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The Rum Jungle Rehabilitation Project, Northern Territory, Australia: history and initial implementation

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Abstract

The Rum Jungle mine site is located approximately 100 km south of Darwin in Australia's Northern Territory. The mine was operated between 1952 and 1971 to produce uranium, and later for copper and other metals. During operations, local groundwater and the water quality of the East Branch of the Finniss River were severely impacted by acid and metalliferous drainage (AMD), and no meaningful closure or rehabilitation orks were completed when mining operations ceased. In the mid-1980s, a major rehabilitation works program works was implemented, which resulted in a substantial reduction in metal loads in the river and a significant improvement in aquatic ecosystem health downstream. The improvement was not sufficient, however, to meet contemporary environment protection standards. The Australian and Northern Territory governments therefore set up a National Partnership Agreement (NPA) to develop and implement a rehabilitation plan to bring the site to current standards.

The Northern Territory Department of Mines and Energy (DME) has developed a preferred final rehabilitation strategy for the Rum Jungle site involving backfilling the Main Pit with the highest sulphide-containing materials relocated from the existing waste rock dumps (WRDs) and constructing two new above-grade waste storage facilities (WSFs) to contain residual mine waste materials. The initial phase of rehabilitation involves dewatering the Main Pit, which commenced in September 2025, and the construction of a groundwater water treatment plant (GWTP) to treat AMD-impacted groundwater and contact water during the construction phase of rehabilitation. This paper provides an update on the rehabilitation plan and supporting technical studies, including geochemical characteristics of mine waste materials to be relocated and the water management plan, and the data collected during the initial stages of implementing the preferred rehabilitation plan.

Keywords: *mine closure, acid and metalliferous drainage, acid rock drainage, pit backfilling, limestone amendment*

1 Introduction

1.1 Site location and history

The Rum Jungle mine site is located approximately 100 km by road south of Darwin, in Australia's Northern Territory (NT), near the town of Batchelor. The key features of the current site, including the historical waste rock dumps (WRDs) and the Main Pit, Intermediate Pit and Dyson's Pit are shown in Figure 1. The Main Pit and Intermediate Pit are flooded, and Dyson's Pit was backfilled as part of initial site rehabilitation (see further details below). The East Branch of the Finniss River (EBFR) flows through the mine site. The mine

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operated between 1952 and 1971 and produced 3,530 tonnes of uranium oxide, 20,000 tonnes of copper concentrate, and lesser amounts of cobalt and lead concentrate (Davy 1975). Figure 2 is a 1957 historical photo of the Main Pit during operations. Untreated, finely ground tailings was discharged into either a poorly constrained surface tailings dam or Dyson's Pit from 1953 to 1965. Post 1965, tailings was discharged sub-aqueously into the Main Pit. The Main and Intermediate orebodies were polymetallic deposits of uranium, copper, cobalt, nickel and zinc. The Main orebody was mined from 1950 to 1958 (Figure 2), and the Intermediate orebody was mined in the 1960s (see Davy 1975 for additional details). The Main Pit was mined to about 111 m below ground surface and the Intermediate Pit was mined to about 57 m below ground surface. During mining operations, waste rock removed while mining the Main, Intermediate and Dyson's orebodies was stored in three WRDs: the Main WRD (the largest of the dumps), Intermediate WRD and Dyson's WRD.

Copper from sub-grade ore and the oxidised capping from the Intermediate orebody was extracted via heap leaching on a pad located between the Main and Intermediate pits. According to Davy (1975), pregnant liquor was intended to drain from the heap primarily via a series of lined channels and culverts. Seepage losses were substantial, however, and led to significant impacts on groundwater between the Main and Intermediate pits. Active mining operations took place before the establishment of the Northern Territory *Aboriginal Land Rights Act* (1976), the *Sacred Sites Act* (1989), *Environmental Protection Act (1990)* and the social responsibility considerations of the modern mining industry. The mining and mineral processing at Rum Jungle caused major environmental impacts, primarily due to elevated dissolved copper that characterised the acid and metalliferous drainage (AMD) from the WRDs and tailings. The EBFR was significantly impacted (see Jeffree et al. 2001, and references therein) and the site was not rehabilitated when mining operations ceased in 1971.

