supervising scientist report **193**

eriss research summary 2005–2006

DR Jones, KG Evans
& A Webb (editors)

Australian Government
Department of the Environment and Water Resources
Supervising Scientist

It is SSD policy for reports in the SSR series to be reviewed as part of the publications process.

This Supervising Scientist Report is a summary of the 2005–2006 research program of the Environmental Research Institute of the Supervising Scientist and has been reviewed internally by senior staff and the editors of the volume.

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Preface

The Environmental Research Institute of the Supervising Scientist (***eriss***) is part of the Supervising Scientist Division (SSD) of the Australian Government's Department of Environment and Water Resources. ***eriss*** provides specialist technical advice to the Supervising Scientist, and conducts research into:

- the impact of uranium mining on the environment and people of the Alligator Rivers Region, and
- on the protection and management of tropical rivers and their associated wetlands.

The objective of the mining-related research is to develop best practice methodologies for the monitoring of impact and for the development of management guidelines to protect the environment during the operational and closure phases of mine life.

eriss also applies its expertise to carrying out a limited program of contract research on the impacts of mining elsewhere in the northern tropics.

This report documents research projects undertaken by ***eriss*** over the 2005–06 financial year. The final section contains a summary of the non-uranium mining related external projects. Commercial-in-confidence projects have been excluded from this compilation. For additional information, readers are referred to the annual publications list (Appendix 1) that details all of the material published, and conference and workshop papers presented by ***eriss*** staff in 2005–06.

The balance and strategic prioritisation of work within the uranium component of ***eriss***'s project portfolio is defined by Key Knowledge Needs (KKNs) developed by consultation between the Alligator Rivers Region Technical Committee (ARRTC – see ARRTC membership and function in Appendix 3), the Supervising Scientist, Energy Resources of Australia and other stakeholders. The KKNs comprise six thematic areas based primarily on geographic provenance (Appendix 2). The content of the research programs developed for each of these areas is assessed and reviewed annually by ARRTC in consultation with stakeholder groups (Appendix 3).

eriss contributes to the addressing of the KKNs by applying its expertise in:

- Ecotoxicology
- Environmental radioactivity
- Hydrological and geomorphic processes
- Monitoring and ecosystem protection
- Biophysical pathways and ecological risk assessment
- Aquatic chemistry

Not all of the KKN research areas are able to be covered by ***eriss***, since not all of the required disciplines are available within the Institute. To address these gaps, collaborative projects are initiated with researchers from other organisations. KKN projects related to the detailed hydrogeology or tailings management on the Ranger lease are conducted and reported separately by consultants engaged by Energy Resources of Australia Pty Ltd.

Communication between research providers is addressed by stakeholder presentations and interactions at ARRTC meetings, as well as by conduct of formal multi-stakeholder workshops, and presentations at conferences and workshops. Communication with local Indigenous people and other regional stakeholders is an integral part of the project approvals and reporting processes. A dedicated Indigenous Communications Officer is stationed at the Jabiru field station for this purpose.

The following factors provided the context for the planning and design of the 2005–06 research program:

- Mining of uranium at Ranger is expected to cease in about 2008. This will be followed by milling until about 2015 and rehabilitation is expected to be largely completed by about 2019.
- Nabarlek is decommissioned but has not reached a status where the NT Government will agree to issue a Revegetation Certificate to the mine operator. Assessment of the success of rehabilitation at Nabarlek is ongoing and is being used as an analogue for rehabilitation at Ranger.
- Jabiluka will remain in a care and maintenance condition for some years, at least until mining ceases at Ranger.
- SSD will provide ongoing assistance to Parks Australia on matters relating to the assessment and rehabilitation of the cluster of small abandoned historic uranium mines in the South Alligator River Valley.

This report has been structured under five main headings, consistent with the KKN framework:

1 Ranger – Current Operations

2 Ranger – Rehabilitation

3 Jabiluka

4 Nabarlek

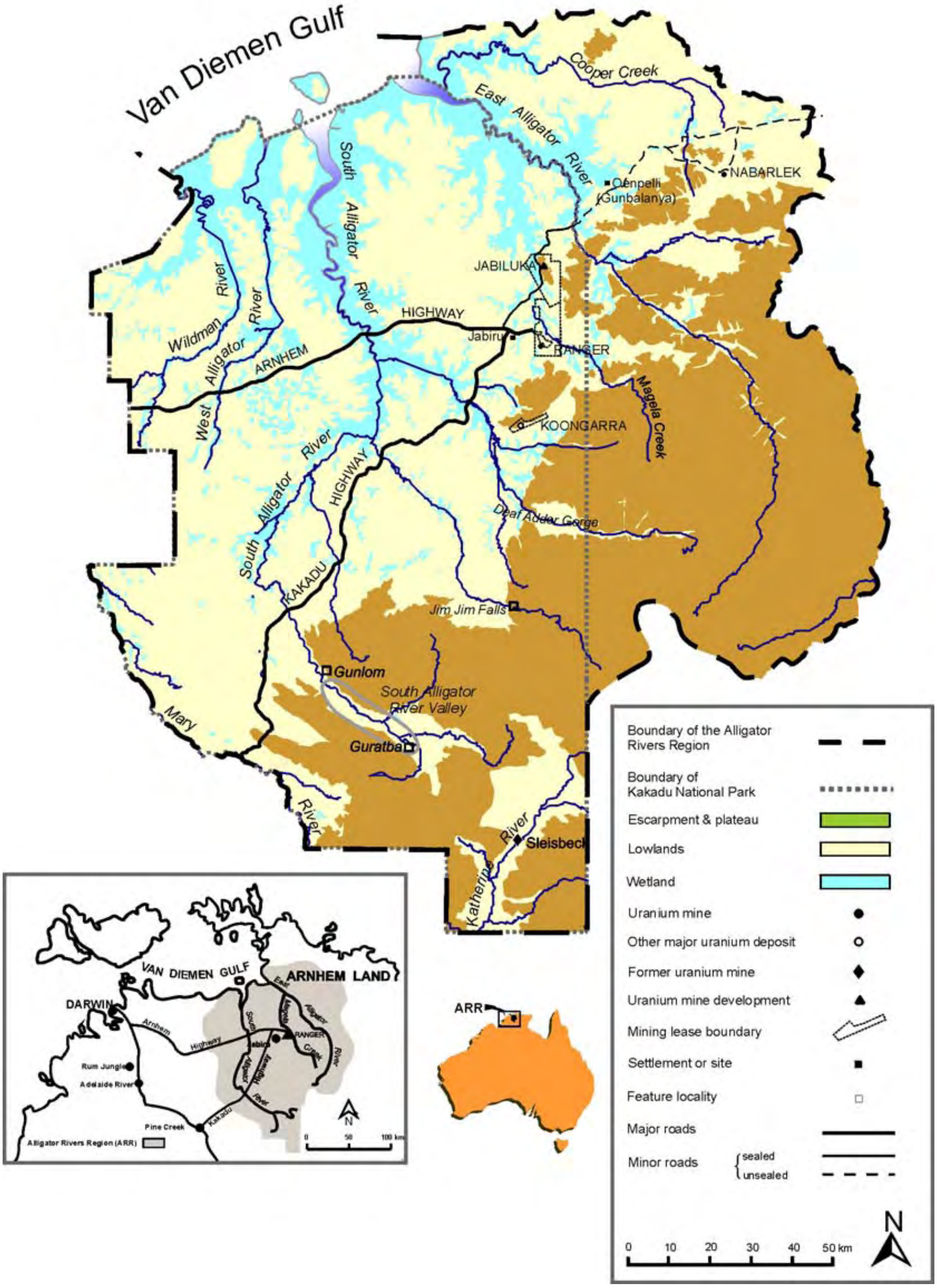
5 General Alligators Rivers Region

Three maps (following this Preface) provide the regional context for the locations that are referenced in the research papers. Map 1 shows Kakadu National Park and the locations of the Ranger Mine, Jabiluka project area, the decommissioned Nabarlek Mine, and the South Alligator River Valley. A schematic of the Ranger mine site is provided for reference in Map 2. Map 3 shows the locations of billabongs and waterbodies used for the aquatic ecosystem monitoring and research programs for assessing impacts from the Ranger Mine.

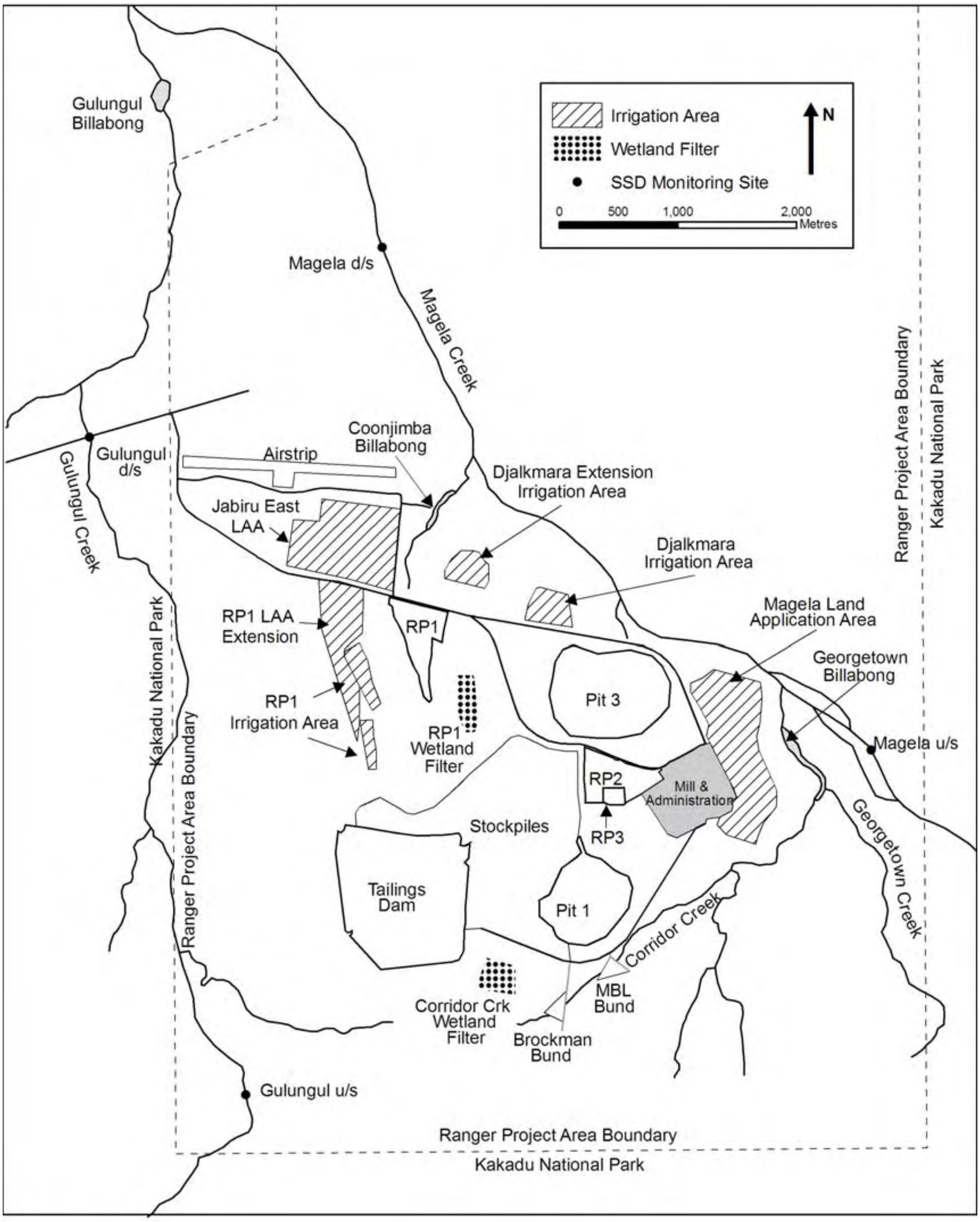
The final section of this report contains a summary of the non-uranium mining related external projects carried out in 2005–06.

