AAEC/E366

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AUSTRALIAN ATOMIC ENERGY COMMISSION

RESEARCH ESTABLISHMENT

LUCAS HEIGHTS

RUM JUNGLE ENVIRONMENTAL STUDIES

SUMMARY REPORT

by

G.M. WATSON

September 1975

ISBN 0 642 99708 X

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ABSTRACT

Sources of pollution were identified and their relative importance assessed. Observations were made on seasonal variations and differences were noted between the dispersion patterns of several metals of interest. The geographical extent of chemical and biological pollution was examined. Some understanding of the basic mechanisms involved in continuing pollution was obtained and an attempt was made to determine the fate of heavy metals.

National Library of Australia card number and ISBN 0 642 99708 X

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CONTAMINATION; ENVIRONMENT; LIQUID WASTES; MINING; POLLUTION; RADIOECOLOGICAL CONCENTRATION; RADIUM; RUM JUNGLE; SEASONAL VARIATIONS; URANIUM

CONTENTS

1. INTRODUCTION

In 1949 a prospector discovered uranium ore at Rum Jungle, in the catchment of the Finniss River system, 64 km south of Darwin and 80 km west of the Finniss River outlet to the Timor Sea. Over the next three years the original discovery was confirmed and extended with the result that, by the beginning of 1953, formal arrangements had been made for the uranium to be mined and sold. The sales were by contract to the joint Anglo-American purchasing organisation, the Combined Development Agency (CDA) who advanced funds for the development. The Commonwealth Government, which held title to the uranium under the Atomic Energy (Control of Materials) Act 1946-1952, authorised Consolidated Zinc Pty Ltd (CZ) to develop and operate the Rum Jungle field on behalf of the Commonwealth, control being exercised by the Department of Supply. For this purpose, CZ set up a wholly-owned subsidiary, Territory Enterprises Pty Ltd (TEP) to take immediate responsibility for exploration, mining or milling, of uranium, until 1971 when the Rum Jungle project terminated. The Australian Atomic Energy Commission was established in April, 1953 immediately assuming control of the project under the provisions of the Atomic Energy Act, 1953, which replaced the Atomic Energy (Control of Materials) Act, 1946-1952. TEP then acted as the management company on behalf of the AAEC.

In 1962, CZ merged with the Rio Tinto Mining Company of Australia Ltd to form Conzinc Riotinto of Australia Ltd (CRA), without change to the arrangements between TEP and the AAEC. In addition to uranium, copper was mined and extracted at Rum Jungle. Some copper was present in the uranium orebodies, but a separate copper orebody existed at the Intermediate Prospect (Figure 2). This orebody was mined and extracted, as a separate operation in the mid-1960s, by another wholly-owned subsidiary of CRA, the Australian Mining and Smelting Company Ltd (AM & S). It should be noted that this subsidiary subsequently changed its name and has no direct link with the present company of that name. The AM & S operations were conducted on a separate lease, now held by CRA Services Ltd, and some of the contaminants released at Rum Jungle come from this source as well as from the uranium mining operation.

At the time when the Rum Jungle uranium mining project was initiated, present environmental legislation did not exist and the possible environmental consequences of mining operations received much less attention than now. Practices were adopted which would not now be sanctioned, and have resulted in environmental degradation that is unacceptable by contemporary standards. Data collected over the years by the Water Resources Branch of the Department of the Northern Territory, and a preliminary AAEC study in 1969-70, indicated that there was a substantial problem of chemical pollution arising from the mine area.

In 1973, the AAEC initiated a field and laboratory study to investigate this problem in more detail and, possibly, to suggest remedies; this report is a summary account of the study, which is more fully described in a separate publication. Some aspects of the study are complete, while work on others is being continued. It had been intended that staff of the Department of Northern Australia would contribute sections to the full report relating to local remedial measures and to potential land use at Rum Jungle, but since their work was disrupted by Cyclone Tracy and the consequent dispersion of available effort, their contribution consists only of an account of a revegetation experiment at the mine site.

The Rum Jungle mining operation was unusual in being undertaken in an area with monsoonal rainfall and flood patterns, thereby presenting environmental problems which would not be encountered in arid or temperate areas. Since the extent and importance of the uranium finds in the Alligator Rivers area were then known, it was hoped that the study at Rum Jungle would provide information of value for the prediction and control of the environmental effects of uranium mining in that area, or other monsoonal areas. The Rum Jungle study had the following specific objectives:

- to identify the sources of pollution and their relative importance;
- to determine the extent of pollution and its seasonal variation;
- to obtain an understanding of the basic physical, chemical and biological mechanisms concerned in the continuing pollution;
- to determine the fate of radium and other heavy metals discharged during the operations of the mines; and
- to propose, assess and cost remedial measures.

The study has been a joint project of the AAEC and the Department of Northern Australia* (DNA), and staff from both organisations have

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* Formerly Department of the Northern Territory (DNT).

contributed; individual contributors are identified by chapter in the full report.

2. THE MINING OPERATION

2.1 Some Regional Characteristics

The mined area is 6 km north of Rum Jungle siding on the North Australian Railway; its relations to Darwin, the Finniss River system and the coast are shown in Figure 1. The country is undulating land with extensive interspersed plains. The small hills, often locally dignified by the title 'Mount', do not usually rise more than 150 m above the adjacent plains. Terrestrial wildlife is plentiful and the perennial sections of the rivers are generally well stocked with fish. The soil is generally poor except in river valleys which flood during the Wet. Other than mining, use of the land has been almost exclusively pastoral.