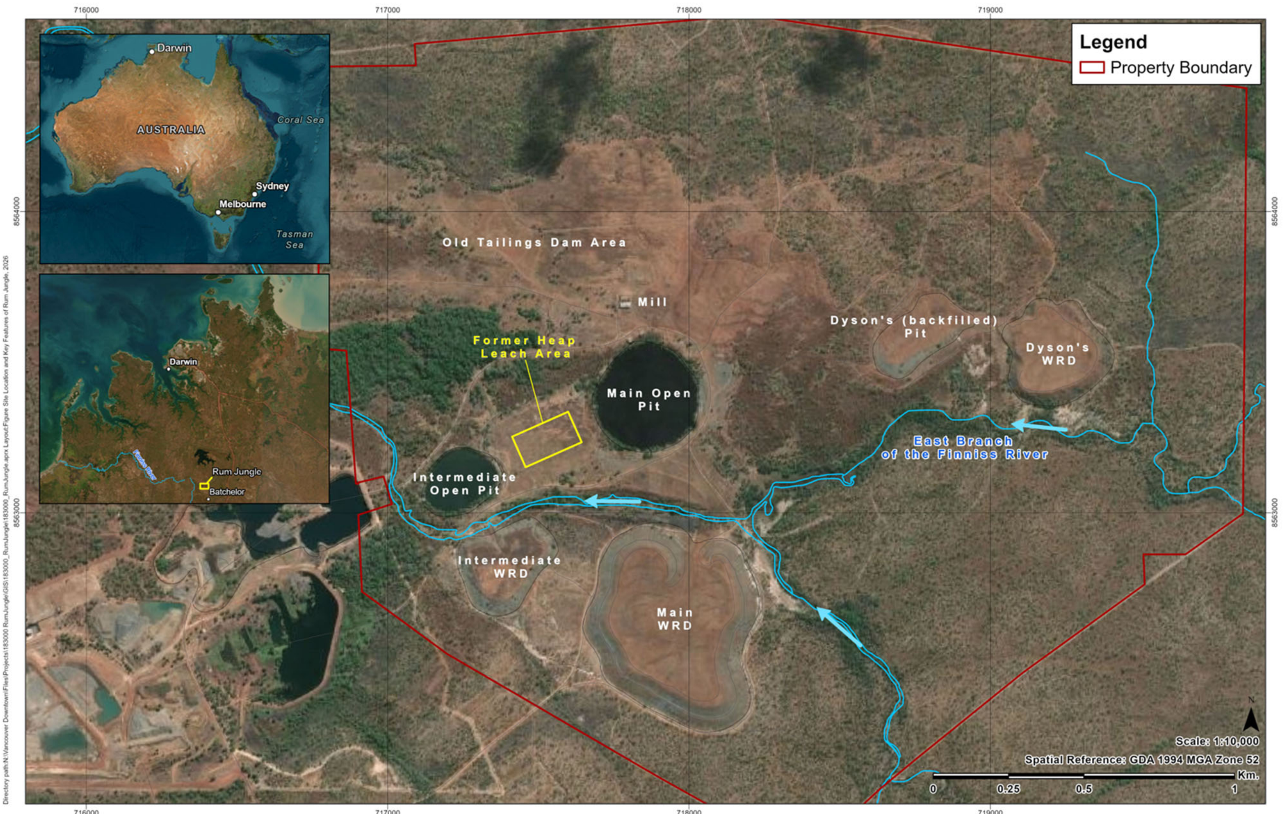


Figure 1 Site location and key features of the current Rum Jungle legacy site

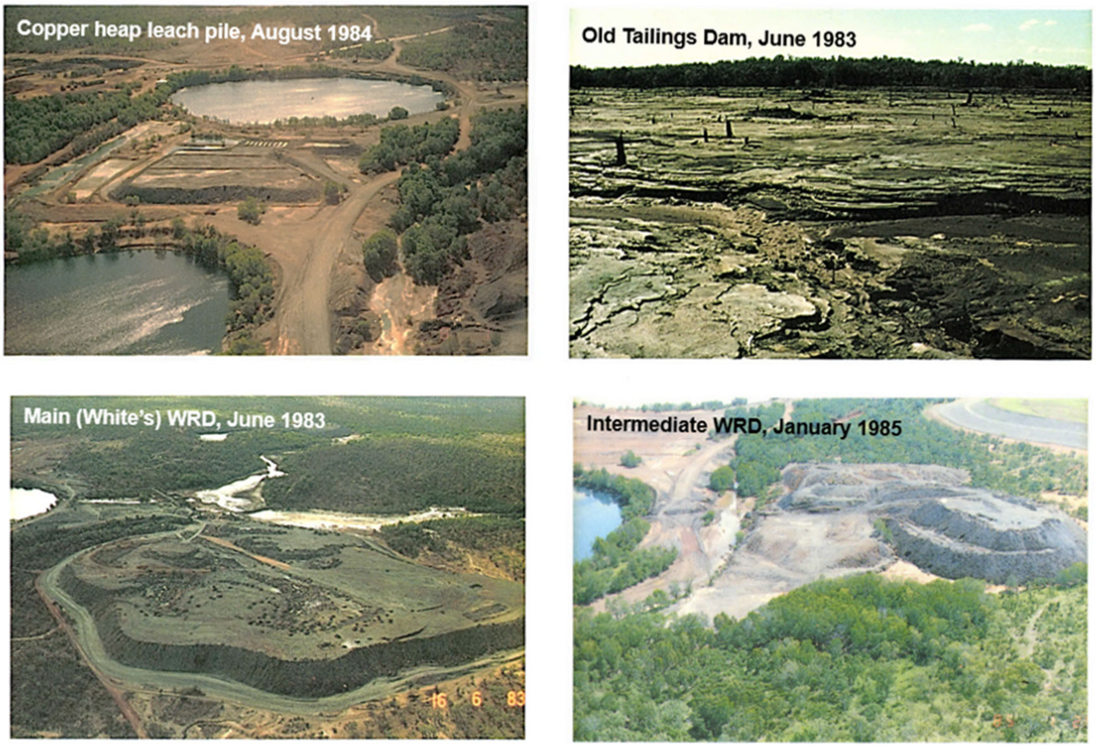
Figure 2 Main Pit: photo from Australian National Archives

