

REHABILITATION OF WASTE ROCK DUMPS AT THE RUM JUNGLE MINE SITE¹

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Abstract. --The release of acid, copper, manganese and zinc was a major environmental problem at the abandoned Rum Jungle mine site in the Northern Territory, Australia. The main sources of pollution were the three waste rock dumps and the heap leach pile, all containing pyritic material. The site was rehabilitated between 1982 and 1986 and, as part of this program, the dumps were reshaped and covered with a three-layer cover, including a compacted clay layer. A monitoring program has been carried out to assess the effectiveness of the works on two of the dumps. Lysimeters installed in the dumps have shown that less than 5 % of the incident rain percolates through the covers. The distribution of heat production in the dumps has been derived from measured temperature distributions and shows that the rate of pyritic oxidation was greatly reduced by emplacement of the covers. Comparison of oxygen concentrations in the two dumps before and after rehabilitation shows that the covers have greatly reduced the transport of oxygen into the dumps and effectively stopped thermal convection.

INTRODUCTION

There are many surface mine sites where acid drainage and the release of heavy metals create a major environmental problem which can continue long after mine operations cease. The problems of acid drainage occur at many mine sites around the world. There is an urgent need to know the effectiveness of techniques for controlling the release of these pollutants. At present there is inadequate knowledge and experience to allow the advantages, disadvantages and costs of various rehabilitation techniques to be compared.

Opencut mining to extract uranium/copper ore was carried out at the Rum Jungle mine in the Northern Territory, Australia, between 1954 and 1964, and the site was abandoned in 1971. However acid, copper, manganese and zinc continued to be released into the local river system (Northern Territory Department of Mines and Energy, NTDME 1987). The climate

at the site is tropical with most of the 1.5 m annual rainfall occurring in the wet season from December to March.

The main sources of pollution were the three waste rock dumps and an abandoned heap leach pile, all containing pyritic material which oxidised in the presence of oxygen and water to produce sulfuric acid and heavy metal salts. These pollutants were leached by rainwater percolating down through the dumps and carried by groundwater to the river. Other sources of pollution were three opencuts, two filled with polluted water and one largely filled with tailings. The site was rehabilitated between 1982 and 1986. This paper discusses the results from monitoring two of the dumps (White's and Intermediate) and compares conditions before and after rehabilitation. Gibson and Pantelis (1988, elsewhere in these proceedings) describe the groundwater monitoring being carried out at the site.

Probe holes were drilled down to the original ground surface in White's and Intermediate dumps (fig. 1) to provide access for measuring temperature, gas composition and water content. Three types of liner have been used. Type "n" holes (six on White's and two on Intermediate dumps) are lined with a 50 mm i.d. polyethylene pipe and sealed at the bottom to exclude water. Type "g" holes have gas ports inset into the liner at depths of 0.5, 1.0, 1.5, 2.0, 3.0, 5.0 m and then at 2.5 m intervals to the bottom of the hole. Type "p" holes have pairs of gas sampling tubes attached to the outside of the polyethylene liner to directly sample the gas in gravel-filled zones at each meter down the hole.

The first drilling program was in 1976 when six n-holes were installed in White's dump. In 1982 three g-holes were

