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Development of biological monitoring programs used to assess mining impact in the ARR: A report to the Alligator Rivers Region Technical Committee, December 1997

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In 1987, the ***eriss*** established a program of research to develop biological monitoring programs that would be used to assess the impact of mining upon aquatic ecosystems of the ARR. The objective of this briefing paper is to summarise progress made in developing this program since its inception. In particular, the paper describes and summarises (i) past efforts to develop biological monitoring programs, (ii) progress made to date, and (iii) further research needs and future monitoring roles that ***eriss*** proposes to carry out in the short-term (next 3 years). It is intended that the proposals outlined in (iii) be refined in the ensuing 6-7 month period following feedback and endorsement from ARRTC members.

It is important to recognise that the ***eriss***'s biological monitoring program does not include an assessment of the impact upon people and ecosystems of radionuclides associated with U mining and milling in the ARR. These issues were the subject of a previous review paper 'Radiological protection research in the Alligator Rivers Region' presented to ARRTC in December 1995.

1 Review of past studies

1.1 Rationale, objectives and key elements to include in biological monitoring programs used to assess mining impact

1.1.1 Rationale

At the inception of the extensive programs of environmental research conducted by the ***eriss*** and its consultants in 1978, it was recognised that the major potential impact of mining operations in the Alligator Rivers Region would arise from the dispersion of contaminated mine waste-waters to surface waters. Thus a large part of the research program of the ***eriss*** has focused on development of techniques, particularly those incorporating biological indicators, that would be used to monitor and assess such impact. Use of biological monitoring techniques to assess impact upon aquatic ecosystems follows the pattern now well established worldwide, including Australia, in recognising that only studies conducted on aquatic organisms can define or be used to assess the overall effect of waste-waters on the biota of these ecosystems. As with environmental monitoring programs developed elsewhere, however, there is also the recognition that chemical and biological monitoring programs are *both* necessary to most effectively assess the extent and importance to ecosystems of any impact.

In this report, reference to any Ranger mine 'waste waters' that, up to the present, are dispersed to the environment, is overwhelmingly in relation to runoff from waste rock dumps, as opposed to waters that have been in contact with uranium in the Restricted Release Zone.

An integral part of the assurance to Government of the highest standards of environmental protection afforded to ecosystems of the ARR, has been the development at the ***eriss*** of a two-fold approach to the biological assessment of effects that could result from dispersion of mine waste-waters to the environment. The elements include a regime of pre-release toxicity testing and a field program of biological monitoring.

1.1.2 Environmental protection objective

Given the high conservation values of the ARR, successive Supervising Scientists have sought to develop a monitoring program that is sufficiently comprehensive and sensitive that if no effects were observed amongst the responses measured, it would be regarded by environmental scientists generally, that the environment had been sufficiently protected. (The adequacy of the program developed to 1993 was assessed by an external review panel of expert environmental scientists at a workshop held in September of that year - see section 1.2.2 below.) Up to 1993 at least, the monitoring program was to be used to demonstrate the adequacy of regulatory measures (toxicity testing and chemical standards) in meeting the overall environmental protection objective, ie *no observable effects* upon the organisms investigated in such a monitoring program. Background to the formulation of this objective (or more correctly, 'target') is provided in Appendix 1.

It is worth noting that since pronouncement by the Supervising Scientist in the late 1980s of the aforementioned environmental protection objective for the ARR, little progress has been made in reaching consensus amongst stakeholders in the Region of its appropriateness - or of alternative objectives proposed since. Whilst it is outside the scope of this paper to provide a full treatise on the issue of appropriate environmental protection objectives for the ARR, it is sufficient to add that determination of suitable objectives and criteria is essential for researchers whose task it is to develop monitoring programs of a sensitivity sufficient to meet the criteria. Hence, this issue is raised at a number of stages of this document, highlighting recent developments on this issue reached at a national level and possible ways forward in negotiating agreement on the issue for mining in the ARR.

1.1.3 Key elements to include in a biological monitoring program conducted in the ARR

Biological assessment objectives

There are two important needs to be met in biological monitoring programs developed for the ARR:

- *Early detection* ('warning') of possible effects is an essential element of any water quality management program. Pre-emptive or preventative information is required so that substantial and ecologically important impacts are avoided.
- Often it is not sufficient simply to have 'detected' change in an 'early detection' indicator for the reason that such information cannot easily be linked (if at all) to effects at the population, community and/or ecosystem level. To determine effects upon the ecosystem as a whole - or the *ecological importance of effects* that are observed - measurement of ecosystem surrogates is usually required. Typically these surrogates are communities or assemblages of organisms, or habitat or keystone-species indicators where these have been closely linked to ecosystem-level effects. Information on the ecological importance of effects is best met in programs that have regional coverage and that encompass a full disturbance gradient (see Appendix 2), ie programs that can provide some context to the gathered data. Sampling of aquatic populations and communities is typically conducted at much less frequent intervals (- once per year in Magela Ck -) than measurement of early detection responses (- several observations per Wet season). As a consequence, a period of several years may be required to accrue sufficient baseline data on populations and communities.

Early detection. For Magela Creek, early detection indicators have been developed to detect effects both in the water column of the sand channels near Ranger and at depositional sites (eg sediment of the upper floodplain). Creekside monitoring is a procedure used to detect effects in the water column by measuring sublethal responses of organisms exposed to creek waters pumped up to creekside shelters in the Wet season. Responses of test organisms are measured at two sites, one located upstream of Ranger and the other several kilometres downstream. For early detection of effects at depositional sites, two approaches are being adopted, (i) measurement of elemental concentrations in the tissues of long-lived organisms resident at these sites (eg mussels and fish), and (ii), toxicological assessment of sediment to sediment-dwelling species (under development). For either water column or sediment effects, location of sampling sites for any measured response in 'mixing zones'/ or in suitable water bodies located on the mine site itself – effectively creating spatial disturbance gradients – will also enhance early detection and predictive capabilities.

