RESPONSE TO THE ICSU REVIEW OF THE SUPERVISING SCIENTIST'S REPORT TO THE WORLD HERITAGE COMMITTEE

Supervising Scientist
Environment Australia

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1 Introduction

The Supervising Scientist recognises the review by the ICSU panel of his report to the World Heritage Committee on the Jabiluka project (referred to in this response as 'the Report') as a thorough and independent review of the issues raised in the Report. In preparing this response, staff of the Supervising Scientist had the benefit of several discussions with the Chair of the ICSU panel, Professor Brian Wilkinson. These discussions were aimed at clarifying the views expressed by the ICSU panel and ensuring that, in his response, the Supervising Scientist addressed the various issues raised in a manner that would be expected to meet the expectations of members of the panel.

The approach adopted in this response is to concentrate, in the main text, on responding to the recommendations of the ICSU panel. Where the response required is lengthy, a summary is provided in the main text and a more complete response is provided in an appendix. In addition to the issues raised in the context of the recommendations, the panel raised a number of other issues in the main text of its review. Clarification of these remaining issues is provided in an appendix.

The ICSU panel referred to lack of information on some specific issues in the Supervising Scientist's report. In several of these cases, the issue was one that was raised in chapter 7 of the Report. These issues are addressed in this response. However, a description of the scope of the Supervising Scientist's report is presented below to explain why the issue was not fully addressed in the Report.

In other cases, eg climate change, it is important to be aware of the regulatory regime under which mining in the Alligator Rivers Region is carried out. Without such knowledge it is understandable why the ICSU panel expressed some reservation about the approach adopted by the Supervising Scientist. For this reason a brief description of the regime, particularly the adoption of ongoing review, is given below before the specific recommendations of the panel are addressed.

Scope of the Supervising Scientist's report

The scope of the Supervising Scientist's report was determined by the decision of the Committee in Kyoto and the clarification sought by the Supervising Scientist from the Chair of the Committee. This is described in section 2.4 of the Report. The Supervising Scientist was concerned that there had to be agreement, prior to commencement of the preparation of his report, on those issues that required 'a full review' (as stated the decision of the Committee) so that 'there would be no misunderstanding at a later date'.

Thus, the issues that were addressed in detail in the Supervising Scientist's report were those specified, in agreement with the Chair of the Committee, on page 19 of the Report; they are assessed in chapters 3–6 of the Report.

The Chair of the Committee also proposed that the Supervising Scientist could address any other issue that the Supervising Scientist believed would be necessary for the Committee to determine whether or not the threats identified by the Mission continue to persist. In the Report, the Supervising Scientist assessed what some of these issues might be and provided what was described as clarification of the issues but not what could be described as a 'full review'.

This point was again made in the Conclusion chapter as follows:

> *It must be emphasised that this report does not purport to be a complete environmental impact assessment of the Jabiluka project. There are many environmental protection issues related to the development of Jabiluka that were not raised in the Mission's report or in the decision of the World Heritage Committee. These broader issues have already been addressed in the environmental impact assessment process to which the Jabiluka project was subjected and are covered by the requirements that the Commonwealth Government imposed in granting its approval for the project to proceed.*

In particular, issues before the World Heritage Committee refer only to the values of the World Heritage Property. Thus, possible environmental impact within the Jabiluka lease area, provided such impact does not have the potential to affect the Park, is not considered in the Supervising Scientist's report and is not, in his view, an appropriate issue for assessment by the ICSU panel. Such issues were considered by the Australian Government in the EIS/PER process and the Government reached its conclusions on them in making its decision.

Status of approval of the Jabiluka Project

It is important to note that, in the granting of approval to Energy Resources of Australia (ERA) for the Jabiluka Project, the Commonwealth Government made the approval subject to a number of requirements with which compliance will be required before construction of the mill at Jabiluka or mining of the orebody can commence. Approval for mill construction or for mining of the orebody has not yet been given. Such approvals will be given by the Northern Territory Government only if the Northern Territory Minister and the Supervising Scientist are satisfied that full compliance with these requirements has been achieved.

Some of the requirements are pertinent to the issues raised by the ICSU panel in its review of the Supervising Scientist's report. These include the following (see Environment Australia 1998):

- ERA must prepare an amended proposal under which 100% of tailings are placed back underground in the mine void.
- ERA must ensure that there will be no significant release of contaminants to the environment, through physical or chemical means, for at least 10 000 years.
  - Note that this requirement arose from consideration of dispersal of contaminants in tailings in the Environmental Assessment Report of Environment Australia.
- ERA must submit an analysis of options for the management of runoff from the waste rock stockpiles in a manner that will ensure that there is no significant impact on Swift Creek from suspended solids as measured at or near the exit of the lease.
- ERA is to conduct an assessment of the chemical composition of waste rock in stockpiles and the rate of its weathering and should amend the operational management plan, if necessary, to address the results of this assessment.

ERA has not yet completed its amended proposal nor has it submitted its analysis of groundwater dispersion of solutes from tailings repositories or its management plans for the waste rock dumps. Thus, the Supervising Scientist is not in a position to provide definitive assessment of these issues. The approach adopted by the Supervising Scientist, both during the environmental assessment process and in the preparation of the Report to the World Heritage Committee, was to carry out sufficient analyses to enable a conclusion to be reached on the likelihood of significant impact on the natural World Heritage values of Kakadu National Park and on the availability of management tools to reduce any possible impact to an acceptable level. The final assessment of these issues will be made when the proponent submits its detailed proposals.

Regulatory framework

The regulatory framework that applies to mining in the Alligator Rivers Region is briefly mentioned in the Report and, to a slightly greater extent, in Attachment A to the Report. However, no great detail was presented to the reader. In the light of some of the ICSU panel comments it is appropriate to provide some information on this framework.

In Attachment A, Johnston and Needham (1999) specified the audit/supervisory functions of the Supervising Scientist as:

- Review of, and provision of advice on, all applications to the Northern Territory Government for the introduction of new procedures or changes in mining operations,
- Review of all environmental data and reports related to environmental protection aspects of uranium mining,
- The conduct of Environmental Performance Reviews of mining operations which focus on environmental outcomes and continual improvement,
- Participation in technical committees which consider in detail practices and procedures for the protection of the environment, and
- Ensuring a high level of information exchange between stakeholder groups through management of the Alligator Rivers Region Advisory Committee.

It is probably useful to expand on these functions a little. The Environmental Performance Reviews are held six monthly and, as stated, they focus on continual improvement. In addition to general environmental performance, a particular topic (such as water management) is chosen for each review and the issues associated with that topic are examined. In parallel with the EPRs are the Minesite Technical Committee meetings. Again, these are held at least every six months for each mine and the committee members (the Supervising Scientist, the Northern Territory Department of Mines and Energy, the Northern Land Council and the mine operator ERA) assess all current issues related to the environmental regulation of the mine. Sub-committees are usually established to examine issues of complexity, particularly those associated with any new proposal.

It is within this framework that continual assessment of performance in environmental protection is assessed and approval for new actions is given. For example, the performance of the water management system at Ranger is under continuous review and the same would be true of Jabiluka. Thus, the Minesite Technical Committee will examine, throughout the life of the project, the adequacy with which the Environmental Requirements specified by the Commonwealth Government are being met. Issues such as climate change will be subject to periodic review and, if upward trends in rainfall are observed and deemed to be significant enough to demand the provision of additional storage capacity to meet the agreed specifications on exceedence probability, the mine operator would be required to provide this additional capacity.

An example of this approach is water management at the Ranger Mine. This was formally reviewed about five years after operations at the mine began and a report (Supervising Scientist 1986) was submitted to the Commonwealth Minister for the Environment that took into account actual rainfall and evaporation measurements experienced at the minesite, observed runoff coefficients etc. On the basis of this report, the mining company was required to increase the storage capacity of Retention Pond No 2 at the Ranger Mine.

Thus, the regulatory framework specifically allows for the fact that calculations carried out at the EIS stage may not prove to be entirely accurate and has the power to require alterations of the mine design to take into account experience obtained during operation. It is worth noting that, in addition to the mine operator and the regulator, the Minesite Technical Committee membership includes the Supervising Scientist and the representatives of the Traditional Owners of the land on which the mine is being constructed.

The main point being stressed here is that the mine design approved following the EIS process will not only be improved at the detailed design stage but will be subject to continuous review and improvement throughout the life of the mine.

2 Response to the ICSU Recommendations

The Independent Science Panel (ISP) has made a number of recommendations on the proposed mining of uranium at Jabiluka. The Supervising Scientist's response to the individual recommendations is given below.

RECOMMENDATION 1.

> *Because the rainfall measurements at Oenpelli may be underestimated due to wind effects etc and in view of the crucial importance of the rainfall record in terms of the design of retention pond capacity, the rainfall record should be increased by 5% unless there is any evidence to the contrary. The hydrological analysis, including the stochastically generated data, should be repeated using this enhanced rainfall data (2.2).*

The Supervising Scientist has referred this issue to the Australian Bureau of Meteorology for comment.

The Bureau of Meteorology notes that it has not been its policy to adjust rainfall station measurements upward in an attempt to incorporate the effects of wind on the measurement of rainfall. In addition, the adjustment of recorded rainfall does not constitute standard design procedure in Australia. The degree to which wind affects the accuracy of rainfall measurements depends on the siting of the station, the distance of the recording gauge from the ground (30 cm at Oenpelli), the wind regime etc. Also, wind induced errors in rainfall measurement will be greater in regions of low rainfall intensity than in monsoonal regions such as the Alligator Rivers Region.

The Supervising Scientist also notes that there are already a number of areas in the design of the water management system in which conservatism is inbuilt. For example, the analysis by Chiew and Wang (1999) of the rainfall data generated by their stochastic rainfall model shows that, while good agreement is obtained between the generated distribution and the observed distribution for daily and monthly rainfall, the skewness obtained in the generated annual data is, unlike the observed distribution, significantly positive. This results in the use in the model of much higher rainfall values for extreme rainfall years than one would predict using the observed distribution of annual rainfall. For example, the 1 in 10 000 AEP annual rainfall derived by Chiew and Wang (1999, page 13) is about 10% higher than that obtained by the Bureau of Meteorology (1999, page 5) using the observed distribution of annual rainfall.

It is the view of the Supervising Scientist that care needs to be taken not to incorporate so much conservatism in the hydrological model that the results obtained become quite unrealistic. It is considered that a better approach entails being as realistic as possible in the use of data and modelling methods and then to adopt a conservative design criterion that provides the degree of reassurance that the public requires. Thus, the analyses contained within the Supervising Scientist's report and its attachments show that, within the context of the data and modelling methods used, the probability of exceeding the retention pond capacity proposed by ERA is about 1 in 1000 over the 30 year life of the mine. The analyses presented in section 5.3 of the Report indicate that the risks associated with this design are, using conservative values of constituent concentrations, very small. (Issues raised by the panel on this assessment are addressed separately below.) However, to provide the assurance that the public requires for the protection of the World Heritage Property and to take into account possible underestimates in key parameters in the assessment, it may be considered desirable to require a design of the water retention capacity with an exceedence probability of 1 in 10 000 over the life of the mine.

Nevertheless, if after consideration of this issue of the cumulative effect of conservative values, the ICSU panel still recommends increasing the rainfall values, the Supervising Scientist will accept the recommendation.

RECOMMENDATION 2.

> *Rainfall and class A pan evaporation measurements should be commenced at Jabiluka as soon as possible (2.4).*

The Supervising Scientist is able to inform the ICSU panel that rainfall, wind and temperature data have been collected by ERA from one site at Jabiluka since mid-1994 and at a second site from March 1996. Class 'A' pan evaporation has been measured at the mine site since September 1998. Since these records are very short, they were not included in the assessment of the Jabiluka project in the Supervising Scientist's report. In addition, staff of the Supervising Scientist have installed 3 extra weather stations in close proximity to the mine, and a further 3 rainfall stations within the mine catchment.

Data from all of these stations will be assessed at regular intervals by the Minesite Technical Committee and will be used to assess the need for any revision of the water management system during the operation of the mine.

RECOMMENDATION 3.

> *The predictions of climate change from observations and atmospheric models should be kept under review during the life of the mine and the design of the retention pond area should enable the storage to increase to accommodate a predicted increase in runoff should this be necessary (2.9).*

The Supervising Scientist agrees with this recommendation. The Supervising Scientist's position on this issue has apparently, perhaps understandably given the wording used in the text of the Report, been misunderstood by the ICSU panel. The principal issue considered in the Report was whether or not the climate change analysis conducted by Jones et al (1999) required a revision of the hydrological modelling of the Jabiluka water management system carried out by Chiew and Wang (1999). The conclusion of the Report was that such a revision was not justified at the detailed design stage of the project and this conclusion appears to be supported by the panel.

However, the Report did not, as is outlined in the Introduction to this response, provide sufficient detail on the review mechanisms currently in place at Ranger and which will also be applied during the operational phase of the Jabiluka project. It has always been the Supervising Scientist's position that water management practices and infrastructure must be adapted for changed environmental conditions, new knowledge and improved technology so that the highest standards of environmental protection are maintained.

As described in the Introduction, the Minesite Technical Committee conducts regular reviews of the water management system at Ranger and will conduct similar reviews of the operation of the Jabiluka mine. Such a review at the Ranger mine about five years after milling commenced resulted in a requirement that ERA increase the water retention capacity at Ranger. Thus, the Supervising Scientist can give a commitment that climate change data and modelling will be kept under regular review during the life of the Jabiluka project and additional storage capacity will be installed if required.

RECOMMENDATION 4.

The runoff coefficients used by Chiew & Wang in the runoff modelling should be validated on the basis of hydrological measurements from the Ranger site. The runoff models should be modified if necessary (2.10).

The review panel has proposed that the runoff coefficients used by Chiew and Wang (1999) should be validated at the Ranger site. The runoff coefficients were, in fact, derived from experience at the Ranger mine.

McQuade (1993) conducted an extensive analysis of the water management system at Ranger. This report included a detailed analysis of the historical rainfall records for the Ranger site, analysis of evaporation from the various retention ponds at Ranger, rainfall – runoff analyses for the catchments of each of these ponds, and the development and application of a Monte Carlo based predictive model for the complete water management system at the mine. The runoff coefficients used by ERA in the EIS and PER were conservative values based upon this experience. Chiew and Wang (1999) adopted these average values from the EIS, but used a soil moisture budgeting procedure, which results in greater runoff during wet periods.

It is, therefore, the Supervising Scientist’s assessment that this recommendation has already been fully implemented and that the modelling used in the Report errs on the side of conservatism with respect to rainfall – runoff.

RECOMMENDATION 5.

An assurance should be obtained that the uncertainties in relation to water requirements at the mill, effluent disposal routes etc has been adequately dealt with in the design of the water management system. Due to lack of information it is not clear to the Independent Science Panel that this was the case [2.10(a to d)].

The ISP has requested in section 2.10 further information on four components of the water management system. A diagramatic representation of the water balance figures for the proposed mine facilities is given in figure 1 and a discussion of the four specific issues raised by the panel is given below.

(a) *What happens to the 180 000 m^3/year of water used in the mill?*

This water will be used in the milling process, where some will be lost by evaporation and some held in the tailings. Excess water from the tailings dewatering will be returned to the mill process, where it is complemented by water from the retention pond at an annual rate of 180 000 m^3/y. The water volumes used in the water budget calculations were based on experience from milling at Ranger.

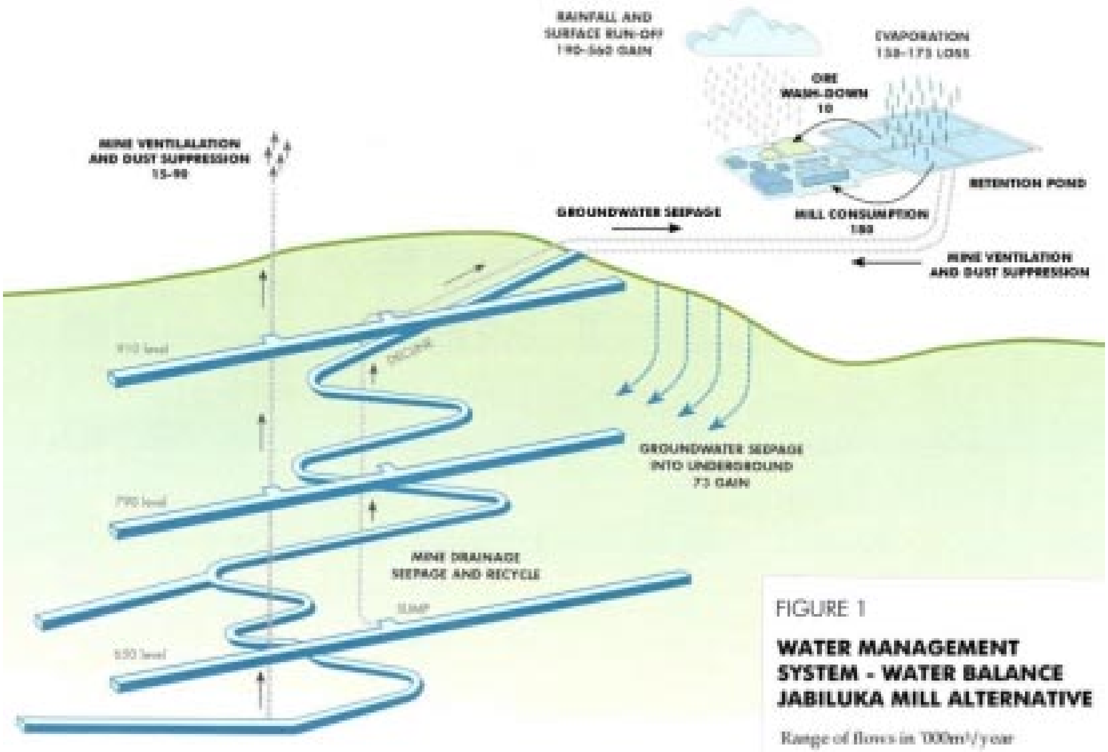


FIGURE 1

WATER MANAGEMENT SYSTEM - WATER BALANCE JABILUKA MILL ALTERNATIVE

Range of flows in '000m³/year

(b) *How is the ore wet-down and plant wash water disposed of?*

The ore wet-down water will be applied in a controlled manner to the surface of the ore stockpile and will be subsequently lost through evaporation from the stockpile. Runoff from the stockpile during rainfall events will be returned to the containment pond, as outlined in the Report. The plant wash water volume used in the water budget calculations will all be lost by evaporation (based on experience at Ranger). Wash-down water inadvertently applied in excess of this volume will be returned to the containment pond. Although water volumes used for these purposes will be small, they have been included in the water budget calculations.

(c) *What is the quantity of groundwater inflow into the mine and how is it disposed of?*

The groundwater inflow into the mine has been estimated at 73 000 m^3/year in the Jabiluka PER. The intention of the mine operator is that this water would be pumped to the retention pond. This annual water volume has been added to the water budget calculations undertaken by Chiew and Wang for the design of the retention pond (see table 2.1 of Chiew & Wang 1999).

Since the publication of the PER and completion of the Supervising Scientist's report, the mine decline and shaft has progressed some 1600 m underground and has passed through both the sandstone and schist aquifers. It is now apparent that groundwater inflows are lower than expected in the PER and EIS and that the estimate of

73 000 m^3/year for groundwater inflow may be an overestimate. Revised estimates of groundwater inflow will be used in the detailed design of the water management system.