Dr DR Jones

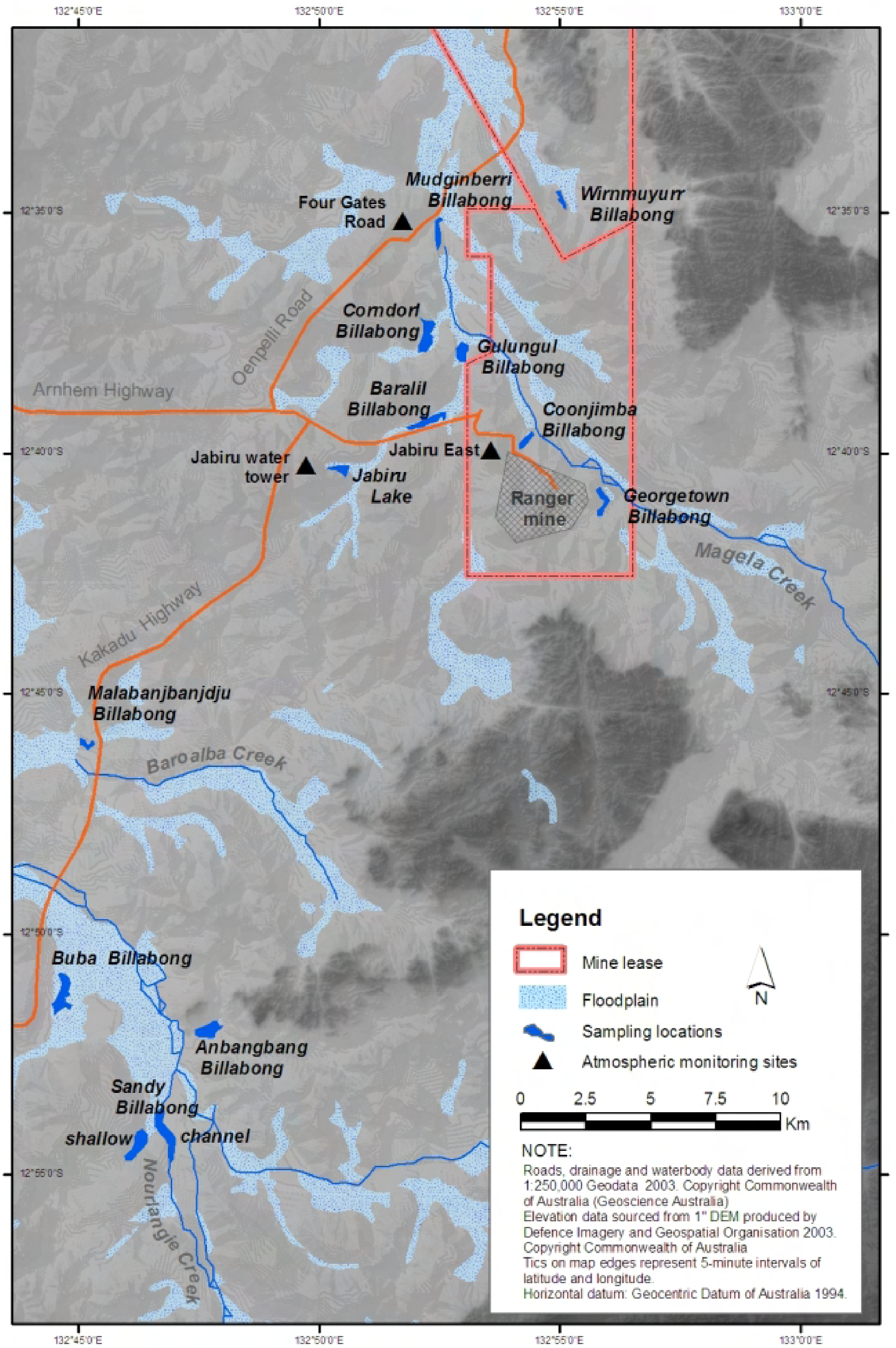
Director, Environmental Research Institute of the Supervising Scientist



Map 1 Alligator Rivers Region



Map 2 Ranger mine site



Map 3 Location of water bodies and atmospheric monitoring sites used in the SSD's environmental monitoring programs

Part 1: Ranger – current operations

Contents[1]

1.2 Ongoing operational issues

KKN 1.2.1 Ecological risks via the surface water pathway

KKN 1.2.4 Ecotoxicology

1.3 Monitoring

KKN 1.3.1 Surface water, groundwater, chemical, biological, sediment, radiological monitoring

1 List of papers grouped by Key Knowledge Need

Development of a contaminant pathways conceptual model for Ranger uranium mine

R van Dam & P Bayliss

The ARRTC Key Knowledge Need (KKN) 1.2.1 states that:

> In order to place the off-site contaminant issues at Ranger in a risk management context, a conceptual model of transport/exposure pathways should be developed. This process should include a review and assessment of the existing information on the risks of the bioaccumulation and trophic transfer (ie biomagnification) of uranium and other Ranger mining-related contaminants from all exposure pathways and including the identification of key information gaps.

This paper summarises the progress on the contaminant pathways conceptual model only. The assessment of the ecological risks via the surface water pathway was reported to ARRTC at the 16th Meeting in September 2005, and has only been briefly reported on again, in KKN 5.1 'Undertake an ecological risk assessment of Magela floodplain to differentiate mining and non-mining impacts'.

Background

A conceptual model of contaminant pathways from the operational phase of Ranger uranium mine is being developed. Progress has been documented by Finlayson and Bayliss (2003), van Dam et al (2004) and van Dam et al (2006). The primary purpose of the conceptual model is to place the off-site contaminant issues at Ranger in a risk management context. Moreover, the final product, as well as being used for formal risk assessment (see summary for ARRTC KKN 5.1.2), will serve as a communication tool for both scientists and traditional owners.

Progress

A meeting was held on 31 May 2006 between key ***eriss*** and EWL Sciences staff to discuss the technical aspects of the model. Good feedback was received and, on the whole, EWL Sciences affirmed the technical information contained within the model. Consultation with Traditional Owners to obtain their inputs on the content of the model has not progressed as far as originally planned through 2005–2006 owing to the higher priority that had to be given to initiating the consultation process for closure planning.

Given that the current model represents probably the last iteration of a conceptual model of contaminant pathways for the operational phase of the Ranger mine, and has already been verified as being technically appropriate, it could be considered more important to focus Traditional Owner consultation time on the subsequent phase of this activity. That is, developing a contaminant pathways conceptual model for the closure and rehabilitation phase of the mine.

Steps for completion

If possible and considered a priority, consultations will still be held to seek Traditional Owner views and opinions on the issues and the conceptual model itself. A number of minor revisions/amendments will be made to the conceptual model, and the surface water pathway sub-model will be refined and incorporated into a comprehensive journal publication on the Magela floodplain ecological risk assessment.

References

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Van Dam R, Finlayson M & Bayliss P 2004. Progress on the development of a conceptual model of contaminant pathways from Ranger uranium mine. Internal Report 474, June, Supervising Scientist, Darwin. Unpublished paper.

Chronic toxicity of uranium to *Lemna aequinoctialis* and *Amerianna cumingi*

R van Dam, A Hogan, M Houston, S Nou[1] & N Lee

Background

Historically, uranium has been the primary toxicant of concern for the aquatic ecosystems downstream of Ranger uranium mine (van Dam et al 2002). Consequently, many ecotoxicological studies had been undertaken for almost 20 local aquatic species, to assess the toxicity of uranium and the influence of selected environmental variables (eg pH, alkalinity, water hardness, dissolved organic carbon) on the toxicity of uranium.

However, the majority of data for these species were derived from acute toxicity rather than chronic toxicity test endpoints. The latter are required for the derivation of *high reliability* water quality guidelines (ANZECC & ARMCANZ 2000). Chronic data exist for only five of those species tested: namely the green alga, *Chlorella* sp. (72-h growth inhibition); the cladoceran, *Moinodaphnia macleayi* (3-brood reproductive inhibition); the green hydra, *Hydra viridissima* (96-h population growth inhibition); the chequered rainbowfish, *Melanotaenia splendida inornata* (7-d survival and growth); and the purple-spotted gudgeon, *Mogurnda mogurnda* (7-d exposure/7-d post-exposure survival and growth).

