REHABILITATION OF THE RUM JUNGLE MINE SITE[1]

by

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Abstract. A rehabilitation program was carried out at the abandoned uranium/copper Rum Jungle mine site in the Northern Territory, Australia, between 1982 and 1986. The results of post-rehabilitation monitoring show that the surface water quality criteria have been met. There is some decrease in water quality of the flooded open cuts during the dry seasons but the quality improves with annual wet season flows. The covers on the waste rock dumps continue to limit the infiltration of water and the oxidation of pyrite.

ADDITIONAL KEY WORDS: Uranium; Copper; Acid mine drainage; Reclamation; Surface mining.

Introduction

The long term control of acid drainage and the release of heavy metals from abandoned mine sites can be a major environmental problem long after mine operations cease. Control of these pollutants is essential if mining is to be a temporary land use. It is important to establish the effectiveness of different rehabilitation programs so that the international community can benefit from the lessons learnt at different sites. This paper describes the rehabilitation of the Rum Jungle mine site and the results of monitoring in the two years since the completion of the rehabilitation works.

Rum Jungle Mine Site

Open cut mining to extract uranium/copper ore was carried out at Rum Jungle in the Northern Territory, Australia, between 1954 and 1964. Figure 1 shows a map of the location. The East Branch of the Finniss river flows through the site. Three main ore bodies were mined using open cut techniques. When the site was abandoned in 1971 there were three water-filled open cuts, four waste rock heaps (dumps) containing pyritic material, a tailings disposal area and a pile of low grade ore where an attempt had been made to extract copper by heap leaching, Figure 2.

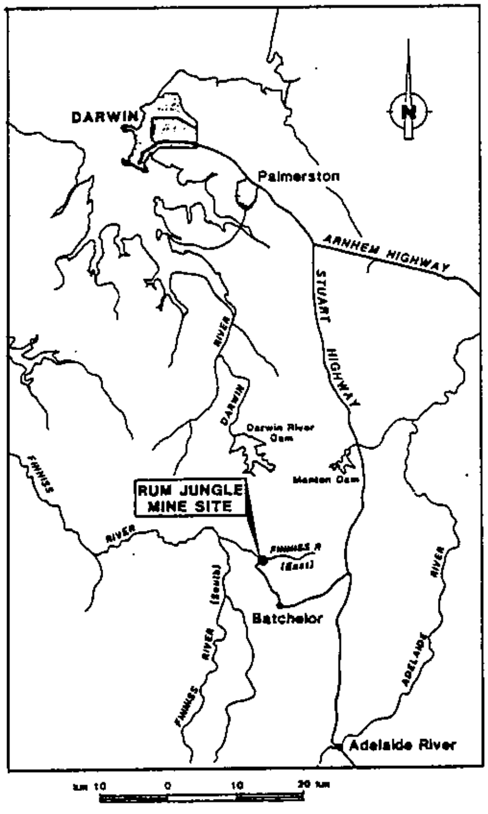

Figure 1. Location of Rum Jungle Mine Site

The largest of the open cuts was White's which was completed in 1958 at a depth of just over 100 m. The waste rock from this open cut was formed into a dump the top of which was