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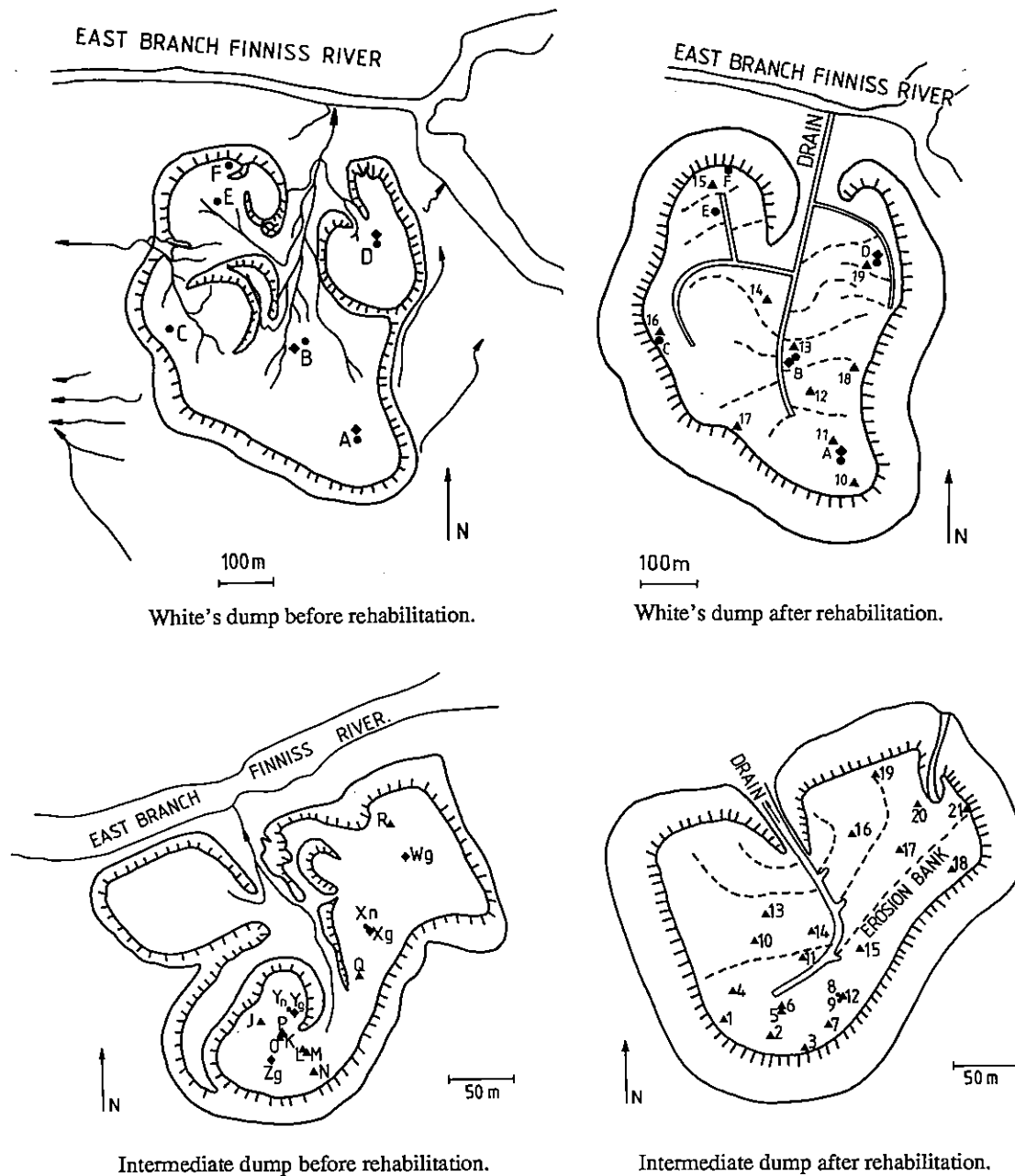


Figure 1. --White's and Intermediate dumps showing positions of probe holes before and after rehabilitation. The n-holes are shown as circles, the g-holes as diamonds, and the p-holes as triangles.

installed in White's dump. The holes in White's dumps were preserved during the earthworks which took place on White's between August 1983 and June 1984, although the length of the liners of most holes had to be adjusted to conform with the recontoured dump. Finally ten p-holes were installed in White's dump in June 1987 (fig. 1).

The first drilling program on Intermediate dump was in 1982 when four g- and two n-holes were installed. In 1984, nine p-holes were installed in Intermediate dump to provide more information on temperature and pore gas composition profiles before rehabilitation. All the holes in Intermediate dump were lost when Intermediate was rehabilitated between August and December 1985. Nineteen new p-holes were installed in Intermediate dump in November and December 1985 after the earthworks on the dump were completed (fig. 1).

