The Rum Jungle U-Cu Project: A Critical Evaluation of Environmental Monitoring and Rehabilitation Success

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Abstract. The Rum Jungle uranium-copper project, located south of Darwin, Australia, operated from 1954 to 1971. The poor solid and liquid waste management practices during the project led to long-lasting environmental impacts. A large rehabilitation project was undertaken in the 1980's followed by nearly 15 years of monitoring. This paper reviews the environmental performance of the project during operation, its subsequent rehabilitation and the implications of ongoing problems at the site, especially acid mine drainage and impacts on water resources.

Introduction

In the Australian mining industry, the former Rum Jungle uranium-copper project holds a special place for many reasons. It was the first project to commercially mine and export uranium (for nuclear weapons) in the 1950's, it was a major part of the post-war Northern Territory economy, it caused ongoing environmental pollution which reached many kilometres downstream, it was among the first generation of polluting former mine sites to be rehabilitated in the 1980's and this was followed by a decade-long post-rehabilitation monitoring program. It is therefore possible to assess the pollution loads leaving the site prior to and following rehabilitation, providing a unique and important case study for such mines, especially the long-term effectiveness of rehabilitating former uranium mines. Although there are numerous papers on Rum Jungle, this paper seeks to synthesize the key data and analyse it from an independent environmental perspective. The paper briefly reviews the Rum Jungle project, followed by a detailed compilation and critical evaluation of the available environmental monitoring data, giving a unique case study of the environmental performance of uranium mine site rehabilitation.

The Rum Jungle U-Cu Project – A Brief History

The Rum Jungle uranium-copper project (U-Cu) has been an important mining project in Australia, for many reasons as noted previously. This section is a brief history to understand the project, rehabilitation and environmental monitoring.

The mineral potential of the 'Rum Jungle' region, just south of Darwin, had been noted since the 1870's, primarily for Cu and gold (but nothing of interest). The region is located in the tropical wet-dry climate of northern Australia; Fig. 1.

Following the advent of the nuclear weapons race in 1945, the Australian government vigorously promoted uranium prospecting. In 1949, local pastoral owner and amateur prospector Jack White realised that his green minerals from the bed of the Finniss River were most likely U. The significance was realised, with the Australian government taking over in the 'national interest' (Lichaz and Myers 1977). By late 1951 two modest U deposits were proven at White's (U-Cu) and Dyson's (U). During 1952 export agreements were finalised for nuclear weapons. The project was owned by the Australian government, operated under contract by Consolidated Zinc (CZ, later to become CRA Ltd, now Rio Tinto Ltd) and was financed by the US-UK Combined Development Agency (CDA).

First uranium oxide (U_3O_8) production was in 1954. White's and Dyson's were mined as open cuts and were completed by late 1958, with the mill processing stockpiled U and U-Cu ore as well as a small amount of purchased U ore. In 1959, exploration discovered the Rum Jungle Creek South (RJCS) U deposit, and proved larger than White's and Dyson's combined. The RJCS site was mined over 1961-63, and allowed processing to continue at Rum Jungle until 1971.

The Intermediate Cu deposit adjacent to White's was mined by CZ over 1964-65 separate to the CDA contract and toll processed through the mill, plus a Cu heap leach experiment. The Brown's Pb-Cu-Ni-Co-Ag prospect was studied but abandoned as uneconomic due to low grades and difficult processing (Brown's 'oxide' mine was developed in 2008, a major sulphide project is expected soon).

The project was operated on a 'production' basis – environmental impacts were clearly not considered important. During the early years of operation (1954-61), tailings were discharged to a flat low-lying area (later known as 'Old Tailings Creek) adjacent to the mill, though the tailings proved highly eroded.

About 1 ML/day of liquid effluent was discharged into the Finniss River, containing acids (pH 1.5), metals and radionuclides. At times liquid wastes would disappear into holes which opened up at the Cu cementation launders for several weeks, until the area was covered and later abandoned (see Davy 1975). About 640,000 t of tailings was also discharged and covered 35 ha, with some 10-25% of these tailings having been eroded by 1984. In 1961, tailings were directed to the former Dyson's open cut, and then to White's from 1965-71.

The site was a major source of environmental pollution for the Finniss River – due to tailings and liquid waste discharges but also due to the acid mine drainage (AMD) derived from the tailings but especially waste rock dumps. The scale of the problem was identifed by the late 1950's but was ignored due to the political nature and perceived importance of the Rum Jungle project.