Effects of ecological importance. Studies of natural populations and communities of aquatic organisms can most usefully provide information about the ecological importance of impact. As surrogates for ecosystem-level effects, inclusion of more or less discrete assemblages or communities of organisms in biological monitoring programs is particularly useful. There are a number of advantages to the community approach, including the potentially wide range of sensitivities to toxicants that such study offers and the need for such study wherever there is concern for the conservation of diversity in the ecosystem.

Selection of monitoring organisms, geographical coverage and timing of sampling
In the ***eriss*** monitoring program, fully aquatic organisms (or life stages of organisms) have been selected for monitoring, it being accepted generally that these are the groups that are most at risk from the release of contaminants to aquatic ecosystems. Macroinvertebrate and fish communities, or representative species therein, have been selected for study in the ARR. These groups have been shown in biological assessment programs conducted elsewhere to be particularly sensitive to mine-related disturbances. Macroinvertebrate communities are the most popular group of organism used for biological monitoring in Australia and abroad whilst the high public profile of fishes is a particularly important attribute governing their selection in monitoring programs. Further discussion and rationale behind the selection of these groups for biological monitoring in the ARR is provided in section 3.2 below.

Up to 1993, all monitoring techniques being developed for the Ranger mine were restricted to the catchment of Magela Creek. For studies in Magela Creek, all parties involved in the management of mine discharges had agreed that creek waters downstream of the gauging station GS8210009, located several kilometres downstream of Ranger, constituted the 'receiving' water in which 'observable impacts' upon aquatic organisms should be absent. It is convenient that apart from naturally-occurring changes, water quality upstream of this point is otherwise influenced by mining activities alone. (Thus, unlike a number of billabongs included in the monitoring program, anthropogenic changes at the GS0009 site are not confounded by effects arising from Jabiru township.)

Creekside monitoring in Magela Creek is conducted within the 6-7 month period of flow in the creek adjacent to Ranger. Sampling of natural populations and communities is generally conducted annually in late April - early May (the Wet-Dry season transition period); at this time accessibility is enhanced and sampling easily conducted, water clarity is high (a factor important in fish monitoring), measured responses represent the summation of effects of mine waters released during the preceding Wet season, and abundances and taxa richness are generally high.

*Elements of the **eriss** biological monitoring program, pre-1993 (Workshop)*
Prior to the external review of the ***eriss*** biological monitoring program that was held in 1993, active development of the following techniques was underway in the program for the Ranger mine (Magela Creek):

Early detection

- Creekside monitoring using freshwater snails and larval fishes;
- Bioaccumulation in long-lived organisms (mussels and fishes).

Studies of natural populations and communities

- Macroinvertebrate communities in the seasonally-flowing portion of Magela Creek;
- Fish communities in billabongs;
- Fish migration in the seasonally-flowing portion of Magela Creek.

1.2 Key developments in biological monitoring approaches applied in the ARR

1.2.1 Monitoring vs research

The ***eriss***'s objectives for its sub-program of research on biological monitoring have always been documented explicitly in terms of technique development (ie a research role). At the inception of the ***eriss*** monitoring program in 1987, the development of biological assessment techniques both in Australia and abroad was in its infancy though enormous advances have been made worldwide in the intervening period. As might be expected, the process of developing and refining suitable approaches for biological monitoring in Magela Creek has involved the testing of different hypotheses and trialing of different techniques. Hence, the period since 1987 has represented a developmental rather than routine monitoring phase for this sub-program. Despite this, very valuable data have accrued in this time from which conclusions have been drawn about the extent and degree of mining impact in Magela Creek - see section 2.4 below. Some of the problems in acquiring repeatable samples and continuous routine monitoring data from the early 1980s to the present in Magela Creek, are described in the following section.

1.2.2 Refinements made to the monitoring program

Refinement and changes in approach have been required since inception of the monitoring program in 1987, thus:

(i) *Changes required as a consequence of environmental change unrelated to mining.* Changes to the monitoring design and methodology of fish studies in shallow lowland billabongs have been required as a consequence of environmental change in the billabongs. (In particular, increased aquatic plant growth, associated with buffalo removal, has changed the structure of fish communities in these sites.)

(ii) *Peer review - 1993 Workshop and key recommendations.* Exemplifying the developmental aspect of past and current work, an external review of the program conducted in 1993 in the form of a workshop, recommended changes to the study design from 1994 onward, in line with then-current, 'best practice' in biological monitoring research. Amongst the recommendations were included:

- The addition of control sites from other adjacent streams to the design of studies of aquatic communities. These additional controls would increase statistical inferences and provide a sounder basis for assessing the ecological importance of any impact observed downstream of the Ranger mine. (As outlined in the Jabiluka EIS, ERA is also committed to the inclusion of independent control sites from outside of Magela Creek in the design of monitoring programs proposed for Ranger and Jabiluka.)

- Rapid assessment approaches to monitoring studies using macroinvertebrate communities should be considered for ARR programs.

- The need to conduct additional ecological studies to underpin/ justify approaches being adopted in the monitoring program.

Following the 1993 Workshop, these recommendations were assessed and in most cases, implemented in studies conducted from 1994 onwards.

2 Current status of biological monitoring programs

2.1 Environmental protection objective

It is convenient at this point in time to assess the appropriateness or otherwise of the former Supervising Scientist's environmental protection (EP) objective/ target of 'no observable impact' for ARR ecosystems, as measured in a comprehensive and sensitive monitoring program. 'Best practice' in determining and prescribing EP objectives for a number of 'ecosystem conditions' (grading from pristine to highly modified) is described in the current draft of the National Water Quality Management Strategy (NWQMS) Water Quality Guidelines. EP objectives are negotiated, *a priori*, and in a spirit of cooperation, viz a number of key *decision criteria*. The criteria are critical to establishing the level of change that needs to be detected and the statistical sensitivity with which a monitoring program is able to detect that change. Thus, the criteria are (i) effect size or a level of (acceptable) change; (ii) α, the probability of falsely rejecting the null hypothesis of no impact; and (iii) β, the probability of failing to detect a real impact.