REHABILITATION

The Rum Jungle site was rehabilitated between 1983 and 1986 to reduce the level of pollutants in the river, reduce public health hazards, reduce pollution levels in the flooded open cuts, and achieve aesthetic improvements including revegetation (NTDME 1987). The total cost was \$(Aust)18.6 million of which \$2.8 million was spent rehabilitating the three waste rock dumps (in June 1986 \$(Aust)1.00 = \$(US)0.68). The areas of White's, Intermediate and Dyson's dumps before rehabilitation were 26, 6.9 and 8.4 ha respectively.

The treatment applied to the waste rock dumps was designed to reduce the ingress of water and the release of pollutants. First the dumps were reshaped so that the tops had a maximum slope of 5° and the sides a maximum slope of 1

in 3 horizontal. The tops were then covered with a three-layer cover consisting of a layer of compacted clay (minimum thickness 225 mm) on the bottom as a moisture barrier, a layer of sandy clay loam (minimum thickness 250 mm) as a moisture retention zone to support vegetation and prevent the clay layer drying out, and a layer of gravelly sand (minimum thickness 150 mm) on the top to provide erosion protection and act as a pore breaking zone to restrict moisture loss by evaporation in the dry season. A similar three-layer cover was emplaced on the sides of the dumps, but the layers were thicker (minimum thickness 300 mm of compacted clay and minimum thickness 300 mm of sandy clay loam) and crushed rock was used for the erosion barrier (minimum thickness 150 mm). 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.

HEAT PRODUCTION

The oxidation of pyrite to sulfuric acid and ferrous sulfate is exothermic and releases $1440 \text{ kJ mol}^{-1} \text{ FeS}_2$. It is unlikely that there are other reactions occurring which release significant amounts of heat. The released heat causes elevated temperatures in the regions where pyritic oxidation is occurring. Before rehabilitation, the temperatures at some locations within the dumps exceeded 50°C . 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 holes A, C, D and F (fig. 2). After rehabilitation, the heat production was either very low or zero in all holes, with the possible exception of hole C. Comparison of heat production distributions before and after rehabilitation shows that the oxidation occurring before rehabilitation was effectively stopped by rehabilitation.

PORE GAS COMPOSITION

Before rehabilitation, the supply of oxygen was the main process limiting the rate of oxidation in the Rum Jungle waste rock dumps. The oxygen profiles 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 these 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 the atmospheric pressure leads to short-term changes in the oxygen concentration over timescales of less than 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