(d) *Have any simulations of the type reported in the RCS been carried out at the Ranger mine? If so, they could provide some insight into runoff co-efficients, evaporation rates etc for the Jabiluka mine.*

As described in the response to Recommendation 4, detailed analyses of rainfall, runoff coefficients and evaporation have been carried out for the Ranger mine and Monte Carlo based modelling methods have been applied to the water management system at Ranger (McQuade 1993).

The Monte Carlo calculations, unlike those described by Chiew and Wang, were carried out on a monthly basis rather than on a daily basis. However, the sensitivity analysis carried out by Chiew and Wang (page 19, section 5.3) demonstrated that the effect on required storage volume arising from the use of a monthly period rather than a daily period should be less than 2%.

As advised under Recommendation 4, these analyses provided the information from which the runoff coefficients for Jabiluka were deduced. In addition, these analyses provided the basis for the review by Hatton (1997) of evaporation rates at the Ranger mine, work that was reviewed by Chiew and Wang (1999) in their assessment of the pan factors that should be used in hydrological modelling at Jabiluka.

In summary, the estimates of water consumption in the mill, loss of water in the ore wet-down and plant wash-down processes, runoff coefficients and pond evaporation have been based upon experience at the Ranger mine and uncertainties in these estimates are considered to be relatively small. Estimates of groundwater ingress into the mine, and hence into the water management system, were always expected to be improved once the decline had been constructed and these estimates will be revised at the detailed design stage to take into account observations made on groundwater flows into the decline. In addition, the Supervising Scientist can provide an assurance that, in common with all other aspects of the mine management, there will be ongoing review of these issues during the operational stage of the mine and amendments will be made to the water management system, if required, to ensure that environmental protection objectives continue to be met.

RECOMMENDATION 6.

Justification for the use of the Ranger 'Public Exposure Radiation Model' at Jabiluka is required. A risk assessment based on the chemical toxicity of uranium is needed with particular reference to (a) soil ingestion, and (b) dust inhalation (3.3).

The approach adopted by the Supervising Scientist in the preparation of his Report to the World Heritage Committee was:

(a) apply the Ranger radiological model in the first instance to obtain initial estimates of the radiological risks involved,

(b) if the results obtained indicated radiation exposure rates comparable with the public dose limit, develop a model specific to Jabiluka,

(c) if the results obtained indicate radiation exposure rates that are small compared to the public dose limit, use these in the assessment and develop a Jabiluka specific model at a later stage.

This approach was adopted because the hydrological regime was known to be sufficiently similar to the Ranger situation that it would provide a useful first approximation, the traditional diet is the same for both cases, and because the assumptions used in the Ranger model were known to include a significant degree of conservatism, particularly for 'one-off' exposures.

The results obtained using the Ranger model indicated that the maximum radiation exposure expected over the 30 year life of the mine (with a probability of occurrence of about 1 in 100 000 000) would be about one tenth of the annual dose limit for members of the public. That is, the predicted maximum exposure was calculated to be about $1/300^{th}$ of the permissible exposure over the life of the mine. In these circumstances, it was considered unnecessary to extend the model to the specific case of Jabiluka although it was intended that a specific model would be developed for Jabiluka.

Since the submission of the Supervising Scientist's report, a specific Jabiluka model has been developed (Martin 1999). The principal difference between the Ranger and Jabiluka models lies in the hydrological component. In the latter case, a conservative approach has been adopted in which the discharged loads of radionuclides are converted to water concentrations using only the small volume of water contained within the small backwater swamp (area 4.5 km^2) into which Swift Creek flows just north of Jabiluka. Similarly, a conservative assumption is made that 20% of the entire annual food consumption of members of the critical group is derived from traditional hunting and fishing in this area. The conservative values of transfer coefficients (particularly that of radium in freshwater mussels) has been retained in the calculations. The results obtained are similar to those presented in the Report. Hence, the conclusions drawn by the Supervising Scientist in his Report to the World Heritage Committee are supported by the Jabiluka specific model.

The assessment given in Martin (1999) includes effects arising from the chemical toxicity of uranium through drinking water ingestion, soil ingestion and dust inhalation. The analysis shows that these effects are negligible.

RECOMMENDATION 7.

> *The effects of biological recycling of contaminated material in the aquatic ecosystem should be investigated (3.4).*

Section 3.4 of the ICSU response expresses reservations about the approach adopted by the Supervising Scientist in assessing ecological risk associated with the discharge of water from the water management system at Jabiluka under extreme weather conditions or following catastrophic failure of the retention pond embankment. The panel questions the reliance on single species toxicological data as a means of assessing impact on the whole aquatic ecosystem and notes that there is a need to assess the likelihood of longer term impact arising from biotic and abiotic recycling.

The first point to note is that the use of the phrase 'surrogates for the whole ecosystem' in the Supervising Scientist's report was a poor choice of wording. A better choice would have been 'surrogates for all aquatic animals directly exposed to the chemical constituents of the effluent'. That is, the issue being addressed was direct chemical exposure in the water column during passage of the mine derived water through the natural water course.

In this limited context, the Supervising Scientist believes that the analysis procedure used is entirely justified. This confidence is based upon the extensive program of toxicological research and testing that has been conducted in the region and which was briefly described in the Report. The specific measurements referred to in the Report were conducted following a program in which 19 different local native species of aquatic animals and plants were investigated to establish their suitability for incorporation in an ecotoxicological testing program. From this initial screening, 8 species were chosen for the detailed development of testing protocols using a range of sensitive endpoints and using the actual waters in the retention ponds at the Ranger mine, an excellent analogue for Jabiluka. Eventually three species were adopted in the routine program on the basis of their sensitivity of response to exposure to waters in the retention ponds at the Ranger mine and suitability with respect to rearing and captive husbandry. The results quoted in the Report were the lowest NOEC and LOEC obtained in tests in which the exposure to uranium took place while the animals were living in waters collected from the Magela Creek system and a factor of safety has been applied to the data. These procedures are in accordance with risk assessment procedures recommended by the USEPA (USEPA 1998) and have been adopted in recommendations for risk assessment of Ramsar wetlands.

The longer term impact arising from biotic and abiotic recycling was not specifically addressed in the Report because our early analysis of these issues for the Ranger mine indicated that direct chemical exposure was the dominant risk associated with release of waters from the mine. This assessment was based upon a comparison of the loads of metals, including uranium, that could be discharged from the mine with the loads that are present naturally in the sediments of the Magela floodplain and are recycled annually by the vegetation on the floodplain. These early analyses can also be used in the current assessment of Jabiluka.

The ecosystems of interest in this assessment are those associated with:

(i) Swift Creek, immediately downstream from the mine,

(ii) A small swamp area into which Swift Creek flows, and

(iii) The Magela floodplain beyond the swamp.

Swift Creek is a high-energy environment containing coarse sandy sediments of low organic content. Only very coarse material is deposited in the creek bed and no significant deposition of material would be expected within the Swift Creek ecosystem during the discharge of waters from the mine site under the conditions considered in the Report. This is similar to the environment in Magela Creek for the first 12 km downstream of the Ranger mine. In Magela Creek, no contaminant build up in sediments has been observed.

As discussed in the Report, there is a probability of about 1 in 100 000 that about 200 000 m^3 of water could be discharged from the Jabiluka mine site in an extreme Wet season in which the annual rainfall gives rise to runoff in the mine catchment that exceeds the pond volume proposed by ERA in the PER. This discharge would occur in a period of time near the end of the Wet season during which flow would be continuous from the mine through Swift Creek, through the swamp and through the Magela floodplain to the East Alligator River. The specified volume of water from the mine would, under the conservative assumptions given in the Report, contain about 160 kg of uranium.

If one makes the conservative assumption that all of the uranium contained in the water from the mine is deposited uniformly on the Magela floodplain north of Swift Creek, about 100 km^2, this would give rise to an increase in the concentration of uranium in the top 0.05 m of the floodplain sediment of about 0.3%. This is clearly a negligible increase and it can be concluded that any recycling of the mine related uranium would be a very small component of natural processes, taking into account the relative mobility of uranium in these different environmental circumstances.

Another useful comparison is with the quantity of uranium that is recycled naturally in the vegetation of the floodplain. From an extensive study (Finlayson et al 1986) of the seasonal variation in floodplain vegetation communities and measurements of metal and nutrient concentrations in leaf litter from the dominant species of *Melaleuca* and of aquatic grasses, estimates were made of the quantity of each of these constituents that is recycled in the leaf litter and detritus of the Magela floodplain each year due to natural processes. For uranium this was found to be about 800 kg, about five times the quantity of uranium that would be discharged from the Jabiluka mine in the extreme scenario considered in the Report. Again, the conclusion is that biotic recycling of mine related uranium will not give rise to significant environmental impact.

If one considers an even more conservative scenario in which all of the uranium released from the mine site in an extreme Wet season is contained within the swamp just north of Swift Creek and is deposited in the sediments of the swamp, the increase in uranium concentrations in the sediments of the swamp would be about 10% giving rise to a total concentration of about 7 mg/kg; ie the increase will be < 1mg/kg. This increase is still small compared to the natural concentration and significant effects due to recycling of the mine related uranium would not be expected.

In addition, we have information from recent experimental work at ***eriss*** (Peck, in press) to develop sediment toxicity tests for the Alligator Rivers Region that provides further reassurance on the likely effects arising from uranium that is deposited in sediments of the region. No effects were observed in animals exposed to sediment containing up to 5000 mg/kg uranium, the highest concentration tested. This concentration, at which no adverse effects were observed, is almost 1000 times higher than the predicted total concentration of uranium in the sediments of the swamp region assuming that all uranium released from the mine is deposited in this region. The same aquatic animals were far more sensitive when exposed to uranium present in water only (eg 72 h LC50 of 37 mg/L and LC5 (equivalent to the NOEC) of 20 mg/L, water pH of 6). These experimental results conform with others worldwide regarding the relative sensitivities of biota to contaminants in water and in sediment.

In conclusion, it is acknowledged that the longer term impact arising from biotic and abiotic recycling was not specifically addressed in the Report because our early analysis of these issues for the Ranger mine indicated that direct chemical exposure in the water was the dominant risk associated with release of waters from the mine. The information presented above indicates that the same conclusion can be reached for discharge of waters from Jabiluka because the total quantity of uranium released into the aquatic ecosystem downstream from the mine would be small compared to that present naturally in the sediments and would be small compared to the quantity that is recycled annually in vegetative litter and detritus on the floodplain.

RECOMMENDATION 8.

> *The design of the retention pond system should include consideration of the partitioning of the storage volume so as to reduce the risk of the total water volume being discharged should an embankment fail (3.5).*

This recommendation essentially repeats the recommendation of the Supervising Scientist given on page 70 of the Report but reinforces it by pointing out that its implementation will provide an additional level of environmental protection should embankment failure occur for any reason. The recommendation will be implemented.

RECOMMENDATION 9.

> *Isotope measurements should be used to determine the age of groundwater and surface water base flow as a means of assessing flow rates and bulk permeabilities in the aquifers. Comparisons should be made between these values and those already available from borehole tests and if necessary additional groundwater modelling should be undertaken using the new data (4.2);*

[Note that, in addressing Recommendations 9, 10, 11 and 12, reference will be made to information contained in Appendix 2 in which groundwater issues are addressed more extensively.]

This recommendation arises from the discussion in section 4.2 of the text of the ICSU review in which it is acknowledged that the permeabilities derived from bore hole pump tests should be acceptable for rocks of the type described in the Report. However, the ICSU panel notes that confirmation of the flow rates and permeabilities from other techniques would be valuable and suggest that isotope measurements, eg O^{18} and deuterium ratios, could be used to obtain this confirmation. Hence, the primary thrust of the recommendation appears to be that other available data, such as groundwater age data, should be used to provide confirmation of the flow rates and permeabilities used in the modelling of Kalf and Dudgeon (1999).

Some groundwater dating has been conducted in the region from the Ranger Mine to just west and south of the Jabiluka site (AAEC 1982). (For information on this work see Appendix 2.) This work was conducted as part of an extended research program on analogue sites for high level waste repositories, and sites that were investigated in the Alligator Rivers Region were the Ranger, Koongarra and Nabarlek orebodies. [Note: these sites were considered to be analogues for waste repositories; they were not being considered as possible actual repositories.] In this program, groundwaters were analysed for tritium, deuterium, carbon-14, lead-210, radium and thorium. The work was carried out in order to establish the rate of movement of uranium away from the Jabiluka and Ranger orebodies, both of which lie in the Cahill Formation schist.

The groundwater was dated as being modern near the Ranger mine and about 4000 to 5000 years old just south-west of Jabiluka, about 15 km to the north of Ranger with the age increasing the more northerly the sampling location. A travel time of approximately 500 years per kilometre was derived by AAEC from these data. This result is comparable with the median result obtained by Kalf and Dudgeon (1999) in the Report and indicates that the extreme values adopted in the Kalf and Dudgeon report are highly improbable.

Further assessment of the appropriateness of the permeabilities used by Kalf and Dudgeon (1999) is now available from observations of groundwater inflow into the Jabiluka mine decline. The decline is approximately 6 m by 6 m in area and is 1150 m in length. With constructed headings and footwall drives the total length of tunnel is now approximately 1600 m, with about 550 m in the schist aquifer and about 1050 m in the Kombolgie Sandstone. The decline passes through the unconformity between the sandstone and the schist.

Hydrologically the shaft approximates a very large sloping borehole and flow into the shaft represents a very long duration pumping test resulting in a fully dewatered borehole. The shaft intersects a large number of fractures, over an extensive area of sandstone and schist, and enables sampling which could only otherwise be achieved through an extremely large number of conventionally constructed boreholes.

A recent inspection of the decline and tunnels led to the following observations and conclusions:

- The total flow of groundwater into the shaft is significantly lower than was predicted by ERA in the EIS and the PER confirming that the values of permeability of both the sandstone and schist aquifers used by Kalf and Dudgeon (1999) are appropriate and conservative.
- Observation bores constructed in the weathered sandstone above the shaft show no significant hydrologic response to the construction of the decline. This is indicative of the very low permeability in the underlying Kombolgie Sandstone.
- From a comparison of flow rates at specific locations in the shaft observed in January and June 1999, it is clear that a significant portion of flow arises from drainage from water storage voids. Total flow in the shaft is therefore larger than that which would result from aquifer permeability alone.
- The unconformity between the sandstone and schist was dry.

These observations confirm that the values of permeability adopted by Kalf and Dudgeon (1999) were reasonable and conservative. In addition the lack of spring flows from the sandstone suggests that this aquifer does not contain major fissures. Evidence from these two sources supports the conclusion that no major fissure system exists which could invalidate flow calculations undertaken by Kalf and Dudgeon.

It is the view of the Supervising Scientist that this recommendation is satisfied by the provision of the above information.

RECOMMENDATION 10.

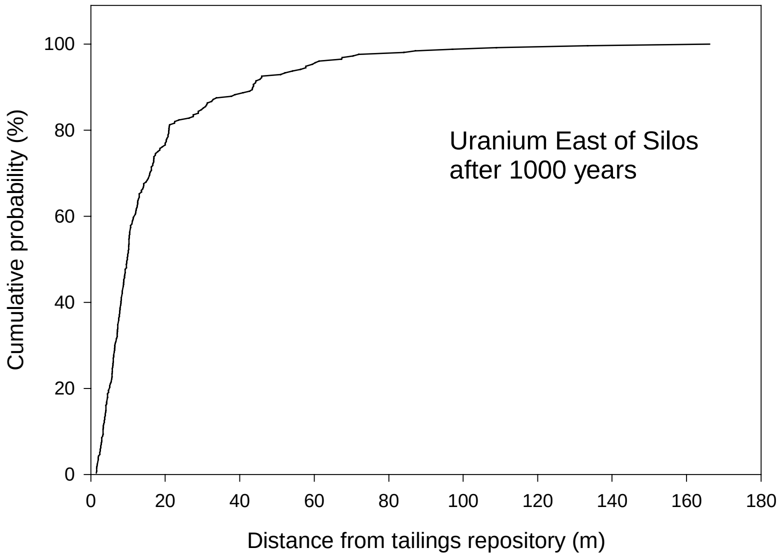
The results of the Monte Carlo simulations from the groundwater models should be presented as cumulative probability plots (4.2).

In general, the Supervising Scientist agrees that the use of cumulative probability plots is a valuable way of presenting the results of Monte Carlo simulations because this method fits naturally into procedures for quantitative risk assessment. In the present case, the risk that needs to be assessed is the probability of harm to the surface water aquatic environment in the wetlands of Kakadu National Park arising from the dispersion of tailings constituents in groundwater.

As was stated in the Report (section 6.4), to carry out such an assessment would require the extension of the analysis of groundwater dispersion to the quantitative prediction, using Monte Carlo analysis methods, of the concentrations of solutes in the waters of the Magela floodplain and the probability with which these concentrations will occur. While it would be possible to estimate, with a reasonably high degree of reliability, concentrations of solutes in the deep aquifer at relatively short distances from the tailings repositories, the small upward gradient of flow and the strong absorption mechanisms in the soils of the floodplain imply that any surface expression of tailings derived constituents will be extremely small and it will be difficult to attribute a probability to its occurrence.

For this reason, it was decided that the most appropriate way of presenting the results was to plot the variation of the predicted median concentration of solutes versus distance from the tailings repository and to indicate in the text the extreme values obtained in the analysis for distances moved by the solutes.

In response, however, to the ICSU panel recommendation, the uranium data have been reanalysed to enable their presentation in the form of cumulative probability distributions. The data are presented in figure 2 for dispersal both east and west of the tailings repositories. These data indicate that there is a 95% probability that uranium will not travel more than 58 m east of the silos in the sandstone aquifer after 1000 years or 540 m west of the mine void in the schist aquifer.



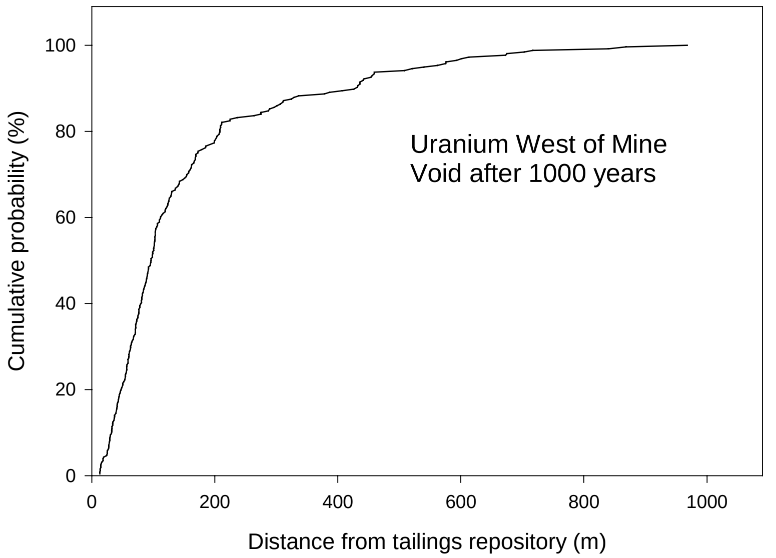


Figure 2 Cumulative probability distributions for the movement of uranium from the silos in an easterly direction (upper graph) and from the mine void in a westerly direction (lower graph)

These estimates are considered conservative upper limits for a number of reasons. The probability distribution assumed by Kalf and Dudgeon for the model variables (permeabilities, velocities etc) was a uniform distribution, not a normal distribution as stated in the ICSU panel report. If a normal or log-normal distribution were assumed, the 95% estimates would be much smaller than given above. Also, the groundwater velocities and absorption coefficients assumed in the model are considered to be conservative. For example, the data in Appendix 2 derived from radionuclide dating of groundwater indicate that travel times in the schist aquifer are more consistent with the median value derived by Kalf and Dudgeon than the extreme values used in their report.

