AN ASSESSMENT OF THE WATER MANAGEMENT PROGRAM PROPOSED IN THE RANGER EIS AND ITS ENVIRONMENTAL IMPLICATIONS

by

D.R. Davy

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1. INTRODUCTION

An assessment of the water management program proposed in the Ranger EIS has three components:

(a) A statement of the water quality criteria and standards that the program must meet.

(b) A set of calculations, based on best available estimates, that compares the expected levels of waste with the standards set for the release.

(c) The plan of the surveillance program aimed at demonstrating compliance with these standards and at revealing deficiencies in the choice of criteria, the derivation of standards from them and unforeseen departures from expectation.

2. WATER QUALITY STANDARDS

Water quality criteria are needed to assess both short-term and long-term consequences of the presence of contaminants in the environment. Realistic standards to govern the release of contaminants must derive from an adequate definition of water quality, and must not be unnecessarily restrictive since this would imply a wasteful use of water resources.

Acute toxicity tests measure the immediate effects of pollutants on aquatic life, and may be extended to include physical or chemical modifying factors such as acidity, hardness and temperature.

The presence or absence of effect in a test of acute toxicity may appear to suggest there is an absolute threshold of concentration, below which effects are not seen. This may be misleading; more refined choice of endpoints can successively lower the apparent threshold, and it becomes difficult to determine, in any simple test, just what is harmful. We need the ability to define water quality standards which will not lead to progressive deterioration in the system of interest. The specification of application factors, to reduce the acutely lethal concentrations defined by conventional toxicity tests, is an attempt to meet the longterm requirement of no observable deterioration.

Field observations provide a valuable check for the application factors specified since they indicate the levels of pollutants at which aquatic life is unaffected and the graded effect of increased pollution on the deterioration of an ecosystem.

The establishment of criteria to meet this requirement could be achieved if reliable data, obtained from the ecosystem at risk, were available on the acute, chronic and sub-lethal effects of the pollutants together with field observations.

No river in Australia has been studied to this ideal state. However, despite the undeniable gaps in our basic knowledge of the Magela system, we are better placed for the setting of realistic standards for the Ranger operation than would be the case for any other development in Australia either existing or planned. Factors that have led to this position include:

- Water quality studies extending over a range of wet seasons that were average (1971/72), late (72/73) and very wet (73/74 and 74/75).
- A good working arrangement between the proponent (RUM Pty. Ltd.) and the AAEC field team during the planning phase.
- Our decision (taken in November 1971) to carry out bio-assay work at Jabiru and to back this work up with sub-lethal studies at Lucas Heights.
- The opportunity to study the polluted Finniss River system which has many features similar to those of the Magela system.

These factors have led to water quality standards for any particular contaminant being based on whichever is the most restrictive criterion out of:

- Acute toxicity tests combined with application factors recommended by the Australian Water Resources Council (AWRC) (Technical Paper No.7).
- The results on indicator species and biological diversity indices for the Finniss River.
- Requirements for agricultural and pastoral use based on AWRC recommendations and Australian pastoral experience (Underwood 1972).

- The requirements for potable water as recommended by the World Health Organisation (WHO), AWRC and, for the case of radioactivity, the International Commission on Radiological Protection (ICRP).

2.1 Standards Based on Acute Toxicity Studies

The general procedure adopted in determining criteria regarding levels of toxic contaminant at which sublethal effects will be absent, has been to modify the acutely toxic concentration that will lead to a 50% survival after a 96 hr exposure (TL_m), with an application factor (or safety factor).

2.1.1 Sensitivity of aquatic organisms to heavy metals

The AAEC acute toxicity studies carried out at Jabiru (Giles 1974) concentrated on fish. This emphasis was consistent with results available from the literature at that time. Acute toxicity studies have been very numerous over the past 18 months but papers dealing with fish still outnumber those for other organisms by about a factor of 50. A review of this recent work is complicated by the importance that water chemistry plays in changing the state of the added toxicant and thus the recorded results (see section 3.1). A critical review will be tabled during this hearing (Simpson and N. Williams in press) but Table 1 presents a resumé of their findings.

2.1.2 TL_m results for the N.T.

Results for acute toxicity studies are presented in Table 2. With one exception these results are as reported by Giles for fish and water from Magela Creek. The exception is for the effect of alamine-336 on *Gambusia* which was done at Lucas Heights using mock Magela water (Anisimoff - unpublished data). A survey of fishes of the Magela indicated that 26 species exist there (Pollard 1974). These are listed in Table 3 where those species known to be, or reasonably expected to be, migratory in wishing to pass Ranger's proposed discharge pipe on the way to upstream habitats, are asterisked. (N. Williams private communication). Bowerbird water hole and other permanent waterholes near it, all of which are upstream of the Ranger area, have not been sampled, our information on species present coming simply from inspection. Detailed sampling should be done before the project becomes operational.

2.1.3 Application factors recommended by AWRC

Table 4 lists the application factors (AF) recommended by AWRC and some derived in a similar manner, for the contaminants known or expected to be present in the waters discharged from the proposed Ranger operations.

The purpose of an application factor is to extrapolate from an observed acute exposure-response curve to levels where no effect occurs. It is not possible to calculate values for application factors from acute toxicity studies. The general principle used to arrive at values for AF is to set it numerically smaller than any reported ratio between experimental TL_m values and that concentration of the contaminant that has been shown to have some measurable effect in long term laboratory studies of sub-lethal effects (behavioural response, growth rate, disease resistance, respiration, swimming performance etc). The difficulty in this approach is to know if these responses are ecologically meaningful. An AAEC officer (N.J. Williams) has a continuing program on behavioural response under low concentrations of contaminants that is run in parallel with field observations of what responses are ecologically meaningful but the work has not advanced far enough to influence this submission.

Wherever possible the AWRC used reported results to arrive at their recommended values for AF but for the contaminants listed in Table 4, a factor of 0.01 was arbitrarily chosen if the contaminant has been shown to be persistent or cumulative and a factor of 0.05 for non-cumulative toxic agents. Most of the heavy metal contaminants that we are dealing with (Cu, Mn, Zn, Mo) are essential trace elements for aquatic organisms. These values are as low as any, and lower than most recommendations existing for other countries. That they are conservative is easy to establish; the product of the recommended AF with the experimental values for TL_m gives derived working levels below the maximum concentrations found to exist naturally.

Studies of fish populations in polluted rivers in the U.K concluded that fish populations can generally exist where soluble toxicants do not exceed 0.3-0.4 times the TL_m.

