FORECASTING THE EFFECT OF MINE SITE REHABILITATION WORKS ON LOCAL GROUND WATER QUALITY[1]

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Abstract.--A large rehabilitation project has been carried out on an abandoned uranium mine at Rum Jungle in the Northern Territory of Australia where oxidation of pyritic mine wastes has led to substantial water pollution. This pyritic oxidation has been halted by the exclusion of air and water from two rock heaps by contouring and installing a clay cap. Ground water levels and quality have been monitored for acidity and dissolved metals over the four years since the project began. Although the contaminant input to the local river has dropped markedly, there has been no significant change in ground water quality. The purpose of this work is to estimate the time scale over which an improvement might be expected to occur. A model in which the main store of pollutant is assumed to be the contaminated water below the heap leads to the very low estimate of less than four years. A more complex model which accounts for contaminants stored in pore water held within the dump produces an estimate, so far consistent with observation, of 20 years. The possibility of heavy metals being stored in the form of a buffered precipitate cannot be excluded. Thus, the importance of continuing the monitoring of the site is emphasised.

INTRODUCTION

Rum Jungle is on the East Finniss River, about 70 km south of Darwin in the Northern Territory of Australia. From 1954 to 1971 it was the site of a mining operations where uranium and copper were extracted by opencut mining. The East Finniss River was significantly contaminated by heavy metals during mining, and this continued after the mine was abandoned. The mean concentrations of the metals in the river were a few mg/l, but owing to the strong seasonal variation in the rainfall, the actual concentrations varied widely, being rather high at the periods of small flow at the beginning and end of the wet season. The average rainfall is about 1.5 m/y falling mainly in a wet season over the period October to April.

During the 1970s the environmental problems of the site were investigated to elucidate the nature of pollution caused by mining. It was demonstrated that most of the heavy metal pollution arose from three large overburden dumps (one of 7 million tonnes and two of 2 million tonnes) and a heap leach pile, in which pyrite was oxidising, catalysed by bacteriological activity (Harries and Ritchie 1987). Heavy metals in the pyritic rock were solubilised in this process and were eventually transported by water movement into the river system.

The rehabilitation works were carried out from 1983 to 1985. The tailings were disposed of in one of the three opencut pits. The water in the other two pits was treated, the pH being raised from about 3.5 to 7.5, with consequent precipitation of the dissolved heavy metals. The tops of the waste rock heaps were contoured and capped with layers of clay, loam, and sandy gravel with total thickness of about 600 mm (Northern Territory Department of Mines and Energy 1986(a)). The dumps were vegetated with a mixture of grasses and legumes, and erosion was controlled with a system of bunds and rock drains. The sides of the heaps were sloped at a maximum of 1 in 3 and faced with rock.

The clay cover was designed to reduce the infiltration of water through the heaps. Measurements with collection lysimeters have shown that the infiltration of rain water has been reduced to less than 10% of its former value. Measurements of the oxygen levels and heat generation in the dumps

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have shown the pyritic oxidation has also been greatly reduced (Harries and Ritchie 1987). Two overburden heaps were selected for intensive study. The ground water in their vicinity was monitored by about 30 boreholes for the purpose of estimating the rate at which the quality of the ground and surface water could be expected to improve over the coming years following the cessation of pollutant generation.

MODEL OF POLLUTANT RELEASE FROM BELOW WASTE ROCK HEAP

Estimated pollutant release was based on a simple two-dimensional model applied to the White's heap, the largest waste rock heap. This heap extends for about 600 m along a gently sloping ridge. It is about 20 m high and 600 m wide. The ridge continues for some 200 m upslope of the dump to a water divide at the top of the hill. The underlying ridge has a permeable layer of soil about 2 m thick sitting on fairly impermeable rock. This is shown in schematic form in figure 1, in which the x-axis coincides with the fall of the ridge.