RECOMMENDATION 11.

Three-dimensional groundwater models should be run once new information is available on the tailing/cement/water/rock interaction studies. The models should be extended to encompass regional groundwater flow and to identify its contribution to surface waters (4.4).

As noted in the Introduction, there is a requirement on ERA to prepare an amended proposal under which 100% of tailings are placed back underground in the mine void. In preparing this proposal ERA is required to address a number of issues that were raised in the environmental impact assessment report prepared by Environment Australia on the Jabiluka Mill Alternative. These include assessment of the geochemical issues raised by the ICSU panel in section 4.4 of its report concerning interactions between tailings, cement, water and host rock. Many of these issues were identified in a report by the University of New South Wales (Waite et al 1998) that was commissioned by Environment Australia as part of the assessment of the Jabiluka PER.

In response to this requirement, ERA is undertaking a research program on the geochemical issues. In addition, it has commissioned an international consulting company to carry out solute transport modelling using a three dimensional groundwater model and incorporating the results of the geochemical research program.

Nevertheless, while the geochemical studies and the three dimensional modelling have yet to be completed, there is little doubt that the concentrations of tailings derived solutes will remain very low in surface waters compared to their naturally occurring concentrations. This is discussed further under Recommendation 12. As stated above, approval for construction of the mill and mining of the orebody will not be given until these studies are completed.

RECOMMENDATION 12.

The contaminant transport groundwater modelling studies should be extended to 10 000 year runs (4.2).

As noted in the Introduction, there is a requirement that ERA needs to ensure that there will be no significant release of contaminants to the environment from the tailings for at least 10 000 years. Thus, the modelling referred to under Recommendation 11 will need to be on a 10 000 year time scale and the Supervising Scientist will need to be satisfied that there will be no significant impact on the environment over that time scale before approval to proceed with the construction of the mill and the mining of ore at Jabiluka. Hence the Supervising Scientist fully accepts this recommendation.

The full analysis of groundwater dispersion in three dimensions and over 10 000 years will not be available for some time. However, the Supervising Scientist has extended the analyses presented in his Report to 10 000 years. The details are discussed in Appendix 2 and are summarised below.

For radium, the use of a constant source term over a period of 10 000 years is justified because ^{226}Ra will be supported by its highly immobile radioactive parent ^{230}Th which has a radioactive halflife of about 80 000 years. For this reason Kalf and Dudgeon (1999) have been able to extend their calculations to 10 000 years and the results are given in Appendix 2. The results show that the median value for the maximum distance travelled by radium from the tailings repositories is about 50 m east in the sandstone and 400 m west in the schists. At these distances the radium concentration arising from the tailings is much lower than the naturally occurring concentration.

As stated above, it is necessary to take into account the finite leaching of the source when estimating the transport of uranium over a period of 10 000 years. Kalf and Dudgeon have rerun the 3-dimensional numerical model for the source over 10 000 years to determine the effect of leaching. Using the worst case scenario for permeability of the source, it was found that about 60% of the total uranium mass still remains in the source after 10,000 years. These calculations will soon be extended to include the Monte Carlo analysis of dispersion in the aquifers. However, the source result alone provides important information that can be used to assess the significance of uranium transport.

The total amount of uranium that will be contained in the tailings is about 3800 tonnes. The above worst case leaching result implies that about 40% of the mass will be leached from the source over 10 000 years. Assuming approximately linear leaching, this implies that the amount of uranium moving into the environment will be about 150 kg per year. Kalf and Dudgeon estimate that only a fraction of 1% of the water from the deep aquifer would enter floodplain waters. Even if we assume that up to 10% of the groundwater enters the surface waters the quantity of uranium entering the system from the tailings, about 15 kg, will be small compared to the quantities that are recycled naturally in the system.

For example, the total amount of uranium that is recycled annually in the leaf litter from trees and the detritus of aquatic grasses in the Magela floodplain is about 800 kg per annum (Finlayson et al 1986). About 5000 tonnes of sediment containing uranium at a concentration of about 6 mg/kg is deposited on the surface of the floodplain each year (Wasson 1992) providing an annual input of about 30 kg of uranium each year. The water budget of the Magela floodplain provides an additional 100 kg per year through the system. Thus, placed in the context of the ecosystem of Magela floodplain, the contribution of uranium dispersed from tailings will be small compared to the natural budget of uranium in the wetlands of the Magela floodplain.

If the estimate of the uranium load entering the floodplain annually is coverted into water concentrations using the annual flow of the Magela system, the resultant increase in water concentration is about 0.014 μg/L. This would increase the water concentration by about 20% to a total of about 0.1 μg/L. This is very low compared to the safe concentrations derived from toxicological data on local biota.

Similar calculations will be required for sulphate. Nevertheless, the fundamental point made in the Report is that the concentrations of sulphate in the natural waters of the Magela floodplain are high, in the range 1500–7000 mg/L. These arise from the acid – sulphate soils of the floodplain. Thus, a dilution of only a factor of three is required, if a component of tailings derived groundwater reaches the surface aquifer, to ensure that sulphate remains within the range of natural concentrations. Given the rates of groundwater movement, such a dilution will be readily available from surface water recharge each year in the monsoon season.

In summary, it is recognised that more extensive groundwater modelling is required before final approval of the Jabiluka project is given and that this modelling needs to be extended to 10 000 years. Nevertheless, the existing modelling demonstrates that the wetlands of Kakadu will not be threatened as a result of transport of contaminants from the tailings repositories, even on a time scale of 10 000 years.

RECOMMENDATION 13.

The proposals to contain the sediments from the waste rock stockpile should be examined in relation to potential impacts on the aquatic ecosystem (5.3).

As noted in the Introduction, there are specific requirements on ERA that need to be satisfied before approval is given to proceed with the Jabiluka Project. These include an assessment of the potential environmental impact on Swift Creek arising from sediments from the waste rock dump. These requirements arose from a consideration of the issue by the Supervising Scientist during the environmental assessment process. ERA has been required to manage erosion of the stockpiles in a manner that will ensure that suspended solids concentrations in Swift Creek do not deviate significantly from naturally occurring values.

The principal methods available for controlling sediment loss from the stockpiles include the use of suitably designed sediment traps, soil stabilisation measures, selective spatial and temporal dumping of waste material, and progressive revegetation of the stockpiles.

Estimates of the sediment yield from the waste rock dump were made by the Supervising Scientist in his assessment of the Jabiluka PER. These were based on the results of an extensive research and measurement program on the waste rock dumps at the Ranger mine (eg, see Willgoose & Riley 1998, Evans et al 1998). This program included the monitoring of sediment loss under natural rainfall conditions and under simulated rainfall conditions, the effect on sediment loss of various treatments such as surface ripping and revegetation, and the calibration and use of landscape evolution models to predict the long-term erosion of waste rock dumps.

As noted in Appendix 4, this work resulted in an estimated increase in the sediment load of Swift Creek of about 40% arising from erosion of the waste rock dump. It was this result that led to the requirement that ERA manage the sediment losses from the waste rock dump carefully. From the results of the ***eriss*** research program at Ranger (Evans et al 1998), it has been established that the most effective way of minimising erosion is to ensure that progressive revegetation is implemented. The above estimate for sediment yield from the waste rock was based upon an unvegetated rock dump. Evans et al (1998) have shown that surface ripping and revegetation reduces the sediment yield by more than an order of magnitude. Such an improvement would reduce sediment losses to an extent that the increase in sediment load in Swift Creek would be negligible.

For these reasons, the Supervising Scientist is satisfied that a suitable management program can be implemented at Jabiluka that will ensure that sediment losses from the waste rock will not have adverse effects on the aquatic ecosystem of Swift Creek. The proposals from ERA will be assessed, as required by the Commonwealth, to ensure that this is so.

To ensure that the Supervising Scientist is in a position to properly assess any proposals from ERA, he has established an extensive research and monitoring program, with a number of interactive projects, in the catchment of Swift Creek comprising:

1. A program of streamflow and sediment measurement along catchment flowpaths and within the water column of the creek and three tributaries.
2. An associated chemical monitoring program both in the Swift Creek catchment and in creeks to the west of the mine.
3. Ongoing measurements of macroinvertebrate community structure in Swift Creek, other potentially affected streams and control streams.
4. A monitoring program designed to quantify any impacts on fish community structure.

During the construction phase of the portal, decline and interim retention pond, ERA implemented a number of measures to minimise sediment discharge into Swift Creek. Sediment traps were installed around the site, the banks of the retention pond were topsoiled and hydroseeded with local species, jute mesh was applied to increase slope stability, other exposed areas were topsoiled and hydromulched, drains were lined with rock, and access roads were compacted and contoured to minimise sediment discharge. These measures resulted in minimal sediment discharge to local creeks. Preliminary results from the Supervising Scientist's monitoring program indicate there was no detectable difference in creek turbidity at the downstream monitoring station in Swift Creek between the year before and that after construction of the portal and pond.

In summary, the Supervising Scientist has carefully assessed the possibility of sediment loads being transported to Swift Creek in the light of experience gained at Ranger, has determined stringent criteria to be met by the mining company, and has implemented a monitoring program so that any impacts are quickly detected. The current monitoring program will be continued through the mining phase and appropriate mitigation measures will be implemented if required.

RECOMMENDATION 14.

> *Environmental impact assessment (including a full ecosystem analysis) should be undertaken assuming a mine life of 40, 50 and 60 years (5.3).*

This recommendation arises from the discussion in section 5.3 of the ICSU review in which it is recommended that the probability analyses carried out by the Supervising Scientist in the Report should be extended to 40, 50 and 60 years to account for the possibility that additional ore reserves may be found at depth. It has been extended in the recommendation to include a full ecosystem analysis over this time scale.

The risk analyses carried out by the Supervising Scientist in the Report are dependent on the length of operation in two ways. First, an extended operational life will affect the actual probability of a specific occurrence (eg an earthquake or exceedence of the storage capacity) linearly. That is, the probability of the occurrence of an earthquake of sufficient magnitude to cause structural failure of the pond embankment is estimated in the Report as 0.0006 over a 30 year mine life. For a 60 year mine life, this probability would be about 0.0012. Thus, to take into account the effect of an extended mine life, the results given in the various figures of the Report can be scaled appropriately.

A second way in which an extended mine life could impact upon the results obtained would arise if there is a time dependence in the concentrations of solutes in the retention pond water. Evapoconcentration could give rise to such an effect. Similarly, extended weathering of ore or waste rock on the stockpiles could give rise to increasing concentrations with time.

The issue of weathering was discussed in the Report, particularly with respect to the concentrations of Mg and SO_4. It was noted that $MgSO_4$ mobilisation occurs at a rate similar to the rate of erosive degradation of the schist and that this process had been studied by the Supervising Scientist (leGras & Klessa 1997) for the waste rock dumps at Ranger. It was found that there is an initialisation period of about 3 years during which little solute is released. Given the short storage times predicted for ore in the stockpile at Jabiluka, it was concluded that the estimates given by ERA for $MgSO_4$ concentrations in the retention pond were significantly overestimated in that they represented concentrations that might be expected for weathered rock. Nevertheless, this worst case scenario was modelled by the Supervising Scientist in the Report. For this reason, it is not considered necessary to adjust the calculations to take the effect of weathering into account in a 60 year mine life scenario. Similarly, the concentrations of uranium in runoff from the ore stockpile were deduced from experience gained at Ranger and it is not expected that higher concentrations will occur during an extended mine life.

Evapoconcentration was not explicitly taken into account in the modelling presented in the Supervising Scientist's report. The reason for this is that, while evaporation accounts for about 45% of total water losses in the water management system in an average year, total losses through evaporation and mill consumption in an average year approximately equal total inputs. Hence, although there will be an increase in concentrations during the Dry season in any given year, there will not be a long-term buildup in concentrations in the retention pond due to evapoconcentration because, on average, solutes will be transferred from the pond to the mill circuit. Hence, uranium in the pond arising from runoff from the ore stockpile will be removed in the mill and the remaining solutes will be transferred to the tailings. For these reasons, a simplified assumption of constant concentrations in the pond was made.

Thus, it is not expected that there will be any significant time dependence in the concentrations of solutes in the retention pond water. Hence, extending the risk estimates made in the Report to 40, 50 and 60 years can be achieved simply by scaling the probability results presented in the various figures in section 5.3 of the Report.

The issue of full ecosystem analysis is considered fully under Recommendation 15. The conclusion reached, however, is that the principal hazard that requires assessment, other than the issues addressed explicitly in the Report, is the potential impact on Swift Creek arising from the transport of suspended sediments from the sandstone waste rock dump. This issue has been addressed under Recommendation 13. The conclusion drawn there was that, if the Supervising Scientist's estimates of suspended solid loads are found to be correct, progressive ripping and revegetation of the waste rock dump will be implemented to reduce the impact to a negligible level. In this way, the area of exposed untreated waste rock would be constant with time and an extension of mining to 40, 50 or 60 years would not give rise to a change in this impact.

RECOMMENDATION 15.

> *A comprehensive risk assessment, including ecological, biogeochemical and hydrological factors, at the landscape/catchment scale for both Ranger and Jabiluka should be undertaken in the context of the Jabiluka World Heritage Area (5.4).*

[Note: We assume that the insertion of the word 'Jabiluka' before 'World Heritage Area' in the above recommendation was an oversight by the panel and that the context of the landscape wide analysis proposed is that of Kakadu National Park. Parts of the Jabiluka lease are registered as Australian Heritage areas but, since they are not in the World Heritage Area, they were not assessed in the Supervising Scientist's report.]

The issue of landscape-wide analysis was briefly addressed by the Supervising Scientist in chapter 7 of the Report. As noted in the Introduction, this chapter of the Report addressed issues that were not specified by the World Heritage Committee but which, in the view of the Supervising Scientist, required clarification, not a full review. Hence the brief treatment given to this issue. It would appear, however, that this brief treatment 'muddied the waters' rather than providing clarification.

The Supervising Scientist agrees that the potential impact of the Jabiluka Project needs to be assessed at the landscape scale. However, the scale that is assessed should be appropriate to the individual issues being addressed. For example, the issue of potential impact on surface water ecosystems arising from the dispersal from the mine of chemical constituents in surface waters needs to be assessed at the scale of the Magela Creek floodplain as was done at the

EIS and PER stage of assessment and in the Supervising Scientist's report. It was for this reason that the proposal by Wasson et al (1998) that such assessments need to be carried out on the scale of the 'entire Kakadu National Park' was not accepted by the Supervising Scientist. Indeed, in some cases the appropriate scale extends beyond Kakadu National Park. An example is the potential impact arising from the dispersal of radon from the mine site. In this case, the assessment in the EIS extended beyond the Park to the township of Oenpelli in Arnhem Land because it was essential that the radiation exposure of members of the public living in Oenpelli was properly addressed.

The issues raised in section 5.4 of the ICSU report were all considered in the EIS, the PER and the assessment of these reports by Environment Australia. The movement of contaminated water (on the surface and underground) was fully assessed in these documents and in the Supervising Scientist's report. The movement of uncontaminated water, eg the possible effects that draw-down in the water table due to dewatering of the mine and pumping of the bore field might have on terrestrial vegetation, was also considered and requirements for further research on this issue prior to final approval were implemented. Atmospheric transport of contaminants was assessed and, in addition to radiation exposure estimates, further work has been carried out to assess the impact of dispersed dust on the rock art sites of Kakadu. The effects of the mine and the haul road were assessed for the potential impact on the movement and well-being of aquatic and terrestrial animals. As a result, requirements were imposed on the installation of dry culverts along the haul road to ensure that the passage of small terrestrial animals would not be unduly impaired. Similarly, a requirement was imposed that the approaches to bridges along the haul road route should be designed to ensure that the migration of small fishes would not be impaired and that they would not be forced out into deeper waters where they would be more susceptible to predation by larger fish.

Thus, the environmental impact assessment process considered all of the issues raised by the ICSU panel. These issues were not addressed in the Supervising Scientist's report because their assessment was not requested by the World Heritage Committee.

While the Supervising Scientist believes that the environmental assessment of the Jabiluka Project properly considered these issues and came to conclusions on the most significant issues that required further research or management action, the significance attached to this issue by the ICSU panel is such that he has engaged Dr Graham Harris of CSIRO Land and Water to carry out a holistic ecological assessment of the Jabiluka Project from the landscape perspective. Dr Harris' report is attached at Appendix 4.

The principal conclusions of this landscape scale analysis are:

- The extensive ecological, physical and chemical data sets that have been collected over the years, and the continuous assessment of the impact of the Ranger mine for the past twenty years, have led to the conclusion that the dominant risk arising from the Jabiluka Project is likely to arise from physical and chemical exposure in the surface water environment.
- Nevertheless, the broader issues arising in an ecological risk assessment process had been identified and assessed at the EIS and PER stage although not addressed in the holistic manner implicit in an ecological risk assessment. These included assessments of the possible impact of the proposed haul road on fish migration, terrestrial animal pathways etc and specific recommendations had been made by the Environment Minister to deal with these issues.

- The conclusion reached in the assessment is that the most significant possible effect arising from construction of the mine and mill at Jabiluka is the probable increase in the suspended solid load in Swift Creek arising from the presence of the sandstone waste rock dump in the catchment.
- Other risks to the natural World Heritage values of Kakadu National Park would appear to be small.

Thus, the ecological risk analysis carried out by Dr Harris has come to the same conclusion as the Supervising Scientist. The conclusion is that the risk to the World Heritage values of Kakadu National Park is very small provided that the waste rock dump is managed in a manner that protects the environment of Swift Creek. That this is achievable? was the conclusion of the discussion under Recommendation 13.

RECOMMENDATION 16.

Assurance should be sought that the rehabilitation fund is adequate to meet any long term rehabilitation task should the mine be prematurely closed (5.5).

As stated in the Report, a rehabilitation plan for the Ranger site is submitted each year by ERA to the Department of Industry, Science and Resources (DISR). The Supervising Scientist provides an assessment of the adequacy of the plan to DISR. The purpose of this annual plan is to provide the basis for estimating the appropriate size of the Ranger Rehabilitation Trust Fund, an ongoing contingency for the cost of rehabilitation of the Ranger Project Area if mining operations were to cease at the date of the preparation of the plan. ERA is required to provide any additional funds required to the Trust Fund to ensure that adequate funds are always available for rehabilitation should the mining company cease operations prematurely for any reason.

The approval for the development of the Jabiluka Project by the Commonwealth Government included a similar requirement that ERA prepares an annual rehabilitation plan, approved by both the Commonwealth and Northern Territory governments, and that the two governments agree annually on the level of financial security required to implement the rehabilitation plan. The mine operator, ERA, must provide a Bank Guarantee to cover the level of security agreed by the two governments as being required to implement the rehabilitation plan.

Hence, the assurance sought under this recommendation can be given.

RECOMMENDATION 17.

A commitment should be obtained to establish a long term, possibly 100 year programme to monitor surface water, groundwater and the ecosystem at frequent intervals. This to be subject to periodic review (5.5).

In addition to the provision of security to cover the costs of rehabilitation, the Government approval for the Jabiluka Project contained a provision for the lodgement of security to cover the costs associated with long-term environmental monitoring and maintenance of the rehabilitated site. The program would include the monitoring of surface water, groundwater and the ecosystem. Thus a commitment has been given for the monitoring program proposed by ICSU.