For highly-valued ecosystems (eg of high conservation value), responsiveness to 'early change' is emphasised in the draft NWQMS Guidelines (even though links between such observed effects and change of ecological importance may not have been, or cannot be, established). Thus, as applied to the ARR, the approach is a precautionary one that acknowledges our present inability to predict the consequences of enhanced concentrations of mine waste waters in the receiving waters (episodic or sustained) upon ecosystems as a whole.

The decision criteria recommended in the draft NWQMS Guidelines that would be appropriate to apply in monitoring programs conducted in the ARR (ie highly-valued ecosystems) are conservative ones (ie effect size of 10% or 1 SD about baseline mean, and $\alpha = \beta = 10\%$) in meeting the need for early detection and responsiveness. It is worth noting that the statistical design associated with measurement of creekside monitoring responses in Magela Creek is a particularly sensitive one and meets these criteria.

Since 1993, the Supervising Scientist Group has been working towards refinement of environmental protection objectives for mining at Ranger, and has now couched these in the framework of two ESD principles that are directly relevant to ecosystem protection: (i) the precautionary principle, and (ii) the conservation and maintenance of biological diversity. Whilst the former Supervising Scientist's phrase of 'no observable effects' is no longer used in the definition of EP objectives for the Ranger mine, it is worth noting that this target is, nevertheless, highly compatible with both the draft NWQMS Guidelines philosophy and recommendations, and the two ESD principles used in the SSG's current working definition. (An appraisal of other issues associated with determining a level of acceptable impact is discussed further in Appendix 2.)

2.2 Early detection of change

Creekside monitoring approaches for detecting effects arising in the water column have been successfully developed. A period of technology transfer has occurred between ***eriss*** and ERA and the company is now in a position to conduct tests independently of ***eriss***.

Elemental concentrations in tissues and organs of aquatic organisms is one approach advocated for the early detection of effects arising at depositional zones of Magela Creek (in particular, sediments of upper floodplain). Baseline data on the metal content of freshwater mussels are available and more limited data on freshwater fishes. In general, development of protocols for the early-detection of sediment toxicity using field assessment procedures is at an early stage in Australia and elsewhere. The draft NWQMS Guidelines recommend a laboratory-assessment approach to this problem. For this, a potentially-contaminated sediment from the field is brought back to the laboratory and standard sediment toxicity tests conducted to determine its toxicity. A suitable uncontaminated sediment is also tested as a reference (ie collected from an adjacent control site or prior to impact from the same site). The ***eriss*** is currently developing a sediment toxicity test that could serve this role.

2.3 Studies of natural populations and communities

2.3.1 Macroinvertebrate studies

Studies in seasonally-flowing portion of streams

Various refinements have been made to the monitoring study using macroinvertebrate communities in the seasonally-flowing portion of Magela Creek. These changes were made either in response to recommendations of program reviewers or from internal review. A summary of the changes to methods and design is provided in Appendix 3.

Studies in billabongs (or 'lentic' waterbodies)

In 1995 and 1996, ***eriss*** sampled macroinvertebrates from a number of billabongs or lentic waterbodies in Magela and Nourlangie creek catchments. A number of the waterbodies occurred on the Ranger mine site. Rapid assessment techniques were applied to sample collection and processing. An objective of the studies was to determine whether macroinvertebrate communities of waterbodies receiving waste waters directly from Ranger were affected by exposure to these waste waters (see section 2.4).

2.3.2 Fish studies

Fish migration

A significant phenomenon that occurs in Magela Creek (- and in no other adjacent stream to the same magnitude -) in the mid to late Wet season is the migration of large numbers of small-growing fish species from the floodplain to permanent refuge sites upstream. Regular counts of fish migrating past the Ranger release pipe have been made each Wet season since 1983, with a view to determining whether or not it might be possible to develop a technique that would enable mining-related changes to the magnitude and pattern of migration to be detected, quantified and assessed. A major inherent weakness of this study has been the lack of spatial controls (ie sites in other adjacent streams) that would be used to make strong inferences about possible mine-related effects upon fish migration. Such controls have been sought but with very limited success. As a consequence, the approach to developing a monitoring technique has been to acquire a relatively long time series of data so that relationships between temporal patterns of migrating fish, and natural environmental factors (in particular, discharge patterns) might be established. Significant positive relationships have been found between December discharge (= determining how early Magela floodplain, the nursery ground for the fish species concerned, fills with water) and numbers of fish moving out of the floodplain later in the Wet season.

Studies in billabongs

Studies in two types of billabong have been conducted in Magela Creek, lowland shallow billabongs (mostly backflow type) and the deeper channel billabongs. As with macroinvertebrate studies, various refinements have been made to the billabong fish monitoring studies in Magela Creek. A summary of the changes to methods and design of studies conducted in billabongs is provided in Appendix 3.

2.4 Have communities of aquatic organisms in Magela Creek changed as a consequence of Ranger mine waste water releases?

Up until 1995, detection and assessment of possible impact arising from mine waste waters dispersed to Magela Creek from Ranger had relied upon results of measurement of short-term, early detection responses in the vicinity of Ranger during the Wet season. Only very localised adverse effects were observed and reported, these being in association with RP4 water releases conducted in March 1985.

As described above, ***eriss*** sampled macroinvertebrates from a number of billabongs or lentic waterbodies in Magela and Nourlangie creek catchments in 1995 and 1996. The objective of the studies was to determine whether macroinvertebrate communities of waterbodies receiving waste waters directly from Ranger were affected by exposure to these waters. Results of the studies indicated mining-related changes to macroinvertebrate communities of waterbodies receiving waste waters directly from Ranger in 1995, but much reduced effects in 1996. Differences in community responses between years appeared to be related to differences in degree of exposure to mine waters in the two years: greater quantities of mine waters were dispersed to the environment in 1995 compared to 1996. The degree of impact observed in 1995 was not regarded as particularly severe. Thus, whilst community structure of macroinvertebrates of a few waterbodies in the vicinity of Ranger was altered, taxa number was only slightly reduced in these waterbodies. As with earlier (1985) observations, any effects were of a localised nature, being restricted to waterbodies on site and immediately downstream of retention ponds.