Based on a cumulative probability (loglogistic) distribution of no-observed-effect-concentration (NOEC) data for these five species that range from 18 to 810 µg/L, a site-specific water quality trigger value (TV) for uranium of around 6 µg/L has previously been derived (Hogan et al 2005). This value represents the concentration that should be protective of 99% of species with 50% confidence. Notably, the TV has high uncertainty surrounding it, as demonstrated by the 95% confidence limits of 0.3–103 µg/L. Moreover, two of the five species represented are fish, which appear to be generally less sensitive to uranium than invertebrate and algal species. Thus, in order to increase confidence in the site-specific TV, chronic toxicity data for additional species, ideally, representing additional taxonomic groups and trophic levels, were required.

The tropical duckweed *Lemna aequinoctialis* is a small aquatic floating macrophyte that occurs in lentic and low-flow waterbodies throughout northern Australia (Cowie et al 2000), including the Alligator Rivers Region (ARR). The freshwater snail *Amerianna cumingi* is a hermaphroditic snail that occurs in lentic and lotic waterbodies within a restricted range that encompasses the ARR (Smith 1992). Both species are of high ecological importance as food sources for other organisms and in their respective roles as a primary producer and detritivore. Toxicant effects on these species are assessed in the laboratory by observing the growth of exposed *L. aequinoctialis* and changes in the egg production of *A. cumingi* over 96 h and comparing them with individuals of the same species maintained in clean water (Riethmuller et al 2003, Houston et al 2007).

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[1] Formerly Supervising Scientist Division; now Kakadu National Park, Parks Australia North, Department of the Environment and Water Resources

Fate of uranium in test system

In order to accurately calculate exposure concentrations throughout the tests, it was essential that the fate of uranium in the test system was understood. Adsorption of uranium to the test container can reduce the uranium dissolved in the test waters and result in the organisms being exposed to a lower than expected concentration. Without quantifying this loss, the toxicity of uranium could be significantly underestimated. It is important to note that, in addition to adsorption of uranium to the test containers/tubes, losses of uranium from the test waters can also be due to uptake and accumulation by the test organisms. As the uptake of uranium by the organisms represents the exposure to uranium, the relative proportions of uranium 'lost' from the test waters due to (i) adsorption to test containers/tubes and (ii) accumulation by the test organisms need to be determined before exposure concentrations can be appropriately adjusted. To address this, uranium concentrations were measured in test waters periodically throughout each test and in the duckweed/snail tissues at the conclusion of a test.

A small but significant loss of uranium (8–18%, $P < 0.05$) was detected in the *L aequinoctialis* test system over the four day duration. Samples taken at 48 h indicated that the majority of the uranium was being lost within the first half of the test, after which uranium concentrations remained relatively stable. When integrated over a four day period (by calculating the area under the curve), these losses ranged from 6–13%, with the proportion lost positively correlated with the initial uranium concentration in the water. Plant tissue measurements indicated that uranium uptake by the plants accounted for approximately 50% of the uranium 'lost' from the test waters. As the overall 'loss' was quite small, and a significant proportion of this was shown to be taken up by the plants, it was decided that no adjustment of the exposure concentrations would be required.

A more substantial loss of uranium was observed from the test waters in the *A. cumingi* tests, with samples taken 24 h after each water change containing 30–70% less uranium than at the start of the test. Figure 1 shows an example of uranium loss for one of the uranium treatments over the 96 h test duration. Because waters are changed daily during *A. cumingi* experiments, and the loss of uranium over each 24 h period was found to be gradual and to decrease in magnitude over the duration of the test, it was essential that the final losses were integrated over each 24 h period, and then over the entire 96 h before calculating the exposure concentrations. Using data from three different experiments, and regardless of whether total or dissolved uranium concentrations were used, it was found that uranium loss over the entire test duration was approximately 25% of the uranium concentration at the start of the test.

An experiment designed to address the uptake of uranium by the snails was being conducted at the time of preparation of this summary and hence could not be reported at this stage. Therefore, the toxicity results reported below are based on uranium concentrations adjusted according to the total losses measured (ie. corrected concentration is 75% of the initial uranium concentration). Should a significant proportion of the 'lost' uranium be found to have been taken up by the snails, then the exposure concentrations will be adjusted accordingly

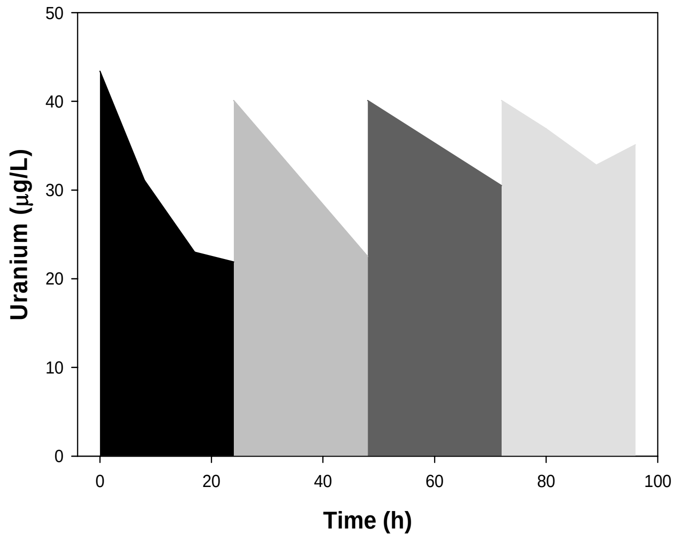

Figure 1 Loss of uranium in an *A. cumingi* test solution initially containing 43 µg/L uranium (measured). Each shaded bar represents a 24 h period between water renewals.

Toxicity of uranium to *L. aequinoctialis*

The toxicity of uranium to *L. aequinoctialis* was reported to ARRTC at the 16th Meeting in September 2005, and is summarised again here for reference. The effect of uranium exposure on the growth of *L. aequinoctialis* is shown in Figure 2. An IC_{10} (concentration resulting in a 10% inhibition of egg production) of 250 (lower/upper 95% confidence limits: 207/288) µg/L uranium was calculated from these data. The IC_{10} is generally considered to be a measure of an 'acceptable' concentration (ie. one that will not result in unacceptable ecological effects at the population level). The IC_{50} could not be calculated, but was >2850 µg/L uranium. When compared to the other local freshwater species that have been assessed for their sensitivity to uranium, *L. aequinoctialis* was found to be less sensitive than most. Only the two fish species, the northern trout gudgeon (*Mogurnda mogurnda*) and the chequered rainbowfish (*Melanotaenia splendida inornata*), have been reported to be less sensitive.

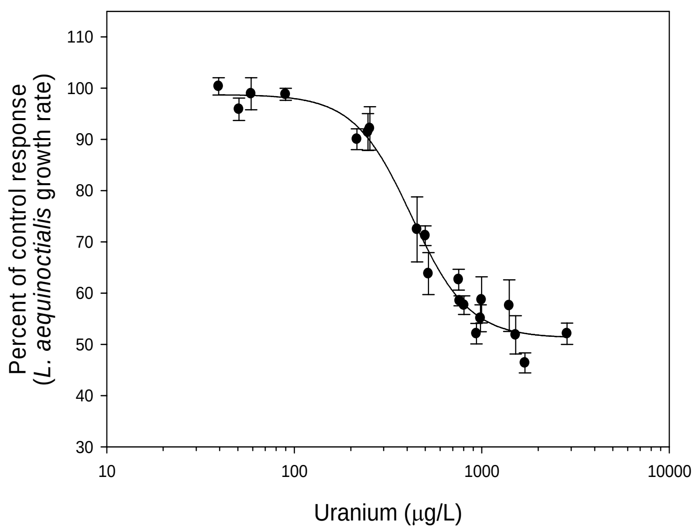

Figure 2 Effect of uranium on the growth rate of *L. aequinoctialis*, expressed as a percentage of the control response (Control growth rates for the three tests were 0.43, 0.42 and 0.45, respectively). The fitted curve represents a 4 parameter loglogistic model (r^2 = 0.98, n = 20, P<0.0001).

Toxicity of uranium to *A. cumingi*

The effect of uranium exposure to *A. cumingi* is shown in Figure 3. Based on the four definitive tests, *A. cumingi* was found to be highly sensitive to uranium, with an IC_{10} of 22 (lower/upper 95% confidence limits: 6/46) µg/L uranium and an IC_{50} of 250 µg/L uranium (an upper confidence limit could not be calculated). Based on these data, *A. cumingi* appears to be more sensitive to uranium than most other species that have been tested. Of the five species already used to derive the current uranium TV, only the water flea *Moinodaphnia macleayi* has been found to exhibit similarly high sensitivity to uranium. It is noteworthy that although the intra-treatment responses of *A. cumingi* tend to be inherently highly variable (as evidenced by the large error bars in Figure 3), the inter-test concentration-response relationships are quite consistent (and in fact were not significantly different from each other based on analysis of covariance; F = 0.563, df = 3, P = 0.647).

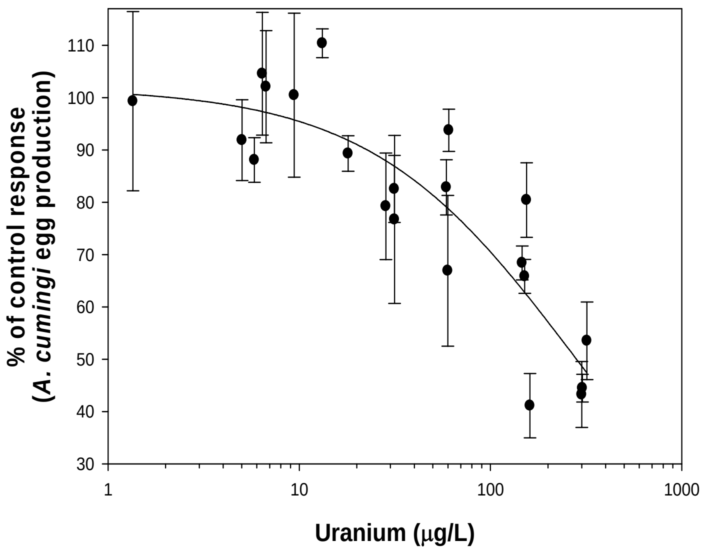

Figure 3 Effect of uranium on the egg production of *A. cumingi*, expressed as a percentage of the control response (control egg numbers for the three tests were 198, 133 and 241, respectively). The fitted curve represents a 3 parameter loglogistic model (r^2 = 0.75, n=21, P<0.0001).