1.2 Rehabilitation history

Severe downstream impacts of AMD occurred until the completion of large-scale rehabilitation works, funded by the Commonwealth Government of Australia and undertaken by the NT Government (NTG) between 1982 and 1986 (Figure 3). The rehabilitation works involved:

- Re-shaping and covering the Main WRD and the majority of the Intermediate and Dyson's WRDs with a multilayer cover system comprising a base layer of compacted clay overlain by growth medium.
- Backfilling Dyson's Pit with tailings from the Old Tailings Dam Area and low-grade ore and contaminated subsoils collected from the former copper extraction area between the Main and Intermediate pits.
- Treating the acidic process water that had flooded the Main Pit by lime addition, via a water treatment plant (WTP) that operated near the Main Pit and treating pit water in the Intermediate Pit in situ.
- Re-directing a portion of the flows in the EBFR through the flooded Main and Intermediate pits via a system of inlets and outlets, which allowed annual flushing and mixing of the top layer of pit water to the EBFR downstream.

Further details on the initial rehabilitation works are provided in Allen & Verhoeven (1986) and recent conference papers, e.g. Hartnett et al. (2024). The rehabilitation works significantly improved the water quality of the EBFR and Finniss River downstream, as evidenced by the substantial recovery of the aquatic ecosystem in the Finnis River downstream of its junction with the East Branch, on which the site is located (Jeffree et al. 2001). However, concentrations of metals remain substantially higher than contemporary aquatic environment protection standards.



(a)

(b)

Figure 3 (a) Historical site layout (1970s) prior to initial rehabilitation; (b) Site conditions after initial rehabilitation in 1984–1985

1.3 Locally derived water quality objectives

The rehabilitation works completed in the 1980s substantially reduced (by >70%) contaminant loads in the EBFR and the Finniss River further downstream. However, the concentrations of sulphate and metals were higher than modern water quality standards that apply to impacted surface waters in Australia. Therefore, the NTG commissioned the development of locally derived water quality objectives (LDWQOs) for the Finniss River based on identified environmental values downstream of the site. The LDWQOs were developed over the period from 2014 to 2022 by Hydrobiology (2013, 2015, 2016), with the starting point in 2013 being the National Australian default guideline values (DGVs). The LDWQOs were subsequently refined for some parameters in 2015 and 2016 and updated again in 2021 with additional in situ biodiversity and water quality data (Hydrobiology 2022). Uranium and selenium were added by Hydrobiology (2019) using international literature review values for these parameters as a basis and adjusting these using site water quality concentrations of toxicity modifying factors where available.

The 7 zones for which LDWQOs were developed are shown in Figure 4 and LDWQOs are provided in Table 1. Then LDWQOs represent the concentrations needed to achieve the 70% level of protection for Zone 1 (the mine site), compared with the current protection level of only 1% in the river. Also, it must be noted that for those parameters that defaulted to standard guideline values from ANZG (2018), these water quality criteria were not met even in zones 1, 5, 6 and 7 where the biological monitoring indicated no significant effect on the receptors investigated. That is, the use of these default criteria is much more conservative than required for ecosystem protection in this impacted system. Further details are provided in Hydrobiology (2022).