The region is drained by the Finniss catchment, the Finniss River being one of the smaller of the rivers draining the northwest part of the Northern Territory. It is about 140 km long, entering the sea at Fog Bay through a wide mangrove swamp estuary. Like many other northern rivers its passage to the sea is interrupted by floodplains in which its course is not clearly defined, leading to some uncertainty about where floodwaters and their contents may be deposited. The more important of the streams forming the upper reaches of the Finniss are the Finniss proper, the East Branch, the South Branch and Florence Creek. The Rum Jungle mine is located directly on the East Branch, which joins the main stream 8.5 km below the mine area. Florence Creek, 28 km downstream from this junction, is the next substantial tributary.

The Finniss catchment is within that part of the Northern Territory which comes under the influence of the northwest wet monsoon, giving it a well defined wet summer and a dry winter, the Wet being from November to March. Annual rainfall in the Rum Jungle area averages about 1500 mm; it is highly reliable and both seasonal and local variations are relatively small. The East Branch has no flow from about July to December, but the main Finniss stream has continuous flow from a point 26 km above its junction with the East Branch, and Florence Creek also has some permanent flow. The seasonal rainfall and flood patterns markedly influence the release and dispersion of pollutants from the mine area.

The geological structure of the Rum Jungle area was created by deposition of a series of Lower Proterozoic sedimentary formations on an Archaean complex, the Rum Jungle Granite. Mineralisation of uranium, copper and some other metals occurs in one of these formations, the Golden Dyke - named for a goldmine in another part of it - near its contact with the underlying formation, the Coomalie Dolomite. If displacements attributable to subsequent faulting are allowed for, all the known mines and prospects appear to follow the line of an embayment in the Rum Jungle Granite, along the Golden Dyke - Coomalie Dolomite interface. The Coomalie Dolomite forms the bed of the East Branch immediately below the treatment plant, and the cavernous nature of this formation must be taken into account in assessing the potential dispersion of pollutants in the area. Another geological factor of importance to the subsequent release of heavy metal and acid pollutants is the presence of pyritic ores in some formations. If present in overburden or waste-rock heaps, or exposed in opencuts, these pyritic ores will promote bacterial leaching of heavy metals from the exposed material. This factor was important at Rum Jungle, though it will not be of concern in all mines and, in fact, was not a problem at the Rum Jungle Creek South deposit, 6 km south of the principal mining area.

2.2 The Mining Sequence

The locations of the principal orebodies at Rum Jungle, with the exception of that at Rum Jungle Creek South, are shown in Figure 2. The extensive mineralisation in the area had been recognised in 1869, and copper deposits had been worked on a small scale early in the present century, but the uranium mining project was the first major development. The first uranium deposit to be recognised was White's, and ore from this body was the first to be treated when milling operations began in 1954. The uranium deposits subsequently discovered at the Dyson's, Mt Burton and Rum Jungle Creek South prospects were also mined and the ores milled in the Rum Jungle treatment plant. Copper mineralisation was associated with much of the uranium ore and, where warranted, copper was recovered, pari passu, by TEP. Copper ore from the Intermediate orebody, which was mined by AM & S, was treated according to grade; high grade ores being treated in the TEP plant on a contract basis while copper in low grade ores was recovered from leach piles. Although nominally a separate company, AM & S at that time depended on TEP for staff, administration and materials.

In January, 1963, mining and extraction of uranium from the White's, Mt Burton and Dyson's orebodies was completed, except for a little Dyson's ore; the CDA contract had been filled. The Rum Jungle Creek South orebody had been mined in 1961-62, and the Rum Jungle plant was kept operating to process this ore, the mining of which was completed in 1963. Treatment of the Rum Jungle Creek South ore was completed in 1971, the uranium oxide produced from it was stockpiled, the treatment plant was closed down and the assets at the site were sold by auction. It might be noted that all the orebodies had been extracted by opencut mining, although it had originally been proposed to recover White's ore by underground mining, and an exploratory shaft was sunk with this in mind. Each of the mined orebodies has an associated overburden heap, whose positions are shown in Figure 2. Leaching from these heaps has been responsible for some of the dispersion of heavy metals from the mining site. The excessive leaching has its origins in the oxidation of pyrites to ferric iron and sulphuric acid. This reaction is catalysed by certain soil bacteria and the resulting acid will leach out other heavy metals if present in the heaps.

An acid leach process, using sulphuric acid manufactured on site, was used to extract uranium from the crushed and milled ores. Until 1962, uranium was recovered from the resultant liquors by ion exchange, elution and precipitation with magnesia. After 1962, extraction was with an organic solvent phase followed by a stripping solution and precipitation with caustic soda. If sufficient copper was present, it was extracted by cementation from the waste liquors before these were disposed of.

2.3 <u>The Disposal of Wastes</u>

The White's and Intermediate orebodies lay underneath the East Branch of the Finniss River which was therefore diverted as shown in Figure 2, the stream being dammed upstream of the orebodies, forming what is now known as the Acid Dam. Later, a second dam wall was built further upstream to create an upper and lower Acid Dam. These dams were concerned with effluent discharges.