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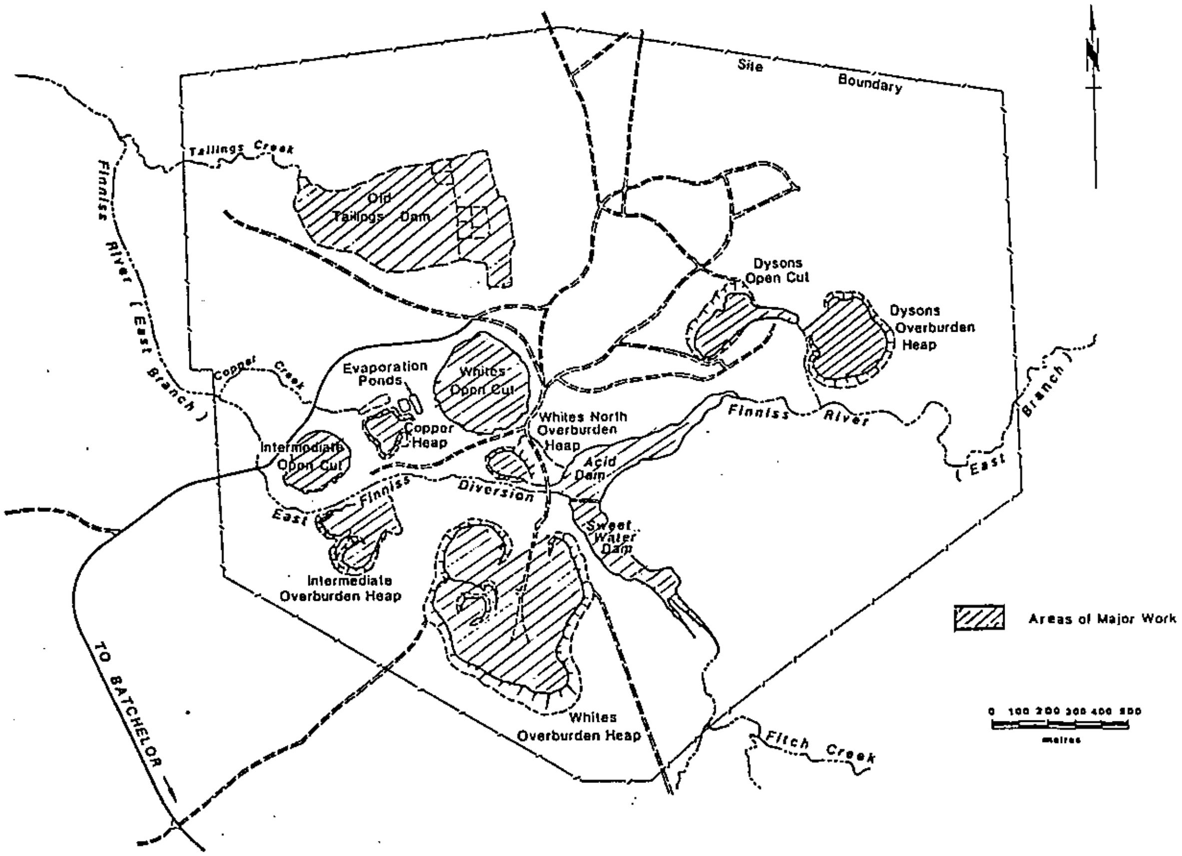

Figure 2. Site plan prior to rehabilitation.

some 13-18 m above the original ground surface and was generally smooth and well graded. The top surface sloped gently down towards the centre of the dump where a main drainage channel collected run-off. The sides were steep (about 30°) and made up about 25 percent of the 26.4 ha area of the whole dump.

White's overburden dump contains about seven million tonnes of material consisting of carbonaceous shales and graphitic schists with an average sulphur content of 3 per cent, mainly in the form of pyrite. Some dolomite is interspersed through the dump.

Dyson's ore body was mined between 1957 and 1958. The overburden dump was similar in shape and composition to White's but smaller with a content of about two million tonnes and an area of 9 ha.

In 1963, the Intermediate ore body, which was only about 500 m west of White's ore body, was also extracted by an open cut operation. This ore body was mined for its copper content not its uranium content. The waste rock dump had an area of about 7 ha and contained about two million tonnes of material with a similar composition to that in White's dump. The oxide and low grade sulphide ore from the ore body were placed in a heap leach pile where an attempt was made to extract the copper by heap-leaching techniques.

Significant pollution of ground and surface waters with acid and heavy metals was apparent when mining operations ceased. An extensive survey in 1973-74 [Davy, 1975] showed that the major sources of pollution were the waste rock dumps and the heap leach pile, copper being the main heavy metal pollutant.

It should be emphasised that the environmental impact of the post-operational phase of the Rum Jungle mine came more from the association between its ore and pyritic material than from uranium in the ore.

Rehabilitation Objectives and Strategy

The Rum Jungle mine site was rehabilitated between 1983 and 1986 by the NT Department of Mines and Energy (NTDME) using money provided by the Commonwealth Government. The total cost was $(Aust)18.6 million of which $2.8 million was spent rehabilitating the three waste rock dumps (NTDME 1986).