Steps for completion

Analysis of the results from the snail uranium uptake experiment will be completed in 2006–2007. A further experiment to quantify the amount of uranium taken up by the lettuce fed to the snails throughout the tests will also be undertaken. The uranium exposure concentrations for the toxicity tests will be adjusted if necessary to account for losses of uranium from solution during the tests and the associated toxicity estimates recalculated. The results for both the *L. aequinoctialis* and *A. cumingi* experiments will be submitted for publication in an international journal.

A paper summarising the uranium toxicity results for *L. aequinoctialis* and *A. cumingi* has recently been presented by Alicia Hogan at the Interact 2006 conference in Perth.

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Chronic toxicity of uranium in Magela Creek water to a local freshwater fish

R van Dam, K Cheng[1], A Hogan & D Parry[1]

Background

Two of the five NOEC values currently used to derive the *high reliability* site-specific water quality limit for uranium in Magela Creek represent estimates for two fish species based on mortality after only relatively short exposure periods (Holdway 1992). The NOEC of 400 µg/L for the purple-spotted gudgeon (*Mogurnda mogurnda*) was based on a 7-d exposure/7-d post-exposure test design, while the NOEC of 810 µg/L for the chequered rainbowfish (*Melanotaenia splendida inornata*) was based on a 7-d exposure test design. Although such estimates satisfy the current ANZECC/ARMCANZ Water Quality Guidelines criterion for a 'chronic' endpoint, their appropriateness as indicators of longer-term, sub-lethal effects is highly questionable. Consequently, to increase our confidence in the uranium limit, an Honours project was initiated to investigate the sub-lethal effects of uranium on one or both of the above two fish species, over an exposure duration of 28 days.

Methods

The project was divided into several discrete parts: (i) development of an appropriate 28-d protocol (based around OECD (1998)); (ii) assessment of uranium toxicity over 28-d; and (iii) derivation of a revised uranium limit. Part 1 involved studying certain test conditions (the diet/feeding regime of the test animals and the stocking density of the test animals) in order to optimise larval growth and minimise adverse water quality impacts, and characterising the fate of uranium in the test system. Larval growth, measured as body length and wet and dry weight, was selected as the primary test endpoint.

Progress

Kim Cheng, from CDU, co-supervised by Professor David Parry, commenced the project in April 2006. Initial test development was focused on *M. mogurnda*, as this species was already established in the ***eriss*** ecotoxicology laboratory. The first experiment showed that larval *M. mogurnda* survived well on a diet of *Artemia* (brine shrimp) nauplii. A second experiment demonstrated that additions of *Artemia* over different time periods (2, 4 and 6 hours) did not significantly affect the concentration of dissolved uranium in the test waters. Unfortunately, the *M. mogurnda* broodstock ceased spawning after these initial two tests.

After several weeks with no further spawning, a decision was made to switch to chequered rainbowfish as the test species. A permit was obtained and approximately 250 adult and juvenile fish were collected from the Nourlangie Creek catchment and established as a broodstock. The broodstock spawned almost immediately, and test development re-commenced. A new set of experiments was developed, focusing on optimising the diet of

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[1] Charles Darwin University, Darwin NT.

larval rainbowfish (which typically require a more diverse diet consisting of smaller-sized food particles than larval *M. mogurnda*). The majority of work since then has focused on this aspect of the test method, with limited success. The problems resulted in substantial delays and, as a consequence, Kim switched to part-time studies.

Steps for completion

A further series of experiments was planned to assess the effect of larval stocking density on larval survival and growth, and to incorporate advice received from outside experts (Doug Holdway and Craig Humphrey) on how to improve survival and growth. If these experiments fail to improve larval survival and growth, the project will probably revert to using *M. mogurnda*, as the broodstock recommenced regular spawning in August 2006.

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Development of a reference toxicity testing program for routine toxicity test species

A Hogan, M Houston, N Lee & R van Dam

Background

Over the past three years, the ***eriss*** ecotoxicology laboratory has been developing and maintaining a regular reference toxicity testing program for the species comprising the routine toxicity testing suite. The reference toxicant being used is uranium. Reference toxicity testing during 2004–05 focused on the green alga, *Chlorella* sp., and the green hydra, *Hydra viridissima*. This summary outlines the progress made during 2005–06.

Progress

The results of the reference toxicity tests completed in 2005–06 are summarised in Table 1.

Table 1 Uranium reference toxicity test results during 2005–06 for *Chlorella* sp., *Hydra viridissima*, *Lemna aequinoctialis* and *Mogurnda mogurnda*.

Species	Endpoint	IC_{50}[1]/LC_{50}[2] (µg/L)	Test Code
Green alga (*Chlorella* sp.)	72-h cell division rate	Invalid test[3]	708G
		Invalid test[4]	712G
Green hydra (*Hydra viridissima*)	96-h population growth	75 (65–97)[5]	707B
		Invalid test[3]	717B
		79 (69–88)	719B
		83 (76–88)	725B
Duckweed *(Lemna aequinoctialis)*	96-h population growth	>854	716L
		Invalid test[3]	732L
		763 (156–1349)	739L
Northern trout gudgeon *(Mogurnda mogurnda)*	96-h sac fry survival	1785 (1604–1943)	724E

1 Concentration that causes a 50% inhibition of the test endpoint.
2 Concentration that is lethal to 50% of the test organisms (sac-fry survival test only).
3 Invalid due to poor control growth. See main text for discussion and steps to rectify this issue.
4 Invalid due to unacceptably high incubation temperature.
5 Values in parentheses represent 95% confidence intervals.

Chlorella sp.

Two reference toxicity tests were completed for *Chlorella* sp. However, both tests were invalid. At least one of these tests was affected by low control growth rates, which also compromised the tests run in 2004–05. The issue of low control growth is discussed in greater detail below.

H. viridissima

Four reference toxicity tests were completed using *H. viridissima*. One of the tests was invalid due to low control growth (refer to discussion below on low control growth). The IC_{50} values of the remaining tests did not exceed existing warning limits (ie. two standard deviations above or below the running mean; see Figure 1A) indicating a consistent experimental technique and response of the test species to uranium over time. The current running mean IC_{50} is 93 µg/L (see Figure 1A).

L. aequinoctialis

Three reference tests were completed using *L. aequinoctialis*. In the first test, the concentration range was insufficient to capture a 50% response, and the result could not be used in a control chart. The second test was invalid due to low control growth, while the third provided a valid result. It is worth noting that the two tests that met the acceptability criterion for control growth were on, or only slightly above, the minimum acceptable control growth criterion (ie an increase of at least 48 fronds over 96 h). The issue of poor control growth is discussed in greater detail below. As tests using this species only commenced in 2005–2006, there are currently insufficient data to generate a control chart (a minimum of five valid test results are required construct a control chart; Environment Canada 1990).

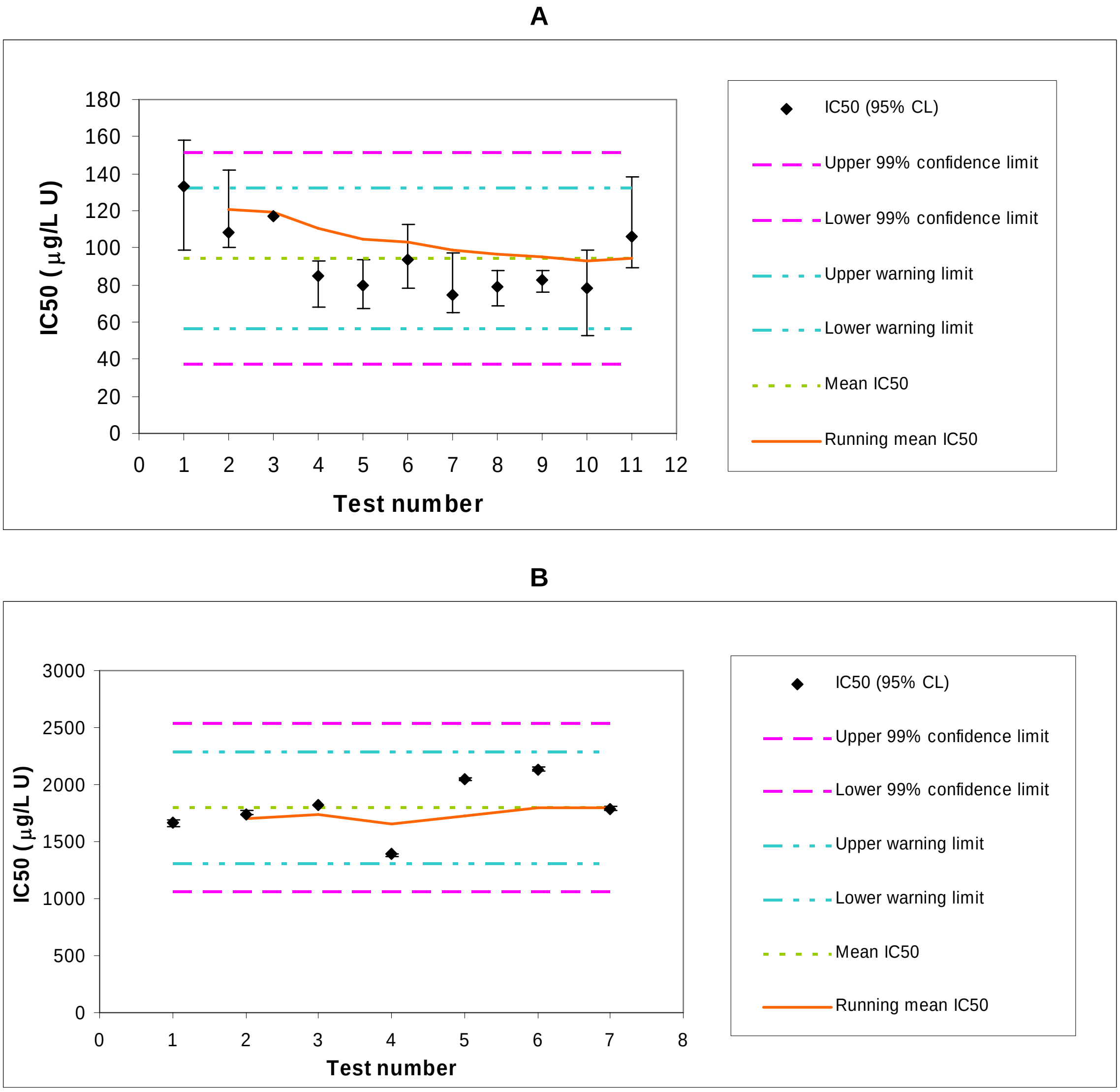

Figure 1 Reference toxicant control charts, based on uranium toxicity (IC/LC_{50}) data for (A) *Hydra viridissima* and (B) *Mogurnda mogurnda*.