When operations began the mill tailings were discharged to an almost flat area, shown in Figure 2 as the Old Tailings Dam. Drainage from this area formed a small creek, Old Tailings Creek, and then reached the East Branch. Originally there does not seem to have been a dam wall to contain the tailings, and these were washed down the creek, as well as the acidic liquors in which the solid matter was suspended. At some later stage a perimeter wall was built, across the bed of tailings and, as this wall was breached and washed away, fresh walls were built towards the eastern end of the area to form a series of smaller dams. These dams were equipped with culverts and overflows, allowing supernatant liquor to drain off. Consequently acidic liquors and entrained tailings still entered the creek. The newer walls were also breached by wet season floods. In

1961 the tailings disposal practice was changed; from then until 1965 tailings were discharged into the Dyson's opencut. By 1965, this was full and, from then until the closure in 1971, the tailings were discharged into White's opencut.

There were also liquid effluents; ion exchange barren liquors, raffinates from the solvent extraction process, and effluents from the cementation ponds or launders. The original cementation ponds were adjacent to the Old Tailings Dam, and the available evidence suggests that barren liquors from the ponds and untreated liquid effluents were discharged via the Old Tailings Dam to Old Tailings Creek. In 1961 or 1962, the exact date being unknown, a hole appeared in the ground near the copper cementation launders and, for a time, effluents vanished into this cavern. Subsequently these launders were abandoned and new ones constructed alongside Dyson's opencut; this was the occasion when the Acid Dam was subdivided. From this time, plant effluent without copper was directed into the lower (downstream) Acid Dam, and effluent from the Dyson's copper launders was directed into the upper Acid Dam. In the Wet, sluice gates to White's opencut and the river diversion channel were opened to allow flood waters to dilute the plant effluents. This policy, which would have allowed an overall average dilution to a pH of 3.9 or thereabouts - an unacceptable degree of acidity, was abandoned about 1967. From that time all liquid effluents, after recirculation where possible, were directed to White's opencut. Until 1969 White's opencut was flushed annually with fresh water; retaining walls were then built to prevent the entry of surface water or the loss of overflows, and all treatment plant effluent was retained until cessation of operations in 1971.

The Intermediate copper heap leach experiment

In 1966, AM & S set up separate leaching piles, shown in Figure 2, for the lower grade sulphide and oxide ores from the Intermediate deposit. These piles were stacked on pads intended to be impermeable, and were leached with an acid liquid made up from plant raffinates and water from White's opencut. The sulphide and oxide heaps were in series, and the final liquors from the oxide heap were collected in a pond and pumped to cementation launders. Overflows and excess barren liquors were discharged into Copper Creek (Figure 2), and from there to the East Branch. It was not a very efficient experiment and there were heavy losses through seepage.

3. EVIDENCE OF POLLUTION

The annual input of pollutants to the Finniss River system may be calculated in several ways; this section describes two such estimates. One is made by measuring flow rates and concentrations of pollutants in the East Branch, which receives all drainage from the mine area, and the second by similar assessment of the three principal subcatchments of the East Branch in the mine area - the river diversion channel, Old Tailings Creek and Copper Creek. These estimates provide chemical evidence on the degree of pollution entering the river system; there is also biological evidence of its effect on aquatic species, and a brief account of an investigation of this is given.

3.1 Input of Chemical Pollutants

The Water Resources Branch (DNA) has maintained a recording station to measure flow in the East Branch, downstream from the mine area, since 1965. Over this period it has also collected weekly water samples for quality analysis. With some assumptions on the relation between concentration and flow, the input of contaminants can be calculated from these data. Estimates for the subcatchments were based on periodic water quality measurements at a representative series of sampling points within the subcatchment area, and the measurement of flow rates in each of the three local tributaries. The results for the two approaches, for the season 1973-74, are given in Table 1; the agreement is reasonably close.

Rainfall in the 1973-74 season was higher than average and this is reflected in the quantities of metals released which are probably about twice the yearly average. The Water Resources Branch data also provide an estimate of sulphate releases; in 1973-74 this was about 13 000 tonnes.

3.2 The Biological Survey

Mining, particularly opencut operations, inevitably produces considerable local disturbance. Rum Jungle is no exception to this: some overburden heaps resist revegetation; trees in the bed of the East Branch have been killed in the mine area, including the dams and downstream from its junction with the Finniss; and earlier practices of tailings disposal allowed them to be swept downstream. Examination of the East Branch, which has intermittent flow but substantial permanent pools, shows no rooted emergent or submerged plants. There is vegetation along the banks, but it is not dense. Live Pandanus palms are rare and there are some dead stumps. At the end of the Dry, concentrations of heavy metals are very high and pH is low. Fish are absent from the East Branch pools, although present in its tributaries. Some families of insects are abundant in the East Branch but other Insecta were absent, as also were some molluscs and arthropods which occur in the main Finniss River and would be expected to occur in the East Branch.

A preliminary survey in 1973 suggested a deficiency of fish species in the main river; this was followed up by field investigations, with sampling sites above and below the entrance of the East Branch. Sampling was made as quantitative as possible, using nets and poisons according to time and location. Two fishkills were observed in the Finniss River, just below the junction of the East Branch, after the tributary had begun to flow. On each occasion 9 or 10 species were identified on the banks. On the first occasion, in 1973, a transient copper concentration of 53 mg dm^{-3} was recorded at the height of pollutant inflow but on the second occasion, in 1974, observations were not possible until 2 or 3 days after inflow commenced, when the copper concentration was not observed to exceed 0.3 mg dm^{-3}. The fishkills are clearly connected with initial flow in the East Branch; this raises two questions - is the fishkill the result of the pollutants coming from the mine area? and does this ingress have some permanent or substantial effect on fish populations?