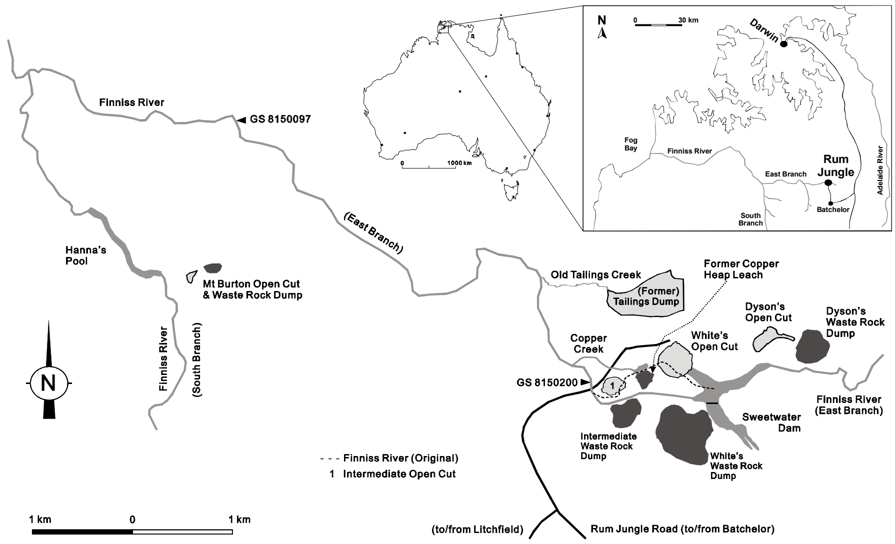

Fig.1. Location and site map of the Rum Jungle U-Cu project, Northern Territory.

After closure in 1971, no major works were undertaken to reduce pollution and by the mid-1970's Rum Jungle project was infamous for its extreme pollution, such as the absence of all biota for 15 km down the Finniss River and contamination of ~100 km^2 of floodplains (Davy 1975). The environmental legacy of Rum Jungle was also a major issue during the Ranger Inquiry (Fox et al. 1977).

The Australian government conducted major rehabilitation works over 1982-86 costing some $18.6 million. The project was amongst one of the earliest in Australia to remediate an AMD site, with the primary objectives being : (i) reduction in Finniss River pollution loads (70% each for Cu-Zn, 56% for Mn); (ii) reduction in public health hazards (including radiation); (iii) reduction in pollution loads in White's and Intermediate open cuts; (iv) aesthetic improvements and revegetation.

Although the RJCS site was ignored during the Rum Jungle program, as it was considered to have no major pollution problems, it was later found to present a public radiological exposure issue due to its popularity for recreational swimming. RJCS was then addressed with additional works in 1991 to cover the waste rock dump and achieve unrestricted public use of the site.

Given the importance of Rum Jungle as a test case for AMD remediation in mining, a major environmental monitoring program was initiated from 1986, running until 1998. The data and associated analysis of results are contained in Allen and Verhoeven (1986), Kraatz and Applegate (1992), Kraatz (1998) and Pidsley (2002), with pre-rehabilitation environmental studies given by Davy (1975).

Rum Jungle has been visited over 2004 to 2007, and still remains a major AMD pollution source to the Finniss River – despite the rehabilitation works. It is in this context that the available environmental monitoring is presented, analysed and discussed. The site remains a critical case study, providing numerous insights into mine rehabilitation, and of particular relevance for uranium mining.

Geology and Hydrogeology of the Rum Jungle Region

The geology and and hydrogeology of the Rum Jungle region is complex, with the most recent descriptions given by McKay and Miezitis (2001) and CR (2005).

Rum Jungle is on the western part of the Pine Creek Geosyncline, with regional geology comprising Palaeoproterozoic metasediments (low-grade greenschist facies) unconformably over-lying Archaean granitic basement (the Rum Jungle Complex). Surficial rocks are often intensely weathered. The Giant's Reef Fault has caused some 4-5km of displacement, leading to an embayment structure which is the location of most mineralised zones. Geologic cross-sections of White's, Dyson's, Intermediate and Rum Jungle Creek South are given by Fraser (1980).