In 1996, ***eriss*** prepared a report for submission to the Senate Inquiry into the mining and milling of uranium in Australia. This report was to include an assessment of impacts, if any, upon the environment surrounding the Ranger project as a result of uranium mining. For this purpose, creekside monitoring data, billabong fish data and data from a limited number of samples arising from the macroinvertebrate study conducted in the seasonally-flowing portion of Magela Creek, were analysed in order to draw preliminary conclusions about the effects of the Ranger Mine on aquatic ecosystems of Magela Creek.

The creekside monitoring data set is characterised by potential to detect small changes in the measured responses with high statistical confidence. There was no evidence in the creekside data of any mining-related effects in the period 1991 to 1996. The pattern of fish community structure in lowland, shallow billabongs was found to be very similar to that observed in 1978-79, ie essentially unchanged since mining commenced. Inferences that could be drawn from the macroinvertebrate study conducted in the seasonally-flowing stream channels were reduced as a consequence of the limited number of samples processed at the time of the request, and changes to methods and the design of the study over the period 1987 to the present (Appendix 3). Nevertheless, there was no evidence from the data analysed of any mining-related changes to macroinvertebrate communities. Thus, the pattern of macroinvertebrate community structure was similar amongst years (1988-1996) at sites upstream and downstream of Ranger, with variation amongst years in community structure being greater than that observed between the two sites.

3 Future directions

3.1 Demonstration program of biological monitoring

In June 1997, ***eriss*** conducted a mini-review of its biological monitoring program to (i) assess developments and progress made since the major workshop review of 1993, and (ii) determine future directions in the program. (Hereafter, this review is termed, the '1997 Review'.) Views of ***eriss*** staff members together with those of an external reviewer, Dr Jenny Davis of Murdoch University (WA), were used in formulating an approach to future research and monitoring, as summarised below. A number of outcomes were provided by the review; the most significant of these to concern ARRTC as this stage, include:

1. The period of development and refinement of methods for biological monitoring is very near completion. Protocols should be prepared for these techniques as a priority task. It is timely that ***eriss*** now enters a period of program implementation, in which core elements serve as demonstration projects that would eventually be handed over to ERA.
2. ARRTC should be engaged as a stakeholder group to provide specific feedback on the ***eriss*** monitoring research and demonstration programs, including advice on adoption of the latter by industry and other agencies. Consideration would be required here on the extent of check monitoring performed and agency responsibilities in this regard.
3. As a short-term priority need, and in line with the draft NWQMS Water Quality Guidelines, there is a need for stakeholders to negotiate suitable environmental protection objectives for the ARR and for these to be ratified.

The SSG is the logical agency to coordinate the process associated with issue (3) above.

In the 1997 Review, it was noted that creekside monitoring techniques for early detection were most advanced in terms of completion (including protocol write-up) and adoption by industry. The latter phase has been preceded by a two-year period of technology transfer between ***eriss*** and ERA. In view of this, the main emphasis in the demonstration program is in conducting macroinvertebrate and fish community studies, as described above (section 2.3). The main elements in the design, sampling and sample processing for these future studies are outlined in Appendix 3. It is anticipated that fish migration counts at one site in Magela Creek would continue for another Wet season to corroborate results found to date. A possible component of the demonstration program not yet confirmed, is the inclusion of macroinvertebrate studies in billabongs. Data from these sites, some of which are located in close proximity to Ranger, could provide important pre-emptive and early warning information relevant to sites off the Ranger lease. Billabong studies are discussed further in section 3.2 below.

It is anticipated that the demonstration program would be implemented during the 1997-98 Wet season, with draft and final protocols prepared by April/May. Supportive documentation would be prepared during 1998.

3.2 Interdependence of the *eriss* biological monitoring program and that proposed by ERA

In the monitoring programs proposed by ERA for use in assessing impact of uranium mining at Ranger and Jabiluka, a considerable emphasis has been placed on a 'whole-ecosystem' approach that measures about 10 major "trophic groups", and linkages between these, associated with natural and artificial waterbodies. According to ERA, it is appropriate to develop a monitoring program that focuses on a whole-ecosystem approach in order "to help understand ecological processes and relationships between living and non-living components." (Jabiluka EIS supplement to draft). In a report prepared for ERA, Corbett (1996) elaborates further on the approach, emphasising its holistic nature and its ability to allow "insight into ecological concepts such as interconnectivity of trophic levels, food webs, minimum viable populations and the conservation of habitats vs species."

The whole-ecosystem approach to biological monitoring contrasts with that developed by ***eriss*** for aquatic ecosystems of the ARR. The approach by ***eriss*** acknowledges that there are never sufficient resources to measure 'everything' and nor is this necessary in terms of measuring change *per se*. Rather, the ***eriss*** approach, in common with that adopted elsewhere in biological monitoring, is to select limited assemblages of organisms shown from previous studies to be sensitive to the contaminants of concern, to act as surrogates of ecosystem 'health'.

The whole-ecosystem approach as outlined by Corbett (1996) has a number of strengths, such as inclusion of: (i) "species" that respond quickly and directly to mine impacts (eg invertebrates); (ii) highly visible and utilised species such as frogs and waterbirds that are *perceived* (rightly or wrongly) to be generally good indicators of ecosystem health; and (iii) in the study design, a number of control sites from adjacent catchments.