In terms of the parameters which are known to be significant in influencing the TL_m value for a particular species of fish, the Finniss River is known to be somewhat more capable of accepting heavy metal contaminants without damage than is the Magela. For example the pH, Ca, Mg and hardness levels, all of which ameliorate heavy metal toxicity, for the Magela and the Finniss Rivers are respectively:

System	Water Quality			
	pH range	Hardness ($CaCO_3$ eq)	Ca mg l^{-1}	Mg mg l^{-1}
Finniss	5.5-7.0	50	10-20	15-30
Magela	4-6.4	4	0.5	0.8

However the Finniss River is a far closer approximation to the Magela than U.K. rivers would be. It is therefore of interest to note under what concentrations of heavy metals there is no apparent deterioration of the Finniss River environment.

Williams and Jeffree (1975) investigated biological indications of pollution of the Finniss River system with emphasis on fish diversity and abundance. They concluded that, with their indices, there was no evidence of pollution downstream of the junction of the Finniss River with Florence Creek (30 km downstream from the mine site). Table 5 lists water quality parameters at this point and for some points along the river on the flood plains during September 1974. A comparison of these results with the TL_m values listed in Table 1 indicates that the U.K. conclusion is probably also valid for N.T. rivers.

Field observations on appropriate values for application factors where avoidance response by spawning fish in U.S.A. rivers is involved, have given similar values to those noted in the U.K. and N.T. field studies. This should be kept in mind when considering the possible effects of the discharge from Ranger's retention ponds Nos. 1 and 2.

2.1.4 Standards for aquatic ecosystems

For operations similar to that proposed by Ranger where wastes are discharged to river systems and dilution at the outfall is relied upon to render the waste innocuous, the vexed questions of what standards are to be met and where, are rarely answered. The general approach adopted in this submission is that:

- Within the far field+ of the mixing zone within the receiving waters the concentration of contaminants must be reduced below avoidance levels (TL_m x 0.3).
- The mixing zone must not extend to encompass the benthos or fish spawning grounds, that is, it must be restricted to the peak flood section of the creek bank.
- After the mixing zone, the concentration of contaminants must not exceed natural levels by more than the product of the AF value recommended by the AWRC and the experimental TL_m value.

An alternative approach is that used in Canada where the Environmental Code of Practice for Mines issued by the Water Pollution Control Directorate, recommends that the waste prior to discharge be below those concentrations that would give 50% survival in a 96-hour bioassay test.

This approach is more restrictive than those proposed above for those operations that rely on jet discharge to obtain the necessary dilution. In effect my proposals and the Canadian criterion are consistent provided that the near field dilution is not greater than 3.3 times. This is so in the Ranger proposal.

It needs to be remembered that acclimatisation and other factors would make it possible to maintain fish in the waste ponds (as practised by the French) even though freshly transferred fish would not meet the 96 hour survival criterion.

The water management program outlined in the 1974 EIS would not have met the Canadian guide-lines for either retention ponds No. 1 or No. 2 for at least some part of each wet season. Supplement No. 1 envisages two significant changes to the program. Firstly, waters collected in retention pond No. 1 during the initial part of the wet are returned to the retention system rather than retention pond No. 2. This ensures that the initial run-off (which will contain much of the sulphate and other contaminants encrusted on the north and east embankments of the retention system during the dry) is contained. Secondly, run-off from the crusher ore feed stockpiles will now be directed to retention pond No. 3 (and subsequently used as make up water in the mill) instead of retention pond

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+ Defined mathematically in terms of the relationship between the transverse and longitudinal dimensions of the plume. Its geographical length depends on water current speed.

No. 2.

Table 6 lists the peak concentration for contaminants now expected to occur in retention ponds Nos. 1 and 2. Retention pond No. 1 will meet the Canadian criterion. If laboratory results which show a decrease in the toxicity of copper to $^1/_3$ for a 10 times increase in hardness from 10 to 100 mg l^{-1} $CaCO_3$ equivalent, hold in the field, then retention pond No. 2 will also meet the Canadian criterion. (Anisimoff - unpublished data).

2.2 Standards Based on Indicator Species

It has been shown by many workers that changes in environmental conditions lead to changes in distribution and abundance of particular species and to changes in the composition of communities. The work done on the Finniss River (Williams and Jeffree 1975) demonstrates how the abundance and diversity of fish species provide an index of the state of a river. Their work also provides an assessment of different measuring techniques - netting, spot-lighting and poisoning of embayments - of use in arriving at such an index.

Williams and Jeffree also noted the invertebrates that were present in the Finniss River proper but absent from the East Branch. Sampling was not detailed enough for the evaluation of diversity indices for the invertebrates. Jeffree is in the process of evaluating stomach contents of fish as an invertebrate sampling technique. He is using the purple-striped gudgeon *Mogurnda mogurnda* and looking for differences in diet between populations living in habitats exposed and unexposed to pollutants during three periods of the year - end of wet, middle of dry and end of dry season.

It is difficult to base standards on biological indices or indicator organisms but, properly used, they can give early warning of undesirable changes. As such, work on these topics is more properly regarded as part of the environmental surveillance program and is discussed subsequently (Section 5).

2.3 Standards Based on Requirements for Potable Water

With respect to man, the World Health Organisation (WHO) has made recommendations on the highest desirable level (HDL) and the maximum permissible level (MPL) of contaminants in potable water. The ICRP has made recommendations on allowable concentrations of radioactive material. In their compilation AWRC has reviewed the range of National standards for potable water in arriving at their recommendations.

Table 7 lists these various recommendations for the contaminants of interest. The daggered values are those standards for potable water that are numerically smaller than the corresponding standard based on the sensitivity of aquatic ecosystems.

2.4 Standards Based on Agricultural/Pastoral Use

In no case is the standard based on agricultural/pastoral use for a particular contaminant more restrictive than the related standards based on preserving aquatic organisms and that for potable water.

There are however two special cases. The first is related to the food web between discharged wastes containing radium and man as a consumer. The second is concerned with the antagonistic effect that an increased ingestion of molybdenum has on the metabolism of copper by grazing stock - this is discussed subsequently (Section 4.7).

The primary standard for radioactivity laid down by the ICRP is a certain annual dose limit that would be delivered once the body is in equilibrium with the regularly ingested (or inhaled) contaminant at the prescribed level. For the bone seeking α particle emitting isotope Ra-226, a 50 year ingestion of 8 nCi y^{-1} will lead, at that time, to the maximum permissible dose of 3.0 rem y^{-1} to bone.

The annual input of Ra-226 to the Magela plains from Magela creek that occurs naturally is in the region of 0.2 Ci.

The general approach used in assessing an allowable annual quantity of released Ra-226 was to assume that the plains are in equilibrium (ie $\sim$ 0.2 Ci arrives and leaves annually). If the source term was to be increased then, in time, a new equilibrium level would be established. It is further assumed that the new equilibrium level would be directly proportional to the new input.

Ranger I is not the only source of naturally occurring Ra-226 in the Magela plains. Work by the AAEC has established that the deposits at Jabiluka and an area NNE of Jabiluka, contribute to the Ra-226 in the plains.