The exact scope of the program and its length have yet to be determined. It is anticipated that the program would be subject to periodic review and that the length of the program will be determined by the results of these regular reviews. The reviews would, however, certainly need to take into account the long-term nature of some of the processes, notably groundwater dispersion, that could give rise to environmental impact.

3 Summary and conclusions

The review by ICSU of the Supervising Scientist's report to the World Heritage Committee considered the report in four parts: (i) Hydrological modelling, (ii) Risk assessment of the ERA proposal, (iii) Long-term storage of tailings, and (iv) General environmental protection issues. This summary is presented in the same way.

(i) Hydrological modelling

The overall assessment on this issue in the ICSU review was that the meteorological and hydrological analyses were carried out in a manner that meets good international practice, that the design of the retention pond is robust, that a number of issues were raised in the review where insufficient information was readily available to the review, and that some suggestions were made that should marginally improve the design.

This response has provided clarification on each of the issues raised under Recommendations 1–5 of the ICSU review. The Supervising Scientist believes that there are no remaining issues under this topic on which there is disagreement between his position and that of the ICSU panel and that a sound and robust methodology is now available for the detailed design of the Jabiluka water management system.

(ii) Risk assessment of the ERA proposal

Three issues were raised by the ICSU panel on the risk assessment of the ERA proposal; the applicability of the Ranger public radiation exposure model to Jabiluka, the effects of biotic and abiotic recycling of contaminants in the surface water system, and partitioning of the retention pond at Jabiluka.

A model specific to Jabiluka has now been developed and the results show that the exposure estimates used in the Supervising Scientist's report are supported by the new model and that chemical toxicity of uranium does not give rise to any significant risk. Recycling of contaminants in the surface water system has been assessed by comparing the total load of uranium discharged from the mine site in exceptional circumstances with the naturally occurring loads in sediments in the region and with the quantity of uranium that is naturally recycled on an annual basis by the ecosystem. As was the case for the Ranger mine, the conclusion drawn is that direct chemical exposure is the dominant risk associated with release of waters from the mine. Partitioning of the retention pond was a recommendation of the Supervising Scientist in his report and is further supported by the ICSU recommendation.

The Supervising Scientist is confident that the additional information supplied should provide the reassurance sought by the panel on these issues.

(iii) Long-term storage of tailings

The ICSU panel has accepted the conclusion of the Supervising Scientist that, once the tailings at Jabiluka are placed underground in the mine void and silos, tailings will not present a threat to Kakadu as a result of erosion processes for some hundreds of thousands of years. The principal threat that requires assessment is that arising from transport of contaminants in groundwater.

While acknowledging that there does not appear to be any risk to the Kakadu environment arising from the transport of solutes from the tailings repositories, the panel recommends that three dimensional models are run once additional geochemical data are available and that these models should be extended to encompass regional groundwater flow and its contribution to surface waters. It is recommended that these calculations should be extended to a 10 000 year time frame.

The Supervising Scientist has noted that ERA is undertaking a research program on the geochemistry of tailings including the effects of the use of cement paste technology, that this program will include three dimensional groundwater modelling, and that the time scale for the modelling will be 10 000 years. Final approval of the Jabiluka Project will not be given until the results of this program are available and the Supervising Scientist is satisfied that the environment of Kakadu's wetlands will not be harmed as a result of dispersal of contaminants in groundwater.

Nevertheless, in preparing this response the Supervising Scientist has been able to provide additional information on the regional groundwater flow regime, in particular the dating of water in the deep aquifer near Jabiluka, and recent information that confirms that the permeabilities used in the Supervising Scientist's Report were reasonable and probably conservative. In addition, the calculations for the dispersion of radium have been extended to 10 000 years and calculations of the leaching of uranium, under a worst case scenario, have demonstrated that the total quantity of uranium that could reach surface waters is small compared to the quantities of uranium that are recycled annually in the biotic and abiotic environment of the Magela floodplain. Similarly, should sulphate from the tailings reach the surface aquifer, dilution from surface water recharge in the shallow aquifer will reduce sulphate concentrations to values that are less than naturally occurring concentrations in the sediments of the floodplain.

The Supervising Scientist's conclusion is that, while refinement of the groundwater modelling remains to be completed and that final approval for the Jabiluka Project will not be given until it has been assessed, there is adequate evidence already available that the wetlands of Kakadu are not at risk.

(iv) General environmental protection issues

The general environmental protection issues raised by the ICSU panel in its review of the Supervising Scientist's report were the need to extend the risk assessment, using a broad ecosystem analysis, to about 60 years, the need for a landscape wide ecosystem analysis of the Jabiluka Project, the provision of assurances on the security of funding for rehabilitation and the provision of assurances on long-term monitoring.

The Supervising Scientist agrees that the potential impact of the Jabiluka Project needs to be assessed at the landscape scale but notes that the scale used should be appropriate to the individual issues being addressed. It has been demonstrated that such analyses were carried out in the environmental assessment of the Jabiluka Project and that the specific issues raised by the ICSU panel had been addressed. This resulted in a number of requirements that were specified by the Minister in granting approval for the project to proceed.

Nevertheless, noting the significance attached to this issue by the ICSU panel, in preparing this response the Supervising Scientist engaged an internationally respected expert in ecological risk assessment to carry out a holistic ecological assessment of the Jabiluka project from the landscape perspective and has attached the report (Appendix 4) on the assessment to this response. The principal conclusions of the assessment were that:

- the most significant possible effect arising from construction of the mine and mill at Jabiluka is the probable increase in the suspended solid load in Swift Creek arising from the presence of the sandstone waste rock dump in the catchment, and
- other risks to the natural World Heritage values of Kakadu National Park would appear to be small.

The report notes that the issue of suspended solids in Swift Creek had been identified by the Supervising Scientist during the environmental assessment process and that a requirement had been placed upon the proponent that would ensure the proper management of this issue in a manner that would protect Kakadu National Park. In this response, the methods available for management of erosion of the waste rock have been discussed and evidence has been presented that these management methods should be successful.

Extension of the risk analysis to 60 years has been assessed. It was concluded that, since it is not expected that there will be any significant time dependence in the concentrations of solutes in the retention pond water, extension of the risk estimates made in the Report to longer periods can be achieved simply by scaling the probability results presented in the Report. In broader ecological terms, the above results from the landscape scale analysis demonstrate that the principal issue to assess, on the longer time scale, is erosion of the waste rock dump. It has been demonstrated that the proposed management method, progressive revegetation, should ensure that there is no significant time dependence in this potential impact.

The assurances sought on rehabilitation funding and on long-term monitoring have been given.

The overall conclusion of the Supervising Scientist's report to the World Heritage Committee was that the natural values of Kakadu National Park are not threatened by the development of the Jabiluka uranium mine and the degree of scientific certainty that applies to this assessment is very high. He is still of that view. He is confident that, following receipt of the information contained in this response, members of the ICSU panel will support the Supervising Scientist's position.

A. Johnston
Supervising Scientist
23 June 1999

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APPENDIX 1 – Clarification of other issues

The section numbers used in this appendix refer to the relevant paragraphs in the ICSU review.

2.3 Tests of rainfall data

(a) In the second paragraph, it is stated that ‘There seemed to be an assumption in the RHU that the presence of an outlier might distort the analyses’.

This appears to be a slight misunderstanding. The reason for this particular discussion in the Bureau of Meteorology report was that ERA, in its analysis of the 1 in 10 000 AEP annual rainfall in the EIS, used the Jabiru data rainfall record and regarded the high rainfall recorded in 1975–76 as an outlier. The Supervising Scientist, in his terms of reference for the study, requested not only that the Bureau should estimate the 1 in 10 000 AEP annual rainfall by the best available methods but should also assess the methods used by ERA in making its assessment and provide critical comment on the methods used. Hence, the Bureau was assessing ERA’s conclusion that this point was an outlier.

(b) In the third paragraph, it is stated ‘This finding was repeated at a number of other stations and RSS suggests that the short term (88 year) Oenpelli record which is dominated by this period of higher than average rainfall has a mean for the 88 years which is higher than the long term mean. We consider that this suggestion could be misleading without the evidence to support it from a longer record’.

Again, a misunderstanding has occurred here. The SSR referred to two periods in the Oenpelli record; (i) the short term record corresponding to the period during which rainfall records are available for both Jabiru and Oenpelli, ie the period 1971–1998 for which data are presented in table 3.2.1 of the SSR, and (ii) the long term record at Oenpelli from 1917–1998, for which data are presented in table 3.2.2. The respective mean annual rainfall and standard errors for these periods are given in the tables as 1500 ± 57 mm and 1397 ± 30 mm. Thus the reference to the short term record being dominated by the period of higher than average rainfall referred to the period 1971–1998, not to the 88 year record.

2.4 Estimation of the 1:10 000 AEP annual rainfall for Jabiluka

In the second paragraph it is stated: ‘However, the synthetically generated data set based on the Oenpelli record leads to a slightly higher AEP and as this data set has been used in determining the retention pond capacity it would appear appropriate to use this higher AEP’.

It should be noted that the 1:10 000 AEP is no longer explicitly used in the design of the water management system. Its use has been overtaken by the use of the stochastic model. The reason for the inclusion of this analysis in the SSR was that the result for the 1:10 000 AEP rainfall obtained by ERA in the EIS had been specifically criticised by Wasson et al (1998) and it was considered appropriate to answer this criticism. The fact that the design of the water management system is being determined by the stochastic model means that the higher value for the 1:10 000 AEP is effectively being used.

3.2 Water quality of runoff from the ore stockpile

‘In the time available, we were not able to obtain a copy of Appendix B of the PER, an ERA review, although a request was made’.

It should be recorded that no request was made to the Supervising Scientist. Had there been such a request, a pdf-format version of the report could have been sent by e-mail.

Appendix 2 – Environmental impact of solutes leached from underground tailings repositories at the Jabiluka Mine

JB Prendergast, FRP Kalf & CR Dudgeon

1 Introduction

Approval has been given by the Australian Government for Energy Resources of Australia (ERA) to mine uranium at Jabiluka. The mining company has been directed to store tailings in underground silos and in the mined out stopes. Questions concerning the transport of contaminants in groundwater from the stored tailings have been raised by the World Heritage Committee. In response to these questions the Supervising Scientist (SS) commissioned a report in January 1999 (see Kalf & Dudgeon 1999) to quantify the transport of contaminants from the stored tailings. Results of the consultancy were summarised by SS in the Supervising Scientist's Report (SSR) which was reviewed by the Independent Science Panel (ISP) for UNESCO. The ISP documented 17 recommendations, four of which (Recommendations 9, 10, 11 and 12) related primarily to groundwater. This report has been compiled to provide additional information to the World Heritage Committee to supplement the SSR and clarify issues raised by the ISP. Two telephone conversations were held with the Chairperson of the ISP, Professor Brian Wilkinson, to help ensure that the information compiled here is pertinent to concerns and points of clarification sought by the ISP. Minutes from these conversations have been distributed to members of the ISP and made available to the World Heritage Committee.

The proposed mining operation at Jabiluka will extract approximately 90 000 tonnes of U_3O_8. After milling on site, the mill tailings will have cement added and be deposited as a paste in the mined out stopes and specially constructed underground silos. The primary contaminants of concern which can be transported downstream from the cemented tailings are sulphate, magnesium, manganese, uranium and radium.

2 Regional overview

2.1 Regional topography

Figures 1 to 3 illustrate the topographic features of the Jabiluka site and its relationship to a wider region of the Kakadu National Park.

Three scales of interest are covered. Figure 1 shows the site in relation to the main drainage systems, which lead to the sea in the Van Diemen Gulf to the east of Darwin. Figure 2 is a plan view showing the elevated sandstone outcrop under which the uranium orebody is situated, the surrounding lowlands and wetlands, the adjacent escarpment to the east and the surface drainage system. Figure 3 is a perspective view intended to help readers form a three dimensional picture of the site. Figure 4 is a conceptual model of the groundwater system surrounding Jabiluka.

As shown in figures 2 and 3, the Jabiluka uranium orebody lies beneath a saddle near the northern end of an 'island' of sandstone, that rises approximately 150 m above the surrounding lowlands. The Magela wetlands, which are about 5 m above mean sea level, occur to the west and north while to the east and south there are sandy stream deposits above weathered sandstone, with ground levels averaging about 20 m above sea level.

An extensive sandstone plateau lies further east, separated from the 'island' in which the orebody occurs by low level streams and alluvial deposits.

A broad band of wetlands which expands in width from about 5 km to 20 km extends north west along the course of the East Alligator River from Jabiluka to the sea in the Van Diemen Gulf.

2.2 Surface water and groundwater systems

Surface runoff around Jabiluka occurs only during the Wet season and significant surface streamflow occurs only during the Wet and the very early part of the Dry. As the Dry season progresses, the sandy bedded streams dry up and the only surface water occurs in a few pools in the creeks and in the low lying wetlands. Whilst groundwater seepage helps to sustain these small pools during the Dry, no significant spring flows are visible around the perimeter of the outcropping sandstone below which the orebody occurs. There is evidence that there are no major water bearing fissures through the sandstone in the vicinity of the orebody, since the water table in the outcropping sandstone remains at a high level during the Dry.

The only groundwater outflow of any significance in the vicinity of the orebody is a small soak (swampy area) at Boiwek, a site of significance to local Aboriginal people on the edge of the wetland at the western end of Mine Valley. This soak is discussed on page 64 of Commonwealth of Australia (1999). The source of the water and its hydrological significance have been investigated by ERAES and specialist consultants (Kinhill 1998, Appendix E). It was concluded that the water emanates from the shallow aquifer, but it is possible that a component comes from upflow from the deep hard rock aquifer.

Whilst there is some groundwater seepage into creek water pools, the absence of flowing groundwater on the sandstone outcrop or lowlands during the Dry (about half the year) indicates that during this part of the year the only outflows from the shallow groundwater are to evapotranspiration and percolation to the deeper aquifer system. Deeper groundwater circulation occurs in both the sandstone and the underlying schist which is host to the uranium ore. The weathered sandstone at the surface is more permeable than the schist and more readily transmits groundwater.

The deep aquifer is composed of two distinct rock types separated by an unconformity. As illustrated in figure 4, deep groundwater moving east from the tailings storage silos will migrate through sandstone while water moving west from the mine voids repository will migrate through schist. The presence of carbonate rocks in the schist sequence probably accounts for the higher permeabilities determined from borehole pumping tests west of the mine site.

2.3 Groundwater recharge/discharge

Because of the surface weathering and resultant higher porosity and permeability of the upper part of the sandstone, most of the recharge/discharge flow occurs in this zone. Evapotranspiration and horizontal drainage to the hill slopes account for most of the storage between Wet and Dry season water table levels in the elevated sandstone. The circulation of groundwater is limited at depth compared to the circulation near the surface because of much longer flow paths and lower permeability of the sandstone at depth. A study by the Northern Territory Department of Lands, Planning and Environment (NTDLPE) of a comparable sandstone outcrop in the Northern Territory has confirmed this aspect of the water balance in isolated elevated sandstone in the Northern Territory’s tropical climatic zone.

Rainwater directly infiltrating the low level alluvium (mainly coarse sand) during the Wet does not contribute directly to the flow through or around the orebody or deep sandstone in which it is proposed to excavate tailings storage silos. However, it provides an important diluting and flushing flow for the superficial aquifers every year.

The extensive area of elevated sandstone escarpment to the east of the Jabiluka lease and adjacent lowland alluvial zone contributes a large surface flow to Swift Creek during the Wet. It would also contribute a higher groundwater flow than would the sandstone in the Jabiluka lease. Surface water flow from the escarpment does provide a very significant volume of dilution water additional to that coming from the lease area. Although dispersion has been included in the modelling, dilution has not been included because an analytical model was used in the analysis, and dilution processes are not included in the mathematical equations.

2.4 Eventual destination of groundwater leaving the mine site

Groundwater flowing west across the mine site and adjacent areas in the sandstone and schist beneath the flood plain will eventually be directed by the prevailing hydraulic gradient towards the north west. The groundwater will then ultimately join the East Alligator River which enters the sea in the Van Diemen Gulf, approximately 60 km downstream from Jabiluka. Groundwater flowing east from the mine site and adjacent areas will join the flood plain path after heading north within the lower Swift Creek catchment.

Deeply circulating groundwater which could contain contaminants from the mine will be only a fraction of 1 percent of the total groundwater leaving the mine site each year. By the time it reaches the sea, the proportion of the total groundwater flow and storage which has flowed from the tailings repositories will be negligible. It should also be noted that natural conditions in the sediments of the floodplain range from acid sulphate in the wetland areas around the Jabiluka site to fully saline at the seaward end of the flow path. In the Dry season, high salinities occur in the East Alligator River system upstream from the sea almost to Cahills Crossing, about 10 km from Jabiluka. It should be noted that the tidal range at the mouth of the river can be up to about 7.5 metres, so that the river is subjected to strong tidal flushing as well as to large fresh water flows during the Wet. The tidal range at Cahills Crossing is about 4.5 m.

3 Aquifer permeability, fissures and model assumptions

3.1 Site visit

An inspection of the Jabiluka Mine was conducted on 10/6/99. The primary purpose of the visit was to follow up on an earlier site inspection in January, when the decline was 550 m long, and to assess the structure and hydrology of the sandstone and schist aquifers. The decline, or inclined tunnel, is approximately 6m by 6m in area, and with constructed headings and footwall drives the total length of this tunnel is now approximately 1600 m. About 550 m of tunnel penetrates in the schist and about 1050 m penetrates the Kombolgie Sandstone. The decline passes through the unconformity between the sandstone and the schist.

Hydrologically the shaft approximates a very large sloping borehole and flow into the shaft simulates a very long duration pumping test from a fully dewatered borehole. The shaft intersects a large area of rock surface, and enables sampling of a large section of the fracture zone which could only otherwise be achieved through an extremely large number of conventionally constructed boreholes.

The inspection revealed a number of features about the hydrogeology of the aquifer systems:

- Total inflow into the shaft was of the order of 1 to 1.5 litres per second. This confirms that the permeability of the Kombolgie Sandstone and the schist is low.
- Construction of the decline through the weathered sandstone above the shaft has created no significant drop in water levels in the overlying bores. This is indicative of the very low permeability in the underlying Kombolgie Sandstone.

- There was significant leakage (<0.5 l/s) from a number of cracks during the inspection in January when the decline was 550 m long. Leakage from these cracks had reduced to negligible flow by the time of the June inspection. Reduction of flow was not due to a fall in the watertable, but to drainage from water storage voids. This implies that the flow measured in the decline at any particular time is mostly derived from void emptying, although it is also contributed to by throughflow (as determined by aquifer permeability). Total flow in the shaft is therefore larger than that which would result from aquifer permeability alone.
- Water flow into the decline was sufficiently low that no grouting of the cracks was required.
- The unconformity between the sandstone and schist was dry.
- The inspection revealed that suitable sites existed in both the schist and sandstone for the construction of silos. There were no cracks over the entire 1.6 km which were considered to be large enough to preclude silo construction.
- The site visit confirmed that the values of permeability adopted by Kalf and Dudgeon (1999) were reasonable and conservative. In addition the lack of spring flows from the sandstone suggests that this aquifer does not contain major fissures. Evidence from these two sources supports the conclusion that no major fissure system exists which could invalidate flow calculations undertaken by Kalf and Dudgeon (1999).

4 Long term dispersal of contaminants

4.1 Background

In Kalf and Dudgeon (1999), simulations were conducted for radionuclides over a 1000 year period. In this section we examine the consequences of uranium and radium dispersal over a 10 000 year period.

