Rehabilitation Commitments for Pits and Waste Rock Stockpiles at Frances Creek Iron Ore Mine

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Abstract

Frances Creek Iron Ore Mine operated for just a few years to 1974, before being re-opened in 2007. The re-opening of the mine provided the opportunity to observe the natural evolution and revegetation of areas disturbed by previous mining, and a reclassification of the reactivity of the waste rock and pits walls, which led to a review of the mine's rehabilitation commitments. Minor geotechnical instability of pit walls is possible, associated with weathering of potentially acid forming rock in the pit walls. Sloughing and erosion of pit walls is also likely. Natural revegetation of pit wall benches occurs over time, dominated by native trees. There is potential acidification of pit water, where potentially acid forming rock is exposed in the pit walls, although this appears to neutralise over time. The angle of repose side slopes of waste rock stockpiles were observed to remain geotechnically stable over time, with only minor face erosion likely, and trees volunteered over time. However, significant face erosion occurs where stockpile top rainfall runoff is allowed to overtop the crest. These observations supported the development of revised rehabilitation commitments for the mine, which are described in this paper.

Key Words: Acidic pit water, mined landform evolution, potentially acid forming rock, revegetation, waste rock classification, waste rock encapsulation.

Introduction

Frances Creek Iron Ore Mine is located in the seasonal tropical climate of the Northern Territory, Australia, about 200 km south of Darwin. The mine was closed following Cyclone Tracey in 1974, when its railway and port were put out of action, and it was re-opened in 2007. Ore is mined from a series of small open pits (numbering 13 to date; typically measuring about 500 m by 200 m and up to 50 m deep) using conventional drill, blast, hydraulic excavator and truck methods, and is then crushed to lump or fines product specifications, transported to a rail siding and then loaded onto trains for transportation to the Company's stockyard at Darwin Port. Ore from Frances Creek is exported to China. The mining lease covers about 1,200 ha, of which less than 15% is currently disturbed by open pits, waste rock stockpiles, ore stockpiles and processing areas, tailings storages, and environmental dams.

Observations of the natural evolution and revegetation of areas disturbed by early mining supported the development of revised rehabilitation commitments for the mine, including the optimal re-profiling of waste rock stockpile slopes, the optimal segregation and encapsulation of reactive waste rock, the selective backfilling of pits with potentially acid forming rock exposed in the walls, and the design of geo-covers over potentially acid forming waste rock. The paper describes the geological and climatic settings of the mine, characterises the waste rock and rock exposed in the pit walls, details observations made of the natural evolution and revegetation of areas disturbed by mining almost 40 years ago, and details the operational guidelines and mine rehabilitation strategies developed in the light of these observations.

Geological Setting

The Frances Creek Mine is on the Pine Creek Orogen, a Lower Proterozoic sequence of sediments. The mineral lease lies within the Brocks Creek Ridge Land System of the Katherine-Darwin Region (Christian and Stewart 1953). A small section in the south-eastern area of the mineral lease is the Cullen Land System, however no mining activity is proposed in this granitic area. The two land systems form part of the broader geomorphologic unit referred to as the Elevated Backbone Country.

Iron deposits in the mineral lease occur as semi-continuous lenses. They are haematitic ironstones with isoclinal folds in the lower member of the Wildman Siltstone. The deposits crop out as prominent, discontinuous ironstone ridges up to 50 m high over a strike length of 15 km (Australian Groundwater Technologies 2006). The largest bodies of ore occur from south to north in the Helene, Thelma 2, Ochre Hill and Saddle deposits (Bureau of Mineral Resources, Geology and Geophysics 1987). The ironstone ridges thicken within fold hinges at the Helene pits and are continued within carbonaceous phyllite and siltstone (Australian Groundwater Technologies 2006).

The ironstone lenses follow a major fold structure, which has resulted in a complex "Z" shaped pattern of outcrop. The Helene deposits are on the western limb of the structure. Various Thelma/Rosemary deposits are on the diagonal or middle limb of the "Z" and Jasmine lies on the eastern limb. Ochre Hill is 5 km north of Jasmine on the extended eastern limb of the structure.

At the Thelma 2 Pit, previous mining exposed a large amount of highly carbonaceous footwall material, which is now below water level in the pit. This waste had the highest sulfur value tested, with a leachate pH value of 4.9. Adjacent pit water has a pH value of 3.5, which represents the sum of organic and sulfuric acids developed over 35 years since mining was completed at this pit.