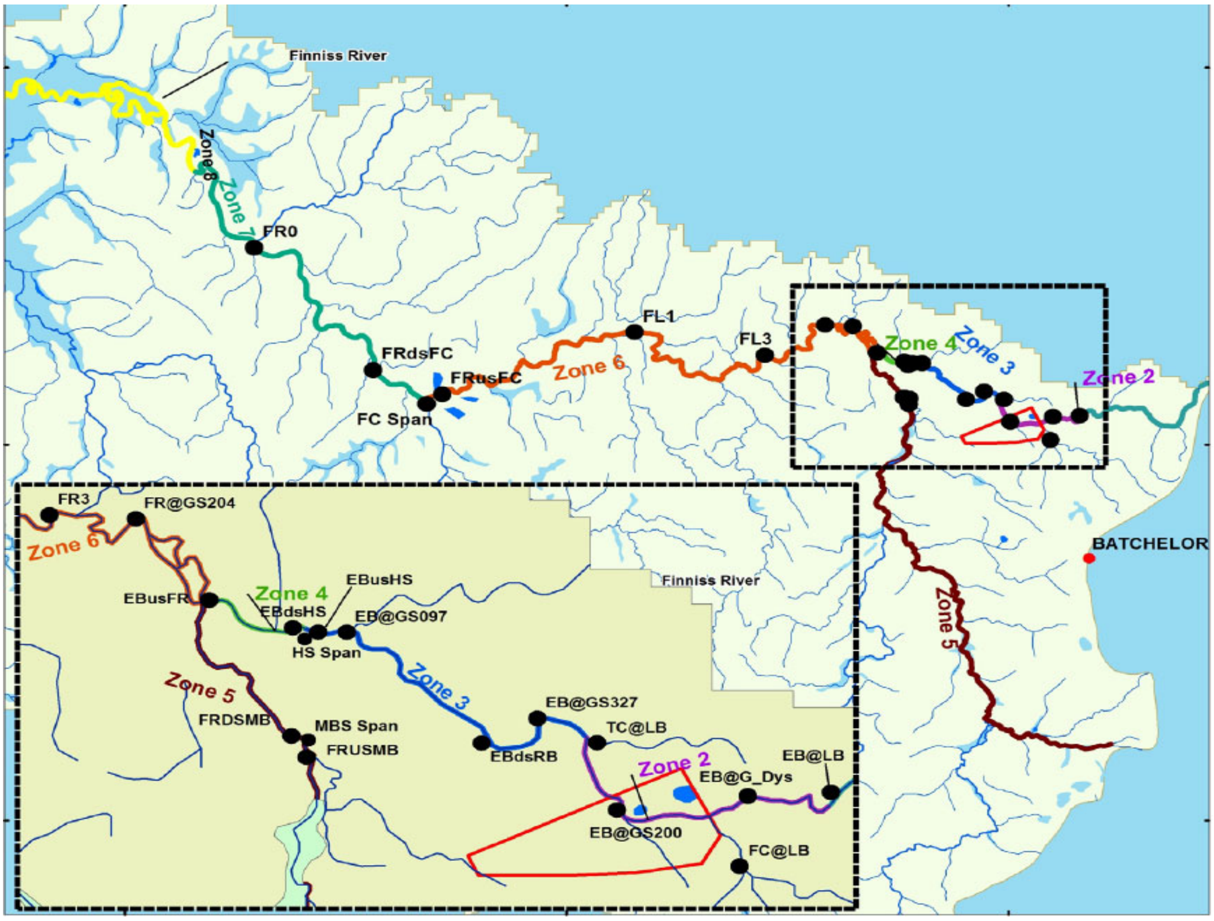


Figure 4 **The Finnis River system showing the 7 zones used to assess the gradient of exposure to develop the water quality objectives. The Rum Jungle site is defined by the red boundary and is located in Zone 2, which is shown in higher resolution in the inset box**

Table 1 Revised LDWQOs in comparison with the 2016 values for each parameter

River zone	Applicable location	Colour code (Figure 4)	EC (µS/cm)	SO_4 (mg/L)	Mg (mg/L)	Al (µg/L)	Cu (µg/L)	Co (µg/L)	Fe (µg/L)	Mn (µg/L)	Ni (µg/L)	Zn (µg/L)
Default ANZG trigger value – 80% protection level												
n/a	Any location if LDWQO not available	–	–	–	–	150	2.5	–	–	3,600	17	31
East Branch of the Finniss River												
1	Fitch Creek and EBRF upstream of mine site	–	190.7	594	33.2	117	3.4	2.8	300	140	20	26.1
2	EBFR at gauge GS8150200	Purple	2,985	1,192	86.6	236	60.8	89	300	795	130.4	227
3	EBFR at gauge GS8150327	Blue	2,985	997	86.6	150	27.6	25.9	300	443	43.1	71.6
3	EBFR at gauge GS8150097	Blue	2,985	997	86.6	150	27.6	25.9	300	443	43.1	71.6
4	EBFR near confluence with Finniss River	Light green	427	761	33.2	117	7.9	3.6	300	228	32.5	71.6
Finniss River												
6	Finniss River at gauge GS8150204	Red	190.7	594	41.1*/39.9	142*/121	14*/7.9	2.8	300	140	20	26.1
7	Finniss River	Dark green	190.7	594	41.1*/39.9	142*/121	14*/7.9	2.8	300	140	20	26.1

*Wet season

EBRF - East Branch of the Finniss River

1.4 Current environmental impacts

Groundwater quality and surface water quality downstream of the Rum Jungle mine site are affected by AMD generated by the sulphide-bearing waste rock in the historical WRDs and shallow backfill materials in Dyson's (backfilled) Pit (Northern Territory Government [NTG] 2020). Observed sulphate (SO_4) and copper concentrations in the EBFR at gauge GS8150200 from 2009 to 2018 are shown in Figure 5. This is the gauging station immediately downstream of the mine site where LDWQOs for Zone 2 apply. Gauges GS8150327 and GS8150097 are further downstream. Total and filtered (<0.45 µm) concentrations are shown if both are available.

LDWQOs for Al, Cu, Co and Fe are commonly exceeded in the EBFR at stations GS8150200, GS8150327 and GS8150097, regardless of the flow in the EBFR. LDWQOs for SO_4 and Mg and Zn are rarely exceeded if there are flows in the EBFR. The greatest impact from the site therefore occurs during the start of the wet season when pools of highly contaminated (by metals and acid) water that have accumulated in the site drainage lines during the dry season are flushed out into the EBFR. First flows at each gauge are observed in early December 2017 and peak flows occur in January and February, before gradually receding in the subsequent months.