The water in the aquifer below the dump is a reservoir of dissolved heavy metals, generated before the clay cap was installed. This contaminated water will be flushed out as rainfall recharges the aquifer upslope of the heap. An estimate of the time taken for this flushing process should provide a lower bound for the time before any improvement in ground water quality can be expected as other processes, such as the flushing of contaminated water stored in the unsaturated zone in the dump itself, will add to this time.

Assuming steady-state conditions, we can calculate a water table height by using the Dupuit-Forscheimer equation (Bear 1972). If the phreatic surface is represented by $\phi(x)$, the base of the aquifer by g(x), the saturated hydraulic conductivity by K_s, and the total horizontal discharge by q, we have

$$\frac{dq}{dx}=-\frac{d}{dx}\left[K_s(\phi-g)\frac{d\phi}{dx}\right]=0, \qquad 0<x<L \tag{1}$$

At x = 0 we have the boundary condition

$$q=-(\phi-g)K_s\frac{d\phi}{dx}=Q \tag{2}$$

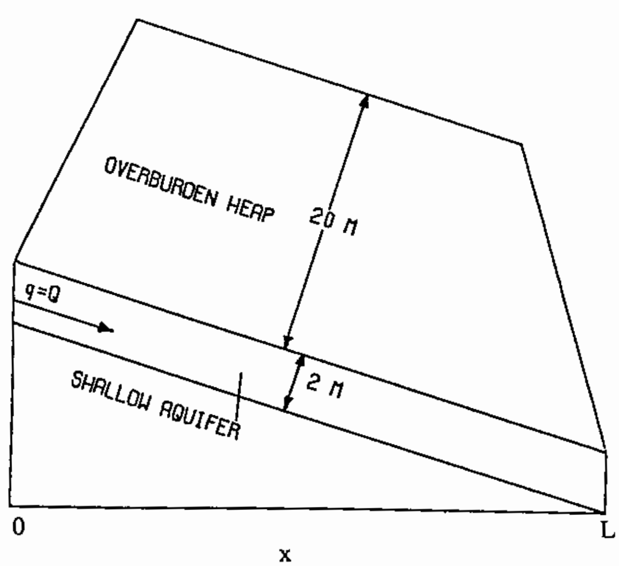

Figure 1.--Schematic diagram of mine waste overburden heap lying on sloping ridge. The vertical scale is greatly exaggerated.

where Q is the recharge from the upslope aquifer. From (1) and (2) we simply have for steady conditions

$$q(x)=Q \qquad 0\leqslant x<L \tag{3}$$

If we take the convection-dispersive equation (CDE) for one dimensional saturated horizontal flow, assume uniform vertical concentration and ignore dispersion, we have

$$\theta_s\frac{\partial c}{\partial t}+\frac{q}{h}\frac{\partial c}{\partial x}=0 \tag{4}$$

where h = ϕ-g, θ_s is the saturated moisture content of the aquifer and c is the contaminant concentration. Under pure advection the fresh water/contaminated water interface is given by the characteristic curve of (4), which is

$$\frac{dx}{dt}=\frac{q}{\theta_s h}=\frac{Q}{\theta_s h} \tag{5}$$

emanating from x = 0 at time t = 0.

Since h is a function of x we may invert (5) and solve for t as a function of x, i.e.

$$\frac{dt(x)}{dx}=\frac{\theta_s h(x)}{Q} \tag{6}$$

The travel time, t_0, for contaminants starting at x = 0 (t=0) and reaching x=L is obtained from

$$t_0=\frac{\theta_s}{Q}\int_0^L h(x)dx \tag{7}$$

Noting that here $0 < h(x) \leq 2$m we have

$$0<t_o\leqslant\frac{2\theta_s L}{Q} \tag{8}$$

An estimated value of Q is given by the product of the length of the recharge region (200 m), the annual rainfall (1.5 m/y) and the infiltration coefficient (0.5). Thus Q = 150 m²/y and an estimate of $\theta_s = 0.4$ were used to yield the estimate of $0 < t_o \leq 3.2$ years for the flushing-out period.