The objectives stated in the 1982 agreement between the Northern Territory and the Commonwealth Governments were: a major reduction in pollution in water courses feeding the East Branch of the Finniss River and in particular the reduction of the annual average releases of copper, zinc and manganese into the river by 70 per cent, 70 per cent and 56 per cent respectively; a reduction in public health hazards and in radiation levels at the site; a reduction of pollution in the water contained in White's and Intermediate open cuts; and aesthetic improvement including revegetation.

The strategy adopted for the waste rock dumps was based on the premise that a reduction in infiltration of rain water into the dump material would reduce the pollution load to groundwater and from there to the East Branch. The strategy was implemented by covering the dumps with a three layer system: the first a compacted clay layer to act as a moisture barrier; the second a layer of sandy loam as a moisture retention zone to support vegetation and prevent the clay layer drying out; while the uppermost layer was gravelly sand to provide erosion protection and act as a pore breaking zone to restrict moisture loss by evaporation in the dry season. Before the layers were put in place the dumps were reshaped so that the tops had a maximum slope of 5° and the sides a maximum slope of 1 in 3. On the top of the dumps the layers had minimum thicknesses of 225 mm, 250 mm and 150 mm while on the sides they had minimum thicknesses of 300 mm, 300 mm and 150 mm. On the sides crushed rock replaced gravelly sand as the erosion barrier.

Engineered runoff channels and erosion control banks were constructed on the tops and sides of the dumps. Vegetation was established to stabilise the dump surface against the long-term effects of erosion.

The tailings from the tailings area together with any contaminated subsoil were removed and dumped into Dyson's open cut. A rock blanket was constructed on a geotextile fabric over the placed tailings to provide a drainage path for pore water. The material from the heap leach pile was dumped on top of the rock blanket. This strategy meant that the tailings were well contained and the heap leach material was above the water table. The filled open cut was covered with the same three layer system used for the waste rock dumps.

A water treatment plant was built to treat the polluted water in both White's and Intermediate open cuts using lime neutralisation. The difference in density between the water in White's open cut and the treated water meant that it was feasible to return the treated water to form a stratified layer above the polluted water in the open cut. White's open cut was treated to a depth of 22 m.

The density of the polluted water in the Intermediate open cut was less than that in White's and it was not possible to use stratification to separate the treated water from the polluted water. The polluted water in Intermediate was treated in situ by direct addition of hydrated lime, with the subsequent removal of the precipitated sludge from the bottom of the open cut.

After the open cuts had been treated the East Branch of the Finniss River was redirected to its original channel through both open cuts. A set of weirs was constructed to limit flow through the open cuts by directing low flow and a large fraction of flood flow down the diversion channel. This annual flushing of the open cuts is designed to prevent the build-up of acidity and metals.

In addition to the main problem areas at the site, revegetation and earthworks were carried out on the river banks, stockpile areas, and borrow pits.

Surface Water

The main gauging station for evaluating the surface water quality from the mine is GS8150097 which is downstream of all mine pollution input. The location of the station is shown in Figure 3. Water samples collected at GS8150097 consisted of twelve, two-hourly samples, each being a composite of three samples taken at 40 minute intervals using an automatic sampler. A daily composite was prepared according to the average discharge for the twelve two hour periods. Water samples were analysed for pH, specific conductance, copper, manganese, zinc and sulphate concentrations. Separate samples were collected for radium analysis.

Daily rainfall was measured using two pluviometers at the locations shown in Figure 3.

As stated above, one objective of rehabilitation was to reduce the annual loads of copper, manganese and zinc in the East Branch. The pollutant load in the East Branch is known to be very dependent on the total annual