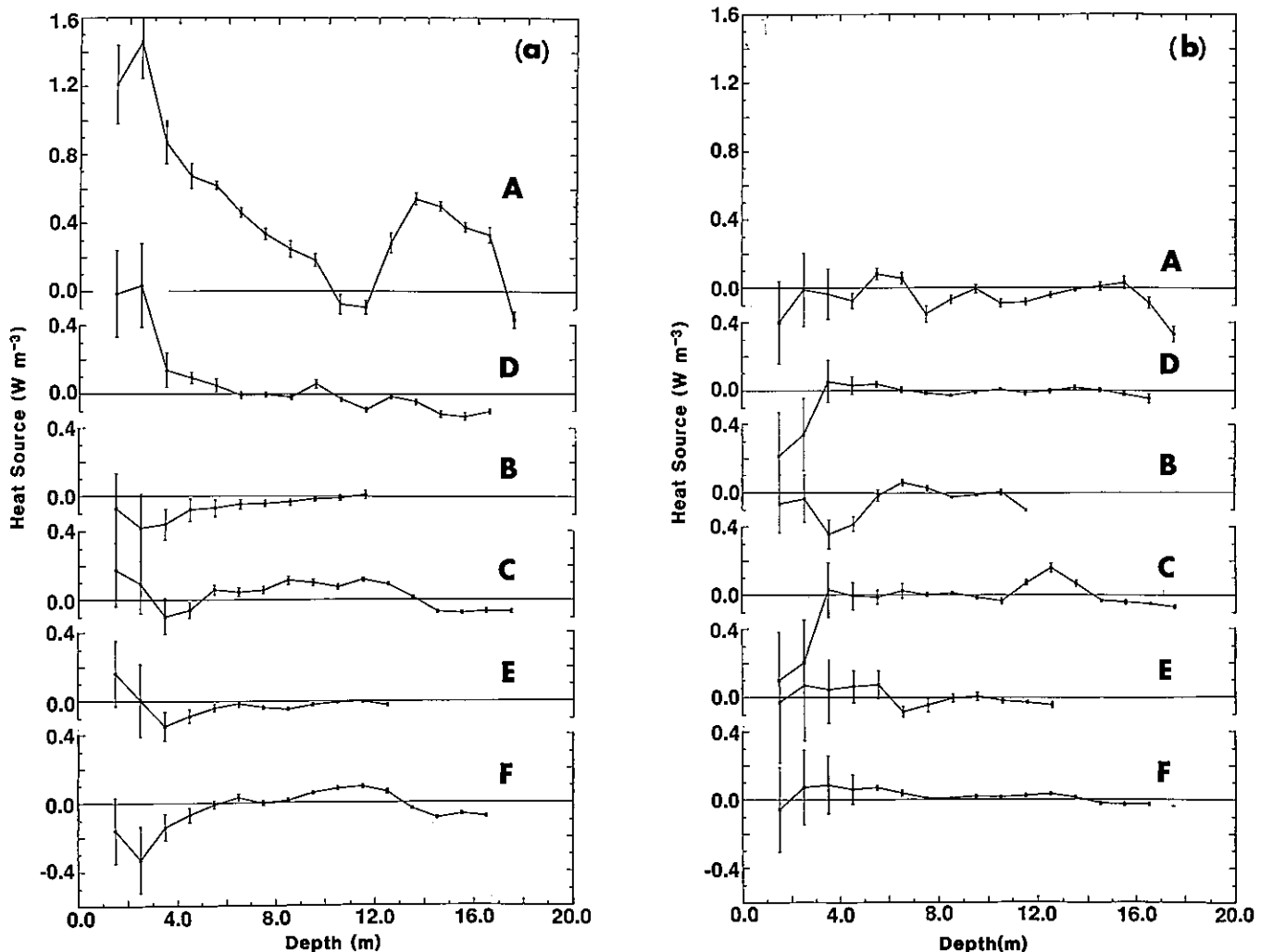


Figure 2. --Heat sources profiles derived from temperature profiles measured in White's dump (a) before rehabilitation (Mar 1979 - Sep 1983), (b) after rehabilitation (Dec 1984 - Sept 1986).

oxygen concentration measured at a given point increases. At tropical locations like Rum Jungle, the dominant atmospheric pressure variations are atmospheric tides which have two maxima and two minima a day. This causes the oxygen concentration at a given point in the dump to have two maxima and two minima a day.

Carbon dioxide concentrations measured in the dumps tended to be anticorrelated with the oxygen concentrations. This suggests that the controlling process was the rate of exchange between the interstitial gas and the atmosphere; the lower the exchange rate between the interstitial gas and the atmosphere the greater the time for the oxygen to be used in the oxidation process and the smaller the opportunity for carbon dioxide to escape into the atmosphere.

The air permeability in the rehabilitated Intermediate dump is high near the surface, lower at mid-depth, and increases at some locations near the base.

The oxygen concentration in the pore gas decreased soon after the installation of the compacted clay cover. Figures 3 and 4 show the distribution of oxygen in Intermediate and White's dumps before and after rehabilitation. The tongue of oxygenated air evident at depth in both dumps before rehabilitation indicates that thermal convection was transporting oxygen from the sides of the dumps and up through the hot regions. Since rehabilitation, the oxygen concentrations have been low at depth at all measuring points except in the northwest corner of White's dump where there are very low levels of pyrite. The clay cover effectively stopped oxygen transport by thermal convection, and greatly reduced diffusion and atmospheric pressure-driven advection.