M. mogurnda

One reference toxicity test was completed using *M. mogurnda*. The current control chart, based largely on historical toxicity data from Riethmuller et al (2000), is shown in Figure 1B. The current running mean IC_{50} is approximately 1800 µg/L (see Figure 1B).

Low control growth

Chlorella sp.

Low control growth was identified as a problem in algal reference toxicity tests in both 2004–05 and 2005–06. Notably, however, acceptable control growth has been consistently measured for toxicity tests using natural Magela Creek water. Analyses of the key components of the stock solutions used to prepare the synthetic softwater (SSW) testing medium used for reference toxicity tests demonstrated that all but the $NaHCO_3$ stock were within 10% of their nominal concentrations. Consequently, the $NaHCO_3$ stock was re-prepared in October 2005 to ascertain if this was the cause of the original problem. However, similarly low control growth was observed in tests undertaken after this stock was renewed. Measures taken to return the algal culture to an axenic condition in August 2005 also resulted in little or no improvement in algal growth in synthetic softwater.

Laboratory staff had noticed, in recent tests, that after adjustment to the prescribed pH of 6.00 ± 0.15 units the pH of the SSW continued to drop whilst in storage. This is thought to be a combined result of not allowing the pH to equilibrate fully during pH adjustment and the lack of buffering capacity in such a low ionic strength medium. Interestingly, in the three experiments where the control growth was lowest, the pH at the start of the test was at or below pH 5.85, even in the presence of a biological buffer (1.3 g/L (1 mM) N-2-Hydroxyethylpiperazine-N'-2-ethanesulphonic acid (HEPES)). Franklin et al (1998) demonstrated that *Chlorella* sp is highly sensitive to changes in pH, and that the optimal pH for *Chlorella* sp. growth is 6.5. This is supported by the valid algal reference tests run in 2004–05, which had a starting pH of 5.95 or above. The fact that this optimal pH had not been previously noted in the protocol for testing with *Chlorella* sp. will be rectified.

Future reference toxicity tests using *Chlorella* sp. will, therefore, be conducted at a starting pH of 6.5 ± 0.15. In addition, the SSW pH adjustment procedure will be amended to allow greater equilibration time, while an investigation into the use of the HEPES buffer to maintain pH at 6.5 will also be undertaken (ie. although satisfactory in Magela Creek water, 1 mM HEPES may be insufficient in SSW).

H. viridissima

With only one out of ten *H. viridissima* reference toxicity tests undertaken in this program being invalid due to low control growth, and the most recent test demonstrating excellent growth, it is unlikely that there is a problem with the experimental techniques used or the health of the laboratory culture. Without a long-term data set for comparison, it is difficult to say whether low control growth in SSW may occur periodically for this species. Consequently, the results of future *H. viridissima* reference toxicity tests will be closely monitored to gauge whether low control growth occurs with unacceptable frequency.

L. aequinoctialis

While sufficient control growth was observed for two of the three tests undertaken using *L. aequinoctialis,* the growth rate of one of these only just met the criterion, and the other was only marginally higher. The nutrient concentrations used in toxicity testing with this species were optimised in experiments using natural Magela Creek water to identify the minimum additions of NO_3 and PO_4 that would sustain good plant growth while minimising the likelihood of unwanted interactions with test toxicants. Therefore, a nutrient trial similar to that undertaken in Magela Creek water will be undertaken in SSW to determine the most appropriate regime for this artificial medium. In addition, although the SSW is modelled on the inorganic constituents of Magela Creek water and is therefore the most relevant standard medium available, it is likely to be lacking organic compounds such as tannins and humic acids that are present in natural waters and which may be required for optimal plant growth. This may also explain why good plant growth is obtained with this nutrient regime in natural Magela Creek water, but is substantially lower in SSW.

Steps for completion

The reference toxicity testing program at ***eriss*** is ongoing and further experiments using the four species already tested are scheduled for 2006–07. In addition, reference toxicity testing using the water flea *Moinodaphnia macleayi* will be initiated using the 48-h immobilisation test protocol. It is expected that approximately four reference toxicity tests for each species will be completed in 2006–07.

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Toxicity of magnesium in Magela Creek water to local freshwater species

R van Dam, A Hogan, M Houston & N Lee

Background

Magnesium sulfate ($MgSO_4$) is the dominant surface water contaminant associated with Ranger uranium mine (Ranger). Although this salt is generally considered to be of low toxicity, aquatic surveys around Ranger in the mid-1990s showed correlations between changes in macroinvertebrate community structure and increasing $MgSO_4$. This finding prompted a full ecotoxicological investigation, including: identification of the dominant toxic ion; assessment of Mg toxicity in extremely soft local creek water, in both the laboratory and in the field; and the influence of calcium (Ca) on Mg toxicity in the laboratory. Much of this research has been described in previous Supervising Scientist Annual Reports (see Supervising Scientist 2002; 2003) and more recently, van Dam et al (2006).

During 2005–06, the aim was to complete the remaining experiments to quantify the effects of amelioration by Ca and to analyse all data to derive a site-specific trigger value for Mg.

Progress

Ten experiments were done in 2005–06. Of these, two experiments (both for *Mogurnda mogurnda*) were invalid (the first due to additions of incorrect volumes of $CaSO_4$ stock solutions, and the second due to excessive control mortality). The remaining tests are briefly summarised below.

(i) Toxicity of $MgCl_2$

As part of the component to determine the relative toxicity of the cation Mg^{2+} and the anion SO_4^{2-}, the toxicity of $MgCl_2$ to the snail *Amerianna cumingi* was assessed (Figure 1). The IC_{50}[1] of Mg when added as $MgCl_2$ (based on linear interpolation) was 20 mg/L (lower/upper 95% CLs: 17/22 mg/L). This was very comparable to the average IC_{50} for Mg of 18 mg/L when added as $MgSO_4$. Considering that sulfate, when added as $NaSO_4$, had no effect on *A. cumingi* up to a concentration of 340 mg/L, these results confirmed that it is the cation Mg^{2+} that is toxic to the snail species. This same conclusion had been reached previously for *Hydra viridissima* and *Lemna aequinoctialis*.

[1] Concentration that results in a 50% inhibition of the test endpoint (eg *Amerianna cumingi* egg production)

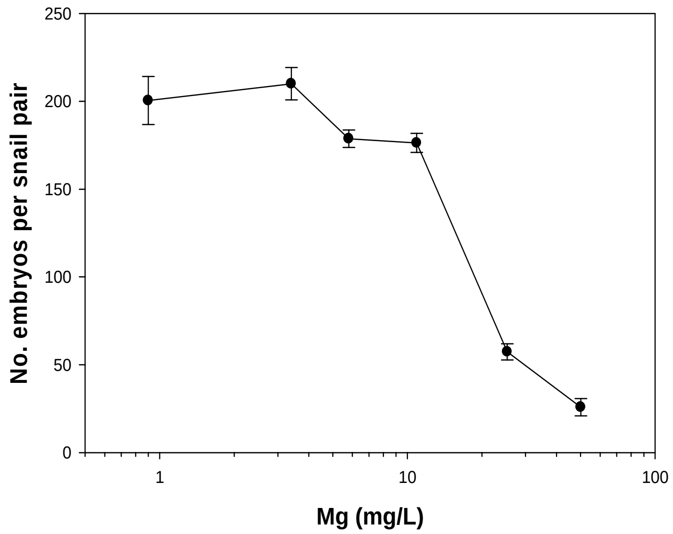

Figure 1 Effect of Mg, when added as $MgCl_2$, on embryo production of the aquatic snail, *Amerianna cumingi*. Data points represent the mean (± SEM) of three replicates.

(ii) Toxicity of Mg at the 'safe' Mg:Ca ratio of 9:1

The remaining tests were focused on assessing the toxicity of Mg at the 'safe' Mg:Ca ratio of 9:1, which had been derived previously based on experiments using *H. viridissima*, *L. aequinoctialis* and *A. cumingi* (as described in van Dam et al 2006), to *Moinodaphnia macleayi* (3 tests), *Chlorella* sp. (3 tests) and *L. aequinoctialis* (1 test). Only the data for *M. macleayi* are described here. Figure 2 displays the toxicity of Mg to *M. macleayi*, with data from four separate experiments (three from 2005–06 and one from a previous experiment) being pooled (analysis of covariance indicated that the concentration–response relationships for each of the experiments were not significantly different; F = 0.064, df = 3, P = 0.978). Based on the fitted regression model (3 Parameter Sigmoid, r^2 = 0.92, n=29, P<0.0001), the IC_{15} and IC_{50} (upper-lower 95% CLs) were 45 (20–65) and 138 (115–160) mg/L, respectively. Interestingly, the IC_{50} value is about two-fold higher than the IC_{50} of 64 mg/L for Mg at background Ca concentrations, indicating that Ca has a relatively small ameliorative effect on the toxicity of Mg to *M. macleayi*. In contrast, results from experiments using *L. aequinoctialis* and *M. mogurnda*, indicated there was a 100-fold reduction in the toxicity of Mg (based on IC/LC_{50}s) when the Mg:Ca ratio was maintained at 9:1. The results for the other species were being analysed, compared and interpreted at the time of preparation of this summary.

Steps for completion

Two fish (*Mogurnda mogurnda*) toxicity tests were required to complete the testwork for this project. These tests were completed in July and August 2006.