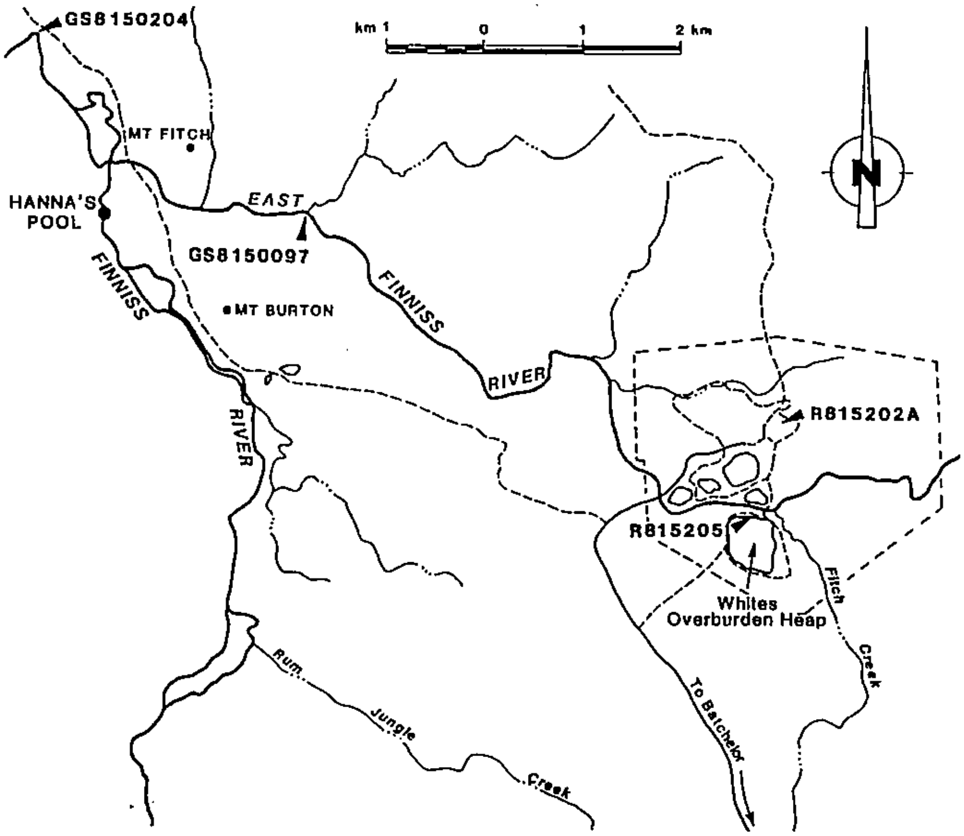

Figure 3. Locations of gauging station GS8150097 and pluviometers, R815202A and R815205.

discharge. Hence the water quality objective has been interpreted to mean that the reduction refers to years of similar river flow.

Figure 4 compares the load of copper in the East Branch during and since rehabilitation to the loads measured before rehabilitation between 1971 and 1973. Since the completion of rehabilitation in 1986 all of the wet seasons have had a very low rainfall and hence a low river discharge. Nevertheless the copper load, and the load of other pollutants, is much less than that indicated by the pre-rehabilitation relationship. In the 1987-88 wet season the pollutant loads were copper 3.2 t, manganese 5.4 t, zinc 2.0 t and sulphate 1230 t. These loads indicate reductions of 90, 90 and 80 per cent for copper, manganese and zinc respectively from the pre-rehabilitation annual load vs discharge relationship.

The maximum daily concentrations for copper, manganese, zinc and sulphate in 1987-88 were 4.4, 4.0, 6.9, and 950 mg/L. All these maxima occurred at the start of the wet season at very low flows when most of the flow comes through the diversion channel. The high level of pollutants at this time is thought to arise from the dissolving of residual salts in the water courses and the rising of the polluted water table; a first flush effect.

Surface water qualities have been measured at various locations around the site to estimate the contribution of different sources to the pollution load. In the 1987-88 wet season the open cuts contributed 65, 58, 3 and 48 per cent of the copper, manganese, zinc and sulphate leaving the site.

An above-average wet season is needed to fully test the integrity of the engineering works and the pollutant load under high flow conditions.

Open Cuts

Water quality profiles have been measured throughout the wet season. The results confirm that the open cuts, particularly White's, are major contributors to copper and manganese pollution in the East Branch of the Finniss River.