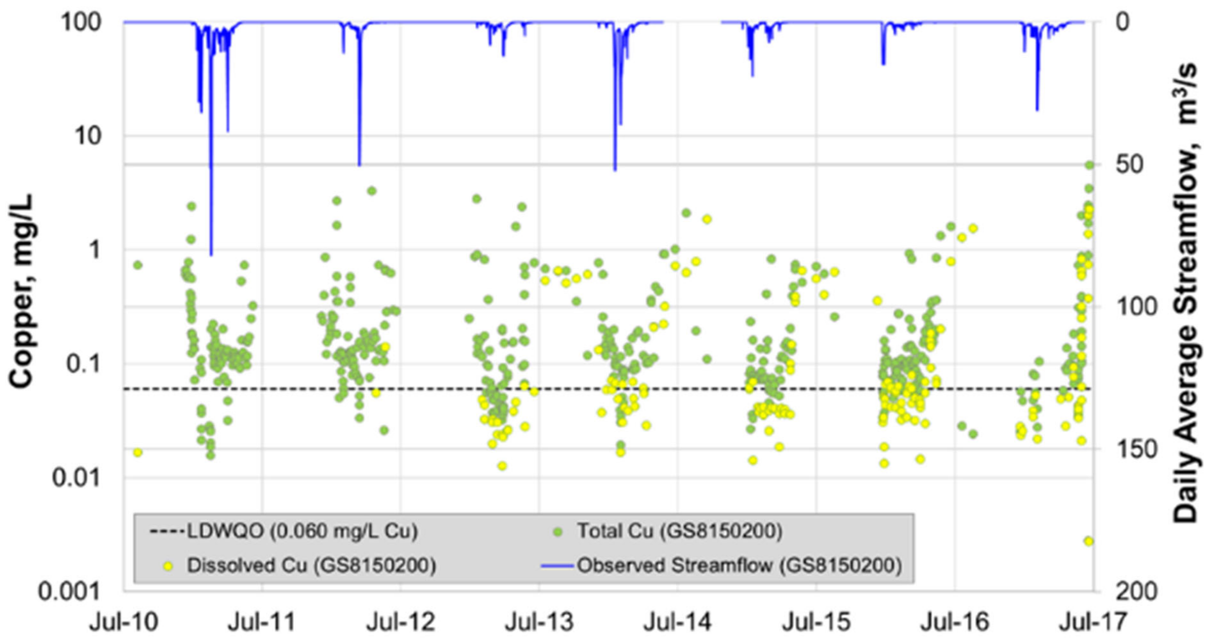


Figure 5 Observed copper concentrations in the East Branch of the Finniss River at gauge GS8150200, 2010–2017

1.5 Key objectives

In addition to achieving LDWQOs for EBFR and Finniss River, key objectives are to: restore the flow of the EBFR to its original course as far as possible, and remove culturally insensitive landforms from adjacent to sacred sites and relocating, ensuring a culturally safe distance from the sacred sites. In mid-2016, the NTG submitted a proposal to rehabilitate the site to both the NT Environment Protection Authority (EPA) and Commonwealth Department of the Environment and Energy (DoEE) under the *Environmental Assessment Act 1982* (EA Act) and *Environment Protection and Biodiversity Conservation Act 1999*, respectively. Both governments determined that the proposal required assessment under their respective environmental protection legislation at the level of an environmental impact statement (EIS). The finalised terms of reference were released to the proponent on 12 November 2019. The EIS was submitted in 2020 (NTG 2020) and approved in 2021.

2 Rehabilitation planning

2.1 Contemporary rehabilitation planning

The combination of not meeting contemporary aquatic protection guidelines, potential progressive failure of containment (i.e. cover system) together with the recognition that any future works needed to also address the Traditional Owners' cultural values, led to the Commonwealth Government of Australia and the NTG entering in 2009 into an NPA for the management of the site. As part of the NPA, the then Mining Performance Division of the NTG's Department of Resources (now the Department of Mines and Energy (DME)) was tasked with characterising current conditions of the site and developing a revised rehabilitation strategy.

That strategy was intended to:

- achieve LDWQOs for the EBFR and downstream
- ensure the long-term physical and geochemical stability of waste rock and tailings stored at the site
- achieve the post-closure land use aspirations of the Traditional Owners.

To achieve these objectives, the DME selected a preferred rehabilitation strategy from 5 alternatives after extensive consultation and technical workshopping with various government departments and Traditional Owner representatives. The current proposed strategy for waste rock relocation at a high level is shown in Figure 6 to provide context for the discussion about the development of the rehabilitation plan. The preferred strategy will involve firstly placing the highest sulphide waste rock (Intermediate WRD and the surface horizon of Dyson's (backfilled) Pit) into the Main Pit; then placing a proportion of the Main WRD on top of this such that the highest sulphide material on site will be permanently submerged beneath a pit lake at the recovered groundwater level, and building new waste storage facilities (WSFs) to contain the remaining waste rock from the Main and Dyson's WRDs. The submergence of high-sulphide potentially acid forming (PAF) waste rock in the Main Pit is consistent with best practices for this type of material, as outlined in LPSDP (2016) and MEND (2015).