As ongoing cutbacks and deeper excavation in other pits expose carbonaceous waste containing chalcophile element compounds, pits previously devoid of potentially acid forming materials are predicted to produce waste rock like that from Thelma 2 Pit, which will require encapsulation within a waste rock landform.

Climatic Setting

Frances Creek Mine site experiences wet season rainfall during the months of November to March, with little rainfall during the dry season. The long-term average annual rainfall is 1,100 mm, although cyclonic depressions can substantially increase rainfall totals. The average annual daily maximum and minimum temperatures are 33.8°C and 20.6°C, respectively.

Rock Classification

Rock at Frances Creek Mine is classified as ore, and waste rock or overburden (Environmental Earth Science 2010). The sedimentary iron ore, which is purple, red, black and grey in colour, is hard, dense, low to high grade, massive to brecciated, and possibly micaceous. The different waste rock units are described in Table 1. The classification of the waste rock and rock exposures in-pit are based on the following criteria:

- PAF: Potentially Acid Forming waste rock containing >0.2% total sulphur, which has the ability to form acid when exposed to oxidation.
- NAF: Non Acid Forming waste rock containing <0.2% total sulphur or contains sufficient acid neutralising minerals to neutralise any acid generated when exposed to oxidation, which does not generate net acidity when exposed to oxidation.

The distribution of PAF rock is geologically controlled, related to the depositional environment and the formation of pyrite. Concentrations of Total Sulfur >0.2% are predominantly confined to the black shale, but are also found in some fresh and moderately weathered siltstone, requiring careful identification. For operational purposes, all black shale is classed as PAF, and PAF waste rock must be encapsulated by NAF waste rock to reduce oxidation and the generation of acidic drainage. Some PAF rock is more readily reactive than other rock containing >0.2% Total Sulfur and shows obvious evidence of oxidisation (generating heat, rapidly efflorescing, and emitting a sulfurous odour).

Table 1. Waste rock and rock exposures in-pit at Frances Creek Mine.

Rock	Colour	Description and Characteristics
Shale	Black	Very soft to friable, commonly laminated, black, very carbonaceous (stains hands), commonly contains pyrite
Mudstone	Grey, cream	Hardened mud; mix of silt and clay-sized particles
Siltstone	Grey, brown, cream	Composed mainly of silt-sized particles
Sandstone	Yellow-brown	Composed of coarse-grained, poorly-sorted quartz
Dolerite	Green, grey, brown, white	Fine visible texture of plagioclase crystals set in a finer matrix of clinopyroxene, with minor magnetite and ilmenite. Ranges from fresh to oxidised and partially haematised

NAF waste rock classification

In addition to its reactivity, waste rock is classified according to its erodability and its ability to be suitably compacted when used as a final cover material, for which only NAF material must be used. NAF waste rock contains <0.2% Total Sulfur and comprises the following identified waste rock lithologies:

- Dolerite: Resistant to erosion, although any erosion products from weathered Dolerite will often form productive soils; compacted weathered dolerite may also be suitable for use as a PAF stockpile cover.
- Siltstone: Makes up approximately 80% of the waste rock; where weathered would probably not be as erosion resistant as other units.
- Sandstone: Expected to be resistant to erosion, and suitable for use as a cover material.

Low grade ore that reports to waste rock stockpiles appears to be of a low erodability and provides a growth medium that appears conducive to the establishment of native trees. Waste generated from the Beneficiation Plant is expected to provide a good vegetation growth medium for use on waste rock stockpiles, although the potential for runoff of highly turbid water from this material requires investigation.

Testing for waste rock classification

Laboratory-based assessment of the reactivity of waste rock may be subject to significant delays, leading to the potential to misplace PAF waste rock. A simple, site-based field test was therefore developed for daily monitoring of the PAF waste rock, including black carbonaceous shale, and fresh and moderately weathered siltstone. It involved field pH (on a 1:5 solid:water paste) and peroxide testing to identify the presence of sulphide sulphur (principally pyrite). These tests are qualitative only and do not quantify the amount or concentration of sulfide sulfur present. Hence, they require regular validation by laboratory-based sulfide sulfur or Total Sulfur analysis.