The water quality in the top 29 m of White's open cut improves during the wet season as a result of the flow of better quality water across the open cut. The top 29 m lost about 9 t of copper and 15 t of manganese. The difference in the pollutant concentrations between the relatively unpolluted water flowing into the open cut and the more polluted water flowing out from the open cut only accounted for about 2 t of the copper and 2.5 t of the manganese. It appears

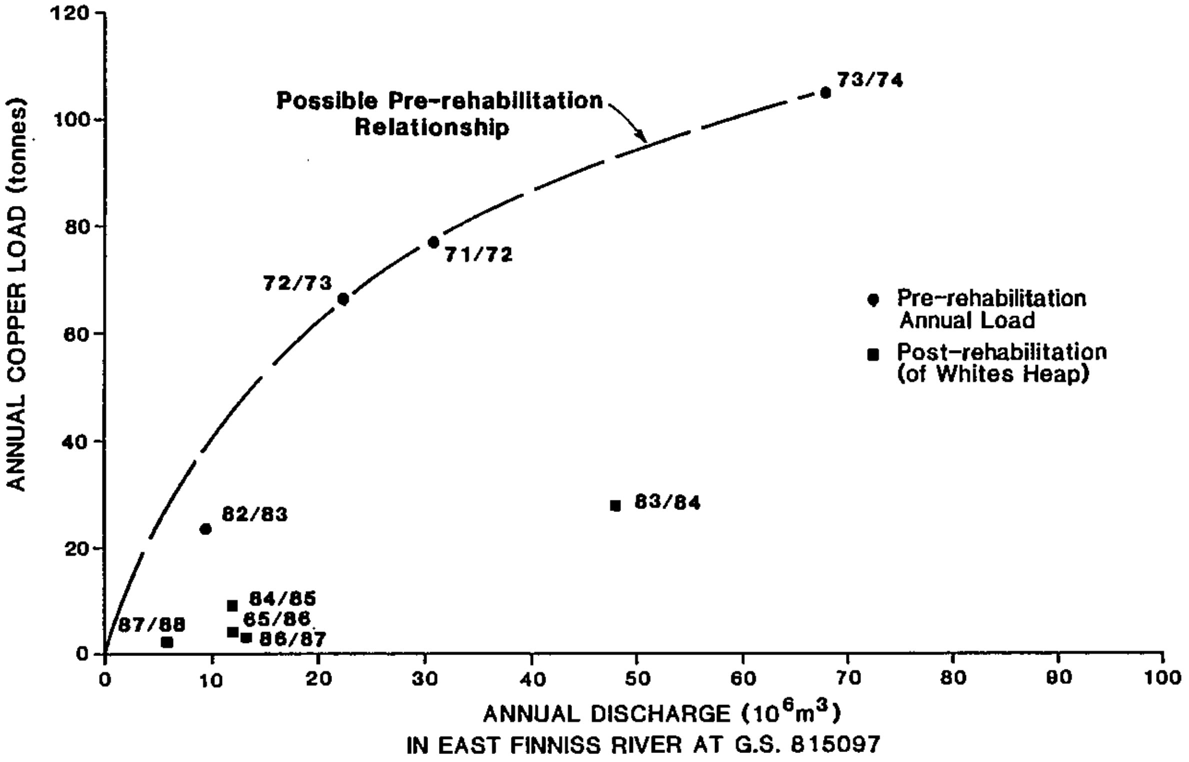

Figure 4. Annual copper loads in East Branch versus annual discharge for various years.

that the high pH water entering the open cut causes precipitation of dissolved heavy metals that sink towards the bottom where they redissolve in the lower pH bottom water.

The water in the top 30 m of Intermediate open cut has been largely replaced by overflow water from White's open cut.

The level of pollutants increases in both open cuts during the dry season probably due to mixing caused by thermal effects and wind action and due to polluted groundwater entering the open cuts.

Overburden Dumps

The main aim of covering the dumps was to reduce ingress of water and thereby reduce the release of pollutants. Sets of lysimeters were installed in the reshaped White's and Intermediate dumps before emplacement of the clay layer. The amount of water collected by the lysimeters in White's dump in each of the three wet seasons between 1985 and 1989 is equivalent to less than 2.5 per cent of the incident rain. That collected in lysimeters in Intermediate dump corresponds to less than 5 per cent of the incident rain. These infiltrations are much less than the 50 per cent of the incident rain which percolated through the dumps before rehabilitation and indicates that the compacted clay cover achieved the desired reduction to 5 per cent or less of incident rain.

Probe holes have been drilled down to the original ground surface in White's and Intermediate dumps to provide access for measuring temperature, gas composition and water content.