The storage volume available to submerge waste rock in the Main Pit (at an elevation below the long-term lowest groundwater level of 56.6 m) is 2,080,000 m^3. This is less than the total volume of the pit to this level since 769,000 m^3 of historical tailings were placed at the bottom of the pit during operations. Approximately 619,000 m^3 of waste rock from the Intermediate WRD and approximately 392,000 m^3 from Dyson's (backfilled) Pit will be relocated to the Main Pit, with approximately 27% of the waste rock in the Main WRD also relocated to the Main Pit. Backfill materials to be relocated from Dyson's Pit consist of spent heap leach material originally sourced from the Intermediate WRD and contaminated soils that were previously relocated from the former copper extraction pad area. These materials are located above the groundwater table elevation in the pit and are therefore oxidising and contributing a substantial amount of AMD leachate that reports to the nearby EBFR.

All remaining waste rock will be placed in new purpose-built WSFs. These will be built from the ground up in thin lifts with interlayer compaction, with a final cover system overlaying the waste, aimed at minimising water and oxygen ingress. All waste rock placed in the pit and in the new WSFs will also be amended with limestone to neutralise the existing acidity contained within this material. If this is not done, the load of metals and acidity would comprise a future source to groundwater (backfilled pit) and surface water and groundwater (new WSFs).

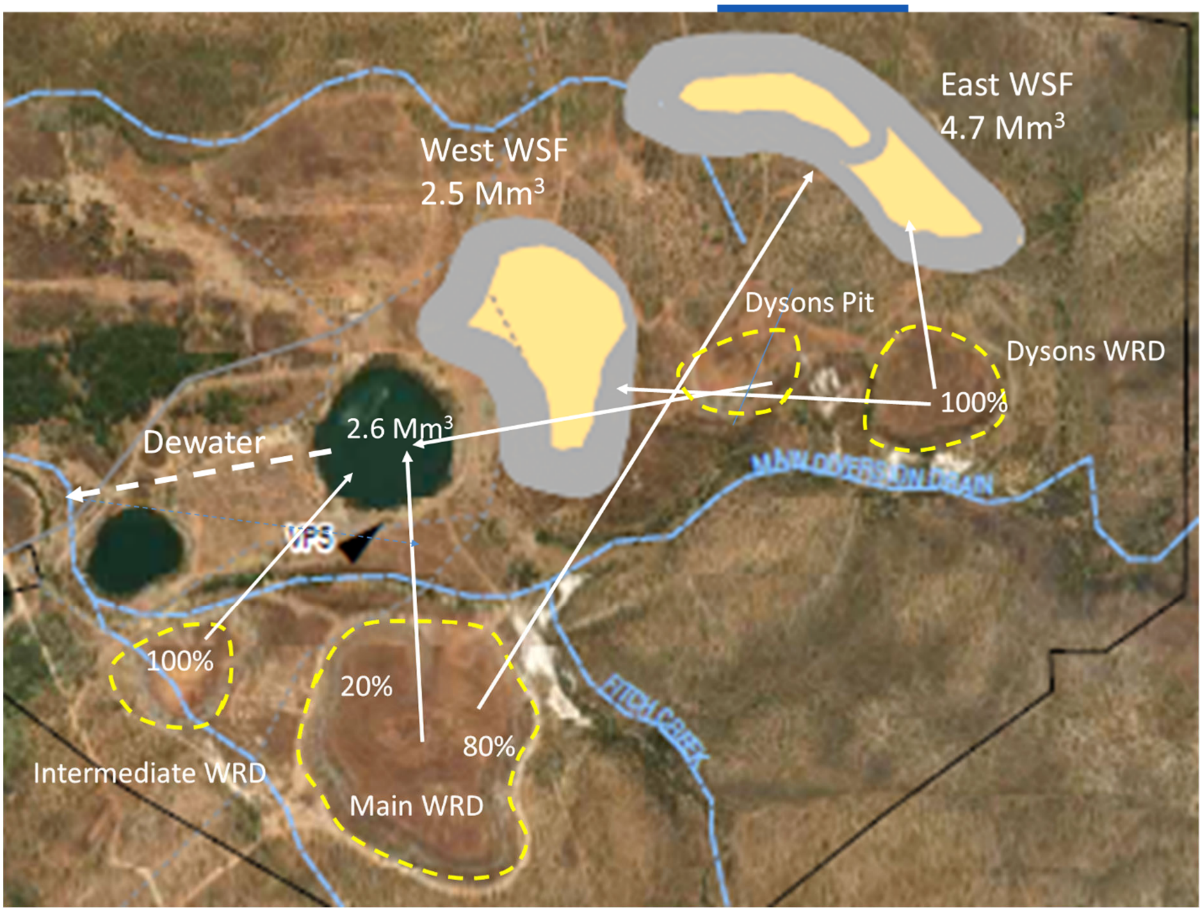


Figure 6 Relocation plan: Main Pit backfilling and proposed waste storage facilities

The Rum Jungle Rehabilitation Project delivery has been divided into two stages. Stage 3A involves backfilling the Main Pit with waste rock from the Intermediate WRD, Dyson's (backfilled) Pit, and a portion of the Main WRD as described above. The remainder (73%) of waste rock in the Main WRD along with Dyson's WRD and pockets of contaminated soil across the site will be relocated to one of two WSFs as part of Stage 3B of the project.