It must be said at the outset that any prediction over a 10 000 year period is within the geological time scale. Hence it involves, changes in climatic conditions which may well alter or even completely change the wetland areas, along the current Magela floodplain, should they still exist after this time.

We make the assumption here that no such changes will occur and that the hydrological conditions present today will be those present in 10 000 years time.

4.2 Dispersal and dilution mechanisms

As described in more detail in Kalf and Dudgeon (1999), the dispersal of contaminants is controlled essentially by three processes, namely advection, dispersion and adsorption. Advection is the transport due to the flow of groundwater, whilst dispersion is the spreading and consequent lowering of concentrations due to groundwater velocity differences. These velocity differences are a function of the non-homogeneity and hence the structural properties of the fractured rock mass which causes any flowing contaminant to disperse. Adsorption is the adhering mechanism where contaminants are adsorbed to the rock mass surface in their passage underground.

In addition to these processes, dilution results from the mixing of groundwater containing the contaminant with water of lower concentration entering the groundwater flow system. This would commonly be recharge water entering the sub-surface system from streams, or other water bodies, or direct percolation of rainfall. Surface waters will also cause significant dilution where groundwater seepage emerges at the ground surface.

Because the movement of a contaminant is in part controlled by the velocity of the groundwater, a longer time period will result in the contaminant being transported a greater distance in a down-gradient direction. Theoretically at least, the 50% concentration of the contaminant front, without adsorption, will move the same distance as the mean groundwater velocity. Therefore the distance computed for the 50% concentration level after 10 000 years would, in theory, be ten times the distance computed for the 50% concentration computed for a period of 1000 years.

In addition to the advective effects there are the dispersion effects, and these will tend to flatten out the concentration curve from the source in a down-gradient direction as time progresses. That is, there is a greater reduction in concentration levels due to greater dispersion of the contaminant.

The above principles and effects also apply if the retardation concept is applied to describing adsorption. In this case however, the movement of the contaminant is 'retarded' compared to the groundwater velocity. For a retarded concentration front the flattening of the concentration curve will be less than for a non-reactive contaminant with no retardation.

4.3 Additional modelling results for uranium

The effects of 10 000 years of groundwater flow on leaching from the uranium repositories is best examined by determining the percentage of mass lost from the silos over this period. To achieve this, simulations were conducted using the numerical model described in Kalf and Dudgeon (1999). In particular, reference is made to the results of figure B-7a, b and c in their report, which was the case simulated over a period of 1000 years with a tailings paste permeability of 10^{-4} m/day, and a retardation factor (for both the aquifer and paste) of 20.

Figure 5 presents the recently conducted simulated results of a 10 000 year concentration profile through the two representative silos using the same parameters as those used to compute the curves in figure B-7a, b and c in Kalf and Dudgeon (1999). The results when compared to figure B-7b indicate that the source plane concentration of the plume (the concentration immediately down-gradient of the silos) has decreased from about 18% (in figure B-7b) to about 10% of the silo concentration. Also, an estimated 40% of the uranium mass has been removed over the 10 000 year period.

Figure 6 presents the case where the paste permeability is 10^{-5} m/day. In this case the source plane concentration is about 1 to 2%, with less than an estimated 6% of the uranium mass removed after 10 000 years.

Finally figure 7 presents the case given in figure 5, but with the retardation factor in the paste increased from 20 to 100. In this case the source plane concentration emanating from the silo is about 17% but the total mass lost over the 10 000 year period is reduced significantly to an estimated 10%.

4.4 Additional modelling results for radium 226

The movement of radium 226 over a 10 000 year period is now examined. The conservative assumption that sufficient thorium 230 will be essentially immobile and will supply sufficient material for the continued production of radium 226 at the source - that is a constant source concentration is assumed.

The model has been re-run for the scenario illustrated in figure 11c for the eastern area of the site given in Kalf and Dudgeon (1999) for a period of 10 000 years using a Monte-Carlo approach. For this calculation we use the dispersion-advection equation given in Appendix A in the above reference. The result for the median curve (ie the expected value curve) is given in figure 8a.

Figure 8b illustrates the median curve for the western area of the site.

The results indicate as expected that the distance of the 50% concentration is about ten times greater than for the 1000 year case. Because of the very short travel distance of the radium, even over the long time scale of 10 000 years, the analysis of environmental impact in section 6 is undertaken for uranium only.

5 Other relevant groundwater studies

5.1 Completed studies

Some groundwater dating has been conducted in the region from the Ranger Mine to just west and south of the Jabiluka site (see Australian Atomic Energy Commission (AAEC) Research Establishment 1981, Airey et al 1983.). This work was conducted as part of a substantial research effort on analogue sites for high level waste repositories, and sites that were investigated in the Alligator Rivers Region were the Ranger, Koongarra and Nabarlek orebodies (see fig 1). Some work was also undertaken on the Jabiluka orebody number 1. In the work undertaken by AAEC groundwaters were analysed for tritium, deuterium and carbon-14, lead-210, radium and thorium. The work was carried out in order to establish the rate of movement of uranium away from the Jabiluka and Ranger orebodies, both of which lie in the Cahill Formation schist.

The groundwater was dated as being modern near the Ranger mine and about 4000 to 5000 years old south of Jabiluka, about 12 km to the north of Ranger. A travel time of approximately 500 years per kilometre was derived by AAEC. Groundwater travel times derived from the extreme highs and lows of the permeability and effective porosity used in Kalf and Dudgeon (1999, table 4) on the eastern side of the site are in the range of 274 to 56 000 years per kilometre. To the west of Jabiluka in the schist/carbonate rocks the range of travel times is 18 to 5500 years per kilometre. Thus the results derived by AEAC are within the bounds used in the Monte Carlo analysis given in Kalf and Dudgeon (1999). It is of interest to note that the median value of the range of (Darcy) groundwater velocities used by Kalf and Dudgeon (5×10^{-5}m/day) and a highly probable porosity of 1% yields a groundwater travel time of 548 years per kilometre. This is in good agreement with the AAEC determined independently through carbon dating.

5.2 Current and future groundwater studies

Whilst some groundwater dating and isotope studies have been carried out in the past, a groundwater sampling program is also currently underway, and this may also serve to refine the range of permeabilities and velocities used by Kalf and Dudgeon. However, it should be noted that Kalf and Dudgeon used a wide range of permeabilities to assess possible environmental impacts. Groundwaters around Jabiluka are currently being measured for radon, oxygen-18, deuterium, uranium, radium, polonium-210, lead-210 and thorium, as well as chemical analyses. This work will be assessed in conjunction with three dimensional groundwater modelling to further improve the understanding of the groundwater systems around Jabiluka. Initial results from measurements in the shallow groundwater show low isotope concentrations and confirm short residence times in the shallow aquifer.

ERA has contracted additional three dimensional modelling work to Ecole des mines de Paris, where Dr Jean-Michelle Schmitt will manage a 3 year project currently in progress. However, this more detailed modelling work will not be completed for some time, and there is considerable doubt that results will be any more useful than the results from the modelling from Kalf and Dudgeon (1999) until substantially more data are collected. Whilst there will always be greater knowledge and understanding to be gained from additional groundwater studies, the pragmatic, conservative approach utilised by Kalf and Dudgeon (1999) has demonstrated that the impact to Kakadu wetlands is not significant.

ERA has commissioned a study on the geotechnical and geochemical properties of the tailings paste and its implications for leaching of contaminants from the repositories. The study is being undertaken by the University of New South Wales and is currently in progress. A range of cement additions are being evaluated and the implications of pH is being assessed. Of major interest is the effect of alkalinity on the mobility of uranium in the leachate.

5.3 Other observations

There is also a suggestion in Recommendation 9 that measurement of surface water baseflow could provide information to assist in permeability and flow rates. During the Dry season there is no baseflow in Swift Creek, and the groundwater inflows to the Swift Creek alluvial sediments are primarily from the shallow aquifer system, as described in section 2.2. Much of the shallow groundwater discharging from the lowlands is transpired and does not reach the Swift Creek billabongs. This fact has been established through observation of lowland vegetation, which remains greener through the Dry season than is usually the case with other vegetation in the region.

6 Discussion

6.1 Additional modelling results

The results of the additional simulation of uranium leaching from the silos indicates that under the worst case scenario (ie fig 5) approximately 40% of the uranium mass will be lost. Less than 6 to 10% will be lost if either the paste has a permeability of 10^{-5} m/day (a distinct possibility) or the paste retardation factor is 100 respectively (fig 6 & 7).

The conclusion that can be drawn from the simulations is that such mass loss over this very extended time period, even in an adopted worst case, will lead to low concentration levels in the far field. The implications of this with regard to total uranium mass and concentration estimated on and off-site is discussed below.

It is emphasised again that dilution is an additional mitigating factor that will operate within the Jabiluka hydrological environment to result in decreased concentrations. The dilution effect plays a major role in the Jabulika region on groundwater quality as a result of the seasonal wet period and there is no doubt that it will also, over time, significantly lower the concentration of any mass that may emerge from the repositories.

6.2 Environmental impact of uranium leached from the underground repositories

The environmental implications of the underground storage of tailings are best assessed from the concentration of the contaminants in the groundwater. Ecotoxicological and environmental impacts are conventionally quantified in terms of contaminant concentration, so an indicative value will be calculated here. Uranium concentrations are calculated below because uranium leaches more quickly than radium and is therefore a worst case example.

The possible increases in uranium can be calculated from the groundwater modelling which indicates in the adopted worst case scenario that approximately 40% of uranium could be leached out of the underground repositories in 10 000 years. Because it is proposed to mine 90 000 tonnes of U_3O_8 at Jabiluka, and about 5% remains after milling, there is about 4500 tonnes that could potentially be mobilised into the groundwaters. Because about 85% of U_3O_8 is uranium, there is approximately 3800 tonnes of uranium in storage. The groundwater modelling described in section 5.3 shows that 40% (1530 tonne) of this uranium could leach into the groundwaters in a worst case over 10 000 years. This equates to a net average loss of about 150 kg per year. If a conservative value of 10% of this leached mass is assumed to be available to the floodplain through upward movement from the deep groundwater (see section 2.4 of this report), then approximately 15 kg per year could reach the floodplain waters under steady state conditions.

The uranium leaving the floodplain annually can be calculated from Hart et al (1987), who give an average uranium concentration of 0.08 µg/l discharging from the Magela floodplain. This value is not inconsistent with work undertaken by Murray et al (1992), and Petterson et al (1993). The mean discharge from the Magela floodplain from 1975 to 1999 was 104 000 Ml/y (NTDLPE pers comm) giving a total uranium discharge of 83 kg/y. The natural load of 83 kg implies that there could be an 18% increase in uranium concentrations in the floodplain waters assuming the worst case scenario for leaching and dispersal of uranium from the tailings repositories. Natural concentrations currently in the floodplain waters are of the order of 0.08 µg/l so that under long term steady state conditions an 18% increase could result in an additional 0.014 µg/l or a total concentration of 0.094 µg/l. Stream and waterbody uranium concentrations more than an order of magnitude greater than this value have been measured in waterbodies within the ARR. For reference, the 'safe' concentration deduced from local toxicology studies reported in the Supervising Scientist's report is about 15 µg/l. Therefore, it can be concluded that no toxicological impacts could be expected from this uranium addition leached from Jabiluka.

It has been reported that uranium exists in natural surface waters at concentrations from 0.01 to 100 µg/l with the global average being 0.25–0.3µg/l (Ivanovich & Harmon 1992, p 279) and, even with a maximum groundwater discharge of uranium as calculated above, concentrations in the floodplain will not approach average world values. The drinking water standard for uranium is approximately 20 µg/l, and, as seen from other potential impacts described above, this value is similar to the concentration at which possible ecotoxicological impacts occur (NHMRC 1996). The additional uranium entering the floodplain surface waters (0.014 µg/l) through groundwater will be more than three orders of magnitude below the value at which an impact will occur.

It is also useful to compare the total mass of uranium likely to be leached into the floodplain from the groundwaters to other components of the current floodplain uranium mass balance. About 5000 tonnes of sediment enters the floodplain each year and it carries approximately 30 kg of uranium annually. The waters entering the floodplain carry an additional 100 kg approximately, so that 130 kg of uranium enters the floodplain naturally each year. The maximum influx of 15 kg/y which could be expected from the groundwater is small compared with the natural influx of 130 kg/y.

Another useful comparison is with the quantity of uranium that is recycled naturally in the vegetation of the floodplain. For uranium this was found to be about 800 kg, about fifty times the maximum quantity of uranium that would enter the floodplain each year from the tailings. Finlayson et al 1986 conducted an extensive study of the seasonal variation in floodplain vegetation communities and made measurements of metal and nutrient concentrations in leaf litter from the dominant species of *Melaleuca* and of aquatic grasses. Estimates were made of the quantity of metal and nutrient constituents that is recycled in the leaf litter and detritus of the Magela floodplain each year due to natural processes.

The overall conclusion that can be drawn is that even with the worst case scenario, the additional uranium concentrations due to leaching from the repositories will not have an impact on the wetland areas. It is significant that for a more plausible outcome where the repository paste permeability is below 10^{-4} m/day, the concentration increases will be even less than outlined above.

6.3 Environmental impact of sulphate leached from the repositories

Groundwater travel times estimated by AAEC are about 500 years per kilometre in the schist, and this time is similar to that derived from the median values derived from Kalf and Dudgeon (1999). Therefore sulphate is expected to reach the groundwater underlying the floodplain within the next 500 years. Both the groundwaters and surface waters become more saline with distance downstream, and the concentration of mine derived sulphate will be diluted to levels below those already existing in the groundwater below the floodplain, 1500–7000 mg/L. Because of the low permeability of sediments underlying the floodplain, the high dilution flows and domination of horizontal gradients in the deeper groundwater, mine-derived sulphate is not expected to be detectable in the floodplain waters.

7 Conclusions

- Inspection of the current mine shaft under construction confirms that the permeability of the sandstone and schist aquifers is low and that the values adopted by Kalf and Dudgeon (1999) are appropriate and conservative.
- The probability of intersecting a large crack during silo construction is low, as demonstrated through inspection of current shaft construction at Jabiluka. By inspecting the silo excavation before tailings placement, assurance can be given that tailings disposal will not occur in an area where significant cracks exist.
- Carbon-14 dating measurements from past work undertaken by AAEC give water travel times in the regional groundwater of the order of 500 years per kilometre. This travel time implies a uranium transport time of the order of 10 000 to 50 000 years per kilometre, depending on retardation. The travel time derived by AAEC is in good agreement with the median value of 550 years derived from the work of Kalf and Dudgeon (1999) for westward movement of groundwater.
- Additional modelling work undertaken for a ten thousand year time frame shows that under the most conservative conditions 60% of uranium will remain in the silos. With this scenario the rate of removal of uranium from the mine is 150 kg per year, which could discharge 15 kg/y to the floodplain waters under extreme assumptions for transfer from the deep aquifer to the surface. Only a very small fraction of the regional groundwater will reach the wetlands, because much of the groundwater will flow to the sea. This amount of uranium which could conservatively enter the floodplain waters is three orders of magnitude less than that which would be required to have a toxicological impact. Similarly, the total quantity of uranium entering the floodplain is very small compared with that which recycles each year in the vegetation of the floodplain. The environmental impact of radium is expected to be much lower because of longer travel times associated with its greater adsorption.
- Sulphate is expected to reach the groundwater underlying the floodplain within the next 500 years. However, both the naturally occurring groundwaters and surface waters become more saline with distance downstream, and the concentration of mine derived sulphate will be diluted to levels below those already existing in the groundwater below

the floodplain. Because of the low permeability of sediments underlying the floodplain, the high dilution flows and domination of horizontal gradients in the deeper groundwater, mine-derived sulphate is not expected to be detectable in the floodplain waters.

- Work completed to date provides a high degree of certainty that surface waters will not be impacted from groundwaters from Jabiluka. Nevertheless, ongoing studies, including numerical modelling work and isotope studies, will help to refine current estimates of model parameters and rates of contaminant movement.

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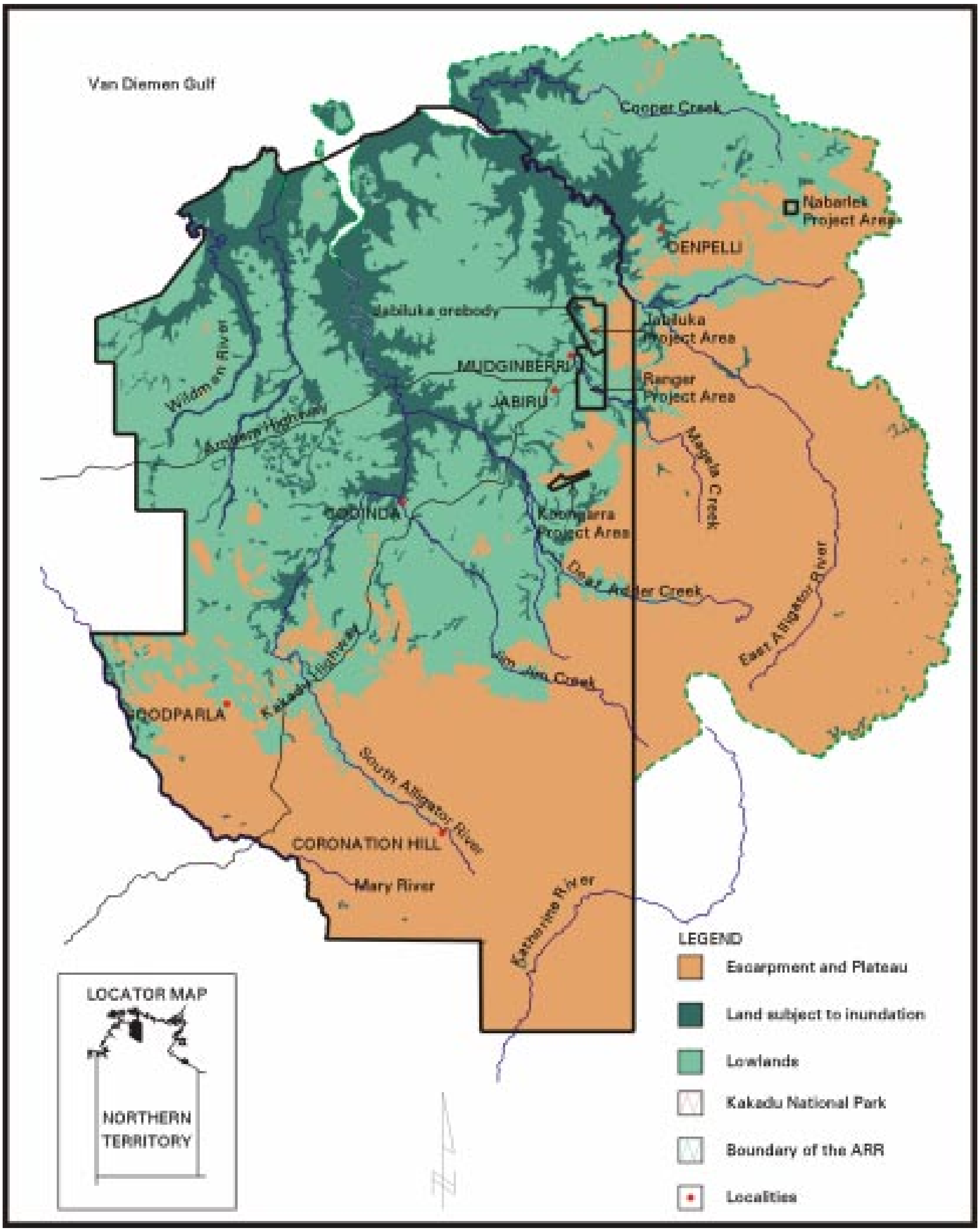