However, after the covers had been in place for about a year, the oxygen concentrations in the top few meters were found to increase in the morning and evenings in the wet season (fig. 5). This behavior is characteristic of advection driven by variations in atmospheric pressure. The fact that these elevated oxygen concentrations were only present in the wet season can be explained by considering the effect of seasonal changes in the permeability of the compacted clay cover on the transport of air into the dump both near and away from the holes. If the clay near the holes was not as well compacted as the clay further from the holes, airflow caused by variations in the atmospheric pressure would tend to be concentrated in the higher permeability material near the holes.

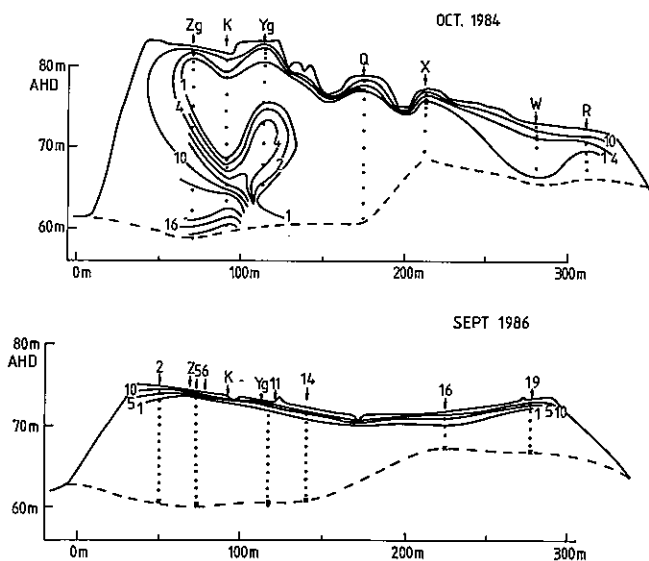


Figure 3. --Oxygen distributions in Intermediate dump (a) Oct 1984 before and (b) Sept 1986 after rehabilitation.

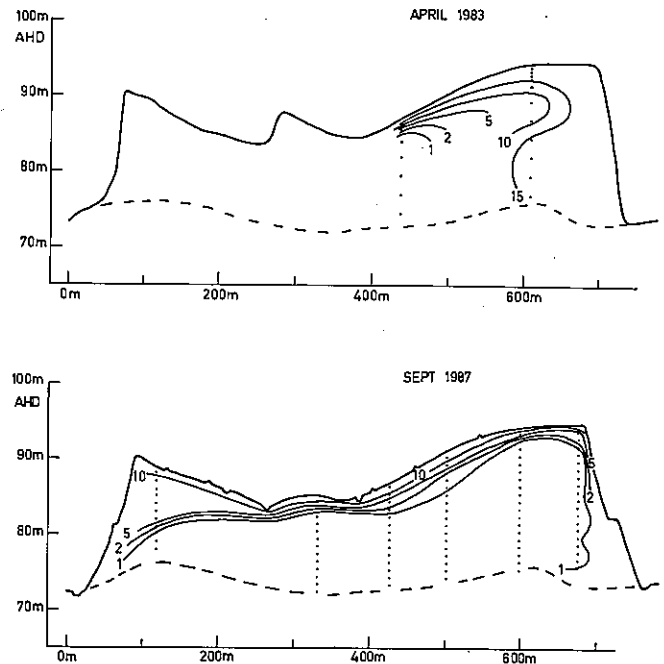


Figure 4. --Oxygen distributions in White's dump (a) Apr 1983 before and (b) Sept 1987 after rehabilitation.

The low oxygen concentrations and the lack of diurnal variation in the dry season indicate that the clay near the holes has a similar permeability to that of the clay further away. This suggests that there is cracking of the clay layer in the dry season, and that the cracks provide paths over the whole surface for advection of air by atmospheric pressure variations. The reappearance of the diurnal variations in the oxygen concentrations early in the wet season shows that most of the cracks close