All toxicity data associated with the Mg toxicity project, which comprised well over 50 experiments, have been quality checked and are being re-analysed. Once this analysis has been completed, revised trigger values for Mg at Mg:Ca ratios >9:1 and <9:1 will be calculated and communicated to stakeholders via the Ranger Minesite Technical Committee. The work is currently in the process of being written up for publication.

A poster summarising the final Mg toxicity project results has recently been presented by Mel Houston at the Interact 2006 conference in Perth.

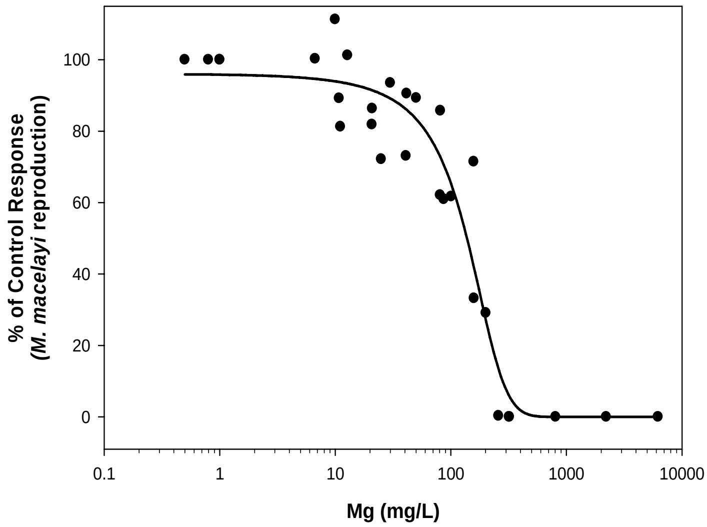

Figure 2 Effect of Mg on reproduction of the cladoceran *M. macleayi*, when the Mg:Ca (mass) ratio is kept constant at 9:1. Plot based on pooled data from 4 separate experiments, with each data point representing the mean of three replicates (individual error bars not shown). The fitted curve represents a 3 parameter sigmoid model ($r^2 = 0.92$, n = 29, $P < 0.0001$).

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Toxicity of treated pond water from Ranger uranium mine to five local freshwater species

R van Dam, A Hogan & M Houston

Background

Several factors, including a number of above average wet seasons, the need to keep the base of Pit#3 dry for mining and the removal of Djalkmara Billabong (a wetland used to hold and polish run-off from the minesite prior to controlled release into Magela Creek), prompted Energy Resources of Australia (ERA) to consider alternative methods for the reduction of onsite waters at Ranger Mine. Proposals for the treatment and discharge of two grades of water, namely 'pond' and the more highly contaminated 'process' water, were discussed with stakeholders throughout 2004–2005. Whilst a pilot plant demonstrated (through water chemistry analysis) that the quality of the treated pond water would likely be suitable for direct release, it was agreed that for additional assurance, SSD would undertake ecotoxicological testing on the reverse osmosis (RO) permeate from the newly commissioned plant prior to release into the Corridor Creek wetlands.

ERA completed commissioning the water treatment plant for pond water in December 2005 and provided SSD with assurance that the permeate being produced at the time was representative of future outputs, and thus, ready for ecotoxicological testing. SSD staff from the Jabiru Field Station sampled the permeate on 12 December 2005 and ERA staff delivered the sealed sample bottles to the ***eriss*** Darwin laboratories for testing the same day.

Methods

Five local organisms, a unicellular alga (*Chlorella* sp.), macrophyte (duckweed; *Lemna aequinoctialis*), cnidarian (*Hydra viridissima*), crustacean (water flea; *Moinodaphnia macleayi*) and a fish species (*Mogurnda mogurnda*), were exposed to concentrations of 30, 44, 67 and 100% treated pond water permeate and a Magela Creek water control. All dilutions of the permeate were undertaken using freshly collected Magela Creek water.

Results and discussion

Exposure to the treated pond water permeate had no effect on the growth of the two plant species and the hydra, nor on the survival of the fish. However, the crustacean (*M. macleayi*) was shown to produce significantly less offspring when exposed to the two highest concentrations of permeate (67 and 100%) (Figure 1). Thus, the Lowest-Observed-Effect-Concentration (LOEC) and No-Observed-Effect-Concentration (NOEC) were 67% and 44% permeate, respectively.

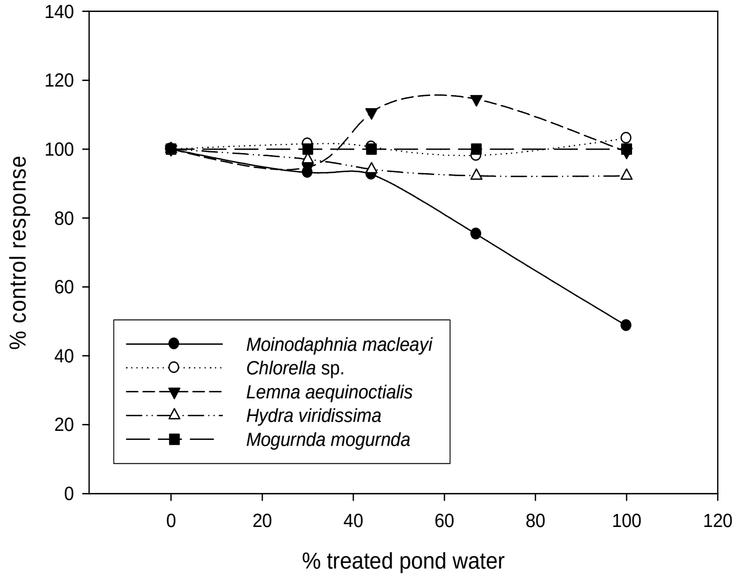

Figure 1 Response of five local species to treated pond water permeate. Each data point represents the mean of three (10 in the case of *M. macleayi*) replicates (individual error bars not shown). Note that the elevated response observed in the *L. aequinoctialis* test was found to be not significantly different from the control (*P*>0.05).

A full ICP-MS scan of metals in the treated pond water found that all metals, other than uranium, were below or around the limits of detection and hence, unlikely to be contributing to the observed toxicity. The 4 µg/L of uranium in the treated pond water was less than what has been shown to cause toxicity to *M. macleayi* in Magela Creek water. However, natural Magela Creek water typically contains 2–8 mg/L dissolved organic carbon (DOC), which has been shown to ameliorate uranium toxicity. A notable characteristic of the permeate was that DOC was below detection limit (<1 mg/L). The absence of DOC in the permeate may, therefore, result in greater uranium toxicity to *M. macleayi*.

An alternative hypothesis is that the absence of DOC and possibly other essential ions from the permeate may result in a reduction in reproduction and survival of *M. macleayi* as a result of nutrient/ion deficiencies. To test these hypotheses, we are planning to test the toxicity of uranium in a 'synthetic' Magela Creek water that simulates the inorganic composition of the water but contains no DOC, and to compare the results to experiments conducted in natural Magela Creek water.

Regardless of the reason for the effect on *M. macleayi*, the treated pond water could be considered only moderately 'toxic', and any potential for an effect on downstream biota could be avoided by diluting the permeate as it is released off-site. It should be noted that the preferred distribution-fitting method for deriving acceptable concentrations/dilutions could not be used in this case because only one of the five species tested responded to the permeate.

An acceptable dilution factor of 1 part permeate to 23 parts Magela Creek water (ie. 4.4% permeate) was calculated using the 'safety factor' approach outlined in the ANZECC/ARMCANZ Water Quality Guidelines (ie. the NOEC for *M. macleayi*, of 44% permeate, was divided by a default safety factor of 10). This dilution factor was adopted as one of the primary criteria for the release of treated pond water to Magela Creek.

Steps for completion

The toxicity of uranium to *M. macleayi* in the absence of DOC, will be assessed. Toxicity testing of treated process water is expected to take place once the plant has been commissioned for this water grade in 2007. The results from the testing of the treated process water may indicate the need to focus more closely on ammonia toxicity. Ammonia was inferred to be the primary toxicant in RO permeate water produced from the process water treatment pilot plant in 2001 (Camilleri et al 2002).

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Atmospheric radiological monitoring in the vicinity of Ranger and Jabiluka

A Bollhöfer

Introduction

Radon is a radioactive noble gas that exhales from the earth's surface. It is an element in the uranium decay chain, and thus the radon exhalation flux depends, amongst many other factors, on the concentrations of uranium and radium in the soil. Radon decays with a half life of 3.8 days and the radon decay products (RDP) – ^{218}Po, ^{214}Pb and ^{214}Bi – can be retained in the lungs after inhalation. Their subsequent decay can deliver a significant dose to the soft tissue of the respiratory system. The greatest fraction of natural exposure of humans to radiation originates from the inhalation of radon decay products (Porstendörfer 1994).

Similarly, radioactive elements trapped in or on dust (long lived alpha activity or LLAA) can deliver a radiation dose to the respiratory system once inhaled and trapped in the lungs. The Supervising Scientist Division conducts an atmospheric monitoring program at Jabiru, Jabiru East and close to Mudginberri Billabong (Map 1), measuring RDP and LLAA. Research and development projects are conducted into the sources, behaviour and atmospheric pathways of radon and dust originating from Ranger mine.

The results of the atmospheric monitoring program are periodically compared with results from ERA's atmospheric radiological monitoring program. In addition radon gas is measured continuously on a half hourly basis at the Mudginberri Four Gates Rd Radon Station and data are downloaded bimonthly. This station is regarded as a radon background and reference site and has continuously acquired radon data for the past 6 years.

Results

Radon pathway

Figure 1 provides a statistical summary of RDP data from Mudginberri, Jabiru and Jabiru East measured by ***eriss*** from early 2002 to December 2005. Median RDP concentrations at Jabiru and Mudginberri are 0.037 and 0.040 µJ/m^3, respectively. Concentrations at Jabiru East are generally higher (median of 0.064 µJ/m^3) and show more variation. The 75th percentile concentration at Jabiru East is twice as high as at Jabiru and Mudginberri.