Figure 1 Alligator Rivers Region

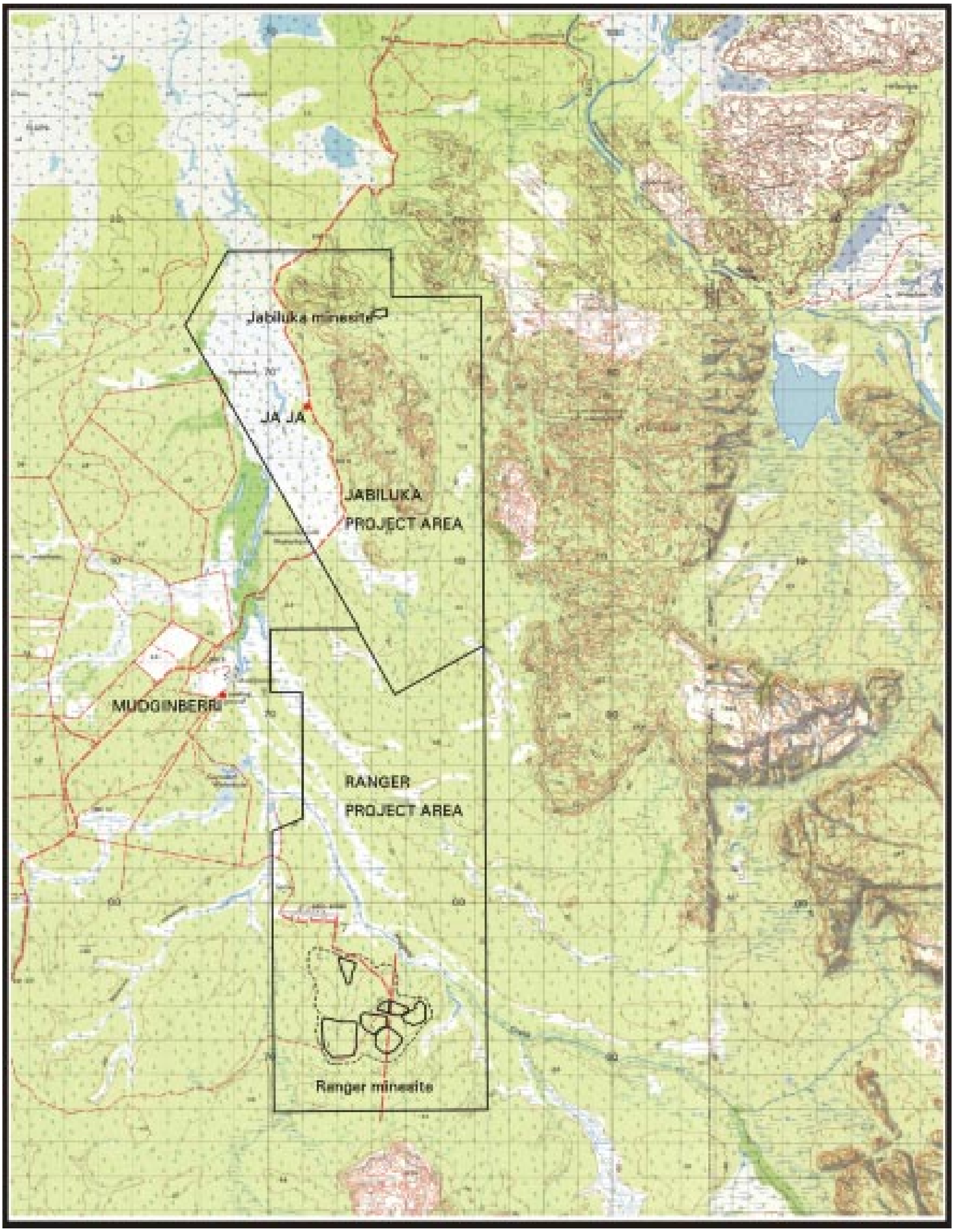


Figure 2 Jabiluka and Ranger mineral leases

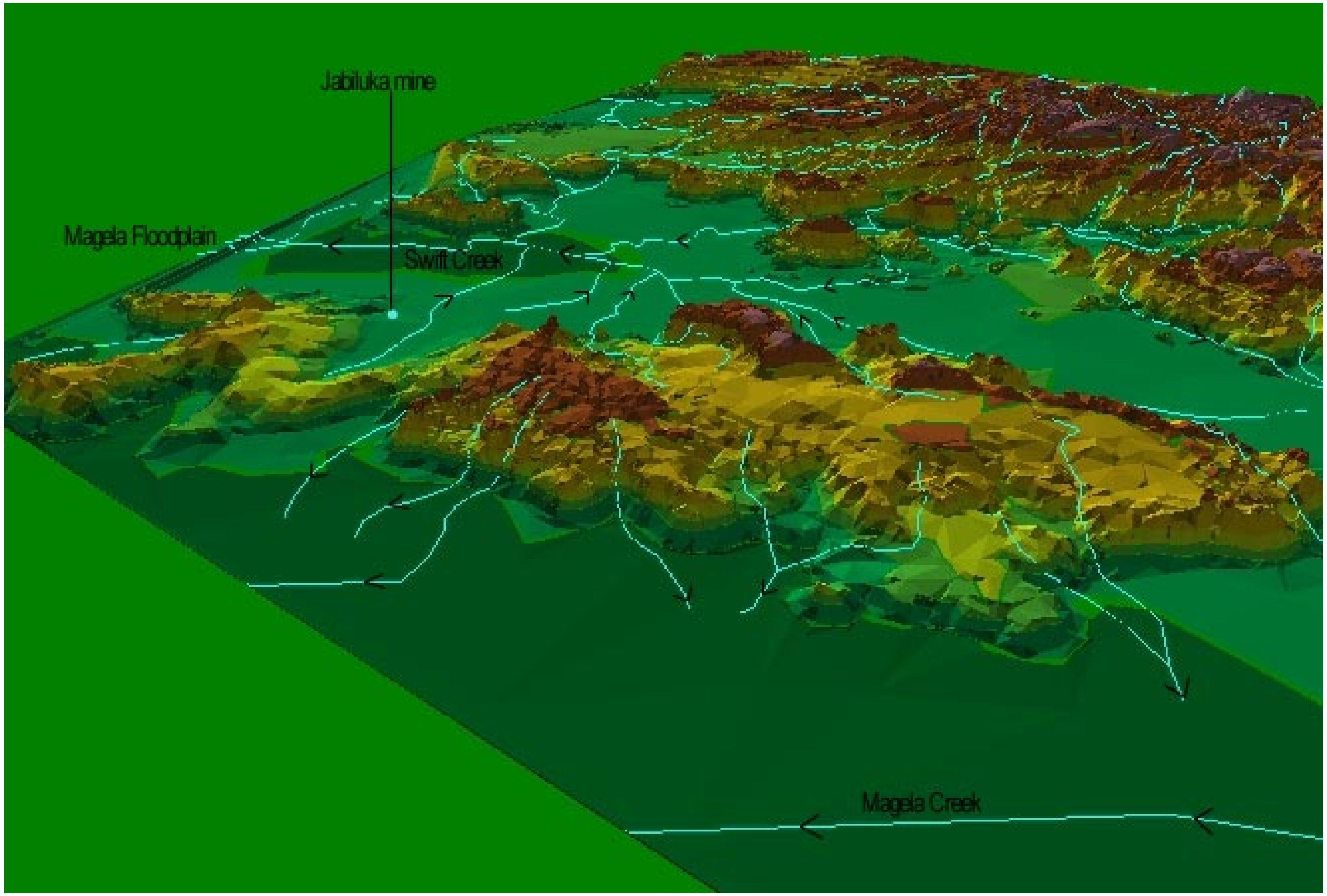


Figure 3 View of Jabiluka and its surrounding landscape from the south west.
Vertical exaggeration factor: 2

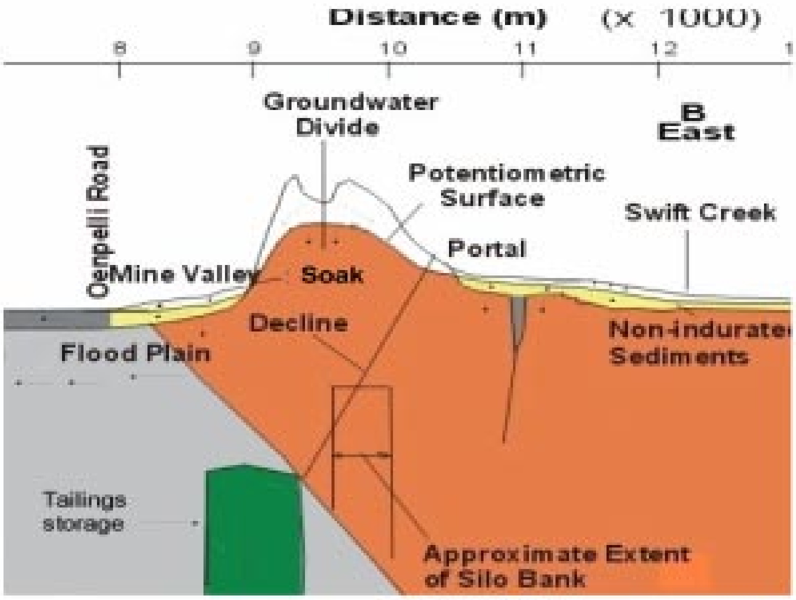


Figure 4 Conceptual model of the groundwater flow system at Jabiluka Mine

Fig 5 Profile - Row 1-Uranium -10,000 years, Rf=21, K(paste)=1e-4 m/d

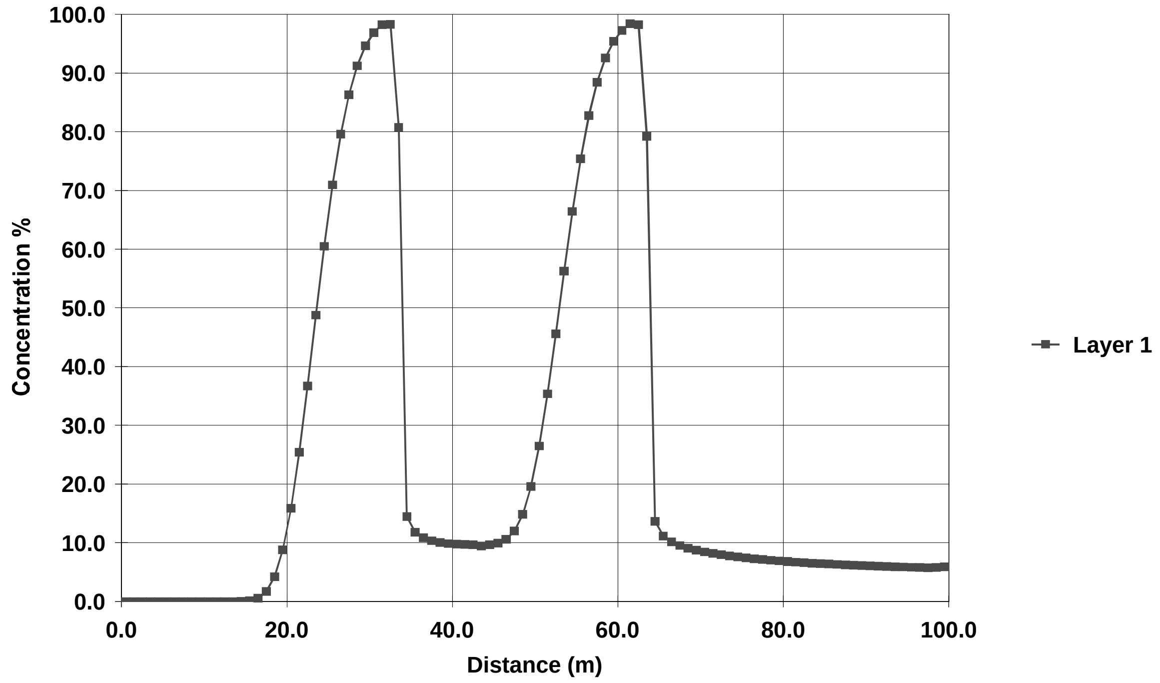


Fig 6 Profile - Row 1 - Uranium - 10,000 years, Rf=21,K(paste)=1e-5 m/d

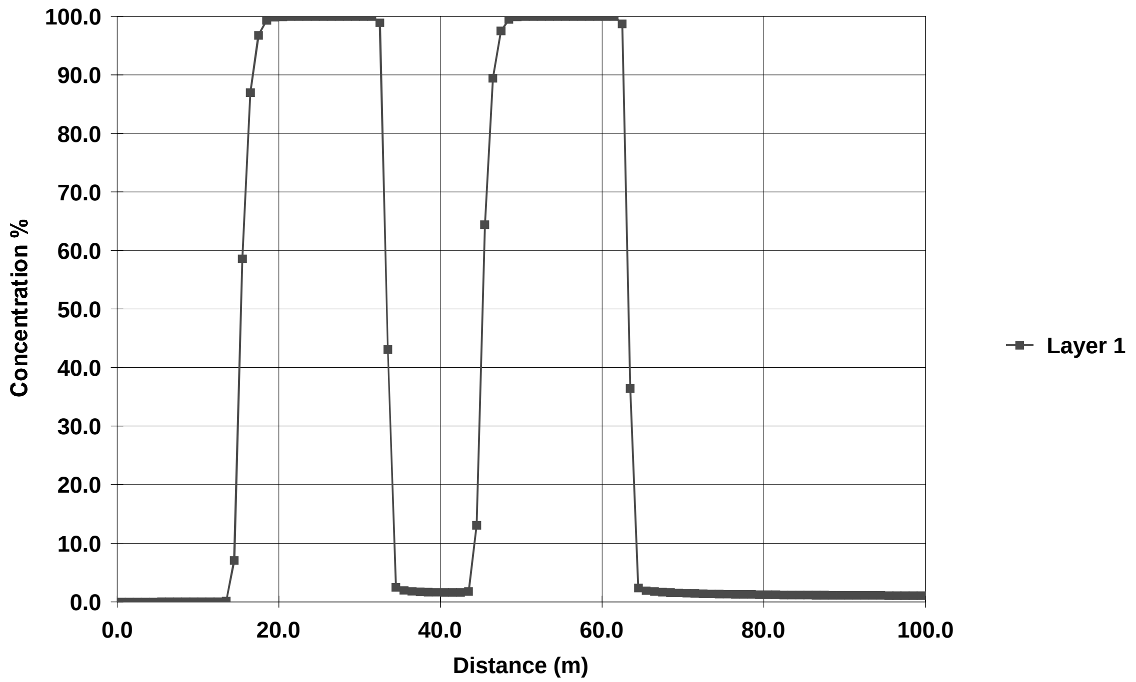
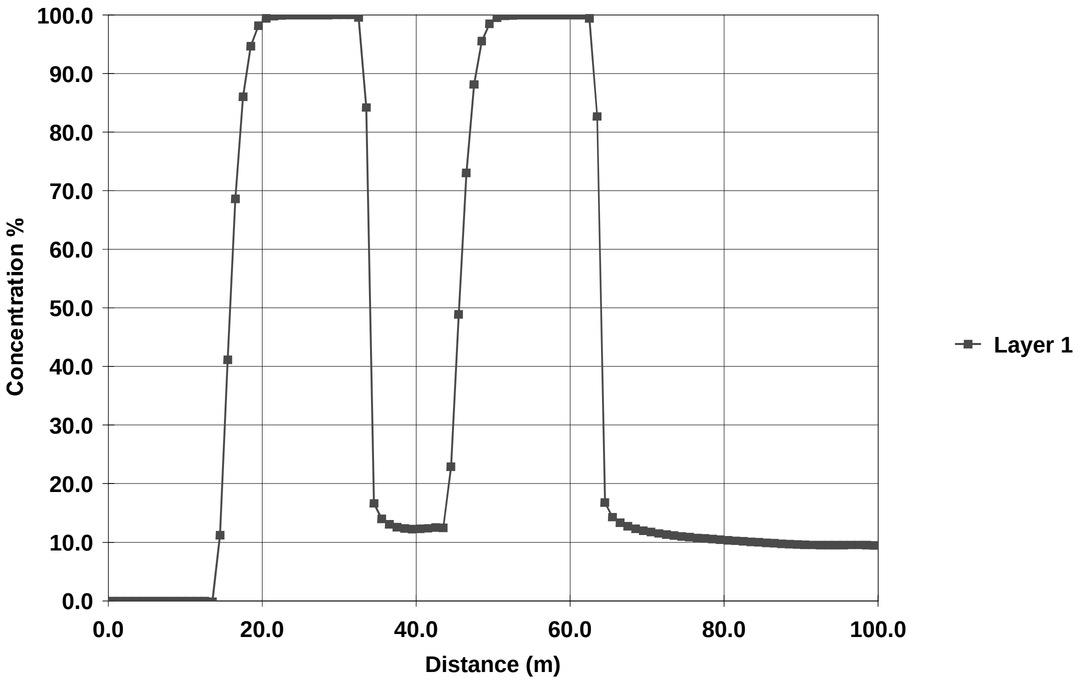


Fig 7 Profile - Row 1 - Uranium - 10,000 years, Rf=100,K(paste)=1e-4 m/d



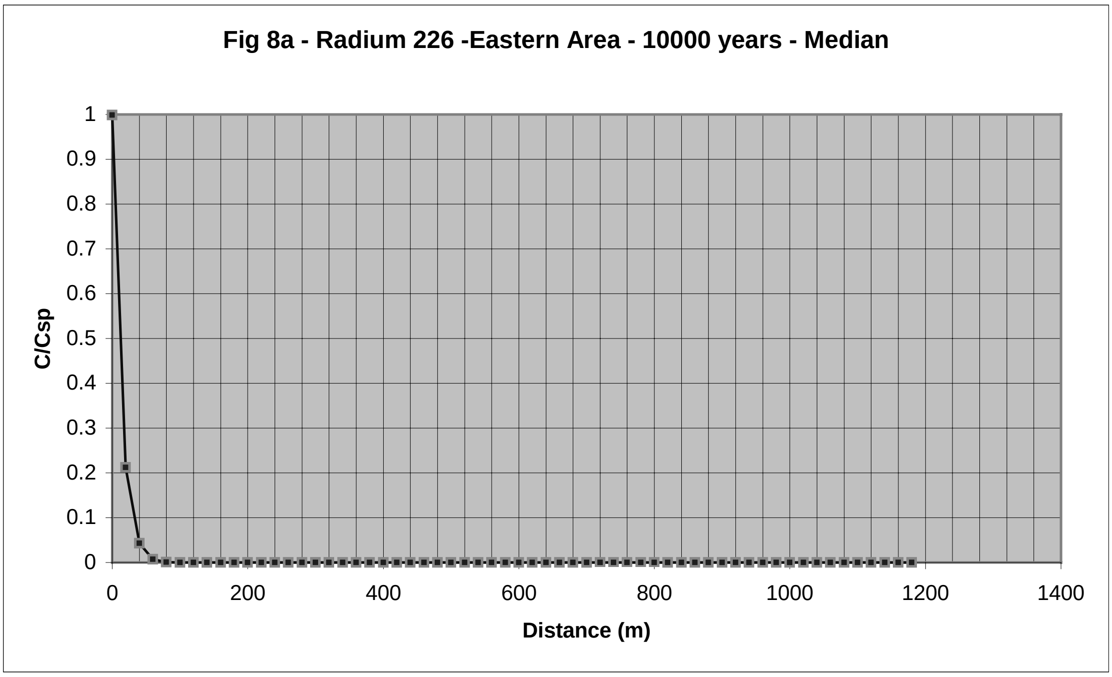


Fig 8a - Radium 226 -Eastern Area - 10000 years - Median
C/Csp
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
200
400
600
800
1000
1200
1400
Distance (m)