A more elaborate model has also been used for this problem, in which the flushing of the unsaturated moisture from the heap was included (Pantelis 1987). A vertical averaging procedure was used to deal with the contaminant profile. In order to avoid making the assumption of uniform vertical concentration in the CDE the product of moisture content and contaminant concentration, θc, was replaced by its vertical average. This somewhat artificial manipulation introduced the vertical integral of θc as the dependent variable. This approach implies a more vertical uniformity of contaminant mass rather than of concentration, which may be more realistic since, in the absence of recharge at the top of the overburden heaps, low moisture contents and low mobility of contaminants could result in higher concentrations existing there. A high concentration of contaminants in the pore water in the upper levels of the dump is supported by measurements made on samples taken from the heap (Goodman *et al.* 1981). However, this assumption, together with the low percentage of rainfall infiltrating the clay capping, could lead to an overestimate of the flushing time. A period of 20 years was evaluated by this model, which, for the above reasons, must be taken as an upper limit. It is stressed that the flushing time could be longer if heavy metals continue to be mobilised, for instance by the remobilisation of metals deposited as minerals during the period of pyritic oxidation.

FIELD MEASUREMENTS

Around the time of the capping of White's heap about 20 boreholes were drilled into the aquifer at various points about the perimeter of the heap; one hole was drilled through the heap into the aquifer below. These have been monitored for water level, pH, electrical conductivity, and concentrations of copper, zinc, manganese and sulphate, approximately at monthly intervals, from the end of 1983 till the present. Results for a typical borehole near the perimeter of the heap and for the borehole through the heap are shown in figures 2 and 3. Estimates of the total annual contaminant loads in the Finniss River have also been made (Northern Territory Department of Mines and Energy, 1986(b)) and are shown in table 1.

As can be seen from figure 2, the ground water quality has not changed significantly over the four years since rehabilitation. It would take considerable stretching of the parameter values used in the simple model to achieve consistency with this time. It is therefore evident that there is a store of contaminants additional to that in the ground water. The 20-year period estimated using our second model, which accounts for the storage of contaminants in pore water held in the dump, is consistent with the data, as is the prediction that no change is expected for the period, after which change is rapid. However, it cannot as yet be demonstrated whether this store is the controlling factor or whether the contaminants are stored in the form of a buffered precipitate.