Energy Resources of Australia estimates the mine-derived RDP using a wind correlation model developed by ***eriss***, and subsequently calculates exposure via the radon pathway. Table 1 shows the average RDP concentration and annual total doses received from the inhalation of RDP at Jabiru provided by ERA (ERA 2006) and calculated from ***eriss*** data (in brackets). This dose assumes an occupancy of 8760 hrs (1 year) and a dose conversion factor for the public of 0.0011 milli Sievert (mSv) per µJ/hr/m^3. ERA also reports an average mine-derived RDP concentration of 0.03 µJ/m^3 for the 1125 hours that the wind was blowing from the mine in 2005, which results in a mine-related dose calculated for 2005 of 0.037 mSv in Jabiru, less than 4% of the public dose limit of 1 mSv/y.

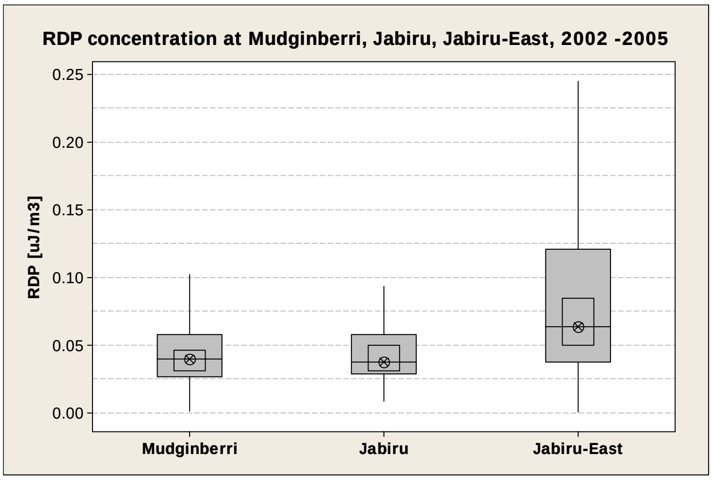

Figure 1 Statistical analysis of 4 years of radon decay product data at Mudginberri Four Gates Road radon station, Jabiru and Jabiru East

Table 1 Radon decay product mean concentrations at Jabiru and Jabiru East, and total and mine derived annual doses received at Jabiru in 2003–2005

		2003	2004	2005
RDP mean concentration [μJ/m³]	Jabiru East	0.075 (0.101)	0.103 (0.095)	0.097 (0.097)
	Jabiru	0.065 (0.043)	0.079 (0.063)	0.088 (0.052)
Total annual dose [mSv] Jabiru		0.63 (0.41)	0.76 (0.61)	0.85 (0.50)
Mine derived dose [mSv] at Jabiru		0.011	0.014	0.037

Dust pathway

The dust inhalation pathway has been quantified using an innovative approach (Bollhöfer et al 2006). Stable lead isotope ratios have been used to discriminate between natural dust and dust originating from the mining and milling of uranium at Ranger. To illustrate the differences in isotopic ratios, Table 2 shows the lead isotope ratios measured in various primary sources of lead.

Table 2 Typical lead isotope ratios in various primary lead sources

	Primordial	**Lead ores** (*Doe 1970*)		**Australian uranium ores**	
Ratio	(*Tatsumoto et al 1973*)	Broken Hill	Mississippi valley	Koongarra orebody 2 (*Dickson et al 1985*)	Ranger (*Gulson et al 1992*)
$^{206}Pb/^{207}Pb$	0.90	1.04	1.33–1.39	7.36	9.69
$^{208}Pb/^{207}Pb$	2.87	2.32		0.724	0.0049
$^{206}Pb/^{204}Pb$	9.31	16.01–16.12		394.1	10602.5

Using the temporal and spatial variability (Figure 2) of lead isotope ratios measured in the vicinity of Ranger, the average annual contribution from Ranger uranium mine to the long-lived alpha activity concentrations at Jabiru East has been estimated to be almost 40%. The contribution at Jabiru is much lower. Assuming that a person lives at Jabiru and works at

Jabiru East, this person would receive an average annual dose from the inhalation of radiogenic dust originating from the Ranger mine of approximately 0.002 mSv.

Although proven to be trivial for the public in the Alligator Rivers Region, dispersion of radionuclides in dust may be more significant in drier, less regulated environments elsewhere in Australia. The large differences in lead isotope ratios of natural soils and uranium mineralised material and the use of ICPMS techniques for isotope analyses, make this a quick and reliable method for apportioning doses between sources, which may be attractive for mining industry managers and regulators.

Summary

Monitoring of the radon and dust exposure pathways has shown that at present the only significant contribution to radiological exposure of the public via inhalation, is the inhalation of mine-derived radon decay products. The current contribution is much less than the public dose limit of 1 mSv per year and is of no concern. Ongoing atmospheric monitoring will continue to provide re-assurance to the public that inhalation of mine derived radionuclides remains low.

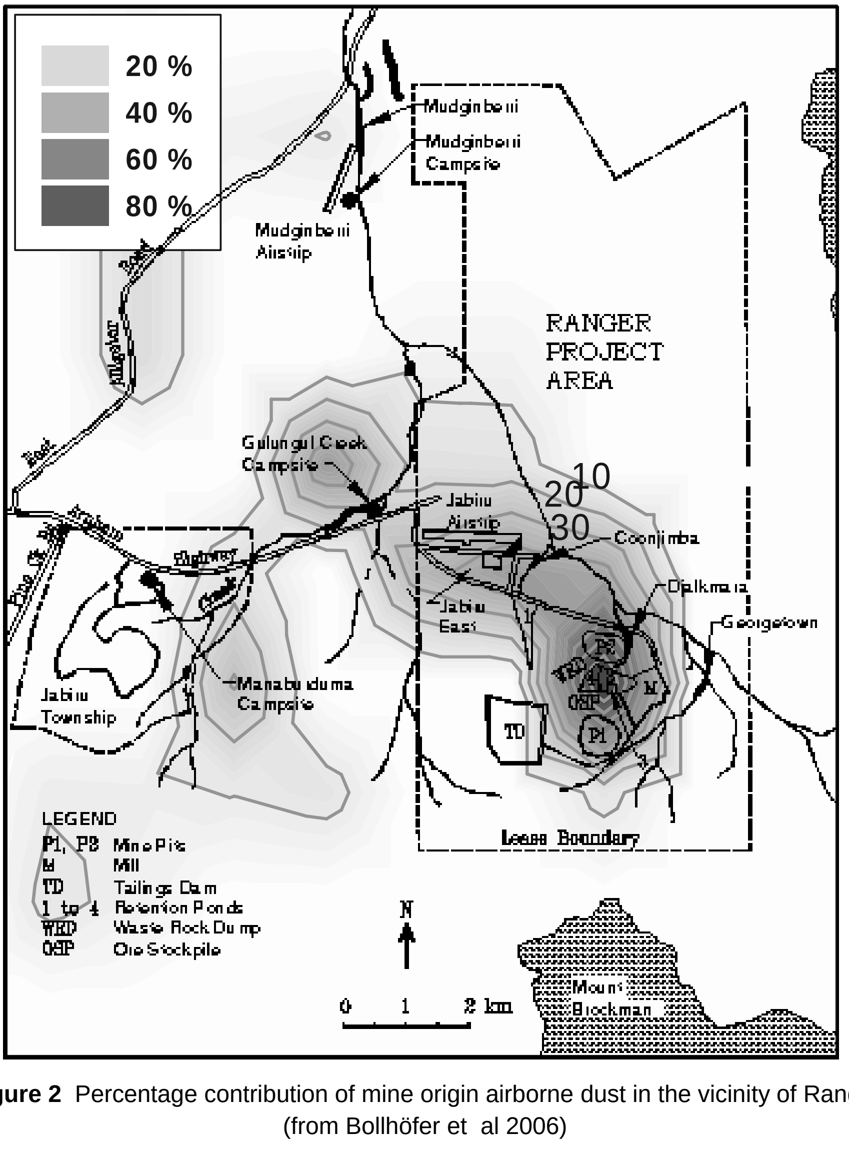

Figure 2 Percentage contribution of mine origin airborne dust in the vicinity of Ranger (from Bollhöfer et al 2006)

Steps for completion

This project is an ongoing project. The routine monitoring of dust and radon progeny will continue at the three monitoring sites of Jabiru, Mudginberri Four Gates Road Radon Station and Jabiru East. A simultaneous sample collection regime, ideally via high volume air samplers at the source and receptor locations, with measurements of stable lead isotope ratios, uranium, thorium and long-lived alpha activity concentrations, provides an ideal tool for dose estimation and unambiguous source apportionment for the dust inhalation pathway. A set of on-site and environmental monitoring dust filters covering a complete annual cycle should be collected to test the method covering a complete annual cycle. Samples will be analysed by ICPMS to calculate the variability of the radiation dose from inhalation of dust originating from Ranger throughout the year. This validated method may be ideal for other sites, where the dust inhalation pathway is more significant.

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Monitoring of groundwater at Ranger

B Ryan & A Bollhöfer

Introduction

The aim of the Ranger groundwater program is to investigate the dispersion of contaminants through the groundwater pathway, from both radiological monitoring and hydrogeological modelling perspectives. Shallow and deep aquifers, and sources of contaminants need to be characterised, both geochemically and hydrogeologically. Once the aquifers have been characterised, in terms of distribution and transport of contaminants and aquifer interactions, models can be developed that predict future groundwater quality, solute transport and its ultimate impact on surface water. The monitoring program will need to be continued for an extended period following the rehabilitation of the site to assess the success of the rehabilitation and the integrity of the pits as tailings repositories.

Radionuclide activity and metal concentrations are measured in groundwater samples collected annually at the end of the dry season from bores around the site. Heavy metal concentrations are determined via ICPMS-OES, and radionuclides of interest are radiochemically separated from the sample, and measured via alpha spectrometry.

As thorium and lead are particle reactive and readily adsorbed and removed from solution, it is not expected that either of these elements will migrate significant distances through the groundwater aquifer unless the water is acidic. This is also assumed to be the case for actinium. Consequently, the reduced list for U-series radionuclides potentially contaminating the groundwater is: ^{238}U, ^{234}U and ^{226}Ra. These radioisotopes are the focus of the groundwater monitoring program.

The $^{234}U/^{238}U$ activity ratio can potentially be used to identify mine-related sources, as they are likely to exhibit $^{234}U/^{238}U$ acitivty ratios of ~1 in contrast to most natural groundwaters with activity ratios > 1 (Ivanovich & Harmon 1982).