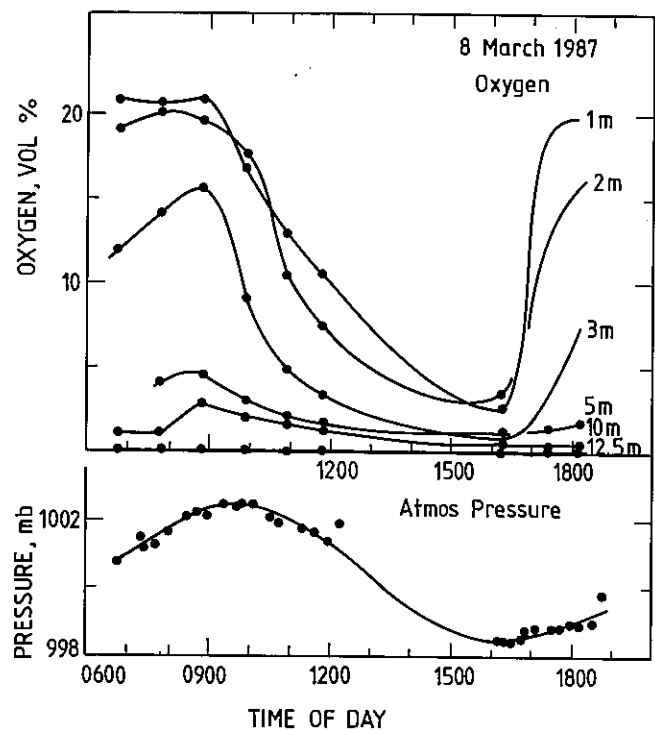


Figure 5. --Diurnal changes in the oxygen concentrations at various depths in Hole 2 in Intermediate dump during the wet season.

as the moisture content of the clay increases, but the clay near the holes does not seal as well as that further away.

Oxygen concentrations at depth in the dumps continue to be much less than they were before rehabilitation. The compacted clay cover does appear to have stopped oxygen transport by thermal convection.

WATER BALANCE

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 lysimeters consist of 200 L drums with pipes to allow any water collected to be extracted and measured. The drums are filled to 300 mm with gravel to make a water collection zone and the rest of the space is filled with dump material. Theoretical models of unsaturated waterflow have been used to verify the effectiveness of the lysimeters in collecting infiltrating water (Gibson 1987).

The amount of water collected by the ten lysimeters in White's dump in each of the three wet seasons between 1985 and 1987 is equivalent to between 2.0 and 2.5% of the incident rain. Lysimeters in Intermediate dump have only been operational for one wet season and the amount of water collected corresponds to 4.8 % of the incident rain. Before rehabilitation it was estimated that about 50% of the incident rain percolated through the dumps. These results indicate that the compacted clay cover is achieving the desired reduction in water ingress.

CONCLUSIONS

Monitoring the waste rock dumps at Rum Jungle has shown that rehabilitation by reshaping and covering with compacted clay has been effective in greatly reducing the ingress of water, the rate of oxidation of pyrite and the transport of oxygen. Further monitoring will be necessary to check that the reduction in pollution generation and water infiltration rates continue in the longer term.

The monitoring program on the waste rock dumps has allowed a quantitative assessment to be made of the effectiveness of the techniques used to reduce pollution loads from dumps. A more complete quantitative assessment will be possible when the effects of rehabilitation on ground and surface waters have been determined. However, it was recognised that improvements in the quality of ground and surface water at the mine site could take some years (Pantelis 1987, Gibson and Pantelis 1988). The lysimeters and gas composition

measurements on White's dump in particular were seen as a means of acquiring early evidence of any gross shortcomings in the rehabilitation strategy which would allow the strategy to be applied to the other dumps to be modified if necessary. The reduced ingress of water and the low or zero oxidation rate (pollution generation rate) gives confidence that the release of pollutants from the waste rock dumps has decreased.

Monitoring was considered to be an important part of the Rum Jungle rehabilitation project and it was costed as part of the project. As well as the program on the waste rock dumps described in this paper, there are monitoring programs on groundwater, surface waters and vegetation. The results from all these programs will allow the cost-effectiveness of the Rum Jungle rehabilitation project to be assessed and used as a benchmark for other projects to rehabilitate mine sites where there are pyritic wastes.

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