Potential deficiencies of the approach as perceived by ***eriss*** include: (i) sampling of redundant elements insofar as demonstrating mining impact (eg waterbirds tend to be adversely affected only in cases of extremely poor water quality - after most other aquatic life has been eliminated); (ii) effort solely focused on billabongs and excluding the main channel of Magela Creek where off-site impacts would be expected to be first and most severely felt; (iii) expense, which could lead to a sampling frequency that is less than annual (L Corbett, pers comm) and removal or dilution of resources from those indicator assemblages that respond quickly and directly to mine impacts; and (iv) potential to downplay effects observed for one indicator assemblage. In the case of (iv), it could be construed, for example, that ecosystem integrity has been maintained when only one of ten assemblages/ indicator groups is affected by mine waste waters; this judgment would be inappropriate given the conservation values to be upheld in the World Heritage ecosystems of Kakadu National Park. Other perceived deficiencies of the approach are described in Appendix 4.

The ***eriss*** sees compatibility between the whole ecosystem approach advocated by ERA and its own monitoring program, providing ERA also includes in its program sites in the main channel of Magela Creek (and corresponding controls in adjacent catchments) and a commitment to sample macroinvertebrate and fish communities at all sites on an annual basis - at least until an adequate temporal baseline has been gathered.

A program of biological monitoring that includes creekside monitoring (at current sites), bioaccumulation in long-lived organisms, and studies of natural populations and communities of macroinvertebrates and fishes in creek channels and lentic waterbodies of Magela Creek and control catchments would be regarded as sufficient for the assessment of mining impact under the scenario of mining at Ranger and Jabiluka, and ore processing at Ranger. Sites in Swift Creek and appropriate control streams would be included in this program. ERA and ***eriss*** have held preliminary discussions to develop a suitable and, ideally, interdependent approach to baseline data collection and monitoring for the future. There is a desire by both groups to avoid any unnecessary duplication of those aspects of biological monitoring programs that are particularly resource-intensive.

3.3 Mining exploration being conducted elsewhere in the ARR

In 1997, ***eriss*** was approached by the NLC and asked to consider initiating surveys of aquatic biota in streams adjacent to sites of active mining exploration in the ARR (ie Arnhem Land). These data would contribute to an initial baseline that could prove of significant value in the event of future mining. Whilst ***eriss*** agrees that this proposal is worthwhile, additional resources would need to be set aside to undertake the work.

3.4 Nature of present and future contaminants arising from Ranger in relation to biological assessment of impact

Of the major constituents found in Ranger mine waste waters (or predicted to occur in future mine waste waters associated with milling of Jabiluka ore), U is the constituent of highest observed toxicity to aquatic organisms. (Excluded from this discussion is the issue of hazard and risk assessment associated with radionuclides.) Only under a scenario of accidental discharge of mine waste waters would concentrations of U pose a significant potential risk to aquatic organisms in the receiving waters. (Current monitoring programs are designed to detect and assess impacts arising from such incidents.) Under normal operational releases of mine waste waters to the environment, U concentrations have been, and would continue to be, at concentrations well below those at which any toxic effects could be expected in the water column.

Rather, the water quality issue associated with Ranger mine water discharges that has most potential to affect the integrity of aquatic ecosystems of Magela Creek is most likely to be that associated with increased salinity. Increasing conductivity observed in the surface waters of Ranger waterbodies and of some natural waterbodies downstream of the mine site is associated with $MgSO_4$ - a product of waste rock erosion. $MgSO_4$ is a relatively benign salt in terms of toxicity to aquatic biota though changes to the Ca:Mg ratio of waters can have adverse physiological effects upon some organisms. (This is potentially an important issue in Magela Creek whose surface waters are extremely soft.) Assemblages of aquatic organisms in waterbodies of Magela Creek in the Wet season and early Dry season have a composition and structure that reflect the natural poorly-buffered, low solute surface waters found at these sites. There is evidence that an increase in the solute concentration of these surface waters at this time can alter the composition and structure of some aquatic (macroinvertebrate) communities (section 2.4).

A challenge in future ***eriss*** research lies in acquiring better information on the effects of $MgSO_4$ upon aquatic organisms. This could be achieved through laboratory (toxicity) and field assessment programs. Field assessment approaches could utilise data from creekside monitoring (eg observations specifically sought for this purpose by drawing water from a 'mixing zone' during pipeline releases of RP4 waters), experimental manipulations by way of mesocosm studies, or billabong studies of invertebrates (see section 2.4 above). A concentration of $MgSO_4$ may be found above which the composition and structure of some aquatic communities is found to be significantly altered. This value could then be applied as a standard for the safe release of mine waste waters to Magela Creek during mining and milling, and as a goal in future rehabilitation.

4 Recommendations and issues to resolve

Based upon consideration of the above issues, it is the view of ***eriss*** that future research in biological monitoring should be allocated priorities as follows (in order of decreasing priority):

- Implementation of annual, routine monitoring under a three-year demonstration program using fish community studies in billabongs and macroinvertebrate community studies in creek channels (Magela Ck and control streams);
- Establishment of fish and macroinvertebrate community studies in Swift Ck and control streams (yet to be identified);
- Fish and freshwater mussel bioaccumulation studis in floodplain billabongs of Magela Creek;
- An additional season of data on fish migration in Magela Creek. This would complete a lengthy baseline. Thereafter, fish migration might be used as a basis for detection of impact arising from say, bridge construction or accidental and/or substantial mine water discharges (ie not necessarily annual sampling as would be conducted with the other community-based studies); and
- A sensitivity analysis study in which the responses of creekside test organisms are sought in a mixing zone arising from possible pipeline release of RP4 water
- Initiating surveys of aquatic biota in streams adjacent to sites of active mining exploration in the ARR (ie Arnhem Land).

Two other more general issues have been identified in this review that should be noted. First, in line with the draft NWQMS Water Quality Guidelines, there is a need for stakeholders to negotiate suitable environmental protection objectives and 'decision criteria' for the ARR, and for these to be ratified. Second, members of ARRTC should note that the issue of which organisation would be responsible for the conduct of check monitoring, and the manner in which this should be carried out, has yet to be determined. If ***eriss*** was to undertake such checks this would clearly have an impact on the Institute's resources.

Reference

Corbett L 1996. Aquatic studies at Ranger mine: a whole-ecosystem approach. Final Report prepared by CSIRO Div Wildlife & Ecology, Darwin, for ERA Environmental Services, Darwin.