Overnight netting, nocturnal spotlighting and daytime poisoning, three largely independent methods of fishing showed the number of species at the sampling sites near the East Branch junction to be about one quarter of the numbers found 30 km further downstream, below the entry of Florence Creek. The numbers of individuals netted were also less. Previous studies have suggested that copper concentrations of about 0.1 mg dm^{-3}, and zinc of 0.2 mg dm^{-3}, would be lethal to some of the species found locally.

4. SEASONAL EFFECTS

The highly seasonal rainfall and the high annual evaporation determine a characteristic pollution cycle in the Rum Jungle area. Several mechanisms are involved.

4.1 Erosion

The waste rock heaps and the original tailings area are bare of vegetation. About 1 cm of tails material is eroded during an average Wet, some 400 tonnes. Not all this enters the creek system, some being deposited nearby to give a continuing expansion of the area. Deposited tails material can be identified along the whole course of the East Branch below the mine. Erosion from the overburden heaps is more difficult to measure but was estimated at 0.3 cm y^{-1}. Runoffs from the overburden heaps may carry pollutants either in solution or as suspended solids, but there will be little soluble material from the tails.

4.2 Bacterial Oxidation

The waste heaps contain sulphide minerals which may be oxidised by thiobacilli present in soils, through a series of reactions which require the presence of oxygen and water but no additional energy source. The growth of Thiobacillus ferroxidans is optimal at a pH of 2.5 to 3.0; soil acidity and the acidity of seepage from the waste approached this level. Bacterial oxidation may lead to pollution of the river system as the result of runoff and seepage from the overburden heaps and the tailings dump, and from sulphide-containing sediments deposited in the creek beds.

4.3 The Seasonal Cycle

For convenience, this description begins in April at the end of the Wet, when the river flow is from groundwater storage and the pollution inputs are seepages from overburdens and opencuts. These seepages contain high levels of pollutants, e.g. 60 mg dm^{-3} copper in that from White's overburden, leading to a rapid deterioration in water quality in the East Branch. During this period seeps entering the East Branch from dolomite beds precipitate much of the heavy metal load, so that water quality improves with passage downstream; this is made evident by comparing the quality of samples taken at the road bridge and the railway bridge shown in Figure 2. The precipitated materials, Ca, Al, Mg, Cu, Zn, Mn, SO_4 etc., settle out as a flocculent on the river bed. In the early part of the next Wet much of the precipitate will be redissolved and contribute to the heavy metal load of the first flush. Precipitates are also seen within the mine area.

At the end of the Dry three substantial pools remain in the East Branch, and these contain high levels of metal pollutants although, in any one pool, there can be considerable variation from local conditions of seepage and chemical reaction. Flow is erratic in November and December and sustained flow usually begins in January. During this period the sources of pollution change from those left over from the previous Wet, and that produced by bacterial oxidation in the creek beds during the Dry, to new inputs deriving from runoff from the waste heaps. By January, the water table has risen and contributes to the creeks; this may be regarded initially as the displacement of groundwater contaminated by seepage from the waste heaps and opencuts. With increasing flow, the quantity of pollutants carried daily by the East Branch increases but the concentration decreases. It is the first intense rain, usually in January, that carries the largest slug of pollutants. This slug presumably enters the floodplains at those locations where vegetation shows increased concentrations of heavy metals.

5. SPECIFIC SOURCES OF POLLUTION

The major sources of metal and sulphate pollution are the overburden heaps, the opencuts, the old tailings dump, and the Intermediate copper heap leach piles. An attempt was made to estimate the contributions of copper, zinc and manganese from each of these sources to the pollution load in the East Branch. In each case the estimate is made complex by the need to take into account a number of factors, e.g. rainfall, runoff, evaporation, spring water or groundwater, and some data were lacking - e.g. the proportion of rainfall in springwater, runoff and groundwater. Therefore some assumptions and uncertainties were inevitable, even though a considerable amount of analytical data on samples was collected. The estimated annual releases from each source, for the year 1973-74, are given in Table 2, along with the totals.

Some confidence is lent to these estimates by the fact that the totals are in quite good agreement with the two sets of estimates, obtained by independent methods, given already for the total pollution load in the East Branch.

6. A THEORETICAL APPROACH

Concentrations of heavy metals high enough to cause problems of pollution are frequently found in waters flowing from mine wastes, overburden heaps, tailings dumps and coal mines. The metals result from the oxidation of ores, a process which may be catalysed by soil bacteria. The best-known example is seen in waste heaps or exposed rocks which contain pyritic ores. In this instance, oxidation is catalysed by the presence of autotrophic bacteria, thiobacilli or ferrobacilli, which meet their energy requirements from the oxidation of sulphides and need no other energy source. They do, however, require a supply of water and oxygen, and these requirements may provide limiting factors to the rate of the leaching process. Some other elements are needed, but are less likely to be limiting. The chemical reactions involved are complex and, in some respects, not fully understood but simplified versions are adequate to allow estimates of the relation between the consumption of sulphide ores and oxygen on the one hand, and the production of sulphate and oxidised metal ions on the other. There is a net production of acid in the process, and consequently metals may be leached from ores other than the initial sulphides. The process is commonly used to extract metals from low grade pyritic ores, in giving nature a little assistance by pumping weak acid onto heaped ores; this provided a rationale for the Intermediate heap leach experiment.

