetation species. The MCS cover system material at TP2 did not significantly change over the long-term monitoring program in terms of its material properties (O’Kane Consultants 2022).
- Tap roots of *Acacia* sp. and *Senna artemisioides* subsp. *helmsii* (Symon) Randell were observed and analysed to extend to 3.0 m through MCS cover material and into underlying NAF waste rock material. Further eDNA analysis of roots taken from cover and waste rock material samples found evidence of other *Senna* and *Triodia* species to a depth of 2.4 m in the MCS cover but not in the waste rock profile samples.

Based on the data collected through this project, and long-term performance monitoring data, a store-and-release cover system utilising MCS between 2 m to 3 m thick would reduce atmospheric interactions with underlying PAF material, in addition to sustaining a range of vegetation communities (O’Kane Consultants 2022). Cover system thickness may be increased to cater for the deeper roots and limit the risk of roots penetrating the waste material; there is no limit to the thickness of material that may be placed at the final landform for vegetation growth and sustainability. However, with consideration of cover system requirements to limit the generation of acid metalliferous drainage, in addition to sustaining a vegetation community, consideration must be paid to the economic costs of the rehabilitation works plus availability of materials. Recommendations from this project include consideration of shallow-rooted species (above 2.4 m) to be selected for the final cover system to ensure the waste material is not penetrated, thereby reducing the potential for migration of contaminants to the surface. This risk can be minimised through selectively managing the seed mix utilised in rehabilitation, with the full understanding, however, that seeds of deep-rooted species could be deposited through wind or fauna dispersal.

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References

- Bonan, G, Levis, S, Kergoat, L & Oleson, K 2002, 'Landscapes as patches of plant functional types: An integrating concept for climate and ecosystem models', *Global Biogeochemical Cycles*, vol. 16, no. 2, pp. 5-15-23.
- Dawson, TJ & Ellis, BA 1994, 'Diets of mammalian herbivores in Australian arid shrublands: seasonal effects on overlap between red kangaroos, sheep and rabbits and on dietary niche breadths and electivities', *Journal of Arid Environments*, vol. 26, no. 3, pp. 257–271.
- Hazelton, P & Murphy, B 2016, *Interpreting Soil Test Results. What Do The Numbers Mean?*, CSIRO Publishing, 3rd edn, Collingwood Victoria.
- Hillel, D 1982, *Introduction to Soil Physics*, New York: Academic Press, New York.
- International Network for Acid Prevention 2017, *Global Cover System Design Technical Guidance Document*, INAP, viewed 20 May 2022, <https://www.inap.com.au/wp-content/uploads/global-cover-system-design.pdf>
- Levin, S 2013, *Encyclopedia of Biodiversity* 2nd edn, Elsevier, Amsterdam.
- NSW Agriculture 2002, *Acid Soil Action: Interpreting Soil Tests for Calcium, Magnesium, and Ca:Mg Ratios*, Leaflet no.7, viewed 12 November 2021, https://www.dpi.nsw.gov.au/__data/assets/pdf_file/0005/166415/ca-mg-test-ratios.pdf
- O’Kane Consultants 2022, *Tom Price MMSO Cover Trial Monitoring Data Interpretation DRAFT*, O’Kane Report No. 662-227-01, Perth.
- Randell 1989, '*Senna artemisioides* subsp. *helmsii* (Symon) Randell', *Journal of the Adelaide Botanic Gardens*, vol. 12, pp. 236.