The hydrogeology is comprised primarily of surficial weathered aquifers and underlying fractured rock aquifers of varying significance. Groundwater is found between 2-12 m from the surface, and varies with the wet-dry monsoonal climate (see Fig. 2), suggesting active recharge into unconfined aquifers and dynamic discharge processes such as transpiration or to surface water features (CR 2005). Karstic solution features in dolomite are often present. The extent of hydraulic connection between shallow and deep aquifers remains uninvestigated.

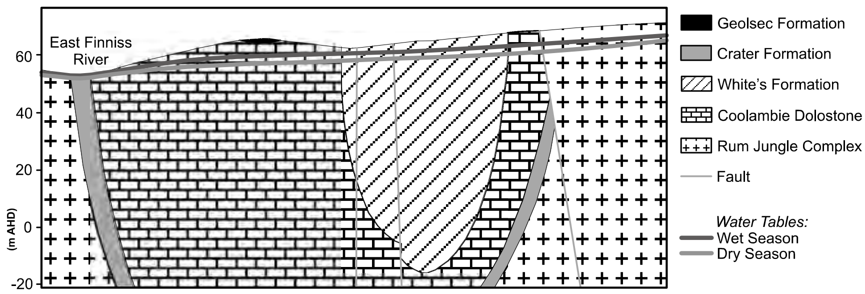

Fig.2. Hydrogeologic cross-section of Brown's area, Rum Jungle (adapted from CR 2005).

Rum Jungle Rehabilitation Project

Given the environmental significance of the ongoing pollution at Rum Jungle, the Australian government funded a major rehabilitation program from 1982 to 1986. As this was amongst the first generation of former mines with major acid mine drainage to be rehabilitated in Australia (as well as it being a former uranium mine), a decade-long environmental monitoring program was established.

Rehabilitation Measures (1982-86)

The Rum Jungle rehabilitation program was primarily aimed at reducing the metal loads reaching the Finniss River, as well as reducing public hazards. Specific components included : excavation of remnant tailings and the Cu heap leach pile for deposition into Dyson's open cut, re-contouring of waste rock dumps and construction of soil covers to limit infiltration and AMD generation, treatment of polluted waters in White's open cut, rehabilitation of the former mill and stockpile areas, and partial re-diversion of the East branch of the Finniss River and removal of the Acid and Sweetwater Dams.

Environmental Monitoring (1986-1998)

Environmental monitoring was undertaken during rehabilitation works and for some 12 years afterwards, including surface water hydrology and water quality, groundwater, biodiversity (eg. fish or macroinvertebrate surveys), waste rock dump hydrology, and sediment analyses. Sampling and analytical methodology are detailed in the four principal reports (see earlier). All results presented below are derived from these reports (unless otherwise noted). Some additional data has been included from research work (years 1998/99 to 2000/01).

No pre- and post-rehabilitation radon or gamma surveys are available, despite recent recommendations of the need for such assessments (see Pidsley 2002).

The primary point for determining the effectiveness of rehabilitation project in reducing metal loads in surface waters was set as GS8150097 (~5.6 km downstream, see Fig. 1). Monitoring has been reported as both concentration and load data, usually including metals, sulphate and pH. Analytical methods have evolved over time, such as early years being totals only, while latter years included total and dissolved metals. Despite U being a critical issue, it has commonly not been included in routine water quality analyses for all wet seasons. Similarly, radium (^{226}Ra) was only monitored for the first two wet seasons after rehabilitation.

Monitoring Results

Open Cuts

White's open cut (OC) remains a major source of pollutants, with Intermediate OC minor only. A water quality profile of White's OC is given in Table 1, and clearly shows the more polluted waters at depths below 30m. It is considered that White's OC is still contributing some 2-3 t Cu per wet season at GS8150097.

Table 1. Water quality profile of White's open cut, April 1998.

Depth	pH	DO	E.C.	Ca	Mg	SO_4	Cu	Mn	Zn	Ni	Fe	Al
m	-	mg/L	µS/cm				all mg/L					
0	6.8	6.6	157	4	13	61	0.1	0.31	0.04	0.06	0.46	0.09
5	6.5	5.9	172				0.1	0.34	0.05	0.06	0.44	0.13
10	6.1	5.3	110	3	8	41	0.1	0.32	0.03	0.06	0.35	0.18
15	5.7	5.2	115				0.1	0.46	0.04	0.06	0.19	0.13
20	5.4	5.5	151	6	11	64	0.2	0.74	0.04	0.09	0.06	0.13
25	5.4	5.4	171				0.2	0.78	0.05	0.08	0.07	0.14
30	4.4	4.6	274	12	20	137	0.8	2.45	0.11	0.23	0.13	1.88
31	4.1	3.6	458				1.3	4.42	0.18	0.37	0.21	5.2
32	3.7	0.1	993				3.1	17.65	0.42	1.01	0.87	14.8
33	3.8	0	7168				54	244	5.49	18.55	378	215
34	3.8	0	7478				60	269	7.4	16.7	404	226
35	3.8	0	7558	481	902	8270	62	254	7.75	19	420	236