Appendix 1:

Environmental protection objectives

The following is an excerpt from a paper prepared by A Johnston for the 'Proceedings of a Specialist Workshop to Assess the ARRRI Biological Monitoring Program', held 24 September 1993 at the University of Canberra, ACT.

Before any environmental protection regime can be established it is necessary that government's environmental protection objectives be specified in a manner that enables regulators to identify criteria against which the adequacy of environmental protection (including the protection of humans) will be judged. Similarly, these criteria are needed by research scientists whose task it is to carry out research on the effects of industrial activity on the environment with the objective of making recommendations on standards, practices and procedures to be adopted by industry for the protection of the environment.

As stated above, the Australian Government decided in 1977, following consideration of the recommendations of the RUEI, that mining and export of uranium could proceed in the ARR subject to the adoption of stringent health and environmental standards. Guidelines developed from the RUEI report were laid down by the Government and incorporated in a set of Environmental Requirements (ERs) for each mining operation in the ARR. The conditions of the ERs have been accepted by ERA in its agreement with the Government for operation on the Ranger Project Area. The full list of the ERs for the Ranger Project Area and for the uranium project at Nabarlek operated by Queensland Mines Pty Ltd (QMPL) is included in the Supervising Scientists Annual Report each year.

In addition to the restrictions imposed by the ERs, an agreement was reached in 1990 between the Commonwealth and Northern Territory Governments on the Goal and Objectives for the Rehabilitation of the Ranger Project Area. Mining companies must also comply with various codes of practice. These include the Code of Practice on Radiation Protection in the Mining and Milling of Radioactive Ores and the Code of Practice on Management of Radioactive Waste from the Mining and Milling of Radioactive Ores. The implications of these requirements on criteria for the protection of ecosystems are discussed below.

Protection of ecosystems

The ERs do not specify explicit standards for ecosystem protection. Rather, they impose limitations on practices that are designed to assist in the control of water pollution, atmospheric pollution etc, and make recommendations on the manner in which certain standards might be derived. An important requirement in this context, however, is that related to the technology to be adopted by the operator. This requires that the mine and mill be operated in accordance with Best Practicable Technology, this being defined as 'that technology....which produces the minimum environmental pollution and degradation that can reasonably be achieved having regard to....' a number of factors including best practice elsewhere in the world, cost, evidence of detriment or the lack of it, the location of the project, the age and effectiveness of equipment, and social factors.

The above definition implies that there is some finite level of pollution and degradation of the environment that should be considered reasonable and, hence, acceptable. This conclusion is supported by many of the statements of the Commissioners in the RUEI report; it is clear that some impact on the environment was expected. The problem for regulators and the Supervising Scientist has been specifying the finite level of detriment that is acceptable.

In the case of Kakadu National Park, inscribed on the World Heritage List and the Convention of Wetlands of International Importance, no responsible group in biological scientific research, Park Management or Government has been prepared to specify a level of acceptable detriment.