Observations of Natural Evolution and Revegetation of Early Mine Disturbance

Observations, made during site visits by the first author in November 2010 and August 2011, of the natural evolution and revegetation of 40-year old mine disturbance at Frances Creek Mine, are described in the following paragraphs.

Observations of early pits

Observations of unflattened, 40-year old pits at Frances Creek Mine revealed that minor geotechnical instability of steep pit walls is possible (e.g. Thelma/Rosemary Pit, associated with weathering of PAF rock), that sloughing and erosion of pit walls is likely, and that natural revegetation of benches occurs over time (see Figure 1). Intermediate pit slopes were typically cut at about 60^{o} to the horizontal, are up to 10 m high, and are separated by benches typically 3 m wide. The steep pit walls mimic the steep natural escarpments fringing the site.

Figure 1. Observations of Thelma/Rosemary Pit 40 years after operations ceased.

Geochemically, the potential acidification of pit water has been realised where PAF material is exposed in the pit walls, e.g. the recent Thelma/Rosemary Pit with pit water pH ~2.5, and the 40-year old Thelma 2 Pit with pit water pH ~4 (see Figure 2). The apparent increase in pit water pH with time suggests that as the exposed PAF material oxides it tends to coat with oxidation products, shutting down the reactivity and allowing the pH to recover.

Observations of early waste rock stockpiles

Observations of waste rock stockpiles at Frances Creek Mine, which are up to 45 m high and are usually constructed in 15 m high lifts, reveal that 40-year old, angle of repose slopes have remained geotechnically stable. However, minor face erosion (rilling) of slopes (including recent slopes) comprising weathered waste rock is likely until or unless vegetation becomes established, and gullying occurs if the slope crest is overtopped by rainfall runoff at any stage (see Figure 3).

(a) Recent Thelma/Rosemary pit water at pH ~2.5 (b) 40-year old Thelma 2 pit water at pH ~4

Figure 2. Acidification of pits due to exposure of PAF rock in walls.

(a) Geotechnically stable 40-year old slope (b) Rilling of unvegetated face comprising weathered waste rock

(c) Gullying due to overtopping (note that boulders were placed to control erosion)

Figure 3. Observations of waste rock stockpile slope faces.

Observations at Frances Creek reveal how effective the natural rock cover is in resisting erosion compared with a stripped natural slope, and the comparable texture of natural and angle of repose, fresh waste rock stockpile slopes (see Figure 4). Figure 5 compares natural and 40-year old waste rock stockpile landforms at Frances Creek Mine, which are of comparable scale and shape.

(a) Erosion of stripped natural slope

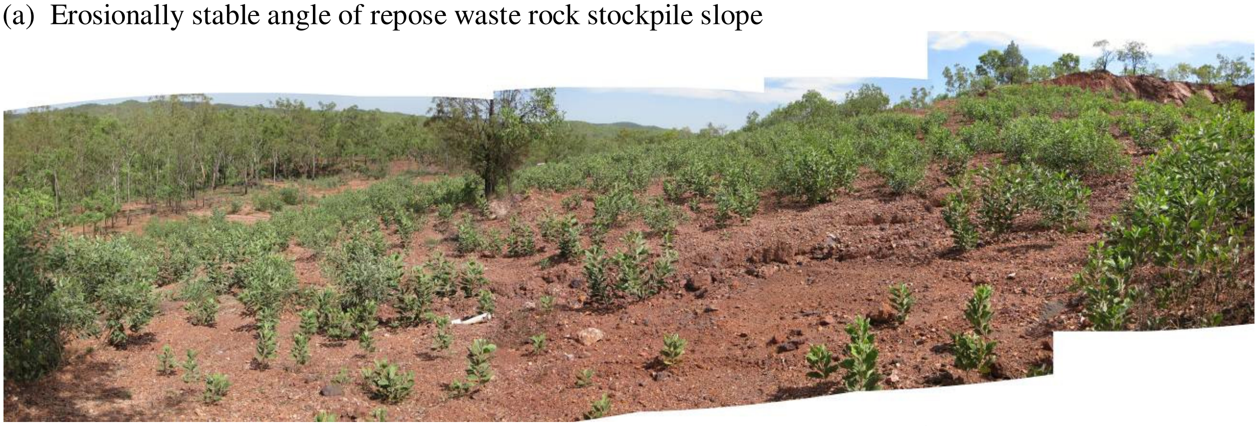
(b) Comparable natural and fresh waste rock textures

Figure 4. Observations of stripped, natural and fresh waste rock slope textures and erosion.