In talking of allowable discharges from each of these areas one needs to meet concentration requirements at each and also to have the sum of all releases to be some constant (c) times the sum of natural arisings from the same areas.

A not unreasonable apportionment of allowable discharges is to have each quota proportional to the ore reserves of that area. This can't be done with present knowledge and instead the apportionment is on the basis of the natural arisings of Ra-226. This should not be too dissimilar to one based on ore reserves.

The required constant (c) is different for present land use than it would be if potential land use is taken into account. The present use of the Magela plains is for buffalo production much of which is exported. The restriction to be placed on the Ra-226 level in buffalo meat needs to be the levels that are (or would be) set by the importing countries. These are not known. An indication of what to expect can be based on an assumed meat consumption of 350 g/d and for the Ra-226 content of this to be such as to lead to an annual intake of 8 nCi. This level would be reached (on the basis of the above assumptions) if $C \simeq 12$; ie for the case of the Ranger I area, present land use restricts the annual release of Radium-226 to ≤ 2.4 Ci.

The Magela plains could be used for irrigated market gardens, as a surface supply of potable water and for meat production.

Compliance with individual dose limits is, in these circumstances, conveniently assessed by reference to a critical group. A critical group of people is one which, through habits of eating, recreation, occupation, location or any other pertinent factor, is more at risk from released radionuclides than the community at large. Critical groups may be identified by census or defined arbitrarily as was done here. Table 8 lists the assumed consumption and radium ingestion (from natural sources) for the group. The estimated dose to members of such a group will equal or exceed that which could be received by any group of real people.

Thus, for this group, the annual ingestion of radium from natural sources is 8 nCi. The ICRP recommended limit for the contribution arising from man's activity is also 8 nCi. Thus an allowable annual discharge to meet potential land use restrictions is numerically equal to the natural arisings.

2.5 Summary of Standards

Table 9 lists the recommended standards that the proposed Ranger operations should meet for the range of contaminants of interest. For each, the recommended value is the lowest of those discussed in the preceding sections.

To reiterate, the recommended standard for radium ($\lesssim 0.2$ Ci y^{-1}) is less than $^{1}/_{10}$ of that derived for present land use. If the ICRP or WHO standard was the one to be applied to the receiving waters, the allowable annual discharge would be 2.5 Ci and 0.8 Ci respectively.

3. ENVIRONMENTAL WATER QUALITY

3.1 Present Status of the Magela System

Environmental water quality is fully discussed in the Fact Finding Study Reports (Davy and Conway 1974, WRB 1974) and a computer output containing the results of all analysis carried out during the 1971-75 period is available for tabling.

Many of the analyses done on water samples collected during the wet season were insufficiently accurate for a proper description of environment water quality since the limits of detection (~ 30 µg l^{-1} for Cu, Zn, Pb; 10 µg l^{-1} for As) were above natural levels. To some extent (Ra being a notable exception) this position was rectified for the 1974-75 sampling program.

We are less well placed with respect to the total quantities of contaminants, of natural origin, carried by Magela Creek during an average wet season. The uncertainty in these estimates stems from the following factors:

- the use of a rating curve that is certain to be in error for readings near the cease-to-flow value. Since natural levels are highest in the early part of the wet season, a significant percentage of the total contaminant flow occurs in the early part of the wet when water flows are relatively low,

- the limits of detection in analyses for Cu, Zn, Pb, Mn etc done by AAEC and DNA (WRB) for the water years 1971/72, 1972/73, 1973/74 were too high,
- spot sampling and infrequent sampling for Ra during 1971/72 and 1972/73 (but with an adequate detection limit of 0.05 pCi l^{-1}) and an inadequate detection limit for Ra for the spot sampling done during 1974/75 (1 pCi l^{-1}),
- most years of sampling have been for years with well above average rainfall (eg 1973/74 and 1974/75).

An indication of the quantities involved can be based on an annual flow of 2.5×10^8 m^3 at average concentrations of:

Cu: 3 μg l^{-1}; Zn: 8 μg l^{-1}; Pb: 2 μg l^{-1};
Ra: 0.8 pCi l^{-1}; Mo: < 0.1 μg l^{-1}; As: < 10 μg l^{-1};
SO_4: 3 mg l^{-1}.

Thus the naturally occurring annual quantities are in the region of:

Cu: 750 kg; Zn: 2000 kg; Pb: 500 kg;
Ra: 0.2 Ci; Mo: < 25 kg; As: < 2500 kg;
SO_4: 750 tonnes.

It is important to note that all analyses reported so far are for the total amount of the element in the dissolved state and not the ionic form which would be lower.

Laboratory work with copper (N. Williams - unpublished) demonstrates the importance of chemical state on the toxicity of heavy metals to fish. For example the TL_m for ionic copper at a pH range of 5.8-6.2 was 60 μg l^{-1}; if the cupric ion is complexed with EDTA, the TL_m value rises to 500 μg l^{-1}.

A situation where these chemical changes appear to be important in the environment is waterholes formed at the end of drainage lines transverse to the main creek channel. In these systems concentrations of heavy metals by the end of the dry season are less toxic than might be inferred from simple analysis of bioassay tests. Ranger in its EIS has given undue emphasis to these observations.

These locations are important feeding grounds for geese during normal years but are of limited value in dry years since they also dry up in these periods.

3.2 The Effect of Uncontrolled Releases from the Ranger Operation

Uncontrolled discharges from the Ranger operation would affect four of the above class of waterholes:

- runoff from the south and west embankments of the tailings retention system (Gulungul waterhole),
- releases from retention pond No. 1 (Goonjimba waterhole),
- runoff from the mine catchment (Djalkmarra waterhole),
- runoff from the tailings corridor area (Georgetown billabong).

Georgetown differs from the other three in that, during the wet season, part of the Magela Creek flow is through Georgetown billabong and its bottom is, in parts, more sandy.

Concentrations of heavy metals in these locations during the wet are predictable but their adsorption on sediments and subsequent release under anaerobic conditions are not. The following sets of slides taken of Boggy Creek during 1972/73 illustrate the enormity of the problem.

It is safest to assume the seepage into this hole will be high in sulphates during the early part of the dry season and that sulphate encrustations will develop on its bed during the drying out phase. The sedge grasses should not be affected but the levels of manganese in the macroalgae will be high (say 1 mg g^{-1} DW). If geese are like hens then they should be unaffected by levels of manganese such as this (Underwood 1972).

The contaminant stress on the other waterholes will be less severe. No census of fish in them is available but these should be done before mining operations start.

Since the catchment of the tailings retention system (100 ha) will no longer be available to Coonjimba waterhole and also since some of the water initially retained by retention pond No. 1. is transferred to the tailings retention system and retention pond No. 2., Coonjimba waterhole may not be permanent after the start of operations.