Since both White's and the Intermediate overburden heaps contain significant quantities of pyritic ores (bulked auger-drill samples show over 3% equivalent sulphur) and they produce substantial quantities of sulphate and metal ions, it is probable that bacterial oxidation is taking place in these heaps. For this reason, it seemed worthwhile to examine a theoretical model of what might be going on in the heaps. At the least, this might provide an estimate of the time over which the heaps might generate significant quantities of metals in solution and, more optimistically, might suggest what limiting factors could be utilised to discourage bacterial leaching. White's overburden heap was chosen for this modelling exercise because it is a larger contributor to heavy metal pollution than the other heaps, and because more information about it is available.

This approach was used to estimate the consumption of oxygen and sulphide in White's overburden heap. When the solubility of oxygen in water, and the large volume of air needed to meet the estimated oxygen demand, are considered, some inferences can be drawn. First, little oxidation can take place below the level of the water table in the stack; second, a large volume of air is required - for White's heap, over 10^7 cubic metres in an average year. If oxidation is confined to the first 30 cm or so of the surface, the pore volume in that part of the heap must be changed several times a day. One or two thousand tonnes of sulphide are consumed in a typical year; if this comes from a surface layer of 30 cm, the sulphide in such a layer would be exhausted in about two years whereas it would take 100 years to exhaust the sulphide in the whole heap. The 17 years since the heap was built correspond to a depth of 2.5 m, if oxidation is limited to a surface layer.

In October, 1974, the heap was sampled to a depth of 1.8 m, in the hope of illuminating the difficulties suggested by the model. There is no significant trend of sulphide, iron, copper or water concentrations with increasing depth. The modelling approach is still inconclusive and is being continued. All that can be said at present is that oxygen supply is the most likely rate-limiting process in the oxidation of sulphides in the overburden heaps and that, since there is no evidence from samples of spring water taken in 1969-70 and 1974-75 that ion concentrations are falling, some mechanism exists which will supply the necessary oxygen and allow continued sulphide oxidation. It is possible that the flow of water over and through the heap provides this mechanism, but this is speculative and is being examined further.

7. THE FATE OF RELEASED HEAVY METALS

The heavy metals released during mining operations, or subsequently leached and dispersed from the mine area, include copper, manganese, zinc and radium in significant quantities. It is necessary to consider the extent to which these metals have accumulated in the Finniss floodplains, and what significance this accumulation may have with respect to land use.

It can be estimated that releases of manganese total about 2300 tonnes, of copper about 1300 tonnes and of zinc, about 200 tonnes. The manganese figure is high because pyrolusite was used as an oxidising agent in the uranium extraction process. There were seasonal and operation differences in the rates at which these metals were released. Radium may have come from waste liquors and may have been leached from tailings. Data on the waste liquors are limited but suggest, again with non-uniform release, that some 90 Ci of radium were discharged from this source. This estimate excludes wastes discharged to White's opencut. There is evidently some efficient removal mechanism for this, since present levels in the opencut are low, but it is not clear whether this removal relates to recirculation of the water through the mill or to some local chemical process in the cut.

The tailings material discharged to the old tailings dump contained about 380 Ci of radium at about 0.6 μCi kg^{-1}. A large sample of the coarser tailings material, collected from Tailings Creek, contained only about 330 pCi kg^{-1}, that is, it was almost free of radium. Therefore the radium in the tailings appears either to have been transported to the lower reaches of the Finniss either in solution or in the fine slime component of the tailings, or transported to the deeper part of the dump. Deep tailings samples could not be obtained, but water samples were obtained, and contained little radium. These investigations are being continued.

The uncertainties in the lower course of the Finniss make it difficult to predict just where these released metals may have gone. Of the four metals considered, manganese is the most affected by seasonal factors, and since there has been no significant input of radium during the past eight years, distributions of the four metals may not be identical.

Pasture grasses and waterhole sediments from the lower regions of the river were sampled. The highest concentrations of the metals occur near riverbanks, particularly at sites where waterholes discharge onto the plains. It appears that about 100 km^2 of floodplain were influenced by the discharges. Average concentrations of copper, manganese and zinc in the surface samples (2-5 cm) were 30, 140 and 4 $\mu g\ g^{-1}$ respectively, compared with likely pre-operational values of 2, 10 and 3. For the three metals over the 100 km^2 area, the increased concentrations correspond to releases of 90, 300 and 30 tonnes per cm depth. If similar values hold down to about 10 cm, then most of the discharged tonnage of the three metals remains on the plain. The situation is otherwise with radium; of the 100 Ci or more released, only a few per cent remain in the surface soil. The remainder has been removed elsewhere, has migrated through the soil profile or, less probably, has yet to reach the plain.

The significance of the observed metal concentrations is rather uncertain, since copper and molybdenum are antagonistic and there are no data on the molybdenum status of the area. However, the present levels of copper and of manganese, which will presumably increase with time, appear to be on the borderline of stock injury though this has not been observed. These results are preliminary and the study is being continued.

8. RADIOLOGICAL CONSIDERATIONS

Standards for the release of radioactivity are based only on its possible effects on man, and standards which are acceptable for man will provide adequate protection for other species. For this reason, the release of radioactivity is treated separately as a special case. The only radioactive element which needs serious consideration is radium-226; some lead and polonium isotopes may be present but are unlikely to be of importance.