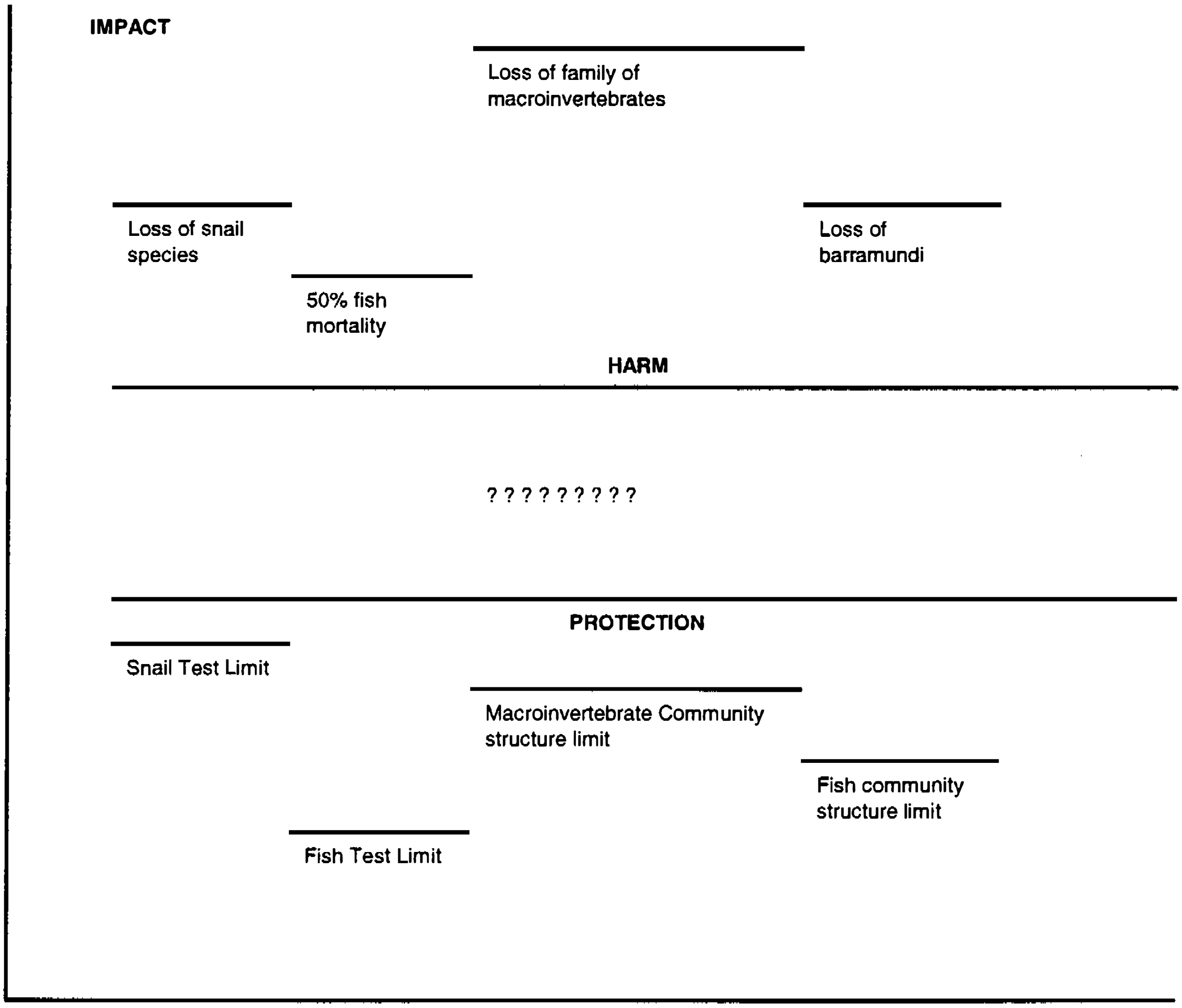

Figure 1 Illustration of possible effects, on an arbitrary scale of impact, observed in four biological monitoring programs.

The approach adopted by the Supervising Scientist has been to concentrate on the concept of 'protection' rather than 'detriment'. That is, rather than specifying an acceptable level of 'damage', he has sought control measures and monitoring methods that will ensure and demonstrate that the environment has not been harmed and will probably not be harmed by the mining and processing of ores. He has concluded that the only practical protection target for the highly valued environment of the ARR is that mining operations produce no observable biological effect in a suitably defined monitoring program comprising a number of organisms selected from different trophic levels and phyla and using a range of sensitive endpoints.

It should be noted that acceptance of this target does not imply that zero detriment to the environment is being sought, merely that no effect will be observed in a program containing a limited number of species and endpoints. To accept zero detriment (which can never be demonstrated) as an aim would be just as impracticable as seeking a definition of a finite level of detriment that would be considered acceptable.

It should also be emphasised that the above criterion is a target, not an objective. Given the conclusions of the RUEI report and the Governments decision to allow mining to proceed there must be an acceptance that harmful effects to ecosystems of the Region might occur and may not be able to be avoided. Thus, the policy of the Supervising Scientist is:

i. seek protection according to the above criterion, and

ii. if full protection cannot be achieved, take steps to minimise harm.

The Supervising Scientist is satisfied that adoption of the above policy for ecosystem protection in the ARR is consistent with the application of Best Practicable Technology to the regulation of mining operations in the Region and is consistent with the Government's policy on environmental protection.

The approach described above is illustrated in Fig. 1 where possible effects (on an arbitrary scale of impact) observed in four monitoring programs on a species of snail, a species of fish, the community structure of macroinvertebrates and the community structure of fish are illustrated. There are levels of impact that would readily be agreed to be harmful to the ecosystem; for example, complete loss of a species of freshwater snail or of a species of fish, the loss of a family of macroinvertebrates, or the occurrence of 50% mortality in a species of fish. Somewhere below these levels of impact there will be a threshold of harm that might be considered as acceptable but, as discussed above, agreement on its magnitude is not readily achievable.

For the same monitoring programs with very sensitive lower limits of detection (eg. a change in the egg production rate of snails of 10%), it is possible to obtain agreement among responsible biological scientists that if no effect were observed in such a program the environment would have been protected provided the program is sufficiently extensive. There is, therefore, a level of impact higher than these test limits that constitutes protection of the ecosystem.

What the Supervising Scientist is seeking to ensure is that mining practices are adopted in the ARR that can be demonstrated to give rise to no observed effects in an agreed sensitive program of biological measurements, and, if that cannot be achieved, to ensure that alternative mining or milling practices are examined (taking into account the factors in the BPT definition) in an attempt to minimise harmful effects.

Appendix 2:

Other approaches to determining a level of acceptable impact

A number of approaches have been recommended in the literature for determining, *a priori*, a level of acceptable impact to apply in impact assessment programs. One approach is simply to prescribe this level of change as the boundary ellipse of natural variation for similar responses measured in similar undisturbed sites.

The above approach may be extended to include, together with data from undisturbed sites, additional data that represent a gradient of disturbance in the measured response, from mild to severe. An observed 'impact' may then be assessed by relative scaling: the impact may be trivial or severe, depending upon where it lies in the gradient of disturbance.

There are a number of practical limitations, however, in using a disturbance gradient approach to determining a level of acceptable change. Thus: (i) disturbance gradients relevant to water quality must be derived for the contaminant of interest (eg metals vs organic pollution); (ii) such disturbance data are generally costly to acquire, particularly as they may only apply over a limited geographical range; and (iii) there may be dangers in applying the approach for planning and design purposes (ie *a priori*) - as opposed to assessing the degree of severity (or otherwise) of impacts that have already occurred. In the case of applying the method *a priori*, to determine a level of acceptable change to 'baseline' situations where the site of interest is in an unimpaired condition, the intention would be to allow development to proceed with a view to keeping all mine-related change below the pre-defined threshold level of change. A problem would arise if the threshold value was approached, or even reached, but the control feedback found to be lagged or worse, the dispersion of contaminants to the environment found to be irreversible (- a 'horse-has-bolted' situation).

The draft NWQMS Water Quality Guidelines provide further guidance on this issue.

Appendix 3:

Changes to methodology and design of monitoring studies in Magela Creek using natural populations and communities

Macroinvertebrate studies

Studies in seasonally-flowing portion of streams

The initial design (1.) and subsequent changes made (2. - 4.), include:

1. 1988-1993: sampling of 7-10 sites (2 upstream of Ranger, 5-8 downstream);
2. 1994: sampling of three sites only in Magela Creek (two upstream and one downstream of Ranger), and similar paired sites in 5 other control streams. Relocation of the downstream site in Magela Creek to GS0009;
3. 1995-96: as for 1994, but rapid assessment approaches used for sampling and sample processing;
4. 1997: sampling and sample processing reverted to pre-1995 traditional quantitative approaches at three Magela Creek sites.
5. 1998 onward: sampling effort at a site is being re-assessed and number of control streams will be reduced to three; sample processing as per 1997.