Heat Production

Before rehabilitation, the temperatures at some locations within the dumps exceeded 50°C, Figure 5. The elevated temperatures were caused by the release of heat in regions where pyritic oxidation was occurring. A one-dimensional heat transfer model has been used to derive the distribution of heat production in the dumps from vertical temperature profiles measured before and after rehabilitation (Harries and Ritchie 1980, 1987). The rate of oxidation of pyrite can be obtained directly from the heat source distribution using the heat of reaction.

Before rehabilitation, heat production was occurring in White's dump at depth in many locations. After rehabilitation, the heat production was either very low or zero at all measuring locations, Figure 5. Comparison of heat production distributions before and after

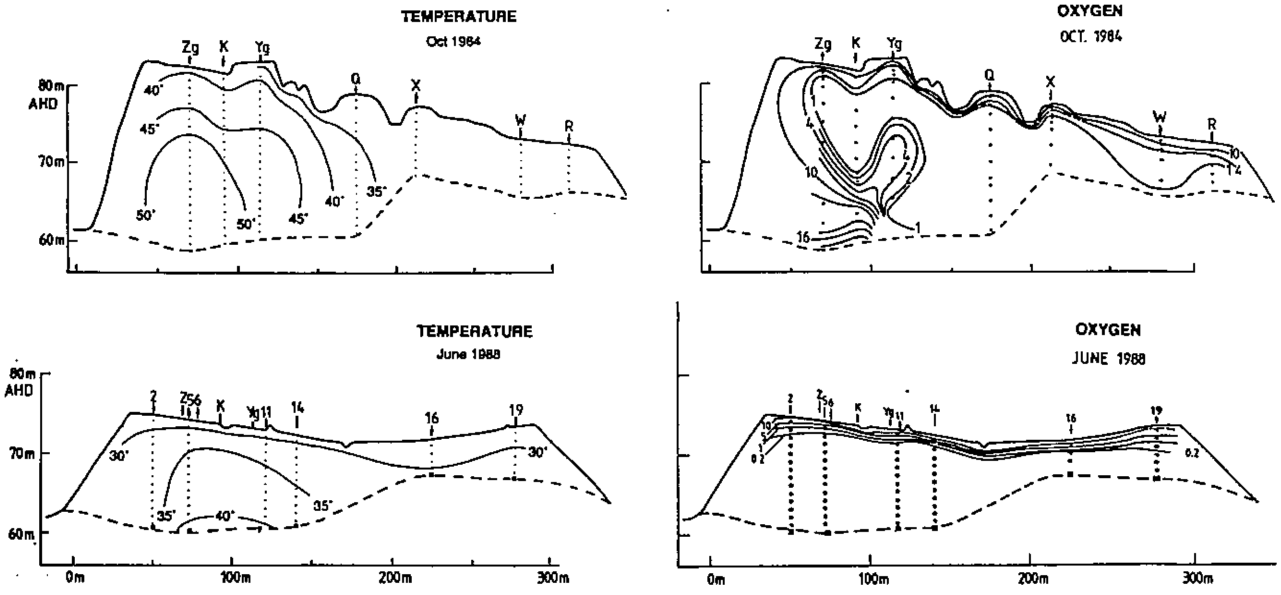

Figure 5. Temperature and oxygen distributions in Intermediate dump before (Oct 1984) and after (June 1988) rehabilitation. Temperature contours are marked in °C and oxygen contours in percent oxygen (by volume)

rehabilitation shows that the oxidation occurring before rehabilitation was effectively stopped by rehabilitation.

Pore Gas Composition

The supply of oxygen was the main process limiting the rate of oxidation in the Rum Jungle waste rock dumps before rehabilitation. Measurements of oxygen concentration in the pore gas showed that oxygen was transported to the oxidation sites by a combination of diffusion, thermal convection, and advection driven by variations in atmospheric pressure (Harries and Ritchie 1985).

Each of the oxygen transport processes leads to a characteristic oxygen concentration profile. Thermal convection causes the oxygen concentration to be higher near the base of the dump. Diffusion causes the oxygen concentration to decrease monotonically with depth. Advection driven by variations in atmospheric pressure leads to short-term changes in oxygen concentration over timescales of less than a day.