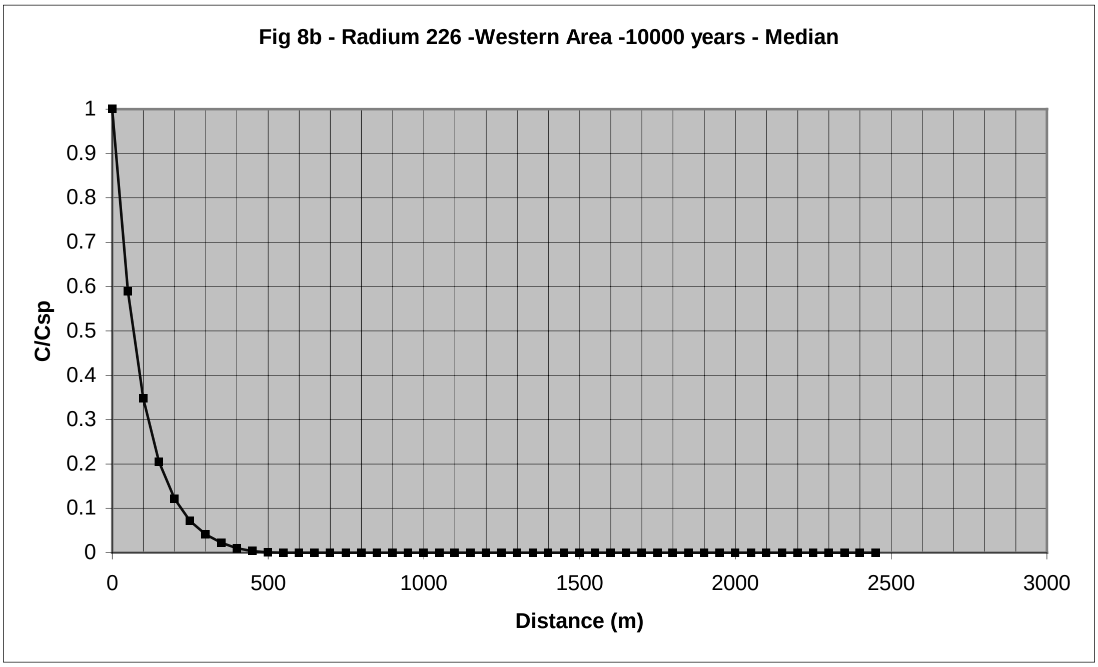


Fig 8b - Radium 226 -Western Area -10000 years - Median
C/Csp
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
500
1000
1500
2000
2500
3000
Distance (m)

Appendix 3 – Potential effects of the Jabiluka Mine upon the biodiversity of Kakadu National Park

C Humphrey

In considering the potential ecological effects of the Jabiluka mine upon Kakadu National Park, there are two main concerns: (i) impacts upon terrestrial biota arising as a consequence of the haul road, and (ii) impacts upon aquatic biota occurring in streams downstream of the mine site and haul road. The ecological significance of impacts upon terrestrial biota arising as a consequence of direct disturbance to habitat on the mine lease area is considered to be small because of the small size of the affected area and the absence of rare or endangered species on this area.

1 Impacts upon terrestrial biota arising as a consequence of the haul road

The haul road has the potential to restrict movement (dispersion and migration) of biota and to injure or kill animals through vehicular traffic. In its response to the Jabiluka EIS, the Supervising Scientist expressed the following concerns about the haul road:

> 'A raised road such as this could represent a major barrier to the movement of some terrestrial animals (especially those that may require seasonal access to adjacent wetlands) and this, combined with other roads in the Park, poses the risk of separating the area into discrete populations of the small non-flying fauna. This has not been assessed but might be readily resolved by incorporation of regular 'dry' culverts interspersed along the route. Reliance on the 'wet' culverts for this purpose, as presently proposed, leaves open the strong likelihood of points of residency for 'ambush' by dominant predators'.

In response to the Supervising Scientist's concerns, ERA is required to install dry culverts along the haul road route. The design of the haul road has not yet been finalised by ERA; such a design needs to be assessed by the Supervising Scientist and others to determine its adequacy in mitigating such effects upon biota.

With respect to road kills, Minister for the Environment's Recommendations (MR) 47 & 48 focus on development of management plans to cover this issue:

- MR 47: ERA should ensure that all drivers are fully educated on the potential for fauna road kills. A record of any significant fauna road deaths should be kept on-site and included in the Jabiluka Annual Report.
- MR 48: In consultation with Parks Australia, ERA must remove road kills, as soon as practicable, to a safe distance from the haul road.

Other aspects of the haul road design aimed at reducing road kills are described below (section 2.3/2).

Amongst terrestrial vertebrates, the only species that has been recorded so far, only, from the Jabiluka area is the skink, the Jabiluka Ctenotus (*Ctenotis arnhemensis*) (ERA 1996). This species has been found at a number of locations on the Jabiluka lease where they are reasonably common. ERAES has been unable to acquire permits to survey in the escarpment adjacent to the lease or along the haul route, hence the current lack of records off the lease. Nevertheless, the skink is found in locations that will not be disturbed by mining and in locations away from the haul road. Moreover, there are no records of road-killed Jabiluka Ctenotus on the Oenpelli Road near Jabiluka where traffic volume is high and speed is unrestricted (L Corbett pers comm). These factors would indicate that the species is not at significant risk from mining and associated transport activities.

2 Impacts upon aquatic biota occurring in streams downstream of the mine site and haul road

Impacts upon aquatic biota may arise as a consequence of accidental discharges from the mine site or road culverts, or from elevated suspended solids or solutes arising from runoff from the waste rock dumps or from road construction activities. The possibility for impacts arising from deposition of mine waste or derived substances in downstream areas of Swift Creek and Magela Creek, and potential for biological re-cycling, are discussed elsewhere (Supervising Scientist's response to ICSU Recommendation 7).

2.1 General description of the creeks potentially affected by the Jabiluka mine

The headwaters of Swift Creek arise in a portion of the dissected sandstone country of Kakadu National Park to the southeast of the Jabiluka mine site. A very short section of Swift Creek, prior to it leaving the dissected sandstone and entering the lowlands, flows year round. On the lowlands and downstream of Jabiluka, Swift Creek is typical of other streams in the Alligator Rivers Region in being a seasonally-flowing anastomosing sand channel. By the end of the Dry season, surface water in Swift Creek in the lowlands and in the vicinity of Jabiluka may be reduced to a series of pools, or may have disappeared altogether, depending upon the severity of the Dry season. The creek well downstream of Jabiluka discharges into a large swamp at its confluence with Magela Creek floodplain that may or may not hold water throughout the Dry season, again depending upon the severity of the season. The floodplain of Magela Creek adjacent to Jabiluka is seasonally-inundated; at the end of the Dry season, surface waters are generally confined to isolated swamps and billabongs.

Other creeks potentially affected by Jabiluka, by way of road crossings for the haul road (culverts, bridges), include 7-J Creek, North Magela Creek and Magela Creek. In general, each of these creeks has a similar hydrology and geomorphology to that described for Swift Creek above. At the proposed road crossings in the lowlands, the creeks are similar in nature to Swift Creek adjacent to Jabiluka.

2.2 General ecology of the creeks potentially affected by the Jabiluka mine

Dry season

Aquatic and semi-aquatic biota of creeks like those potentially affected by the Jabiluka mine take refuge over the Dry season in the headwater sections (of permanent creek flow), in creek pools, billabongs, floodplain swamps, the hyporheos of the dry sand channels, as dormant life stages present in the dry sand bed or floodplain soils, or as adult aerial stages (invertebrates) (Bishop & Forbes 1991, Humphrey & Dostine 1994, Paltridge et al1997 and Gunn 1997).

In the Dry season, the headwater (lotic) sections of creeks draining the sandstone massif and outliers of the Alligator Rivers Region generally contain an invertebrate fauna that is different to that of the lowland (lentic) water bodies (Humphrey & Dostine 1994, Paltridge et al 1997). The fish fauna below the plateau is generally common throughout the length of the creek systems with only a few species restricted to the escarpment stream sections (Bishop et al, in press). The faunal assemblages of the headwater sandstone plateau/escarpment streams are generally well represented throughout the Alligator Rivers Region and, for invertebrates and fishes at least, in other streams of permanent flow in the Northern Territory (eg Litchfield National Park, M Douglas (NTU) & A Wells (ABRS) pers comm). Only species of certain invertebrate groups of the Alligator Rivers Region are restricted to just one or two catchments. In particular, the macro-crustacean groups, the isopods (family Amphisopodidae) and prawns and shrimps (families Atyidae and Palaemonidae) that occur in this habitat display a high degree of endemism and species diversity (Bruce 1993, Bruce & Short 1993, G Wilson (Australian Museum), C Humphrey (***eriss***) & J Short (Qld Museum), unpublished data). Such endemism amongst the macro-crustaceans is presumably a consequence of the antiquity and persistence of the plateau/escarpment and associated perennial streams, springs and seeps, and isolating mechanisms including fragmentation of habitat (long-term climate changes, erosion) and the generally poor dispersal characteristics of these crustacean groups.

Species of the isopod genus, *Eophreatoicus*, occur in streams of the Jabiluka area (***eriss*** unpublished data). Two species have so far been found to occur in only two separate streams near Jabiluka (G Wilson pers comm), both of which will be unaffected by mining at Jabiluka. Isopods present in Swift Creek have not yet been identified because all specimens collected to date are juveniles which are too small to identify. Therefore the distribution of this species is unknown.

The aquatic biota taking refuge in lowland water bodies of streams in the Jabiluka area, whilst diverse, generally occur commonly elsewhere in the Alligator Rivers Region (Humphrey & Dostine 1994, Douglas 1999) – if not across the Top End of the Northern Territory. The high seasonality of the lowland (including floodplain) environment has generally selected for animals and plants that are readily dispersed. Moreover, the freshwater ecosystems of the lowlands are relatively young in geological terms – the floodplains are of the order of ~1500 years old while channels of the lowland streams have been infilling with sand from deeply scoured creek beds over the past ~6000 years (Woodroffe et al 1989, Wasson 1992) – a feature which, together with high seasonality and species vagility, has probably mitigated against endemism at regional and smaller catchment scales. Confirming this observation and from the very extensive surveys carried out to date, no species of aquatic or semi-aquatic vertebrate (fishes, frogs, reptiles, birds) and aquatic macrophyte has yet been found that is restricted to Swift Creek and Magela Creek downstream of the Jabiluka mine site. (Surveys include those of Pancontinental, ***eriss*** and consultants, and ERAES.) This is likely to be true also for aquatic invertebrates found in lowland, including floodplain, water bodies of these creek systems during the dry season. Certainly, amongst the very speciose family of non-biting midges, the Chironomidae (comprising ~120 species in the Alligator Rivers Region), all species found in Magela Creek have also been found in other creek systems in northern Australia (Cranston 1991, P Cranston, ANIC, pers comm). Ongoing studies in Swift and Magela Creeks, as well as in other Alligator Rivers Region and Northern Territory catchments, by ***eriss*** and others will elucidate this further.

Wet season

During the Wet season, Swift Creek near and downstream of Jabiluka and sections of other streams downstream of the haul road crossings, are recolonised by biota from permanent headwaters, residual pools (if any) of the creek channels, dormant life stages present in the dry sand bed and floodplain soils, the hyporheos of the dry sand channels, recruitment from adult aerial stages (invertebrates) or from downstream billabongs (Magela Creek floodplain) (Bishop & Forbes 1991, Paltridge et al 1997, Gunn 1997). Dispersion and breeding of much of the aquatic biota takes place along the length of the creek systems at this time of year. Some of the endemic isopods that occur in the permanent, plateau/escarpment sections of the streams move into the lower, seasonally-flowing, sandy portions of the creeks as juveniles (***eriss***, unpublished data). These animals live and grow over the wet season along the sand channels, migrating upstream at the end of the wet season to the permanent headwater sections (Paltridge et al 1997). In the wet season, the unidentified isopod species found in Swift Creek occurs both upstream and downstream of the Jabiluka mine site.

From the ongoing studies being conducted in the Alligator Rivers Region, no other species of aquatic macroinvertebrate or vertebrate has yet been found that is unique to any section of the streams that would be potentially affected by mining at Ranger (eg O'Connor et al 1997) or Jabiluka (***eriss*** and ERAES, unpublished data).

During the Wet season, upstream migration of some fish species to headwater refuge sites following breeding and growth in lowland and floodplain nursery areas features in a number of Alligator Rivers Region streams (Boyden & Pidgeon 1996, Bishop et al 1995). This migration is most pronounced in Magela Creek, but amongst the streams in the Jabiluka area has also been observed in North Magela and 7-J creeks (***eriss*** unpublished data).

2.3 Potential effects of the Jabiluka mine upon the biodiversity of Kakadu National Park

The Supervising Scientist has assessed the risks to the ecosystems of Kakadu National Park arising from mining in the ARR and concluded that aquatic ecosystems are most at risk from dispersion of water borne contaminants.

1. Organisms at risk from water-borne contaminants arising from Jabiluka

In general, the respiratory surfaces of animals have poor discrimination against toxicants compared with the gastrointestinal tract. It is for this reason that gill-breathing, aquatic organisms are at most risk from water-borne contaminants. In contrast, air-breathing animals linked to aquatic food chains are at risk from only a relatively small and specific suite of water-borne contaminants encountered in the diet; these substances include certain organic forms of metals (eg methyl mercury) and particular non-metallic organic compounds (eg some pesticides) that can biomagnify through food chains to levels of high toxicity (Humphrey & Dostine 1994, NWQMS In draft). None of the constituents predicted to be present in Jabiluka mine waste waters has biomagnifying potential while the dominant toxicant, uranium, has a relatively short biological half-life in the biota that would be expected to accumulate it to the highest concentration, ie freshwater mussels (Allison & Simpson 1987, Martin et al 1994). It is for these reasons that truly aquatic groups, macroinvertebrate and fish communities, have been the focus of biological monitoring programs developed for aquatic ecosystems of the ARR.

Direct poisoning of wildlife (semi-aquatic vertebrates including birds) can occur at mine sites as a consequence of feeding near, and drinking of, waters containing cyanide (involved in the processing of gold ore) or fuel oils and extractants arising from accidental spillages. Significantly, cyanide and flotation chemicals (eg xanthates) commonly used in ore extraction, will not be used in the milling process at Jabiluka. A ministerial recommendation was issued to ensure wildlife are prevented from accessing pond waters, thus:

- MR 21: ERA should develop a contingency plan to deal with risks to wildlife. The plan will detail how wildlife will be prevented from accessing pond waters.

2. Design of the haul road

The haul road will be about 22.5 km long, will be sealed, and will disturb a total area of about 49 ha. Features of the road that are to be incorporated in its design to reduce the risk of harm to terrestrial and aquatic biota include (from the draft EIS and Supplement to the Draft EIS):

- Bridges and culverts designed to minimise changes to surface hydrology (per MR 32);
- Bridges designed to minimise interruptions to migrating fishes, and not to create abnormal opportunities for ambush predators (per MR 31);

- Powerlines at major creek crossings at bridge level to minimise bird strikes (per MR 49);
- Dry culverts at regular intervals to act as animal throughfares along the haul road to allow animals to move underneath the road;
- In the milling-at-Ranger option, haul trucks to operate only during the day (0700–1600 h), and to have a speed limit of only 80 km/h (40 km/h within 500 m from mine site boundaries).

3. Potential effects of the Jabiluka mine upon the biodiversity of Kakadu National Park

(i) As stated above, the potential risks to the one or two locally-endemic species of the Jabiluka area are regarded as small.

(ii) Before approval to mine is granted, ERA is obliged by way of the Ministerial Recommendations to ensure the biodiversity of Kakadu National Park is not compromised by mining activities at Jabiluka, thus:

ADDITIONAL BASELINE ENVIRONMENTAL INVESTIGATIONS REQUIRED BY MINISTER HILL

- MR 1: Flora and fauna surveys, including detailed surveys of the proposed haul road route and mine site with a focus on threatened species and species covered by the China-Australia Migratory Bird Agreement and Japan-Australia Migratory Bird Agreement.

ENVIRONMENTAL RECOMMENDATIONS AND REQUIREMENTS OF MINISTER HILL

- MR 6: ERA should engage a suitably qualified limnologist to conduct an extensive survey of the aquatic fauna that potentially will be impacted by the proposal, to determine species composition and distribution. ERA must take all reasonable steps to ensure the proposal has no adverse impact on aquatic fauna.
- MR 31: ERA should ensure that the design of culverts for migratory fish is designed in consultation with a fish ecologist.
- MR 44: The baseline data surveys to be undertaken by ERA must identify any species in the project area that are considered to be rare or threatened. The project design must be amended, to the extent necessary, to ensure the protection of, and minimal impact on, these species (in the case of threatened species, recovery should not be significantly impeded).
- MR 19: If heavy metal accumulation is detected in any fauna, ERA should immediately inform the Supervising Scientist and Parks Australia, and must take all possible action to ensure that no further accumulation occurs.
- MR 22: Macroinvertebrate and fish communities should be monitored, on a regular basis, to ensure any impacts from the proposed Jabiluka uranium mine and associated activities are detected as early as possible.
- MR 23: ERA must consult with the Supervising Scientist with a view to establishing and conducting a water quality monitoring program that meets the listed water management objectives. This consultation will identify appropriate indicator species, reference sites, sampling effort and sample replication.
- MR 50: ERA must consult with the Supervising Scientist and Parks Australia and must take all possible steps to ensure that the special ‘ecological character’ (as

recognised under the Ramsar Convention) of the Magela Creek floodplain and associated Ramsar wetlands will not be compromised by the proposed Jabiluka uranium mine.

- MR 9: ERA should engage a suitably qualified, independent limnologist to review the quality of all water data (surface and groundwater).

ENVIRONMENTAL RECOMMENDATIONS FROM JMA APPROVAL (Senator Hill)

- MR 10: ERA must, to the satisfaction of Environment Australia and the Supervising Authority, develop and implement measures to ensure the protection of the flora and fauna species listed in s.6.6.3 of the Assessment Report.
- MR 11: ERA must devise and implement, to the satisfaction of the Supervising Scientist, a biological monitoring program that includes Swift Creek and other suitable analogues.

Conclusions

From this review, the following conclusions have been drawn:

- Of the biota associated with aquatic ecosystems, risks from mining are sufficiently small to semi-aquatic vertebrates, including birds, that extensive monitoring programs on these groups of animals are not warranted. The focus of considerable monitoring efforts, rather, is on the truly aquatic groups, the invertebrates and fishes.
- The haul road poses a potential hazard to wildlife through death or injury, or through barriers to movement. Design structures and traffic restrictions more stringent than those applied on other Kakadu roads will feature in the road construction and use to reduce the hazard and risks to wildlife.
- The potential risks arising from mining to the one or two locally-endemic species of the Jabiluka area are regarded as small.
- At least 11 ministerial recommendations aimed at ensuring that the biodiversity of Kakadu National Park is not compromised by mining activities at Jabiluka, must be met by ERA before mining can proceed.