Figure 5. Natural (far-field) and 40-year old, waste rock stockpile (near-field to right) landforms.

Since re-opening the mine in 2007, some waste rock stockpile slopes have been flattened to about 8^{o} and revegetated, by way of rehabilitation. Observations show that this is counter-productive from an erosion perspective, since slope flattening lengthens the slope length and smooths the surface, increasing rainfall runoff and reducing erosion resistance (see Figure 6).

(a) Erosionally stable angle of repose waste rock stockpile slope



(b) Eroding, flattened (8^o) waste rock stockpile slope

Figure 6. Erosional stability of angle of repose versus flattened waste rock stockpile slopes.

Encapsulation of PAF waste rock by NAF waste rock

Figure 7 shows the encapsulation of PAF waste rock by NAF waste rock on the sides and as a cap, in a surface stockpile, and PAF waste rock being dumped in-pit.

Revised Environmental Commitments

As a result of the above observations, the mine revised its environmental commitments, as given in the following paragraphs.

Material identification and management

Both beneficial and potentially contaminating materials need to be identified and managed, as follows:

- Identify and stockpile materials for rehabilitation purposes:

- topsoil, where found in appreciable amounts on areas to be mined, should be stockpiled in <2 m high windrows (to preserve organic matter and seeds), noting that there may be little "topsoil" on natural hill slopes, and pre-stripping will encourage erosion and infiltration (see Figure 8);
- NAF, coarse-textured, durable rock should be stockpiled for use as rip rap; and
- NAF, weathered rock should be stockpiled for use in surface paddock dumping on final waste rock stockpile tops and benches.

(a) Surface encapsulation of PAF

(b) In-pit encapsulation of PAF

Figure 7. Encapsulating PAF waste rock.

Figure 8. There may be little topsoil on natural hillslopes, and stripping will encourage erosion and infiltration.

- Field identification of PAF waste rock, confirmed by laboratory testing, and its management, in order of preference, by:
  - burying it in completed NAF-walled pits below the lowest groundwater table, where it will remain saturated (see schematic in Figure 9), or
  - encapsulating it in NAF waste rock in-pit above the highest groundwater table, to maintain it dry and limit water flow, with a low net percolation top cover (see schematic in Figure 10), or

– encapsulating it in NAF waste rock in surface stockpiles, located deep and centrally (not under side slopes or benches), with NAF waste rock below to carry any base flow-through, and a low net percolation top cover to limit oxygen ingress and water transport (see schematic in Figure 11); with
– treatment, using lime, of any acid mine drainage that might otherwise report to the environment.

- Pits containing PAF rock in their walls (particularly above groundwater) should ideally be targeted for backfilling with waste rock (including PAF waste rock), and provided with a low net percolation rainfall-shedding or a drained, store and release cover.

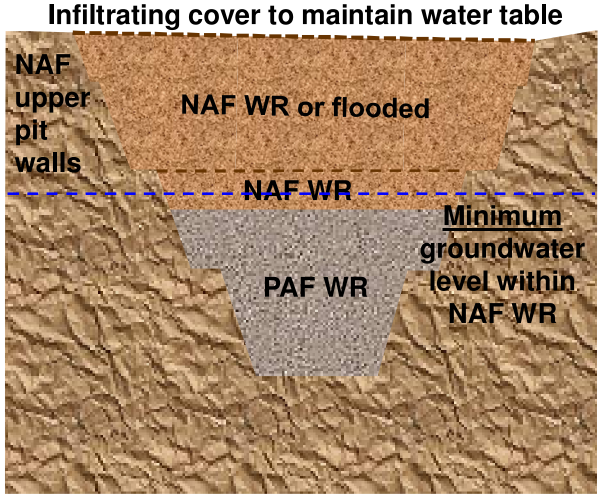


Figure 9. In-pit burial of PAF waste rock below groundwater.