4. LOSS OF CONTAMINANTS FROM THE OPERATION PROPOSED BY RANGER

4.1 Tailings Retention System

Tables 10 and 11 summarise estimates for the loss of contaminants with seepage from the tailings retention system. These tables are based on:

- The Coffrey and Hollingsworth design for the retention system,
- an independent assessment of seepage loss which in turn used, as input data, values recommended by Coffrey and Hollingsworth (Davy 1975),
- the most recent results for chemical analysis of samples of raffinate adjusted to pH 8.

4.2 Retention Pond No. 1

The water management program for retention pond No. 1 has been changed from that outlined in the EIS to one in which the waters collected in the initial part of the wet are returned to the tailings retention system rather than retention pond No. 2. This ensures that the initial run-off is contained. No credit is taken for this reduction in the amount of contaminants released. Table 12 summarises the release from retention pond No. 1 excluding that classed as seepage in 4.1 above.

4.3 Retention Pond No. 2

Table 13 summarises the releases for retention pond No. 2. The effect of diverting the ore stockpile run-off from retention pond No. 2. to retention pond No. 3. is to make a significant reduction (~33% in the case of radium) in the estimated releases from retention pond No. 2.

particularly in the early years.

To a significant degree the amount of contaminants released from retention pond No. 2. arises from the influx of ground water to the openpit being greater than the quantity required as make-up water for the mill (ie to replace the water lost be evaporation and seepage from the tailings retention system and that to saturate the tails material). Thus estimates for the quantities discharged depend in general on the water balance and in particular on the quantity of pit water. In Table 13 it has been assumed that this quantity remains unchanged between the 10th and 15th year of operation. The consequences should this not be the case, and the remedial measures that could be applied, are discussed below. (Section 4.5)

4.4. Total Release of Contaminants

Table 14 lists estimates for the total quantities of contaminants to be released from the proposed Range operations during a year with average rainfall.

4.5 Uncertainties of Estimates for Release of Contaminants

Ranger's proposed water management is one of discharging any water excess resulting from rainfall and pit water sources on the one hand and losses resulting from seepage and evaporation of the other. A large percentage of the volume of water discharged arises as runoff from the mine/mill area with the contaminants coming from waste rock piles and other earth works located within the catchment. There are uncertainties in the estimates for each of the components that go to make up the water balance. These are discussed at length in the EIS and we will discuss here only the magnitudes.

Rainfall

The present estimate (1150 mm y^{-1}) is based on Oenpelli data. The limited data collected at Jabiru and Jabiluka indicates the importantce of local terrain. Error bounds for the current estimate are probably −0% and +10%.

Evaporation

The presently used conversion factor to relate evaporation from the tailings retention system to evaporometer readings is 0.65. This is probably at the low end of the likely range, particularly as the tails at about 1 m depth will have a high albedo for incident sunlight. The error bounds are likely to be −0% and +10% and therefore cancel out the uncertainty in rainfall.

Seepage loss

Over and above any change in the estimated seepage loss from the tailings retention system brought about by changes in the most probable values for the input data, which is being separately assessed by the Snowy Mountain Authority, there is the question of the influence of the rip-rap boundary. If in time, this becomes essentially blocked by tails material, the net seepage would be reduced by about 40% (Davey 1975). This in turn would reduce the amount of sulphate and manganese lost to the environment but would increase, by increasing the pit water discharge, the amounts of copper, zinc and radium that are released. Table 15 provides estimates for this change.

Pit water

The estimate for the quantity of water entering the pit used in the EIS is approximate only. While further draw-down testing might narrow the range in estimated inflow, a meaningful result will only emerge after pit development has gone on for some time. It is impossible to estimate the possible error in the adopted value. If practice proves it is too high then the water balance can be restored by using the tailings retention system as a storage dam for waters from retention ponds No. 1 and 2. If it turns out to be too low then remedial options include:

- sealing aquifers by grouting or other means,
- intercepting water inflows at their source if these are low in contaminants,
- treating all or a proportion of the pit water to remove excess contaminants including the use of barium chloride for the precipitation of radium,
- building additional evaporation ponds.

The last mentioned would involve chemical stabilisation of the embankments since all near impermeable material extracted from pits 1 and 3 is committed for construction of the tailings retention system.

Probably the greatest uncertainty relates to the quality of the pit water particularly during the last years of operation. Surface water from the general area has roughly equal amounts of Ca and Mg. The area may have a marine origin and the ground water at depth could be fossile and saline to a degree greater than sea water.

The solvent extraction plant proposed by Ranger could use make up water of 0.5 g of chloride per litre, and, with some modifications handle CI levels up to 1 g l^{-1}. For levels above 3.5 g l^{-1} it would be inoperative.

4.6 Method of Discharge

Seepage loss from the tailings retention system and overtopping of retention pond No. 1. are uncontrolled releases.

The release from retention pond No. 2. is controlled with respect to both time and rate. Discharges will only be made when the flow in Magela creek is greater than 30 $m^3 sec^{-1}$ and the discharge will be at the rate of 1% of the creek flow to a maximum of 3 $m^3 sec^{-1}$.

The single port discharge line will be at the 30 $m^3 sec^{-1}$ flood line and this arrangement is expected to have the following characteristics:

- a long cigar shaped mixing zone located over an area where the grass dominates the understory,
- good mixing within the plume as a result of eddies generated by flow past paperbarks,
- no contact between the plume and the creek bed proper until mixing is near complete,
- a visual reminder of any discharge being made when the creek flow is below the recommended minimum.

In the early years of operation the discharge system should be evaluated with radioactive tracer techniques and modifications introduced as required.

4.6.1 Discharge Concentrations

Table 16 summarises the expected maximum, minimum and average concentrations for contaminants arising from the Ranger operation. This table lists these values for before and after mixing is complete, as well as the corresponding natural concentrations.

4.6.2 Discharge Quantities

A comparison of discharge quantities and naturally transported quantities for each of the significant contaminants is provided in Table 17.

4.6.3 Fate of Discharged Contaminants

Hydrology of the Magela plains

Recently two attempts were made to determine the percentage of water that enters or rains on the Magela plains which subsequently flows to the East Alligator River (Carruthers 1975, A. Williams unpublished data).

Williams, as a first step in studying the deposition behaviour of the floodwaters, set up a weekly water balance model of the Magela basin under average conditions to predict the discharge behaviour from gauged inputs and flood levels. The overall estimate of yearly discharge as a proportion of total basin input was 80%, the remainder being lost by evaporation. Carruthers, from a model based on basin storage capacity and catchment runoff concluded that the figure should be 90+%.