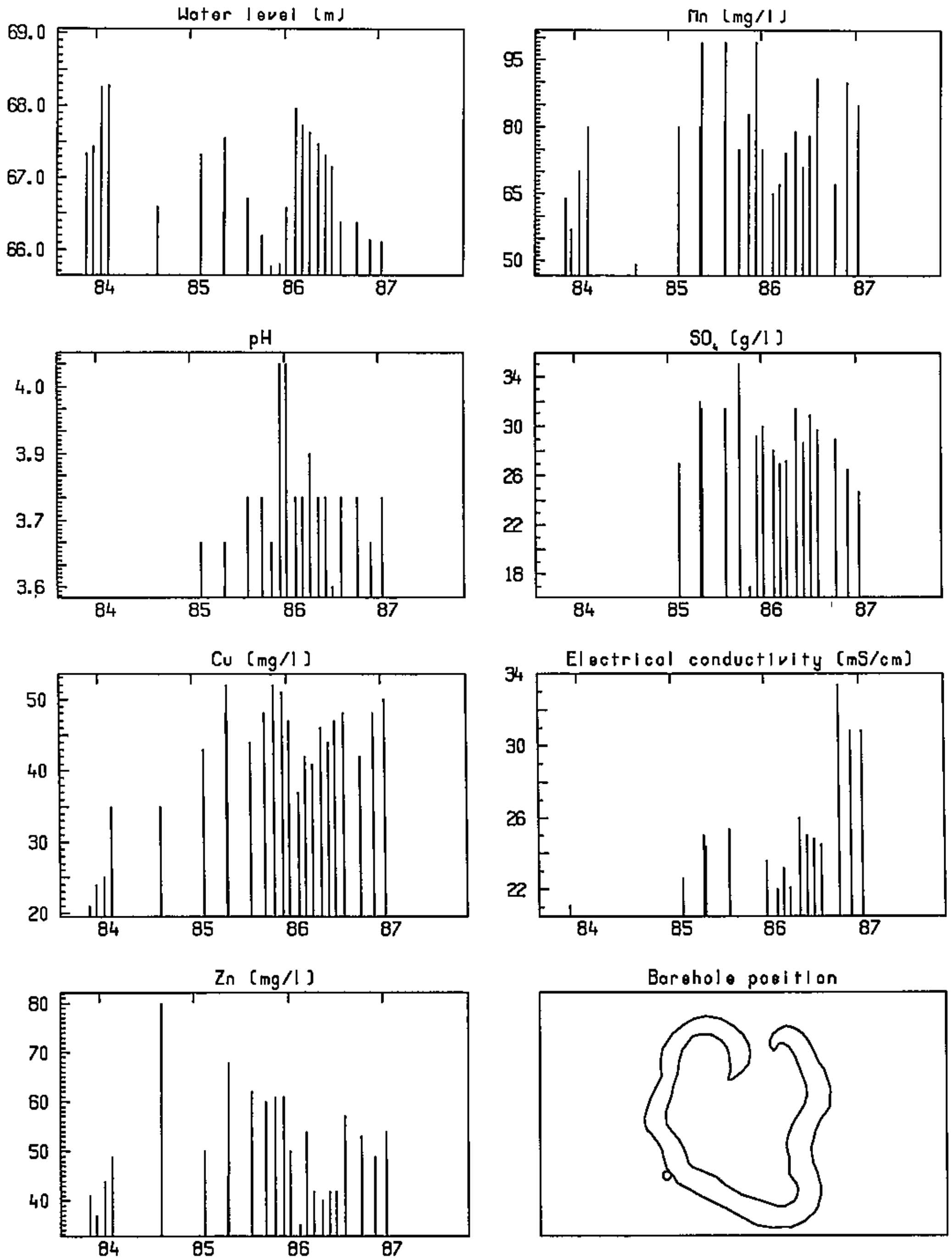

Figure 2.--Data from borehole No. 22084 from 1984 to 1987.

It is interesting to note the seasonal variation of water level and contaminant concentration observed beneath the heap and shown in figure 3. There is obviously considerable water movement below the dump. It also appears that the contaminant concentrations fall during the wet season, due to dilution by fresh water, and then rise during the dry. This could be due to the redissolving of precipitates or to input from the concentrated pore water.

Table 1 shows that the total input of heavy metals to the river system has fallen markedly. Again this is consistent with the prediction of the more complex model that the total discharge of pollutants from waste rock dumps will decrease after capping, because of reduced water discharge.

CONCLUSIONS

The field measurements show that it takes at least four years before ground water quality in the vicinity of a large overburden rock dump will respond to measures that stop leaching of heavy metals from it. We have shown that this period cannot be accounted for on the assumption that the main store of contaminants is in the ground water below the dump. It is, however, consistent with a more complicated model in which contaminants are assumed to be held in concentrated solution in the pore water held in the rock heap. As the system under investigation is a major rehabilitation work and has been well monitored from the outset, it is most important that monitoring continue until the trend in ground water quality becomes clear.