Waste Rock Dumps

The infiltration target for soil covers over WRD's was set at 5% of incident rainfall (compared to ~50% previous). Although there have been technical issues with the lysimeters used to monitor infiltration, including failure of several lysimeters, the available monitoring data shows good performance initially (ie. <5%), followed by a gradual decline or increase in estimated infiltration, shown in Fig. 3.

Recent visits to the Rum Jungle site clearly show that significant infiltration rates must still be occurring, as seepage flows from White's WRD can be seen through-out the dry season (photo included in Fig. 3). Although direct sampling and analysis of this water is not available, it is known to contain U from 1 to 8 mg/L (pers. comm., Brown, 2002). It is abundantly clear that the WRD's continue to act as major pollutant sources for the Finniss River.

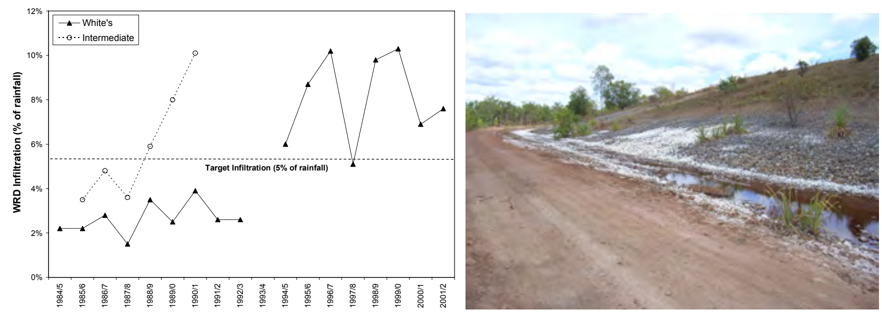

Fig.3. Waste rock dump infiltration : monitored infiltration rate (left), White's WRD in July 2007 (right) – note the active seepage flow and characteristics (photo G M Mudd).

Surface Water

Only a brief examination of hydrologic and surface water quality data is possible herein, and so only key data is presented. The results of a Finniss River water quality profile are shown in Fig. 4, with metal loads for Cu and Zn shown in Fig 5. A comparison of water quality at GS8150097 with guidelines is given in Table 2.

There is clearly seasonal behaviour in metal concentrations and loads (Table 2).

To further illustrate this, typical maximum concentrations in the first flush waters of the early wet season are compiled and shown in Fig. 6. Smaller wet season flows lead to higher concentrations, with a gradual decline over time. Additional photos of the former Sweetwater Dam are given in Fig. 7.

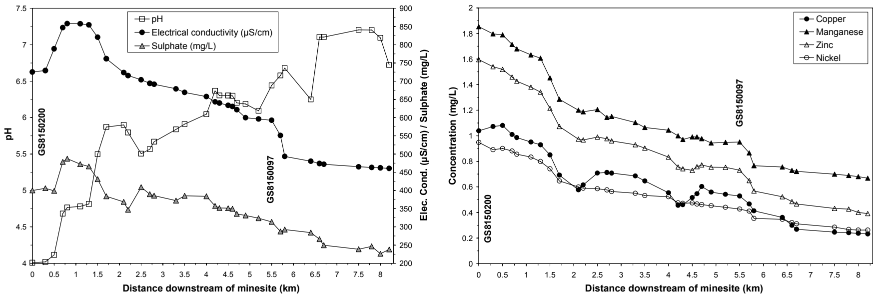

Fig.4. Profile of Finniss River water quality downstream from Rum Jungle (22 April 1994).