The same sort of losses to the East Alligator River may not be true for contaminants present in the flood water. There are many similarities between the Magela and Finniss flood plains. For the quantities of contaminants released from Rum Jungle to the Finniss flood plains it does appear (Davy and O'Brien 1975) that almost all the released zinc and manganese and over half of the released copper was retained on the flood plains. The situation for Ra is less clear. If the Ra found in the deep subsoil is of solute origin, then about half of the radium released from Rum Jungle is still on the plains. If it is of geological origin, the retained percentage is quite low, or, less probably, it has not yet reached the plains.

Our earlier assumption then that contaminants released from Ranger will drive the plains to a higher equilibrium level, proportional to the new total release, seems a reasonable working hypothesis.

4.7 Measurable Changes in Base Line Levels

Sulphate

The major source of sulphate is seepage from the tailings retention system which contains about 3 g l^{-1}. The proposed operations will raise the sulphate levels in the Magela creek by about a factor of 3. The total quantity discharged over the life of the mine will be similar to that discharged from Rum Jungle during its operation. Based on the Rum Jungle studies, it is expected that encrustations will be visible in Boggy Creek waterhole and that increases in environmental levels will be measurable in the stretch of river down to Mudginberry.

Any potential problem associated with the sulphate release is related to the Cu-Mo-SO_4 interaction discussed below.

If, in their own right, sulphate levels are deemed to be too high, they could be reduced by raising the pH of raffinate passed to the retention system or by reducing the seepage from that system.

Manganese

The major source of manganese is seepage from the tailings retention system which contains about 26 mg l^{-1}. Increased levels of manganese in the macro-algae and bank vegetation are to be expected. Data reported by Underwood (1972) suggests that if these increases are to have any effect, it would be an increase in the fertility of buffalo.

Note that surface water at the end of the dry season often exceeds thw WHO value for HDL.

The total quantity released during the operation would be about 10%

of that released from Rum Jungle.

Raising the pH of the raffinate or reducing the seepage from the tailings retention system, would substantially reduce the quantity of manganese released.

Cu/Mo status

The copper concentration in pasture grass from the Alligator River area is, on a dry weight basis, about 5 $\mu g\ g^{-1}$. Judged on Australian pastoral experience, this figure indicates a situation bordering on copper deficiency. AAEC analyses of buffalo flesh, kidney and liver indicate a normal copper status. The reason for this apparent inconsistency is the low environmental level of Mo ($<0.1\ \mu g\ l^{-1}$ during the wet season and SO_4^{--} (~ 2 mg l^{-1}) since molybdenum, particularly when a high sulphur intake occurs, is antagonistic with respect to copper metabolism. The molybdenum concentration in pasture grass is $< 0.3\ \mu g\ g^{-1}$.

The proposed operations will increase the sulphur levels on the Magela plains (release of sulphates and dry disposition of oxides of sulphur from the acid plant). An accurate estimate for the annual discharge of molybdenum is not available but it could be as high as a hundred kilograms, at an inferred concentration of 0.4 $\mu g\ l^{-1}$. The copper status of buffalo and geese should be determined regularly and if found to be deteriorating, copper salt licks could be distributed on the plains.

5. SURVEILLANCE PROGRAM

The surveillance program needs to meet the following objectives:

- To demonstate that the operation is complying with the imposed standards.
- As a check on the accuracy of predictions on measurable effects resulting from the operation.
- To provide better basic data for re-assessment of the mode of operation.
- To better assess available waste management options in term of cost effectiveness.
- To provide better data on the environment for re-assessment of the imposed standards.

5.1 Demonstration of Compliance

The AAEC has said that it will supervise the Ranger operation to ensure compliance with imposed standards and specifications.

A proposed surveillance program is outlined here. This program is provisional and would need to subsequently take into account changes worked out in consultation with other Departments (Departments of Environment, Health and Northern Australia).

The standards imposed on the operation refer to allowable concentrations which are to be met after mixing for controlled releases and at the receiving waters for uncontrolled releases, and to allowable quantities of contaminants that can be discharged annually.

Flow recorders could be installed at the weir of retention pond No. 1. and in the discharge pipe from retention pond No. 2. A proportional sampler will also be installed in the pump line associated with retention pond No. 2. and the daily samples collected during discharge periods will be analysed for the range of contaminants. Weekly samples will be collected from retention pond No. 1. when it is discharging and these samples will be subjected to the same analyses.

No attempt will be made to record the run-off to Gulungul waterhole or Georgetown billabong but water samples from these locations and from Djalkmara and Coonjimba waterholes should be sampled with the schedule:

Weekly	:	Mid November through December; mid March through April.
Mid monthly	:	January, February and May through October.

5.2 Measurable Effects

Relatively little is known regarding the fate of heavy metals in the aquatic environment but the high concentrations that exist in sediments, either absorbed to particulate matter or as insoluble complexes, has been clearly demonstrated from the waterhole systems (Davy and Conway 1974). Sediments should be collected from these sites on the same schedule as outlined for water samples.

It is expected that submerged grasses and water lilies will show, at least, increasing manganese levels at these sites; the former should be sampled in mid April and mid November, and the latter in mid April when leaves from fringe paperbarks and sedge grasses are also sampled.

5.3 Transfer Coefficients

The derived standards are strongly influenced by the value adopted for transfer coefficients from the study of the movement of natural levels of contaminants. This is particularly so with respect to radioactivity. Estimates for these coefficients will improve as the operations proceed.

Water - Suspended solids - Mussels

During early April and early November mussels should be collected from Bowerbird waterhole (upstream mine area), Corndahl waterhole and

Mudginberri billabong. It is important that the November sampling be timed to correspond to surface algal blooms in other waterbodies.

Water - barramundi

Barramundi should be netted from Mudginberri and Georgetown billabongs in early November. Attempts could also be made, by purchase, to obtain a good regional average for radium in barramundi fillets, head and backbone.

Soil - pasture grass - buffalo

A three year geo-chemical, geo-botanical program on this transfer route has been started (A. Williams, AAEC). On his results should depend the routine surveillance program for the operational phase.

Grass - sedge - geese

Geese should be taken during season from the Gulungul waterhole area and from that area where the drainage from the Regional Centre joins that from Ranger I Anomaly VI. Grasses and sedge should be collected from these sites during September, October and November.

Water - crocodile

No routine sampling is planned. Any crocodile taken incidentally should have its muscle and organs examined chemically and histologically.

5.4 Assessment of water management program and available options

Seepage from tailings retention system

To date there is no guaranteed method for measuring seepage from the tailings retention system if the seepage is much less than that estimated. If it is significantly larger than that estimated, the proposed water balance approach should be adequate. Under these conditions, direct spot seepage rate measurements should be feasible.

The installed instrumentation proposed includes: fluxmeter, evaporometer, flowmeters (water discharge and return lines) and anemometers, hydrometers and thermometers with digital recording.

The regulatory authority should also maintain a recording pH sensor on the tailings discharge line.