At tropical locations like Rum Jungle, the dominant atmospheric pressure variations are atmospheric tides which have two maxima and two minima a day. Increasing pressure causes air to flow into the pore space and, because the incoming air has a higher oxygen content than air already in the dump, the oxygen concentration measured at a given point increases. This can cause diurnal variations in the oxygen concentration at a given point in the dump with two maxima and minima a day.

The emplacement of the compacted clay covers greatly reduced the level of oxygen in most regions of the dumps. Figure 5 shows the temperatures and oxygen concentrations in Intermediate dump before and after rehabilitation. Before rehabilitation there was a tongue of oxygenated air at depth in both dumps which indicated that thermal convection was transporting oxygen in from the sides of the dumps and up through the hot regions. Since rehabilitation, the oxygen concentrations at depth have been low. The clay cover effectively stopped oxygen transport by thermal convection.

The oxygen concentrations were found to be low in the dry season and there was no diurnal variation. In the wet seasons oxygen concentrations were still generally low but diurnal variations reappeared near the surface early in the wet season. This is taken to indicate that there were some cracks in the clay layer in the dry season with the cracks providing paths over the whole dump surface for advection of air by atmospheric pressure variation. The reappearance of the diurnal variations in the wet season indicates that most of the cracks closed as the moisture content of the clay increased but the clay near the monitoring holes did not seal as well as that further away.

Groundwater

Intensive groundwater monitoring at the site started in mid 1983. Since that time the number of boreholes has increased to a total of 70 boreholes, with about 35 in the vicinity of White's dump. This overburden dump was the major source of pollution before rehabilitation and groundwater was the principal pathway for the transport of the pollutants to the East Branch.

The monitoring data show that the concentration of pollutants in 1988 in the groundwater close to the dumps was substantially the same as before rehabilitation. The reduced infiltration of rainwater into the dump indicates that there is a reduction in the flow of groundwater from the dump and hence a reduction in the pollutant load. It is calculated that there is a large store of pollutants held in the pore space and that it could take 10 to 20 years for this store to be depleted (Gibson and Pantelis 1988).

Vegetation Establishment

Revegetation at the site was undertaken using introduced tropical pasture species following the completion of the earthworks and at the commencement of the wet season.

The long term stability of the rehabilitated site and the integrity of the earthworks depends on maintaining a sound vegetation cover to minimise erosion of the surfaces.

Monitoring of the vegetation since the 1984 has indicated marked changes in species composition of the revegetated surfaces. Initially the pasture grasses dominated, but with each successive wet season there has been an increase in both introduced legume species and naturalised/native colonisers from the surrounding land. Most of the introduced species achieve two to three seed sets each wet season ensuring an ever increasing seed bank in the soil.

Vegetation cover on the rock mulched batters commenced slowly but after five wet seasons nearly 50 per cent of the larger batters are vegetated. This is expected to continue as the surficial erosion washes soil between rocks and creates a suitable seed bed on the batters.

Some of the revegetated surfaces have been subjected to fire during the dry season but recovery of the pasture in the wet season has been very satisfactory. Colonising of the surfaces with native tree and shrub species has not been vigorous, with the exception of *Acacia* species and fire has slowed their expansion.

After five years the surfaces appear quite stable and soil erosion has not been a significant problem. Some stability problems have been experienced with rip-rap drains, usually where design criteria were not strictly adhered to during construction

Conclusions

Monitoring at Rum Jungle has shown that rehabilitation of the site has been successful.

Monitoring is an important part of rehabilitation because it tests the success of the work in meeting design criteria. Monitoring for the two years following completion of the earthworks was costed as part of the Rum Jungle project. The results from monitoring will allow the cost-effectiveness of the Rum Jungle rehabilitation project to be assessed and used as a benchmark for rehabilitating other mine sites where there are pyritic wastes.

The data obtained to date show the importance of continuing to monitor the site for an extended period. It is planned to continue to monitor surface water, groundwater and oxidation in the dumps for the next five years (Verhoeven 1988). This extended monitoring program will involve less frequent measurements than between 1986 and 1988 but should be sufficient to identify trends and determine the long-term effectiveness of the rehabilitation works.

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