Fish studies in billabongs

For *lowland shallow billabongs* the sequence of refinements and changes to study design have entailed, from initial design (1.) to subsequent changes (2. - 4.):

1. 1979-86: seasonal (4) sampling of 6-14 Magela Creek billabongs in most years using gill nets (supplemented by seine nets in some years). In the latter years of this study, community structure of these billabongs changed and gill netting became inefficient, both a consequence of increases in aquatic plant density of the billabongs (and associated with buffalo removal).
2. 1987-92: different sampling methods trialed to capture fish at sites of high macrophyte density.
3. 1993: pop-netting successfully conducted in 5 Magela Creek billabongs, Wet-Dry season transition.
4. 1994-present: Control sites in another independent catchment included in the design. Pop-netting conducted in 8 Magela Creek and 2 Nourlangie Ck billabongs.

For *deeper channel billabongs* the sequence of refinements and changes to study design have entailed, from initial sampling (1.) to subsequent changes (2. - 3.):

1. 1978-79: seasonal (4) sampling of Mudginberri Billabong (Magela Creek) using gill and seine nets.
2. 1989-1993: visual observations from perspex-fronted canoe conducted in Mudginberri Billabong (Wet-Dry season transition).
3. 1994-present: Control site in another independent catchment included in the design. Visual observations conducted in Mudginberri and Sandy billabongs, the latter located in Nourlangie Ck catchment.

Appendix 4:

Critique of ERA's 'whole-ecosystem' approach for monitoring and assessing mining impact in the ARR

The dual approach adopted by Corbett (1996) of monitoring both sensitive taxa and taxa with a high public profile appears, on the surface, a reasonable and pragmatic approach to biological monitoring. ***eriss*** in the past also included in its research program a major terrestrial ecology component that concerned the possible transfer of mine-related contaminants through the food chain to higher semi-aquatic and terrestrial vertebrates. This program was later disbanded; Humphrey and Dostine (1994) review in some depth the reasons why such organisms are at little risk from mine-related contaminants - at least those hazards associated with the present Ranger mine wastes.

Aside from this issue, however, the "whole ecosystem" approach proposed by Corbett suffers from two major problems: the terminology used and its means of assessing impact.

The term "whole-ecosystem" implies the study of *all* biotic and abiotic components of an ecosystem and the dynamics of their interactions. It is rare for anyone to attempt to do this these days because of the acknowledged complexity of even very simple ecosystems and of course, the resultant cost that would be involved in studying an entire ecosystem at one site, let alone several sites. The study of Corbett (1996) did not include any examination of two major biotic components of aquatic ecosystems, the planktonic and benthic algae and the microbial communities. It involved very limited measurement of physico-chemical variables and no study of ecological processes. Consequently, although the study did involve a comprehensive survey of the composition of most of the remaining aquatic biota and terrestrial biota of the riparian zone, the use of the term "whole-ecosystem" is quite misleading.

The other very confusing expression commonly applied in the Jabiluka EIS and by Corbett (1996) is the term, "trophic groups". This term is not used in any of a number of texts consulted and therefore needs to be defined more precisely than as "essential units comprising food chains". The *major trophic groups* listed by Corbett are groups of organisms classified by a mixture of taxonomic, size and spatial attributes and not by their food or feeding behaviour. The groups named are commonly-studied assemblages of organisms. However, the term "trophic" refers to food (the type of food and/or the manner of obtaining it) and, since this was not one of the attributes involved in defining the groups, the term trophic is inappropriate and misleading.

The subdivision of the *major trophic groups* into further *'trophic groups'* was based on one or more of the following: taxonomy, life form, community structure, feeding guild or feeding niche. In most cases, aspects of feeding were not considered and hence, again, use of the term trophic is inappropriate. The use of different attributes for defining different groups also makes the comparison of different kinds of groups meaningless and undermines the value of any ecological inference that can be made from them.

Corbett also maintains that the use of his "trophic" groups provides a clearer picture of differences between sites because such study does not rely on an understanding of the life history, feeding strategies or population dynamics of different species. He does not provide any supporting literature for this assertion in relation to the way he has classified his groups. The "guild" concept, which refers to groups of species that exploit the same class of environmental resources (Root 1967), was seen as a means of simplifying the number of components in a community when developing an understanding of how the communities are put together (Krebs 1978). This seems to be what Corbett has in mind. However, this is a very different goal from the detection of human impact on natural ecosystems.

Impact detection requires adequate experimental design with testable hypotheses about relevant measured attributes. The general design of Corbett's study in terms of sites and treatment appears adequate. However, in Corbett's design an impact would be shown by differences in the number of trophic groups between potentially impacted sites and control sites rather than in the array of species present as is done in most other monitoring studies. The merit of this process is apparently based on the premise that the loss of species from multispecies groups is of little consequence as long as there is at least one member of the group present. This greatly undervalues biodiversity as a conservation goal and should not be supported in a World Heritage conservation area.

The Corbett approach also pays no attention to changes in abundance of species, data easily gathered in some form in most monitoring studies. Whilst presence-absence data may be adequate for detecting many effects, it may also allow other more subtle effects to pass undetected.

The above criticisms are seen as important but they do not suggest that the basic study design is inappropriate. Rather, the terminology used should be modified and the method of data analysis and impact detection and assessment reconsidered.

References

Corbett L 1996. *Aquatic studies at Ranger mine: a whole-ecosystem approach.* Final Report prepared by CSIRO Div Wildlife & Ecology, Darwin, for ERA Environmental Services, Darwin.

Humphrey CL & Dostine P 1994. Development of biological monitoring programs to detect mining waste impacts upon aquatic ecosystems of the Alligator Rivers Region, Northern Territory, Australia. *Mitteilungen Internationalis Vereinigung Limnologiae* 24, 293–314.

Krebs CJ 1978. *Ecology: the experimental analysis of distribution and abundance.* Harper and Row, New York.

Root 1967. The niche exploitation pattern of the blue-gray gnatcatcher. *Ecol. Monogr.* 37, 317-350.