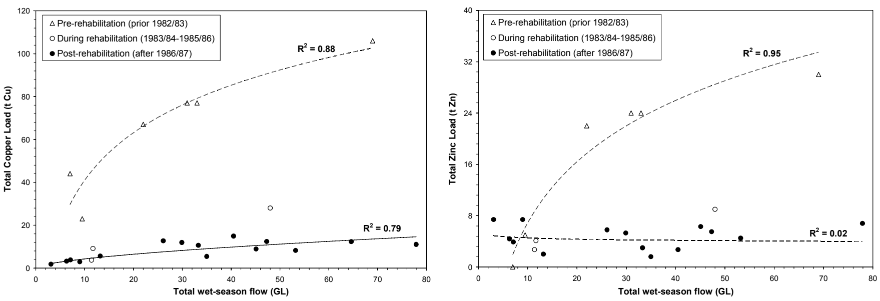

Fig.5. Cu-Zn loads in Finniss River at GS8150097 before, during and after rehabilitation.

Table 2. Summary of GS8150097 water quality during the 1992/93 wet season, compared to current water quality guidelines (ANZECC and ARMCANZ 2000).

	Al	Ca	Fe	As	Co	Cr	Cu	Mn	Ni	Pb	Th	U	Zn
		← all mg/L		all µg/L →									
Average	3.6	9.9	1.7	4.1	176	5	485	860	169	76	3.3	33	209
Minimum	0.21	4.2	0.096	0.6	53	0.7	180	430	53	2	0.02	6	49
Maximum	9	29	14	41	480	33	1100	2000	430	880	26	63	670
ANZECC[a]	ND	ND	ND	14	ND	1[b]	1.4	1900	11	3.4	ND	6[c]	8

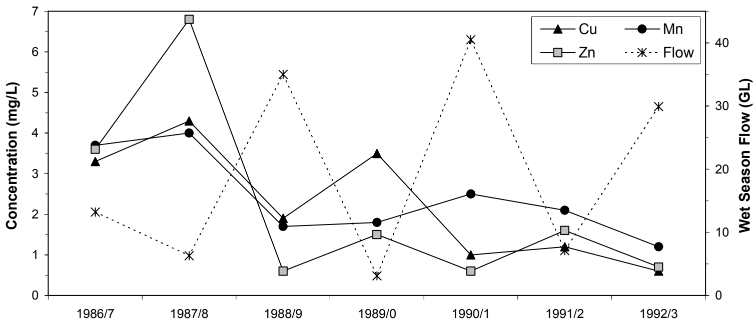

Fig.6. First flush metal concentrations, early wet season, versus total wet season flows.

Fig.7. Former Sweetwater Dam, July 2007; Note – the water and flow in the left photo is continuing seepage from White's waste rock dump (see Fig. 3) (photo's G M Mudd).

ND – not determined (no data). [a] Water quality values based on 95% species protection for fresh waters. [b] Value is for Cr^{6+} only. [c] Value is from the Ranger uranium project.

Groundwater

Groundwater remains the least monitored environmental component of the Rum Jungle site. Although some monitoring and assessment has been undertaken, the latter stages of the monitoring program did not include groundwater (see Pidsley 2002). It is important to note that there was no remediation of contaminated groundwater during the rehabilitation project, despite it being identified as heavily polluted and an ongoing source of pollutants.

The available groundwater monitoring data, shown in Fig. 8, suggests a linear relationship between pollutant concentrations and EC, with Cu and SO_4 generally extremely high. Given the nature of AMD, this relationship can be expected.

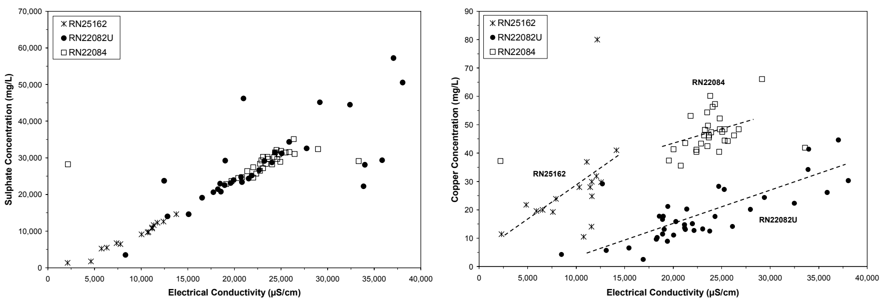

Fig.8. SO_4 (left) and Cu (right) concentrations versus electrical conductivity in 3 bores in the vicinity of White's waste rock dump (dashed lines indicative only).