The current proposal for Stage 3A involves dewatering the Main Pit and the construction of a ramp (on an alignment that reinstates the original operational ramp) to allow access to the pit to place a cover over the in situ tailings and then haul and place neutralant-amended waste rock from the sources described above. Dewatering of the pit is in 2 stages – firstly the removal and treatment of the main body of water which has low contamination levels and can be treated at a high rate, and then the removal and treatment of a heavily contaminated layer (referred to as a chemocline or basal layer) at a lower rate. The proposed timeline for Stage 3A is shown in Figure 7.

The Stage 3B WSFs will be engineered to minimise sulphide oxidation through a combination of oxygen ingress restriction and rainfall infiltration control. Key design elements include low lift (0.5 m) ground up construction with interlayer compaction, addition of neutralant to account for exiting acidity, low-permeability covers to limit infiltration, engineered drainage systems to manage run-off, and structural stability measures to ensure long-term integrity. These features collectively aim to reduce AMD generation potential and ensure compliance with environmental performance standards outlined in the environmental impact statement (NTG 2020).

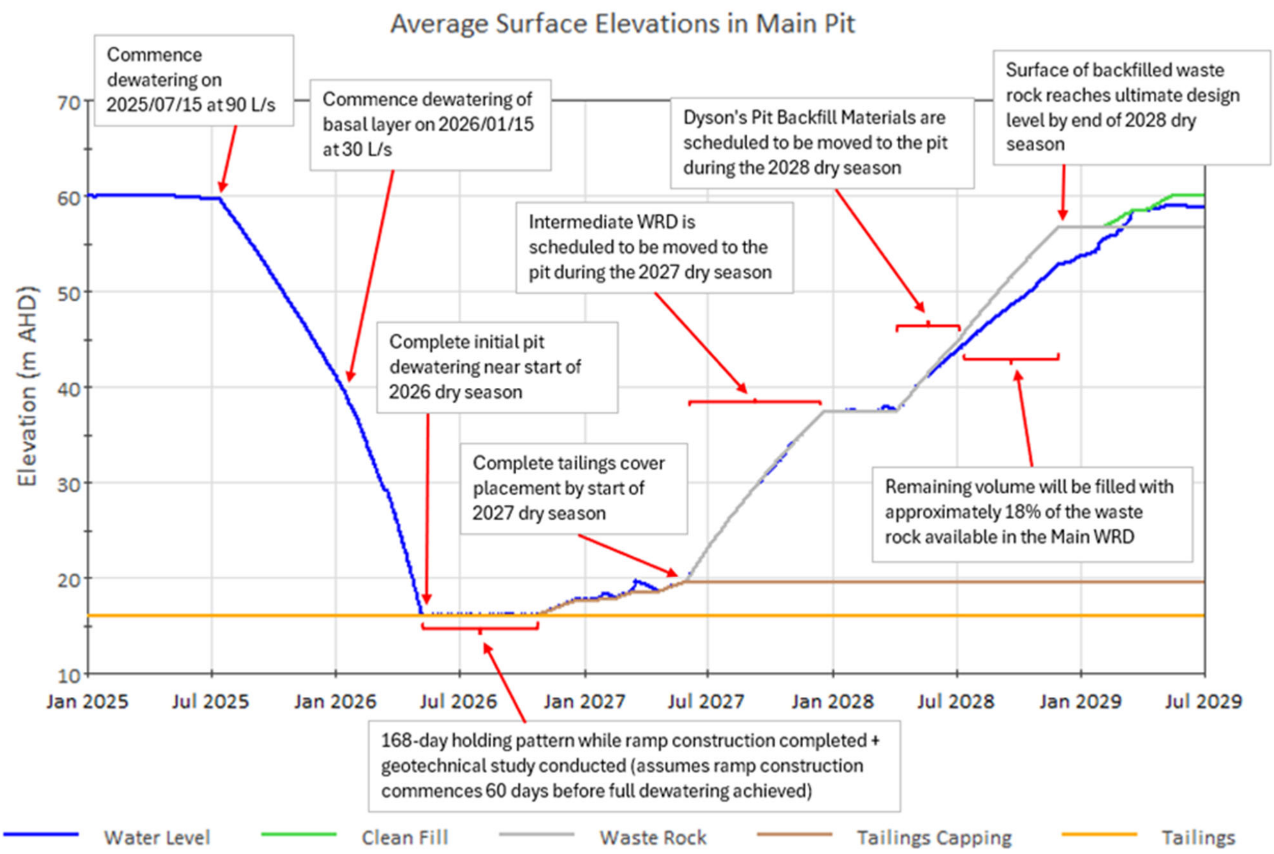


Figure 7 Stage 3A timeline for Main Pit dewatering and backfilling

2.2 Mine waste characterisation to support relocation planning

A test pitting investigation was completed in 2014 to characterise the physical and geochemical characteristics of waste rock in the WRDs that are proposed to be relocated as part of site rehabilitation works (Jones et al. 2024). Waste rock was classified as PAF-I, PAF-II, PAF-III and non-acid forming (NAF) material based on the combined interpretation of acid–base accounting (ABA) results, net acid generation (NAG) test results, and the existing acidity content of the partially oxidised waste rock. PAF-I materials are characterised by the highest sulphide content, followed by PAF-II and PAF-III materials. NAF materials are characterised by less than 0.5 kg H_2SO_4 eq./t of existing acidity and have therefore not produced any net acidity since deposition. PAF material accounts for approximately 83% of the waste rock on site. PAF-I and PAF-II materials predominate in the Intermediate WRD and Dyson's Pit, which do not contain NAF materials. Approximately 78% of the waste rock in the Main WRD is classified PAF-II and PAF-III material and 61% of the waste rock in Dyson's WRD is classified as PAF-III material. PAF-I and PAF-II materials are to be prioritised for relocation to the permanently flooded zone of the Main Pit, thus eliminating long-term AMD generation from these high-sulphide materials.