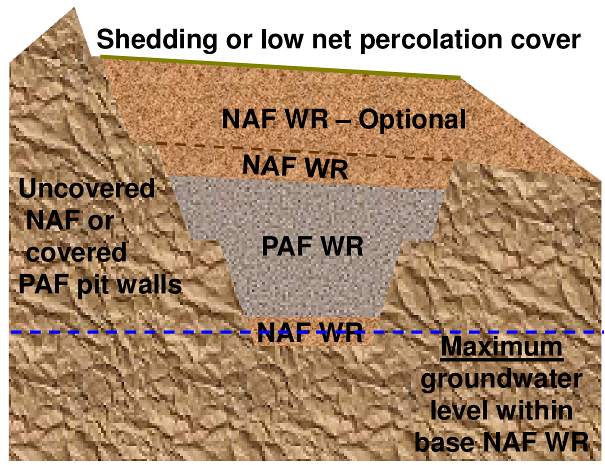


Figure 10. In-pit encapsulation of PAF waste rock above groundwater.

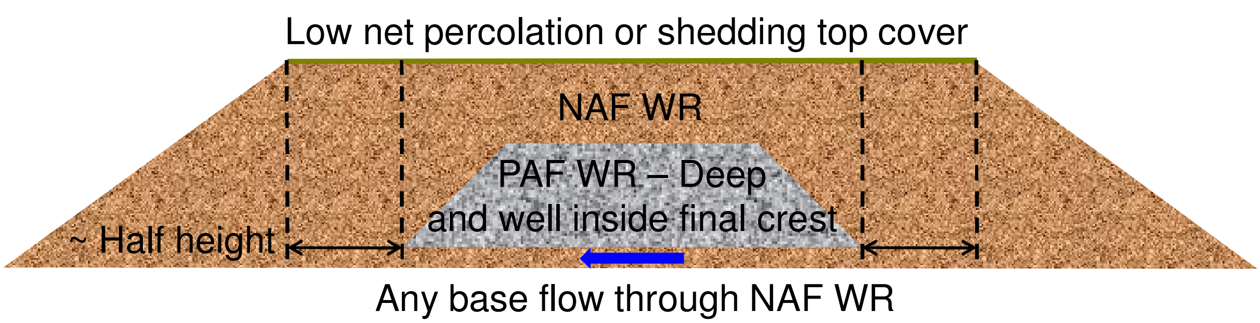


Figure 11. Encapsulation of PAF waste rock in surface stockpiles.

Waste rock stockpile geometry and stability

The geometry of waste rock stockpiles should mimic the surrounding natural ridges and slopes, ensuring stability:

- Waste rock stockpile heights should not to exceed the height of the surrounding ridges and should blend in with the surrounding topography, rather than be limited to some arbitrary maximum.

- Waste rock stockpile slopes should ensure geotechnical and erosional stability, aided by the coarse-texture and minimum length of slopes left at the angle of repose. Hence, low height slopes should be left at the angle of repose, and high slopes should retain the angle of repose for the upper part, retain intermediate benches or fill them, with the lower bench only pushed out to half the angle of repose (18^o or 1 in 3). Reprofiled waste rock slopes should mimic natural concave slopes, which are stable geotechnically and erosionally (see schematics in Figure 12).