Sediments

Concentrations of metals in streambed sediments have been examined, though only at specific times for a Finniss River profile. Some data has been obtained for sediment quality, while other data was obtained during ecological studies. The sediment data, Table 3, clearly shows the essentially background concentrations upstream compared to elevated levels downstream.

Biodiversity

The biodiversity in the Finniss River has been studied in the 1970's and again following rehabilitation works, mainly through fish diversity and abundance surveys and macroinvertebrate species and diversity studies (including benthic surveys and pollutant bioavailability and archival studies in mussels).

The original 1970's surveys established that the Finniss River immediately downstream of Rum Jungle was largely devoid of biota, with the first flush of wet

Table 3. Sediment quality profile along the Finniss River (East Branch), compared to current sediment quality guidelines (ANZECC and ARMCANZ 2000) (mg/kg dry weight).

Distance From Rum Jungle (km)		Ba	Cd	Co	Cu	Fe	Mn	Ni	Pb	U	Zn
Up-Stream	-18	58	0.05	5	17	5454	101	5	16	4	<DL
	-0.2	65	0.04	11	30	9221	230	5	15	2	<DL
	-0.01[a]	77	0.3	7	33	4326	201	3	10	3	<DL
Down-Stream	4	76	0.3	269	**3643**	12284	582	**371**	127	129	**1896**
	8	84	0.35	193	**1061**	8426	209	**191**	138	45	**1748**
	11	58	0.22	202	**404**	10510	551	**98**	37	17	112
SQG low[b]		ND	1.5	ND	65	ND	ND	21	50	ND	200
SQG high[b]		ND	10	ND	270	ND	ND	52	220	ND	410

<DL – less than detection limit. ND – not determined. [a] On upstream junction of East Branch with the Rum Jungle site. [b] For the sediment quality guidelines, 'low / high' means low / high probability of biological effects (that is, 'high' values would give rise to effects).

season rains being particularly problematic (Davy 1975). Following rehabilitation works, various biodiversity surveys have established a return of biota to the East Branch, with apparently lower overall bioavailable metal loads. In addition, recent research on Cu ecotoxicity to black-banded rainbow fish (*Melanotaenia nigrans*) from the Finniss River has suggested an evolving Cu tolerance to the mine leachates still emanating from the site (Gale et al 2003). Thus, overall biodiversity surveys suggest some measure of success, though this has to be moderated with the significant physical and chemical evidence of ongoing pollutant generation and release (eg. Fig.'s 3 and 7).

Discussion and Conclusion

As noted previously, the Rum Jungle rehabilitation project has been a critical case study on AMD pollution and remediation, especially for U mining. There is a common belief that the legacy of the Rum Jungle project has been addressed and rehabilitated satisfactorily (perhaps people who have not visited the site in recent years). The above review of the rehabilitation project and associated monitoring data raises a significant number of issues.

Despite the extent of reported monitoring and studies, critical gaps remain in facilitating a more hollistic and accurate picture of the ongoing pollution cycle at Rum Jungle. For example, samples upstream of the site are extremely rare, with the only known data being that obtained for biodiversity surveys – despite being a very common design in environmental monitoring and impact assessment studies. Sampling and monitoring is often insufficient in spatial / temporal scale to allow an accurate whole-of-site mass balance to be determined, meaning pollutant load accounting from primary source terms is difficult or impossible. In addition, there is possible groundwater discharge ~0.5-1 km downstream of GS8150200 (Fig. 4), potentially explaining spikes in SO_4 and Cu. Groundwater remains heavily contaminated and is very likely to be contributing to major pollutant loads in surface waters along with loads derived from White's open cut and all waste rock dumps.

The radiological characterisation and assessment of the site remains poor, despite clear evidence of extreme U concentrations in seepage from White's WRD and accumulated U in Finniss River sediments (Table 3).

The Rum Jungle remains a polluting site – as evidenced by the range of available monitoring data and recent site inspections. Annual pollutant loads remain 4-12 t Cu, 3-7 t Zn and 1,250-4,800 t SO_4 – although they could be seen as meeting rehabilitation objectives, they are clearly ecologically significant metal loads. Given that groundwater remains contaminated and waste rock dump infiltration is increasing, pollutant loads into the Finniss River can be expected to intensify in the future. The Rum Jungle U-Cu site, despite significant effort, has not met the test of time and remains a recalcitrant and polluting mine.

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