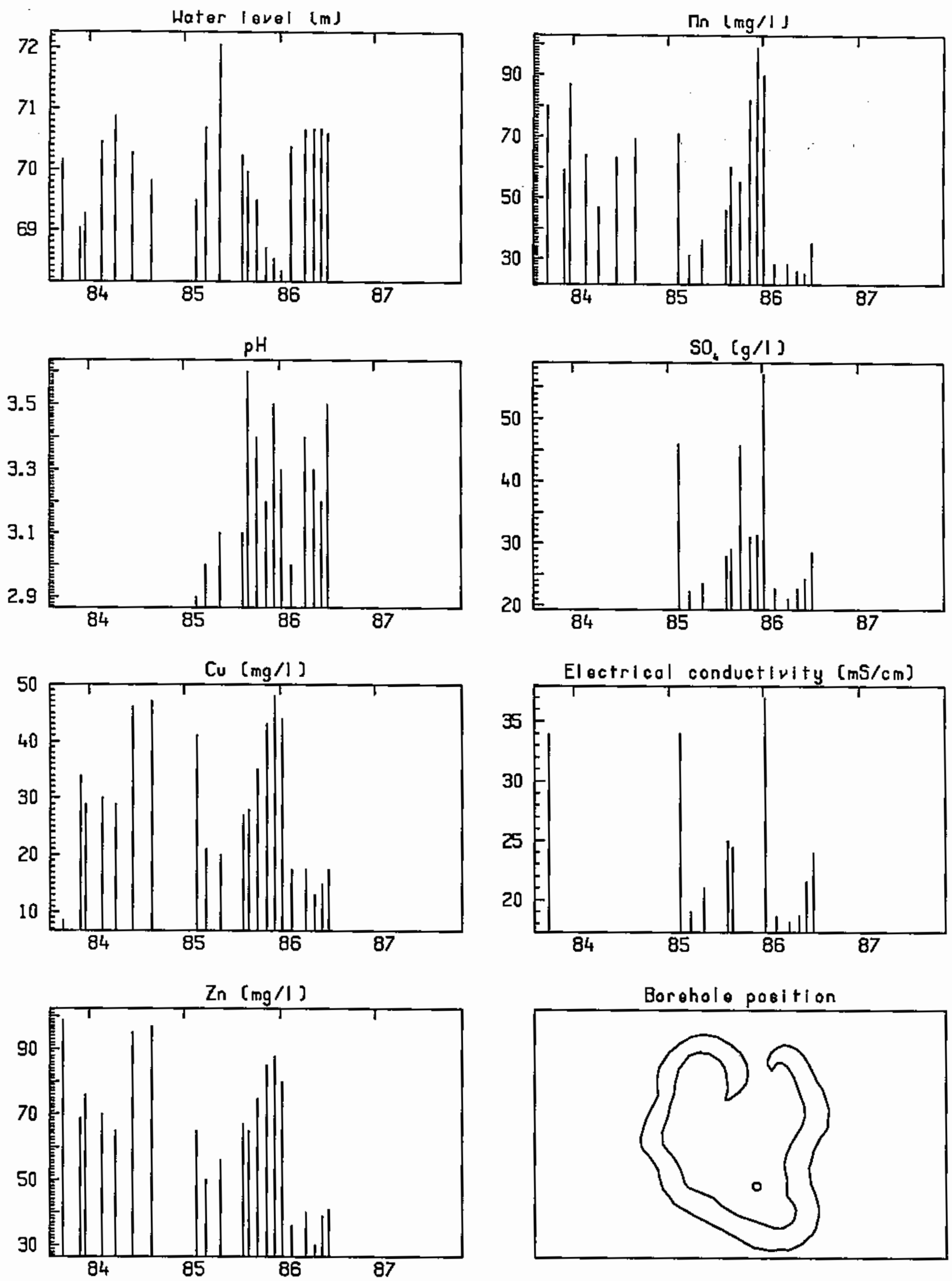

Figure 3.--Data from borehole No. 22082 from 1984 to 1987.

Table 1.--Summary of monitoring results for the East Branch of the Finniss River.

Season	1982/83	1983/84	1984/85	1985/86
Rainfall (mm)	1121	1704	1112	910
Total flow ($m^3 x 10^6$)	9.5	48	11.7	11.4
Metal load (t) Copper	23	28	9	4
Manganese	5	9	4	3
Zinc	5	9	4	3

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