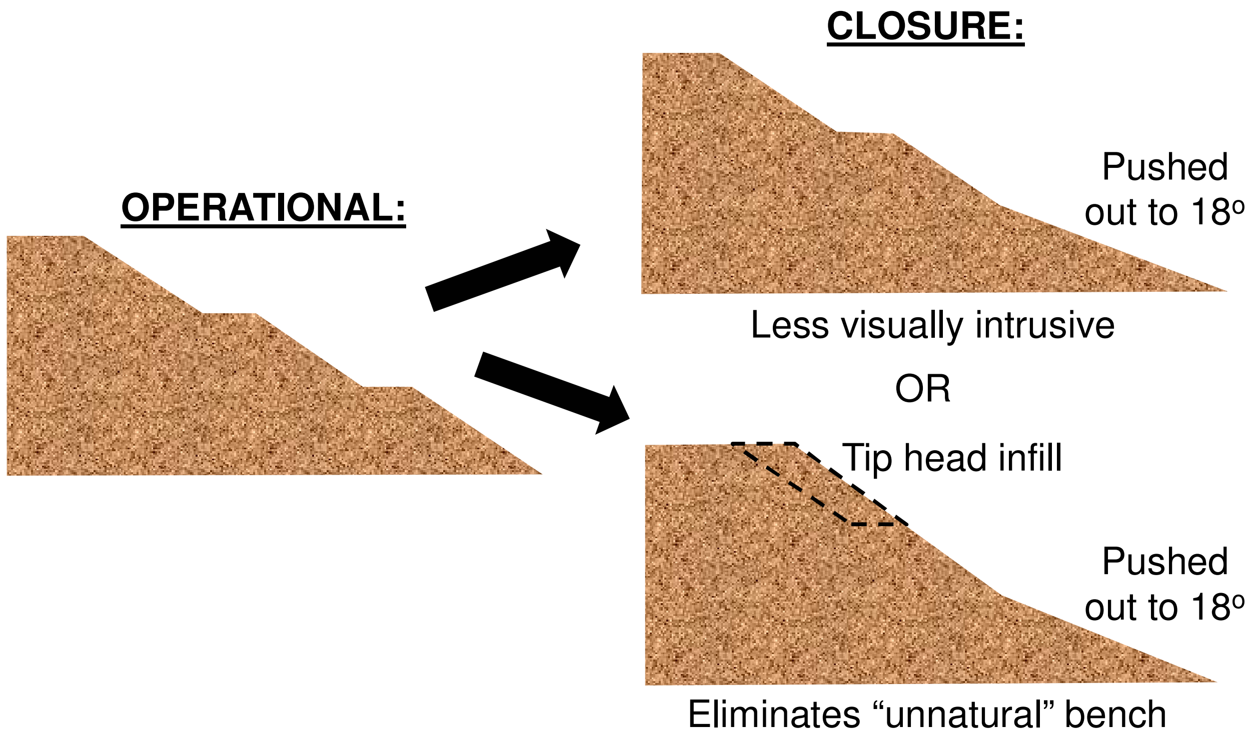


Figure 12. Reprofiling high waste rock stockpile slopes.

Water quality and management

Rainfall runoff needs to be managed to minimise contamination, as follows:

- By diverting clean water around waste rock and ore stockpiles, and pits, and by diverting mine-affected water into completed pits.
- PAF waste rock should not be placed beneath slopes or benches, to avoid the interception and transport of oxidation products.
- Avoid end-dumping waste rock down valley slopes, which interrupts stream flows and may contaminate streams, and results in long and wide waste rock slopes that are difficult to rehabilitate. Rather, infill waste rock across-valley to ultimately store or shed rainfall runoff and limit waste rock slope lengths, enabling attention to be directed at stabilising the relatively small end slope to blend back into the valley.
- Waste rock stockpile tops should not shed runoff over slope crests, which can magnify runoff up to 100-fold, causing erosion. Rather rainfall runoff should be diverted off stockpile tops to intercepting natural gullies, or handled by drainage beneath covers to reduce velocities and erosion. Contour banks and downslope drains are not found in nature, and should not be constructed on waste rock slopes. They would only be temporary, since they would fail due to overtopping or piping.

Covers on waste rock stockpile tops and revegetation

Appropriate covers should be constructed on waste rock stockpiles and in-pit storages, and revegetated:

- Covers on the tops of NAF waste rock stockpiles may involve paddock-dumped NAF waste rock and topsoil, allowed to pond excess rainfall, from which it will infiltrate and evapotranspire. Covers on the tops of stockpiles containing PAF waste rock should minimise net percolation, using a robust rainfall-shedding cover, or a paddock-dumped, store and release cover, with a drain above the sealing layer to divert excess wet season rainfall to remnant pits (see schematic store and release cover with a drain in Figure 13). Store and release covers were first developed for semi-arid climates (Williams *et al.* 1997 and 2006). The incorporation of a drain is intended to prevent overtopping and erosion of the mounded surface due to excessive rainfall in the wetter climate experienced at Frances Creek Mine. An instrumented, trial store and release cover with a drain is planned to be constructed on site during 2012.