The substantial existing acidity content of the relocated PAF-I and PAF-II materials will be neutralised with a suitable neutralising agent to prevent its long-term release with associated dissolved metals via groundwater transport. Existing acidity ranges from less than 1 kg H_2SO_4 eq./t to more than 40 kg H_2SO_4 eq./t, depending on the extent of oxidation, and its average across PAF classes is between about 3 and 10 kg H_2SO_4 eq./t. Most of the existing acidity is contributed by jarosite. Jarosite is stable at pH 3.5 or lower (see Jones 2015; Jones et al. 2020), and jarosite concentrations reach up to 13 wt. % in highly oxidised material from the Intermediate WRD. Jarosite accounts for about 76% of the existing acidity in PAF-I material and about 85% of the total acidity of PAF-II material, both of which are prioritised for relocation to the Main Pit. Approximately 61% of the much lower total existing acidity content of PAF-III materials is jarosite acidity. Total (incipient acid potential (AP) plus existing) acidity is 2 to more than 10 times higher than existing acidity in the Intermediate and Main WRDs, reinforcing the benefit that will occur by submerging the higher PAF material from these waste dumps and backfilled pit. PAF materials relocated underwater will be amended with only enough neutralant to neutralise the existing acidity of these materials, as submergence will prevent further oxidation of any remaining unoxidised sulphide minerals. The dosing rate for these materials depends on the particle size of the waste rock, as finer materials have a larger surface area and are therefore not only more reactive but also contain more existing acidity per unit mass.

An analysis of multiple size fractions from 4 waste rock samples showed that existing acidity in the −19 mm fraction is approximately 3 times higher than that in the +19 mm fraction, noting that the originally proposed conservative dosing rates were derived from the existing acidity contained in the −19 mm fraction. Therefore, a particle size distribution (PSD)-corrected existing acidity and corresponding neutralant dosing rate were calculated for each WRD, accounting for the average distribution of −19 mm and +19 mm material and applying a correction factor of 3 to the coarser fractions. The PSD-corrected dosing rate for waste rock to be relocated from the Intermediate WRD and the shallow backfill materials from Dyson's Pit is estimated to be 17 kg $CaCO_3$ eq./t. The dosing rate for waste rock to be relocated from the Main WRD was estimated to be 9.2 kg $CaCO_3$ eq./t for higher PAF material and will be applied to all material relocated from the Main WRD during Stage 3a. These fixed dosing rates can be applied to all of the waste rock relocated during Stage 3A, with no field testing to determine PAF type during relocation required. Approximately 50,000 t of neutralant ($CaCO_3$) may be needed for Stage 3A. This assumes 2,080,000 m^3 (or 3,744,000 t) of waste is relocated. The mass of neutralant required assumes that it is pure limestone (100% $CaCO_3$). Therefore, any impurities in the selected neutralant product must be accounted for when determining the effective dosing rate and the total quantity of neutralant required. The required amount of neutralant ($CaCO_3$) per month during the relocation of the Intermediate WRD ranges from approximately 2,100 to 3,500 t, and approximately 4,000 t/month is needed for materials relocated from Dyson's (backfilled) Pit. In line with this lower dosing rate, approximately 3,100 t/month is needed during the relocation of waste rock from the Main WRD.

3 Summary: initial implementation

The rehabilitation of the Rum Jungle mine site will be undertaken over a period of 10–15 years, during which waste rock will be relocated to the Main Pit or new, purpose-built WSFs. During this period, a groundwater water treatment plant (GWTP) will be operated to treat AMD-impacted groundwater and run-off. The site will be returned to a condition that is physically and chemically stable and to a landform appearance that will improve the cultural values of the site as far as is possible to achieve in this highly disturbed environment. The direct participation in healing country and return of cultural values to the landscape are crucial in supporting the Traditional Owners' decision to take the land back.

The water quality of the EBFR (and Finniss River) downstream of the site is predicted to substantially improve post rehabilitation, due to a tenfold reduction in solute loads to the creek. The improvement will allow an increase from less than 1% aquatic species protection to 70% in the creek lines on site. Rehabilitation works commenced in September 2025, when dewatering of the Main Pit began and operation of the pit water treatment plan (PWTP) commenced. Pit dewatering will be completed in late 2026, after which the GWTP will treat impacted pit water at the bottom of the pit and flows of AMD-impacted groundwater from the seepage interception system (SIS). Pit backfilling will then proceed and be completed in 2029, at which time Stage 3A of rehabilitation will conclude.

Acknowledgement

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