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Appendix 4 – A landscape scale analysis of the potential impacts of the Jabiluka Mine

Graham Harris
CSIRO Land & Water
Canberra

This brief summary is designed to reply to some of the recommendations of the Independent Scientific Panel[1] (ISP) wherein a full ecosystem analysis is called for as part of the EIS for the proposed Jabiluka Mine. Recommendations 14 and 15 in particular call for a comprehensive risk assessment (including a full ecosystem analysis), including ecological, biogeochemical and hydrological factors at landscape/catchment scales. A similar call to place the proposed mine in its catchment setting was made by Wasson et al[2] in their submission to the UNESCO delegation to Australia.

A catchment and landscape scale approach is certainly warranted. It is certainly true that merely performing eco-toxicological assays and sampling the biota might miss potential impacts at larger scales. Similarly, adherence to ANZECC (Australian & New Zealand) water quality guidelines may also not preclude other longer term and larger scale risks to the ecosystems of the World Heritage Area. If an ecosystem scale, biogeochemical approach is taken to risk then it is necessary to calculate loads and fluxes through the landscape and to compare natural processes with those which might be altered or induced by mining operations.

There are sufficient data to begin to put such an approach together. The UNESCO delegation and the ISP may not have been aware of the extensive research and monitoring that has been carried out in the Magela catchment (which contains the township of Jabiru, the existing Ranger Mine and the proposed Jabiluka site) since the late 1970s by the Environmental Research Institute of the Supervising Scientist (ERISS), environmental research staff from the Ranger Mine (ERA Environmental Services, ERAES) and numerous independent consultants.

This brief document is an attempt to pull together some of this information into a summary of the landscape situation of the proposed Jabiluka mine site together with information about some of the dominant ecological, biogeochemical and hydrological processes at work in the Magela Creek catchment. The ISP also called for a full risk assessment for the proposed life of the mine (up to 60 years). Given the time constraints under which everyone is presently working, such a full assessment is not possible at this time, but such a recommendation is warranted. This document does not address the risk assessment question but does attempt to give a longer term view of the development of the present environment of the National Park and some of the dominant processes which have structured the present landscape. As such it attempts to respond to the ISP's recommendations by taking a functional view of the landscape in which the proposed mine site sits.

Background

The site of the proposed Jabiluka uranium mine lies in a lease separate from, but enclosed within, Kakadu National Park (KNP). The history of the development of KNP, the geographical situation of the proposed mine and the legal and management framework now in place is summarised in a recent response by the Government of Australia to the UNESCO World Heritage Committee regarding KNP [3]. KNP is an area of unique ecosystems and high environmental values which has been populated for at least 50 000 years. The Park contains many sites of great cultural significance. KNP straddles the lowlands of the South and East Alligator Rivers and the escarpment of the Arnhem Plateau and lies in an area of the wet-dry tropics characterised by monsoonal rains and a strongly seasonal climate. The Park is large (19,804 km^2) and contains large expanses of wetlands listed under the Ramsar Convention.

Both the existing Ranger Mine and the township of Jabiru lie in the Magela Creek catchment. Magela Creek flows from the Plateau, through extensive forested lowlands and out onto the floodplain, a vast area of lowland wetlands – an area of high biodiversity. The proposed mine site at Jabiluka lies within the Swift Creek catchment, which itself is part of the Magela Creek catchment. The areas of the Swift Creek and Magela Creek catchments are c. 50 and 1500 km^2; the area of the proposed mine site including the Jabiluka Mill Alternative (JMA) is 26 ha. The total population of Jabiru is controlled to around 1500, although the population is increased by tourism, particularly in the Dry season. The history and development of the Jabiru town site is explained further in ref 1.

The general features of the dominant geomorphological and biogeochemical processes in the Magela catchment have been elucidated through research and monitoring over the last twenty years. The general features of the geology, landforms, soils and vegetation of the Magela Creek catchment, along with details of climate and hydrology are given in Wasson (1992)[4]. In addition to the work of Wasson, a large amount of water quality and ecological sampling has been carried out in the rivers, wetlands and billabongs. Some of the more recent water quality information and sampling data from Swift Creek and other stations are given in Milnes and Jackson[5]. Extensive flora and fauna surveys have been carried for many years out to identify endangered and threatened species, to monitor the effects of the existing Ranger Mine and to provide the basis for KNP management plans.

As Wasson (ref 4) notes, the Magela catchment has been subject to a number of disturbances over the last 1000–1500 years. The freshwater wetlands in their present form first appeared about that time when sea levels stabilised, sediments capped the flood plain and the climate became wetter. Even though there is good evidence of human habitation going back some 50 000 years, the development of the wetlands led to a marked rise in the human population and, later, the arrival of water buffalo. The developing human population used fire extensively and changed the ecology of the catchment. Wasson (ref 4) writes ‘The idea that a pristine, old and stable wetland was shocked by the arrival of Water-Buffaloes late in its life is not supported by the evidence. Nor is the often quoted link between species rich ecosystems, such as the Magela plain, and antiquity’. Over the years the KNP region has been impacted by a number of environmental threats including changes in the fire regime and the introduction of feral animals and weeds. Water buffalo have now been largely exterminated from the Park but *Mimosa pigra*, *Salvinia*, Para Grass (*Brachiara mutica*) and wild pigs continue to be a threat. Management regimes are in place for all these species.

Surface water chemistry

Because of the heavy rainfall during the monsoon, the surface water chemistry of the catchment is characterised by dilute, soft water systems during the Wet. Examples of recent analyses of surface water chemistry are given in Milnes and Jackson (ref 5). Extensive sampling has been carried out in the Jabiluka region since the 1970s. Sodium is the dominant cation, increasing from 40% to 70% of total cations (by mass) at the expense of calcium and potassium as the wet progresses. The dominant anions are chloride and bicarbonate. Conductivity is low (15–20 μS/cm) as is the pH (<5.5). Dissolved organic carbon concentrations are low as are concentrations of nitrogen and phosphorus. Water quality is good and the floodplain supports a diverse array of macrophytes, invertebrates and vertebrates.

Surface water quality is not as good during the first flush after the Dry season, especially if (as often occurs) large areas of the catchment have been recently burnt. Then, surface waters are brown with high concentrations of total suspended solids, DOC and nutrients. The loads to receiving waters are high during this period – with concentrations an order of magnitude higher than the Wet season proper.

During the Dry season a variety of other processes dominate and most streams cease flowing and are reduced to a series of isolated waterholes or billabongs. Water quality in many billabongs deteriorates. Conductivity and concentrations of cations and anions rise as a result of evaporation while oxygen depletion occurs as a result of decomposition of organic materials. In addition the drying of soils and sediments containing old marine sulphides causes the generation of Acid Sulphate Soils (ASS), reduces pH and liberates aluminium and other metals into solution. This was first demonstrated by Hart and others in the late 1970s[6]. Milnes and Jackson (ref 5) have recently repeated much of Hart's work and have come to similar conclusions. In addition this new work records marked rises in sulphate and aluminium concentrations in some billabongs as a result of ASS and sulphide oxidation late in the Dry season. Fish kills are a natural and common occurrence.

The picture that emerges is of a weathered landscape flushed by heavy rains in the monsoon season, with extended wetlands across the floodplain at the end of the Wet season composed of dilute and slightly acid waters of high quality. Evaporation during the Dry season leads, in the case of permanent floodplain waterbodies, to reduced water quality and the release of acids and metals from sulphidic sediments. Toxicity associated with fish kills arises from metals and acid water draining into billabongs from the surrounding flood plain.

Sediment budgets

Wasson et al (ref 4) have done a fairly complete sediment budget for the Magela Creek system and have documented the evolution and sedimentary history of the catchment and flood plain in some detail. Total suspended sediment (TSS) loads from the Magela Creek catchment have been estimated by Wasson et al and by Hart and co-workers[7]. Estimates vary from year to year depending on rainfall but range around 3000 to 10 000 tonnes per annum. Sedimentation rates have been constant for about 3.3 Ky.

Prendergast and Evans[8] have made some preliminary estimates of the impacts of increased erosion and TSS loads from the Jabiluka mine site on Swift Creek using the models developed by Wasson and also comparisons to RUSLE and other standard relationships. Prendergast and Evans have also reviewed previous work in the area on discharges, run-off coefficients and sediment yields. Bringing a wide range of studies together they estimate that about 30 t/y of TSS will pass the sediment traps and get into Swift Creek during the construction period and that about 200 t/y of fine sediments will enter the creek from the subsequent operation of waste rock dumps during the life of the mine.

Prendergast and Evans then extended Wasson's (1992) work to calculate the natural TSS loads from Swift Creek which was not included in the original Magela Creek analysis. A number of standard methods produced TSS loads of between 460 and 500 t/y indicating a probable increase in suspended solids loads due to initial mining operations of about 6% and an increase during the life of the mine of 40% if there was no surface treatment. Impacts on sub-tributaries of Swift Creek which are within the Jabiluka lease area but not the Park, will be greater than this but the impact on the entire Magela Creek system will be small and practically undetectable given the natural variability. Rigorous sediment and erosion control measures have been recommended to ensure that turbidity in Swift Creek is not increased and that ANZECC guidelines are adhered to. The TSS loads from Swift Creek flow downstream and are stored in a deposition zone north of the mine site while the water flows into a large wetland area which is part of the Magela Creek flood plain. These TSS inputs will not have a broader scale impact on the wetlands of the Magela Creek system because they are small compared to the natural TSS inputs of this system determined by Wasson et al (ref 4).

An additional feature of the run-off from the rock dumps is the possibility of elevated magnesium and sulphate concentrations from weathering of the sandstones. If these rocks are similar to those at the Ranger mine then the sulphur content may be of the order of 50 mg/kg. Given the difference in the rock geochemistry (sandstone at Jabiluka, schist at Ranger) this might reasonably be expected to be an upper limit. The sulphur content of these rocks is low but care will be needed to ensure that sulphate concentrations in the streams flowing into Swift Creek do not become elevated. Estimates based upon the above sulphur content and flow rates in Swift Creek show that the expected increase in sulphate concentrations in Swift Creek will be about 1 mg/L, a concentration that is unlikely to cause ecological impact. At present no analytical data or rates of rock weathering appear to have been produced. It should be noted that sulphate concentrations in the floodplain billabongs do vary as a result of the oxidation of ASS during the Dry season.

Ground water

The ground water systems of the Magela Creek catchment have been the subject of recent investigations to see whether or not the establishment of the Jabiluka mine would (a) lead to leakage of tailings materials into local aquifers and (b) disrupt ground water flows in the catchment to the extent that ecological and cultural impacts might be expected.

All the ground water modelling done so far shows that movement of uranium and other elements from the tailings placed back in the underground mine are expected to be small — at most less than 5–50 yrs/km to the west[9]. Ground water movement to the west of the proposed mine is more rapid than movement to the east, but rates are still small — of the order of 50–500 yrs/km. ANSTO data quoted in (Prendergast, ref 11) revealed rates of ground water movement consistent with the slowest estimates of Kalf and Dudgeon and used a retention factor of 100 for uranium in ground water, so that movement of uranium from the stored tailings would be of the order of 50 000 yrs/km.

The aquifers in the proposed mine area are complex with a number of hydro-stratigraphic units (HSUs) being discovered. There appear to be four such HSUs at varying depths. It is considered likely that there is little connection between the upper sand HSU and the lower bedrock aquifers[10] and there is little expectation of significant flow from the deep aquifer to surface waters of the floodplain. The chemistry of the ground water is quite different in the vicinity of the ore body compared to that in bore holes closer to the flood plain. Ground water in the vicinity of the ore body is characterised by near neutral pH, low concentrations of chloride, sulphate, silica and major cations indicating little reactivity with the ore itself (see refs 5, 10, 11).

Shallow ground waters show evidence of being relatively ‘young’ in terms of chemical composition (see Foley in ref 5). The consultants (ref 10) used this information to infer that there was relatively little connection between the surface aquifer and the deeper aquifers that would be impacted by mining operations. This is important because the surface, unconfined sand aquifer is important both ecologically and culturally. Not only are terrestrial and aquatic ecosystems dependent on ground water during the Dry season, but a soak at Boiweg has been identified as a site of great cultural significance so the consultancy studies on the ground water dynamics and the possible impact of the mine specifically addressed these issues.

There are, as yet, insufficient data upon which to base categorical conclusions about the possible impact of the Jabiluka mine on local ground water fluxes and levels. There are no conclusive dating data for the aquifers although Prendergast[11] reports ^{14}C dates obtained by ANSTO in the early 1980s which would indicate that ground water in the vicinity of the Ranger mine is recent, whereas ground water from south of Jabiluka was of the order of 4000 to 5000 yrs old. Most ground water movement seems to occur in the surface unconfined, sand aquifer and at the surface of the fractured upper part of the sandstones. The conclusion to date (albeit based on insufficient data) is that the Boiweg soak and other ecological interactions are dependent on shallow, surface aquifers and will be largely unaffected by mining operations. More discussion can be found in Prendergast (ref 11).

In the context of the regional ground water situation, the water supply for the Jabiru township is obtained from bores which lie approximately 30 km west of the township. It is not expected that the development of the Jabiluka mine will change the regional water supply or sewage disposal situation or will impact on the Magela flood plain in this respect. There is no evidence that the present situation is having an impact and the development of the Jabiluka mine (coming as it does at a time when the Ranger mine will begin to ramp down) will not significantly alter the overall population of the region.

The surface aquifers undergo large changes in level during the Wet and Dry seasons. This has a major impact on water availability for deep rooted vegetation on the flood plain during the Dry season and on seepage into billabongs. There is evidence (quoted in ref 10) that there is a connection between a deterioration in water quality at the end of the Dry season in the billabongs and ground water ingress on the flood plain. Ground water to the west of the Jabiluka site is of poorer quality than elsewhere and may well impact on the biogeochemistry and ecology of the billabongs at the end of the Dry season.

Aquatic ecosystems

The aquatic ecosystems of the Magela Creek systems are diverse and valued. The hydrology of the Magela and Swift Creeks is well monitored and there is a good network of gauging stations within the catchment. Streams and rivers dry up to a series of water holes or billabongs in both catchments during the Dry season and flow does not occur in the lower parts of Magela Creek until relatively late in the Wet season (ref 4). Milnes and Jackson (ref 5) summarise some of the recent ERAES hydrological data from the catchment. Swift Creek is a sandy, braided stream that largely dries up in the Dry season. Well downstream of the Jabiluka site the stream flows into a large semi-permanent wetland that most likely dries only after a Wet season of poor flows, before entering the Magela flood plain proper. Humphrey[12] has addressed the potential impacts of the proposed mine on the ecosystems of the KNP in the Magela catchment. He has provided a general description of the creeks potentially affected by the mine along with a discussion of their ecology in the Wet and Dry seasons.

Extensive invertebrate sampling has been carried out by ***eriss***, ERAES and consultants in the Magela Creek catchment using standard protocols complementary to those used for Australian river health monitoring[13] and allied techniques to monitor possible impacts from the Ranger Mine. Similarly surveys for fish[14] and other vertebrates[15] have been carried out. It should be noted that because of large differences in organic matter inputs from catchments and in flow regimes the distributions and abundances of Australian aquatic macro-invertebrates differs markedly from those in northern hemisphere streams[16]. The aquatic fauna of the Magela flood plain are well known, as are the biology and ecology of the species (see recent data summaries and references in ref 5).

The ecology of the aquatic fauna are largely determined by the seasonal changes in the climate and hydrology. During the Dry season aquatic fauna are restricted to billabongs, small remaining water holes or permanent head water streams which flow from the escarpment. When flows of water return in the Wet there is a migration of fish up stream and down stream from the water holes and of invertebrates down stream from head waters. There is thus a strong dependence on Wet season flows by species such as Rainbow fish which are common throughout and occur in the Swift Creek catchment. Other than through changes in water chemistry (noted above) it is not expected that the contained Jabiluka site will impact on seasonal migrations of aquatic organisms through the catchments.

There appear to be some organisms (isopods and macro-crustaceans) that have restricted distributions in head waters during the Dry season but at present there do not appear to be any that are likely to be impacted by the development of the mine (ref 12). Aquatic fauna that take refuge in billabongs during the Dry season are widely distributed across the Top End of Australia and appear to be adapted to high rates of dispersal in these environments.

The aquatic flora of the Magela floodplain has also been surveyed extensively[17] and the status of introduced alien species has also been documented[18]. There are potentially large impacts on KNP from *Mimosa*, *Salvinia* and Para grass on the flood plains.

The impact of the Ranger mine on the aquatic ecosystems of the Magela flood plain has been studied for more than twenty years. ***eriss*** has been responsible for an extended series of monitoring programs. No impacts from the Ranger mine have been demonstrated during this period.

Terrestrial ecology

The terrestrial fauna and flora of the Swift and Magela catchments are also reasonably well known (although access to some areas has been restricted by the Aboriginal owners) and surveys have been carried out for most major groups (ref 5). Some additional work needs to be carried out on some groups in certain areas. Vegetation surveys have defined the major floristic units and the conservation status of the flora is known fairly well[19]. Specific surveys of the Jabiluka site have been carried out by ERAES (ref 5) and earlier surveys are discussed in Morley[20].

Humphrey (ref 12) and ERAES (ref 5) have addressed potential impacts of the proposed mine on the terrestrial ecosystems of the Magela catchment. While the catchment contains a number of threatened species there do not appear to be any directly affected by the proposed development and the mine site does not lie in any significant migration route or other ecologically significant area. ERAES (ref 5) and Corbett [21] have attempted to take a whole of ecosystem approach to the impacts of the Ranger mine, looking not just for possible impacts on single species but also potential system wide impacts across functional groups and trophic interactions.

Humphrey (ref 12) has examined the potential impacts of the road to the site on migration pathways and as a direct cause of death (road kills). Both aspects of the road are the subject of regulation and management plans. The management plans for the proposed Jabiluka mine also include plans to control dust and other atmospheric impacts. Fire and weed management plans are also in place both on site and along the road to the site.

Conclusions

(1) While a formal risk assessment of the type proposed by the panel had not yet been carried out by ***eriss*** or ERAES, this appears to have been because of the long association of the science community with the region, the familiarity of the scientists concerned with the

extensive ecological, physical and chemical data sets that have been collected over the years, and the continuous assessment of the impact of the Ranger mine for the past twenty years. My discussions with ***eriss*** staff during a visit to the site and written comments provided in answer to other recommendations (eg ISP recommendation 7) show that many aspects of risk and exposure had already been assessed, albeit not in a formal way. Twenty years of research and monitoring has led the scientific community in the region to the conclusion that the dominant risk is likely to arise from physical and chemical exposure in the surface water environment.

(2) Many of the issues arising in an ecological risk assessment process had been identified and assessed at the EIS and PER stage although not addressed in the holistic and quantitative manner required in a formal ecological risk assessment. These included assessments of the possible impact of the proposed haul road on fish migration, terrestrial animal pathways etc and specific recommendations had been made by the Environment Minister to deal with these issues.

(3) As stated in the introduction, the present paper does not constitute a full ecological risk assessment; rather it is an assessment of the dominant processes which have structured the present landscape and ecosystems and an assessment of possible ways in which the Jabiluka mine could impact upon these processes. The conclusion reached in this assessment is that the most significant possible effect arising from construction of the mine and mill at Jabiluka is the probable increase in the suspended solid load in Swift Creek arising from the presence of the sandstone waste rock dump in the catchment. It is reassuring that this issue was clearly identified by the Supervising Scientist in his submission on the PER and that this resulted in a specific requirement that ERA manage this issue in a manner that will avoid impact on the values of Kakadu National Park.

(4) Other risks to the natural World Heritage values of KNP would appear to be small.

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