At this time it is believed that molybdenum and radium are the most significant contaminants present in the raffinate. Both should be monitored very frequently until the variability in their levels is determined. Since it is the level of these contaminants in the seepage leaving the tailings dam that is important, some of these samples should be from depth within the tails material.

Pit water

The quality and quantity of pit water are important parameters in the water management program. These are not expected to change rapidly and monthly sampling from retention pond No. 3. should be adequate.

Waste-rock

Regular geological inspections of the waste rock pile could be carried out. If rapid weathering leading to the release of heavy metals is seen to be occurring, a segregation program could be implemented at the mine face.

During the wet, the water quality of run-off, and its variation with time, should be determined during specific storms.

Once springs have developed at the base of the heap, their flow should be metered and the quality of the water determined. If early results are promising, attempts could be made to structure the heap so that perched water tables are formed. This should assist re-vegetation.

Soil sulphate profile

There is a range of opinions on the shape the sulphate soil profile will take in the buffer zone as a result of seepage from the tailings retention system and how it will change during the next wet season. Much of the uncertainty related to the adequacy or otherwise of the proposed operation of retention pond No. 1. and the uncontrolled release to Gulungal creek is related to these factors. The usefulness of a toe drain, its optimum location and its optimum design, depend on the answers to these questions.

Both the sulphate and radium profiles should be determined, the latter by using track etch techniques.

Test bores

The locations of test bores around the retention system are described in the EIS. With time most, if not all, will intercept the contaminant front. At that time drawn-down testing would yield estimates of average permeability and soil exchange characteristics for comparison with design estimates.

Eucalypt sampling

Sampling of leaves from E. miniata and stringbark should be undertaken as a monitor of preferential seepage paths undetected by the test bores.

5.5 Biological Monitoring

Earlier in this submission I have indicated some biological research that I think should be carried out in the pre-operational stage. This included:

- Fish census of three backflow waterholes.
- Fish census of Bowerbird and other upstream breeding habitats.

- Invertebrate collection.
- Movement of radium on the flood plains.

Since the aim is to define worthwhile biological monitoring routines during this period, this work should be widened to include:

- Evaluation of artificial mosses (so far of limited success in the Finniss River studies).
- Evaluation of artificial reefs (almost useless in the Finniss River studies).
- Tagged fish release/recapture (Bowerbird waterhole to Corndahl waterhole).
- Spot-lighting for, and capture of macrobrachium at Corndahl and Mudginberri. (The Finniss River work indicates that the shrimps are a good indicator species - Williams and Jeffree 1975).
- Water-lilies as a collecting surface for molluscs.
- Histological examination of organs from geese, barramundi and other fishes.

5.7 Botanical Survey

The work on the Finniss River indicated that Pandanus palms are relatively sensitive to the wastes released from Rum Jungle.

An annual mapping of Pandanus stands downstream from the Ranger area should be carried out.

5.8 Fish Kills

Minor fish kills were observed to occur in several billabongs in the Alligator Rivers area prior to the first rains of the 72/73 wet season.

It would be worthwhile to investigate the environmental parameters (temperature, dissolved oxygen, biological oxygen demand, concentration of heavy metals) associated with these fish kills.

6. CONCLUSIONS

My assessment of the water management program proposed by the Ranger participants in their EIS led to the following conclusions:

(1) We are better placed for the setting of realistic standards for the Ranger operation than would be the case for any other development in Australia.

(2) The standards that I have proposed for the Ranger operation are based on whichever is the most restrictive criterion out of:

  - Acute toxicity tests carried out on organisms and water from the Magela Creek combined with application factors recommended by AWRC.

- The results on indicator species and biological diversity indices for the Finniss River.
- Requirements for agricultural and pastoral use.
- The requirements for potable water.

(3) During the early years the program proposed by Ranger is expected to meet these standards in the receiving waters at the boundary of the lease area. By the 5th year of operation present estimates suggest that the standards for manganese and sulphate will not be met at Gulungul creek. Prior to that time, a toe drain, designed and sited to intercept seepage from the south and west embankments of the tailings retention system, will need to have been installed.

(4) Adequate options exist within the proposed water management program to cover the expected range of uncertainties in the parameters involved in the program.

(5) Our knowledge of the local environment is adequate for the planning of a comprehensive environmental surveillance program provided that some further specific tasks are undertaken over the next year or so.

TABLE 1

CONCENTRATIONS OF HEAVY (TRANSITION) METALS LETHAL AND SUB-LETHAL TO AQUATIC ORGANISMS

Organism		Range of Metal Concentrations (μg/l) in the Aquatic Medium											
Freshwater(F)/ Estuarine(E)		Cu		Cd		Hg		As		Zn		Cr	
		Lethal (1)	Sub-lethal (2)	Lethal	Sub-lethal	Lethal	Sub-lethal	Lethal	Sub-lethal	Lethal	Sub-lethal	Lethal	Sub-lethal
Bacteria	F			6000									
Phytoplankton	F	10-12000	1-5				1						
Algae	F	300								700-2400	50		
Protozoa	F		250-320				250-500						530-20200
Trematoda	F										60000		
Rotifera	F							6600-150000				4400-65000	
Annelida	E	540-2300		100						1.5-100			
Crustacea	F	44-120	35	5-60			6			158-1210	115		
	E	> 5000		1000-8000						1000			
Insecta	F			840-2000000									
Fish	F	50-250	6-60	10-100	80-1100	400-800 (0.2)	3-10			10-330000	>100	300-100000	
Application Factor (3)		.05		.01				.01		.005		.01	

(1) The concentration lethal to 50% of the organisms (LC50) has been determined for a number of time periods, although the 96 hour LC50 is becoming widely accepted as a standard.

(2) This accounts for effects on the physiology and biology of the organisms (eg behaviour, growth rate, oxygen consumption, fecundity, damage to organs).

(3) Values taken from AWRC Technical Paper No. 7 (Hart, 1974). The use of application factors is an attempt to set a safe level for the population of organisms as a whole, from the lethal concentrations. That is, Safe Level = Application Factor x Lethal Level. In this case, values from Hart (1974) apply to a 96 hour LC50 Lethal Level.