Compliance with individual limits of radiation dose for man, with respect to environmental releases of radioactivity, is usually assessed by reference to a 'critical group', that is the group of people whose habits of eating, recreation, occupation or other relevant factor, put them at the greatest degree of potential risk. If the calculated dose to such a group is within safe limits, no one else will be at risk. Where a critical group cannot be identified, a hypothetical group, of extreme habits, can be substituted.

Springs in the area, and groundwater from the tails dump area, do not show very high concentrations of radium, usually about 3 pCi l^{-1}, and the highest value in water from a borehole in the tailings dump was similar. Equal or greater values occur elsewhere in the Northern Territory, e.g. Oenpelli, Howards Springs, and Leichhardt Springs, the highest value known being 100 pCi l^{-1} for a spring in Katherine Gorge. The release of radium from tailings seems most marked at the end of the Dry; pools in the East Branch before the first flow in 1973 contained 6 to 10 pCi l^{-1} of radium. During the first flush of that season, the main Finniss upstream of the junction contained 0.8 pCi l^{-1} whereas the corresponding value downstream was 12.2 pCi l^{-1}. During the Dry, radium levels in the Finniss River are quite low; except for two sites, the average value was 0.33 pCi l^{-1}. At the two sites, which were at major bends in the channel, radium concentrations were 2.4 and 2.5 pCi l^{-1} respectively. Sediments at these sites may contain some tailings slimes. Groundwater from the floodplain sedge meadow with the most evidence of heavy metal contamination had radium-226 and lead-210 contents consistent with the soil type and radioactivity of the deeper soil levels. This provides evidence that inputs of radium from the mine site are not occurring now.

Several exposure routes can be postulated for radioactivity in the Finniss area; these include locally grown vegetables, local aquatic food, drinking water and beef or buffalo meat. Vegetables and fish were analysed for radium and the radium content of mussels was inferred from the water content and the known concentration factor, but since samples of local meat were not available, its radium content was inferred from observations on Magela plains beef. With these figures, it was possible to estimate the annual amount of radium ingested by the hypothetical critical group whose eating habits are those indicated in Table 3.

The total intake of just over 8 nCi y^{-1} is slightly in excess of the annual limit of 8 nCi y^{-1} derived from International Commission on Radiological Protection recommendations on dose limits, meat and fish contributing most to the estimate. From the data available it is not possible to say how much of this estimated intake is due to naturally occurring radium and how much arises from past releases of radium from the Rum Jungle area. It should be noted that the estimated radium intake arising naturally in the Magela plains of the Alligator River area is also about 8 nCi per year for a similar critical group. It should also be remembered that in framing recommendations for radioisotopes such as radium, which have very long biological and radiological half-lives, the ICRP assumes that ingestion occurs throughout the life-time of an exposed person; in the case of radium-226, the maximum permissible body burden would be reached only after 50 years' exposure at the recommended limits.

9. REMEDIAL PROPOSALS

One of the objectives of the Rum Jungle study was to assess the costs and merits of various possible remedial actions at the site. These included re-vegetation, levelling operations, the neutralisation of acid pit waters and, possibly, stream diversions. It was also hoped to obtain some estimate of the potential value of the area, for recreational or other land uses. Unfortunately, as noted earlier, it has not been possible to meet these specific objectives, and only very preliminary estimates of costs and feasibilities are available.

Some experimental work on revegetation at the site has been undertaken by staff of the Department of Northern Australia. This took the form of a field trial on White's overburden heap, undertaken after a preliminary study of soil acidity and metal content as indicated by conductivity. After a preliminary trial in 1973, a more detailed trial was undertaken in 1974, using a randomised block design with twelve treatments and two replications. It seems to be possible to grow some species satisfactorily, although the optimal choice of species and conditions may not yet be determined. Estimates of the costs of regeneration are provided, and amount to some $850 per hectare; this is the cost of preparation, materials, plant-hire, labour, etc., for the initial operation only.

10. CONCLUSIONS

The first four of the principal objectives of the Rum Jungle study have largely been met; that is, those relating to the causes, components and extent of pollution, although there is clearly more to be learnt about some aspects of the dispersion of pollutants from the mining area. The results are summarised below :

- The principal heavy metal pollutants have been identified as copper, manganese and zinc. The major sources of these metals within the mine area are White's opencut and overburden heap, the Intermediate overburden and the copper heap leach experiment. Some uncertainty remains about the relative importance of the several sources but these are understood well enough for remedial measures to be planned. There is agreement between the sum of the contribution estimated for individual sources and the total load of chemical pollutants which is observed actually to enter the Finniss system.
- There are seasonal patterns of dispersion and there are differences between individual metals in their behaviour in this respect.
- Chemical and biological evidence of severe pollution is evident at the mine site and along the course of the East Branch from the mine site to its junction with the Finniss River. There is evidence that fish are reduced in numbers in the Finniss River between the East Branch and Florence Creek junctions, but not below the latter point.
- Local and theoretical studies have given some understanding of the mechanisms which maintain the release of pollutants at present levels. The main factors are bacterial leaching of sulphide-containing ores and the highly seasonal rainfall.
- Since 1954, releases of copper, manganese and zinc have totalled about 1300 tonnes, 2300 tonnes and 200 tonnes respectively. Most of the discharged tonnage of these metals has been dispersed on the Finniss floodplains. About 90 curies of radium are estimated to have been released in waste liquors during operation of the mine and some further quantity may have been leached from the tailings dump which originally contained 380 curies. The fate of dispersed radium is uncertain; the concentration of radium is low in the surface layers of the tailings dump and the floodplains.