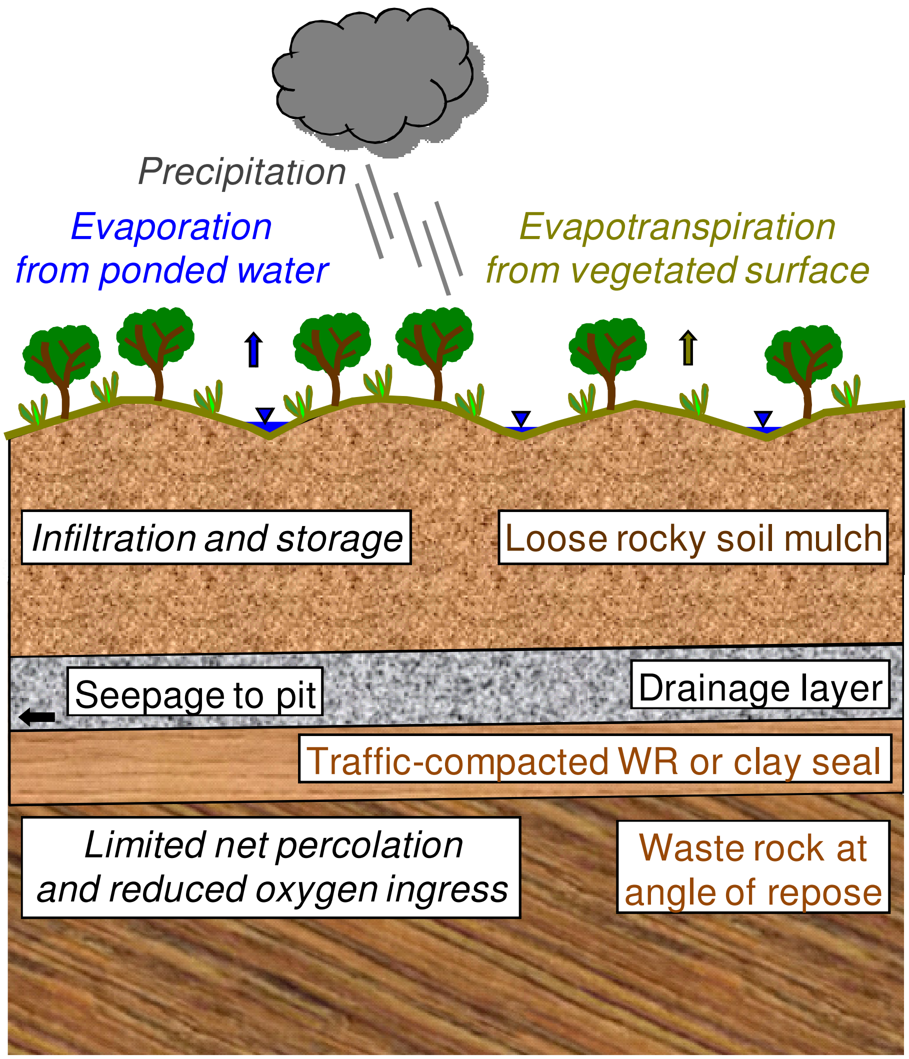


Figure 13. Schematic of store and release cover, with a drain.

- Low net percolation covers on slopes cannot practically be constructed, and should not be needed if PAF waste rock is not placed beneath slopes or benches. The crests of slopes may be over-dumped with fine material to be washed into the coarse NAF waste rock, facilitating moisture retention and revegetation.

- Appropriate revegetation should be established, which also happens naturally over time at Frances Creek Mine, including on angle of repose slopes.

Conclusions

The closure of Frances Creek Iron Ore Mine for almost 40 years allowed the opportunity to observe the natural evolution and revegetation of areas disturbed by previous mining, and a reclassification of the reactivity of the waste rock and pits walls, which led to a review of the mine's rehabilitation commitments. These have been incorporated into the operations of the re-opened mine. The key elements of the revised rehabilitation commitments at Frances Creek Mine are:

- Early identification and stockpiling of beneficial materials for rehabilitation purposes.
- Field identification and laboratory confirmation of PAF waste rock, and its encapsulation, preferably below water or, failing that, isolated from rainfall infiltration.
- Backfilling, where possible, of pits containing PAF rock in their walls.
- Designing waste rock stockpiles, and any reprofiling, to mimic the surrounding natural ridges and slopes, ensuring geotechnical and erosional stability.
- Management of rainfall runoff to minimise contamination and erosion, while avoiding unsustainable surface drains.
- Design, construction and trialling of appropriate covers for the tops of surface waste rock stockpiles and in-pit waste rock storages.

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