TABLE 1 continued

Organism	Freshwater(F)/ Estuarine(E)	Range of Metal Concentrations (μg/l) in the Aquatic Medium									
		Tl		Pb		Ni		Se		Al	
		Lethal	Sub-lethal	Lethal	Sub-lethal	Lethal	Sub-lethal	Lethal	Sub-lethal	Lethal	Sub-lethal
Bacteria	F		20000								
Phytoplankton	F										
Algae	F										
Protozoa	F										
Trematoda	F										
Rotifera	F										
Annelida	E										
Crustacea	F	2000		500							
	E			10000							
Insecta	F										
Fish	F	400-60000		1000-500000	100?	400-43000		3	> 5	500	
Application Factor (3)				.01							

TABLE 2

RESULTS OF ACUTE TOXICITY TESTS

Organism	96 hour TL_m (mg ℓ^{-1})							Average Body Weight (g)
	U	Cu	Pb	Zn	(MnO_4)	Raffinate (Neutral)	Alamine 336	
Hardyheads	4.0-4.5	0.04	0.18(22)	0.14	22	88×10^3	18	1.1
Fry	3.7*(39)	0.08*(1)	2.1*(6)	0.3*(1)				0.23
Striped Grunter	2.5(14)	>0.1(10)	>0.3(18)	0.2(0)				6.7
Spangled Grunter	4.1	>0.1	>0.3	>0.2				22.5
Catfish	72†							37.1
Macrobrachium sp.	>5(3)	0.17(6)	0.5(30)	0.43(11)				0.25
Gambusia affiens							6	

( ) Bracketed figures are average % loss of toxicant during the experiment.

* 48 hour TL_m .

† Catfish taken from Georgetown Billabong.

<u>TABLE 3</u>

<u>SUMMARY OF FISH DISTRIBUTION IN MAGELA CREEK</u>

ped : proposed effluent discharge point.

(*) : species with known or suspected migratory habits.

Species	Collected[1] from downstream of ped	Collected[1] from upstream of ped	Stated [2] to occur well upstream of ped
Ambassis macleayi	+	+	+
Ambassis agrammus	+	+	+
Amniataba percoides	+	+	+
Craterocephalus majoriae	+	+	
Craterocephalus stercusmuscarum[3]	+	+	
Denariusa bandata	+	+	
Fluvialosa erebi	+	+	+
Glossamia aprion	+	+	+
Glossogobius giurus	+	+	
Hepaestus fuliginosus[4]	+	+	+
Hexanematichthys leptaspis (*)	+		
Hypseoletris simples	+		
Lates calcarifer (*)	+		
Madigania unicolor	+	+	+
Megalops cyprinoides (*)	+		
Melanotaenia nigrans[5]		+	+
Mogurnda mogurnda	+	+	+
Nematocentrus maculata	+	+	+
Neosilurus sp. (black)	+	+	
Neosilurus sp. (yellow-tailed)	+	+	+
Ocyeleotris lineolatus	+	+	+
Pseudomugil tenellus[6] (*)		+	
Scleropages jardini	+	+	+
Strongylura kreffti	+	+	+
Synbranchus bengalensis (*)	+	+	
Toxotes chatareus	+	+	+

1 By Pollard or Midgley, reported in Pollard 1974, or by Giles, reported in Giles 1974.
2 By Giles personal communication 1975.
3 Including C. worreli reported by Giles 1974.
4 Including Therapon sp. reported by Giles 1974.
5 Including melanotaeniid sp. reported by Giles 1974.
6 Including Pseudomugil sp. reported by Giles 1974.

TABLE 4

VALUES FOR APPLICATION FACTORS

RECOMMENDED BY AWRC AND THOSE(*) ARRIVED

AT IN A SIMILAR MANNER

Contaminant	Application Factor
Amines (*)	0.1
Copper	0.05
Lead	0.01
Manganese (*)	0.01
Uranium (*)	0.05
Zinc	0.005
Cadmium (*)	0.005
Chronium	0.01
Nickel	0.05
Vanadium	0.05

TABLE 5

WATER QUALITY OF THE LOWER REACHES

OF THE FINNISS RIVER (1974)* (mg l^{-1})

(EB - East Branch Finniss R)

Notes	Ca	Mg	SO_4	Mn	Cu	Zn
3 days after flow EB	< 10	2.8	6	< 0.03	< 0.03	< 0.03
16 days after flow EB	< 10	5.6	16	0.07	0.1	0.5
	2.1		< 1	0.06	< 0.01	< 0.01
	2.8		1.7	0.1		
4 days after flow EB	7.4	13	4.8	0.05	0.01	0.06
	4	5.8		0.04	0.03	0.03
	3.5	5.4		< 0.005	0.03	< 0.005
	3.3	5.5		0.01	0.02	0.03
	4.5	7.3		0.02	0.02	0.01
	4.3	7.1		< 0.005	0.05	< 0.005
	4.3	6.9		< 0.005	0.02	0.02

* The first five results sets are for immediately down stream of the Junction with Florence Creek; the remainder are for the Finniss R. channel due east of the Finniss R. homestead.

TABLE 6

PEAK CONCENTRATIONS OF CONTAMINANTS

FOR RETENTION PONDS NO. 1 AND NO. 2.

DURING PERIODS OF DISCHARGE (STAGE 6)

Retention Pond	Peak Concentration				
	Cu	Pb	Zn	U	Ra
	$\mu g\ l^{-1}$				$pCi\ l^{-1}$
No. 1	50	40	60	65	11
No. 2	120	50	60	250	65

TABLE 7

STANDARDS FOR POTABLE WATER

($\mu g\ l^{-1}$ Chemical Contaminants)

($pCi\ l^{-1}$ for Radioactive Contaminant)

Contaminant	Recommended Concentration			
	WHO		AWRC	ICRP
	MPL	HDL		
Amines			7000	
Arsenic	50		50+	
Copper	1500	50	50	
Lead	100			
Lead-210				100 +
Manganese	500	50	50	
Nitrate			10000	
Polonium-210				700+
Radium-226	3			10+
Sulphates	$4x10^5$	$2x10^5$	$2.5x10^5$+	
Uranium				(50 mg/ (two day ingestion)
Zinc	15000	5000		
Cadmium			10	
Chromium			50	
Mercury			2+	
Selenium			10	
Vanadium				

TABLE 8

ASSUMED CONSUMPTION AND RADIUM INGESTION BY MEMBERS OF THE CRITICAL GROUP

Exposure Route	Consumption (kg y^{-1})	Radium intake (nCi)
Water	730	1.24
Buffalo	200	0.96
Fish	40	0.76
Cultivated Vegetables	70	2.3
Cultivated Fruit	20	0.14
Crocodile	15	0.26
Native fruit	5	0.15
Vegetables	5	0.23
Goose	5	0.007
Mussels	2	2.4

TABLE 9

STANDARDS RECOMMENDED TO APPLY

TO THE RANGER OPERATION

Contaminant	MPL after Mixing Zone
Amines	60 μg l^{-1}
Arsenic	50 μg l^{-1}
Copper	2 μg l^{-1}
Lead	2 μg l^{-1}
Lead-210	100 pCi l^{-1}
Manganese	220 μg l^{-1}
Nitrate	10 mg l^{-1}
Polonium-210	700 pCi l^{-1}
Radium-226	10 pCi l^{-1}
	($\lesssim$ 0.2 Ci y^{-1})
Sulphate	250 mg l^{-1}
Uranium	25 μg l^{-1}
Zinc	0.7 μg l^{-1}
Cadmium	4 μg l^{-1}
Chromium	50 μg l^{-1}
Mercury	2 μg l^{-1}
Nickel	50 μg l^{-1}
Selenium	10 μg l^{-1}