- Little progress has been made in defining and costing remedial measures. However, there is now an adequate factual basis on which to pursue this objective.

Work is being continued on those aspects of the study which are incomplete. These include :

- Further studies of the dispersion of radium from the tailings area.
- A program of beef sampling for the radium content of animals from the Finniss floodplains.
- Continued studies of water quality in runoff from White's overburden, and of the water balance of this heap.
- An investigation of the relations between bacterial leaching and the dispersal of heavy metals, with respect to conditions at Rum Jungle.

A few points arising from the study are worth emphasising :

Since it is probable that bacterial leaching is of major importance in causing the continued dispersion of pollutants, this must be taken into consideration in planning the disposal of wastes, including overburdens and waste rocks. If an ore with a sufficient sulphide content is exposed to air and water, it may cause trouble. Disposal of it into an opencut will not necessarily solve the problem and may make it worse, if microbial action is possible.

Effects may be quite localised; the effluents from White's and Dyson's overburdens, for example, differ substantially while the overburden at Rum Jungle Creek South has presented no problem.

The loss of pollutants from uncontrolled sources may continue for a long time; in White's overburden, for example, there seems to be sufficient sulphide to fuel the leaching process for up to 100 years.

The present work points up some problems of pollution; it does not attempt to assess their cost in terms of lost land use, and has not estimated the cost or necessity of rehabilitation.

TABLE 1

TONNES OF METALS ENTERING THE EAST BRANCH IN THE SEASON 1973-74

	East Branch Data	Subcatchment Data
Copper	130	95
Manganese	100	83
Zinc	40	26

TABLE 2

ANNUAL RELEASE OF HEAVY METALS FROM EACH SOURCE IN THE RUM JUNGLE AREA 1973-74

Source	Annual release in tonnes		
	Cu	Mn	Zn
Dyson's opencut	1	3	
Dyson's overburden	0.2	5	
White's opencut	8	30	
White's overburden	29-53	11-19	17-31
Intermediate opencut	3	3	0.3
Intermediate overburden	16-30	2.5-4.5	13-25
Heap Leach	32-42		
Tailings area	5	3.5	
Old Acid Dam		12	
	95-142	70-80	30-56

TABLE 3

INGESTION OF RADIUM BY A HYPOTHETICAL GROUP

Exposure Route	Assumed Consumption (kg y^{-1})	Radium Concentration (pCi g^{-1}, fresh wt.)	Yearly Intake (nCi)
Water	730	0.000 63	0.46
Meat	200	0.015	3.0
Fish	40	0.086	3.4
Vegetables	70	0.0086	0.6
Fruit	20	0.007	0.14
Crocodile	15	0.04	0.6
Goose	5	0.0043	0.02
Mussels	2	0.13	0.26