TABLE 10

ANNUAL LOSS (Kg AND Ci) OF CONTAMINANTS IN SEEPAGE FROM TAILINGS RETENTION SYSTEM

Seepage Zone and Stage	Contaminants in Seepage													
	As		Cu		Pb		Mo		U		Zn		Ra	
	min	max	min	max	min	max	min	max	min	max	min	max	min $x10^{-4}$	max $x10^{-4}$
North Embankment														
Stage 1	0.11	0.15	0.03	0.04	0.04	0.05	0.57	0.76	0.22	0.29	0.0003	0.0004	4.4	5.8
4	0.37	0.44	0.11	0.13	0.13	0.15	1.9	2.3	0.73	0.88	0.00	0.001	15	17
6	0.8	0.91	0.24	0.27	0.28	0.32	4.2	4.8	1.6	1.8	0.002	0.003	32	37
East Embankment														
Stage 1	0.04	0.05	0.01	0.02	0.01	0.02	0.19	0.28	0.07	0.11	0.0001	0.0002	1.5	2.2
4	0.18	0.37	0.05	0.11	0.06	0.13	0.95	1.89	0.37	0.73	0.0006	0.001	7.3	15
6	0.55	0.73	0.16	0.22	0.19	0.26	2.85	3.80	1.10	1.46	0.002	0.002	22	29
West and South Embankments														
Stage 1	0.05	0.07	0.02	0.02	0.02	0.03	0.28	0.38	0.11	0.15	0.0002	0.0002	2.2	2.9
4	0.37	0.62	0.11	0.19	0.13	0.22	1.9	3.2	0.73	1.24	0.001	0.002	15	25
6	0.91	1.28	0.27	0.38	0.32	0.45	4.75	6.6	1.83	2.55	0.003	0.004	37	51

TABLE 11

TOTAL ANNUAL LOSS OF CONTAMINANTS FROM TAILINGS RETENTION SYSTEM (IN Kg AND Ci)

Stage 1

	As	Cu	Pb	Mo	U	Zn	Ra
Min	0.2	0.06	0.07	1.04	0.4	0.0006	8×10^{-4}
Max	0.27	0.08	0.10	1.4	0.55	0.0008	11×10^{-4}

Stage 4

	As	Cu	Pb	Mo	U	Zn	Ra
Min	0.91	0.07	0.32	4.7	1.8	0.003	37×10^{-4}
Max	1.42	0.47	0.50	7.4	2.9	0.004	57×10^{-4}

Stage 6

	As	Cu	Pb	Mo	U	Zn	Ra
Min	2.3	0.68	0.8	12	4.5	0.007	0.009
Max	2.9	0.88	1.0	15	5.8	0.009	0.011

TABLE 12

ANNUAL LOSS OF CONTAMINANTS FROM RETENTION POND NO.1

Year of Operation	Water Release ($m^3 y^{-1}$)	Contaminant concentration and masses						
		As*	Cu	Pb	Mo*	U	Zn	Ra
		$\mu g\ l^{-1}$ and kg						
Stage 1 (year 2)	$9.4x10^5$	10 (9.4kg)	21 (20kg)	17 (16kg)	40 (38kg)	19 (18kg)	18 (17kg)	4 (0.004Ci)
Stage 4 (year 10)	$1.2x10^6$	10 (12kg)	22 (27kg)	18 (22kg)	45 (54kg)	30 (28kg)	20 (24kg)	4.5 (0.005Ci)
Stage 6 (year 15)	$2.0x10^6$	10 (20kg)	22 (44kg)	20 (40kg)	52 (104kg)	42 (84kg)	22 (44kg)	5 (0.01Ci)

* Crude estimates only

TABLE 13

ANNUAL LOSS OF CONTAMINANTS
FROM RETENTION POND NO.2+

Year of Operation	Mass of contaminant				
	Cu	Pb	Zn	U	Ra
	kg				Ci
Stage 1	4.4	17	22	120	0.015
Stage 4	8.6	36	44	160	0.045
Stage 6	13	56	68	200	<0.05

\+ Inadequate data for an assessment of As and Mo inputs.

TABLE 14

TOTAL ANNUAL LOSS OF CONTAMINANTS

Year of Operation	Mass of contaminant						
	As	Cu	Pb	Mo	U	Zn	Ra
	kg						Ci
Stage 1	>10	26	34	>40	140	39	0.019
Stage 4	>14	31	54	>52	190	64	0.055
Stage 6	>23	34	77	>70	290	90	0.071

TABLE 15

EXPECTED CHANGE IN QUANTITY OF CONTAMINANTS RELEASED AT STAGE 6 AS A RESULT OF SILTING UP OF RIP RAP BOUNDARY (- ve sign indicates reduction; + ve sign indicates increase)

Contaminant

Cu	Mn	Zn	Pb	Ra	U	SO_4
+2 kg	-2600 kg	+4 kg	+2 kg	+0.01 Ci	-5 kg	-920
+6%	-30%	+4.4%	+2.6%	+14%	-1.7%	-30%

TABLE 16

THE CONCENTRATIONS OF SOME CONTAMINANTS FOR THE NATURAL SYSTEM AND FOR THE PROPOSED WATER MANAGEMENT PROGRAM

(Subscript - M : maximum, m : minimum, a : average

Symbol - N : natural, C : added material)

* Indicates considerable uncertainty in stated values

Natural			Retention Pond No. 1			Retention Pond No. 2				Recommended Standard
						Before dilution		After dilution		
N_M*	N_m*	N_a*	C_M	C_m	C_a	C_M	C_m	C_M	C_a	
Cu(μg l^{-1})										
10	< 0.02	3	50	15	22	120	90	≲ 1.2	0.2	2
Pb(μg l^{-1})										
4	0.08	2	40	10	20	50	20	≲ 0.5	0.3	2
U (μg l^{-1})										
70	< 0.1	1	70	10	40	250	150	< 3	2	25
Zn(μg l^{-1})										
14	3	8	60	15	22	60	20	≲ 0.6	0.4	0.7
Ra(pCi l^{-1} and Ci/y)										
5 ± 2	< 0.1	0.8	11	3	5	65	25	≲ 0.7	0.3	10 < 0.2 Ci y^{-1}

TABLE 17

COMPARISON OF QUANTITIES OF CONTAMINANTS
RELEASED IN THE PROPOSED RANGER OPERATION
(STAGE 6) WITH NATURAL ARISINGS

(Kg and Ci)

Source	As	Cu	Pb	Mo	U	Zn	Ra	SO_4
Stage 6	>23	34	77	>70	290	90	0.07	3400000
Natural*	<2500	750	500	<25	250	2000	0.2	750000

* approximate only.