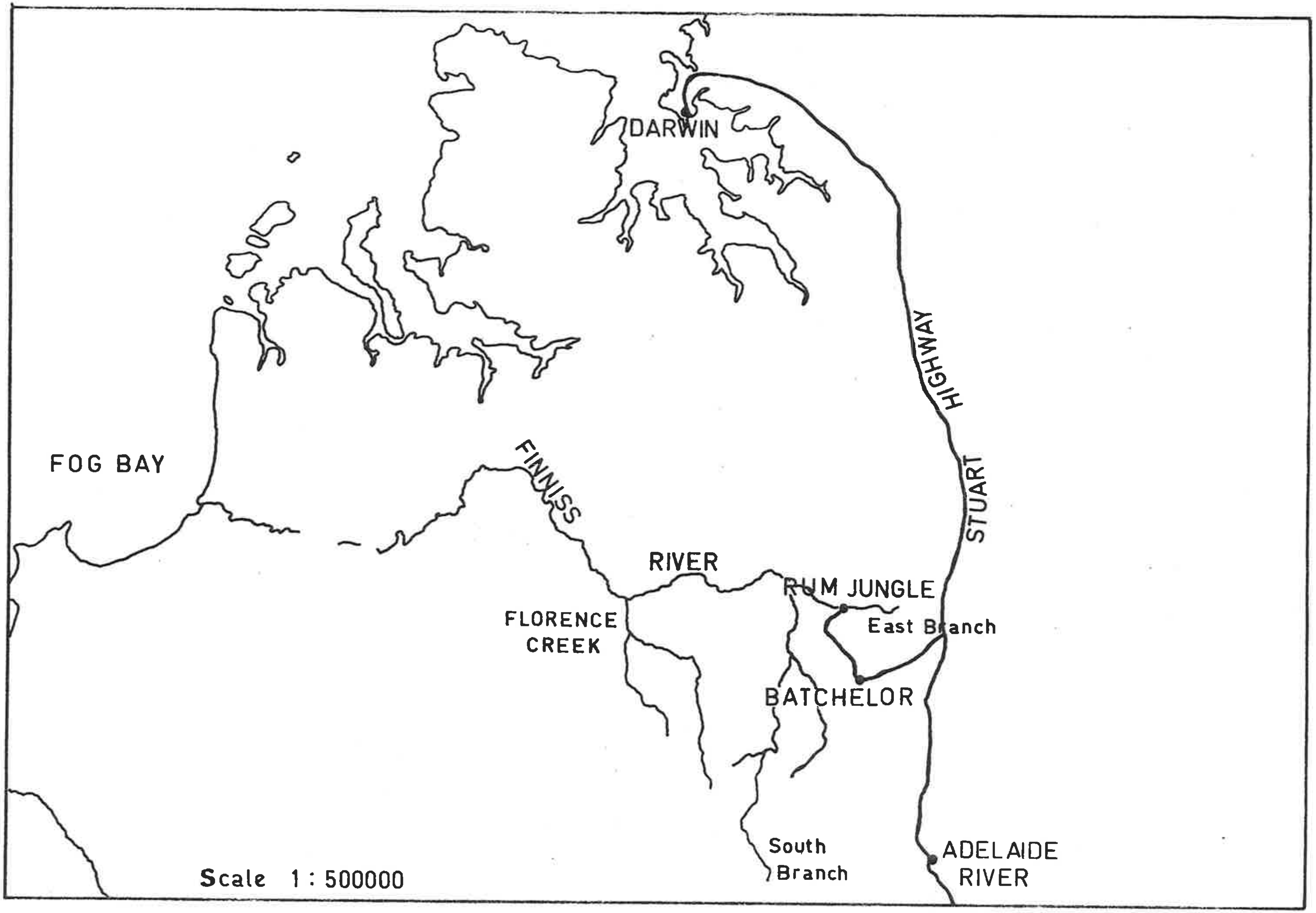
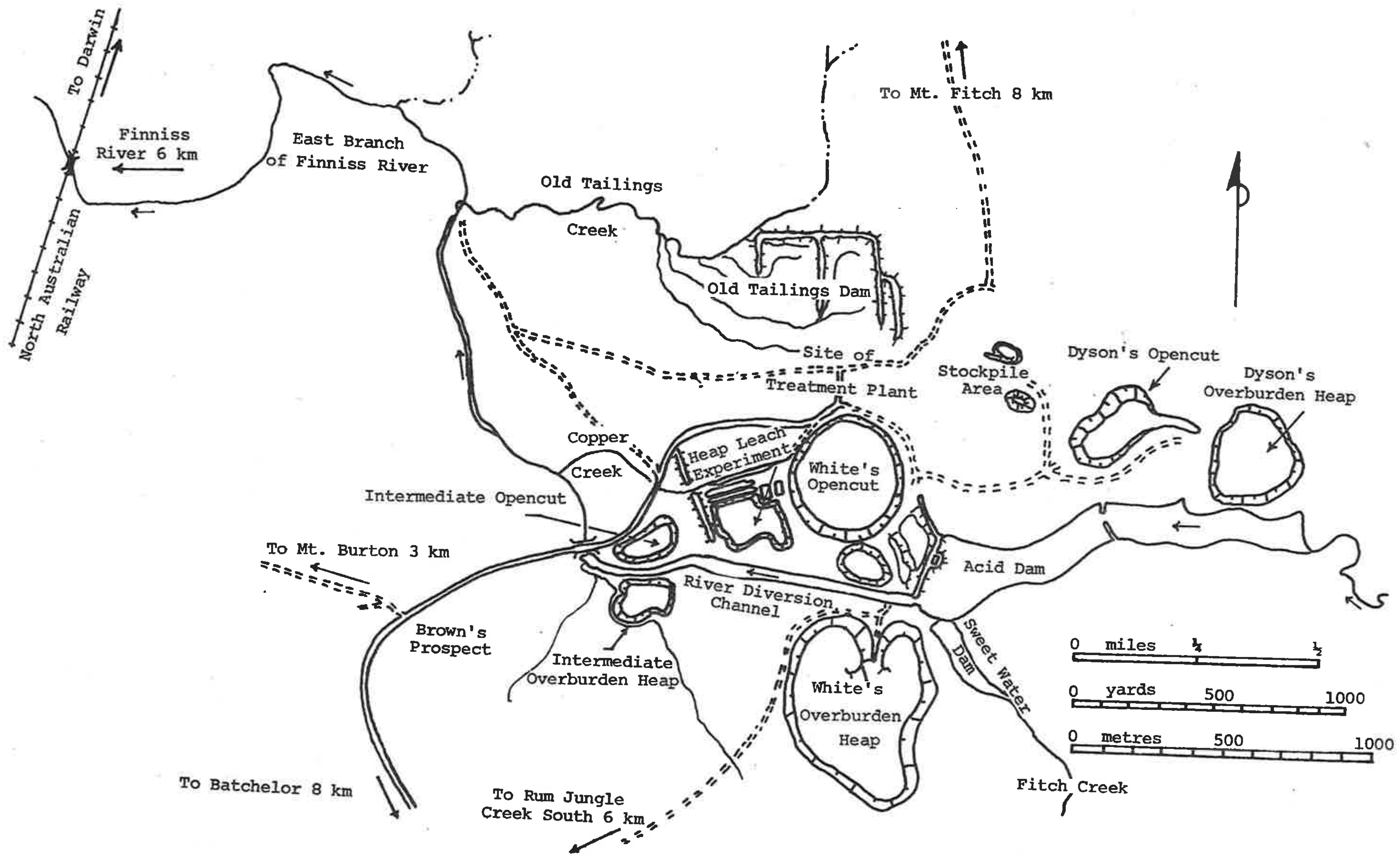


FIGURE 1. FINNISS RIVER AREA



Scale 1: 15840, 1 in: ¼ mile, 1 cm: 0.16 km

FIGURE 2. RUM JUNGLE MINE AREA