Progress to date

The focus for 2005–06 was a compilation and evaluation of groundwater data for Nabarlek (Supervising Scientist Internal Report, Ryan & Bollhöfer, 2006), summarised under KKN 4.2.1 The lessons learned from this work will aid in analysing, interpreting and contribute to modelling the Ranger groundwater data.

Ranger bore water samples were collected by the Northern Territory Department of Primary Industry, Fishery and Mining for ***eriss*** in 2004 and 2005, with aliquots being prepared in the ***eriss*** laboratories for radioisotope analysis. ICPMS-OES analysis of all archived groundwater samples was completed by Charles Darwin University in 2005 for barium, calcium, iron, sulphur, sodium, potassium, magnesium, manganese, vanadium, uranium and strontium. Uranium isotope and radium analyses via alpha spectrometry of archived samples have been completed.

Steps for completion

The metal and radionuclide activity concentration results are now being collated and analysed, and interpretation started of the long-term groundwater data for uranium isotopes and radium. Particular attention is being placed on assessing groundwater movement and identifying any sources of contamination.

ERA has significantly reduced its groundwater monitoring program in recent years and now only has four statutory groundwater monitoring sites. A further 22 bores are sampled in the ERA operational monitoring program at frequencies of quarterly and monthly. ***eriss*** has now acquired sampling equipment to target specific bores. With tailings being stored in Pit #1 and eventually in Pit #3, there will need to be an increase in monitoring bores in the vicinity of the two pits without neglecting important bores in the vicinity of the tailings dam.

It is planned to undertake initial investigations in late October 2006 to profile alluvial water in the Magela Creek channel and near surface groundwater in the Magela Land Application Area, in collaboration with staff from the Northern Territory Department of Primary Industry, Fisheries and Mines. An EM31 geophysical instrument will be used for this purpose. Electrical conductivity measurements will be made over the area and, if feasible, a map produced showing the conductivity down to a particular depth. The data may be used to locate anomalous conductivity zones and investigate potential source inputs of solutes from the Magela and Djalkmara land application areas that may be entering the alluvial flow system as a density plume.

Acknowledgments

The Northern Territory Department of Primary Industry, Fisheries and Mines is acknowledged for collection of the bore water samples and providing the aliquots for analysis.

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Introduction to SSD's stream monitoring program for Ranger, 2005–06

C Humphrey & D Jones

The SSD operates an integrated chemical, physical and biological monitoring program to ensure protection of the aquatic ecosystems of the ARR from the operation of uranium mines in the region. This stream monitoring program is an independent, assurance program, unlike the compliance and check water chemistry monitoring programs of the mining company (Ranger) and the NT government regulator respectively.

The techniques and 'indicators' used in the monitoring program are underpinned by the outputs of research programs that have been carried out over many years. However, the program is not static with ongoing improvements being made both as a result of more recently acquired knowledge and by the implementation of new technologies as these become available. In particular, this is the first year for which continuous water quality parameters have been measured directly in Magela Creek.

The scope of the monitoring program satisfies two important needs of environmental protection: (i) the early detection of significant changes in measured indicators to avoid short or longer term ecologically important impacts; and (ii) assessing ecological or ecosystem-level effects by way of measured changes to surrogate indicators of biodiversity. The suite of monitoring techniques implemented by the SSD to meet these requirements is summarised below.

(i) Early detection of short or longer-term changes in indicators

- *Water physico-chemistry*:
  - Spot measurements: includes pH, electrical conductivity (EC), suspended solids, uranium, magnesium, manganese and sulfate (weekly sampling during the wet season) and radium (fortnightly);
  - Continuous monitoring: use of multi-probe loggers for continuous measurement of pH, EC, turbidity, temperature and dissolved oxygen in Magela Creek, and EC and turbidity in Gulungul Creek;
- *Toxicity (including creekside) monitoring* of reproduction in freshwater snails and survival of fish fry (four-day tests conducted at fortnightly intervals);
- *Bioaccumulation* – concentrations of chemicals (including radionuclides) in the tissues of freshwater mussels and fish in Mudginberri Billabong to detect far-field effects including those arising from any potential accumulation of mine-derived contaminants in sediments (mussels sampled every late-dry season, fish sampled biannually in the late dry season).

(ii) Assessment of changes in biodiversity

- *Benthic macroinvertebrate communities* at stream sites (sampled at the end of each wet season); and
- *Fish communities in billabongs* (sampled at the end of each wet season).

The results from the stream monitoring program and monitoring support tasks and the outcomes of reviews of research programs are summarised below. The complete results for the water quality and biological monitoring programs are reported on the SSD web site (http://www.deh.gov.au/ssd/monitoring/magela-bio.html).

Chemical and physical monitoring of surface waters in Magela and Gulungul Creeks

M Iles

Routine weekly sampling program in Magela Creek

The first water chemistry samples for the SSD surface water monitoring program for the 2005–06 wet season were collected from Magela Creek on 6 December 2005, one day after flow was first observed at the downstream statutory compliance point ('Magela d/s', Map 2). Weekly sampling was conducted throughout the wet season, and continued until the creek ceased to flow on 28 August 2006, with the following exceptions: (i) following an accidental irrigation of the Magela Land Application Area with pond water on 21–22 January 2006, additional sampling of Magela Creek was undertaken on 23 January 2006; and (ii) in the last week of April 2006, sampling did not occur after Tropical Cyclone Monica passed over Jabiru on 25 April 2006 because sites were inaccessible. SSD collected its last sample on 24 August 2006 shortly before Magela Creek ceased flowing.

The values of water quality indicators for the wet season, including the period immediately following the irrigation incident, have been within limits/guidelines (Iles 2004) set by the Supervising Scientist for the protection of the aquatic environment and are within the range seen in previous years.

The summary statistics for the upstream and downstream key water quality data from both the SSD and ERA water quality monitoring programs are shown in Table 1. The time series data for uranium concentrations from both the SSD and ERA routine and investigative monitoring (following the irrigation incident) are shown in Figure 1. There is good agreement between the datasets of both organisations.

Table 1 Summary of Magela Creek 2005–06 wet season# water quality up and downstream of Ranger

Parameter	Guideline or Limit*	Organisation	Median		Range	
			Upstream	Downstream	Upstream	Downstream
pH	5.0 – 6.9	SSD	6.4	6.4	5.6 – 6.8	5.9 – 6.8
		ERA	6.3	6.4	5.5 – 6.7	5.8 – 6.7
EC (µS/cm)	43	SSD	14	17	7.9 – 20	8.5 – 23
		ERA	12	15	4.8 – 20	6.9 – 23
Turbidity (NTU)	26	SSD	2.0	2.2	0.9 – 14	0.8 – 18
		ERA	2.	2.	1 – 11	1 – 14
Sulfate‡ (mg/L)	Limited by EC	SSD	0.2	0.7	0.1 – 0.4	0.3 – 3.4
		ERA	0.2	0.8	0.1 – 0.6	0.3 – 3.8
Magnesium‡ (mg/L)	Limited by EC	SSD	0.6	0.9	0.2 – 1.1	0.3 – 1.4
		ERA	0.5	0.8	0.1 – 0.9	0.2 – 1.2
Manganese‡ (µg/L)	26	SSD	4.4	4.9	2.2 – 13	2.1 – 16
		ERA	3.9	4.1	1.9 – 10	3.2 – 16
Uranium‡ (µg/L)	6	SSD	0.014	0.048	0.003 – 0.044	0.014 – 0.153
		ERA	0.018	0.064	0.006 – 0.060	0.014 – 0.145

ERA data taken from the ERA Weekly Water Quality Report 18 August 2006; ‡ dissolved (<0.45 µm); # SSD results from the last sampling event, 24 August, outstanding at time of report writing; * A compliance limit applies to uranium, management guidelines apply to all other parameters shown.

Uranium, manganese, magnesium and sulfate median values from both datasets were higher downstream of the mine but the concentrations were very low and not of environmental concern. Uranium concentrations remained well below (<3% of) the limit (Figure 1). The low values are indicative of the pattern of improved water quality seen in the past four wet seasons and demonstrated by the uranium results for the last five years (Figure 2).

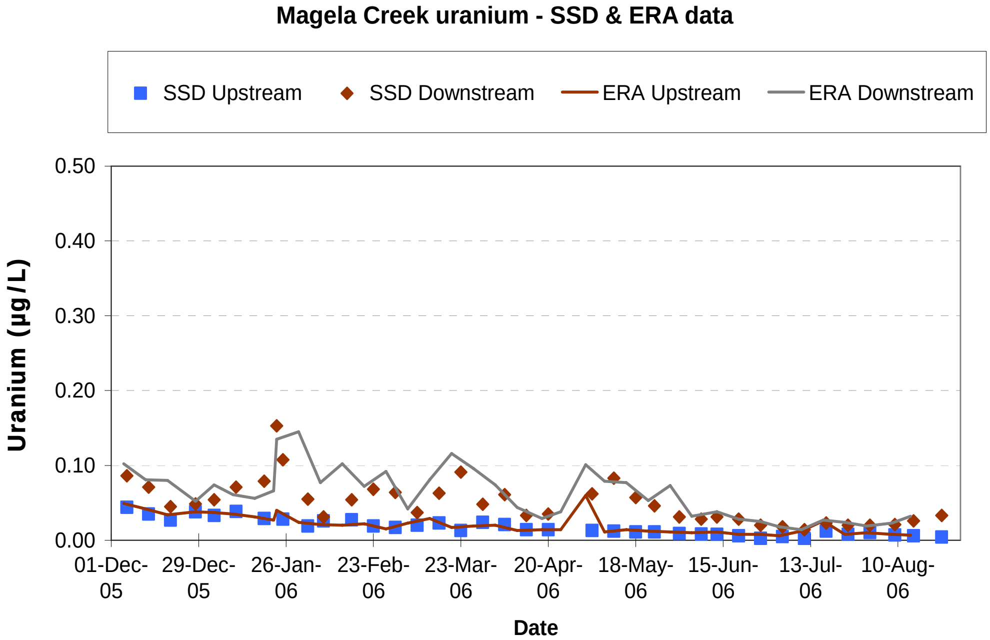

Figure 1 Uranium concentrations measured in Magela Creek by SSD and ERA during the 2005–06 wet season

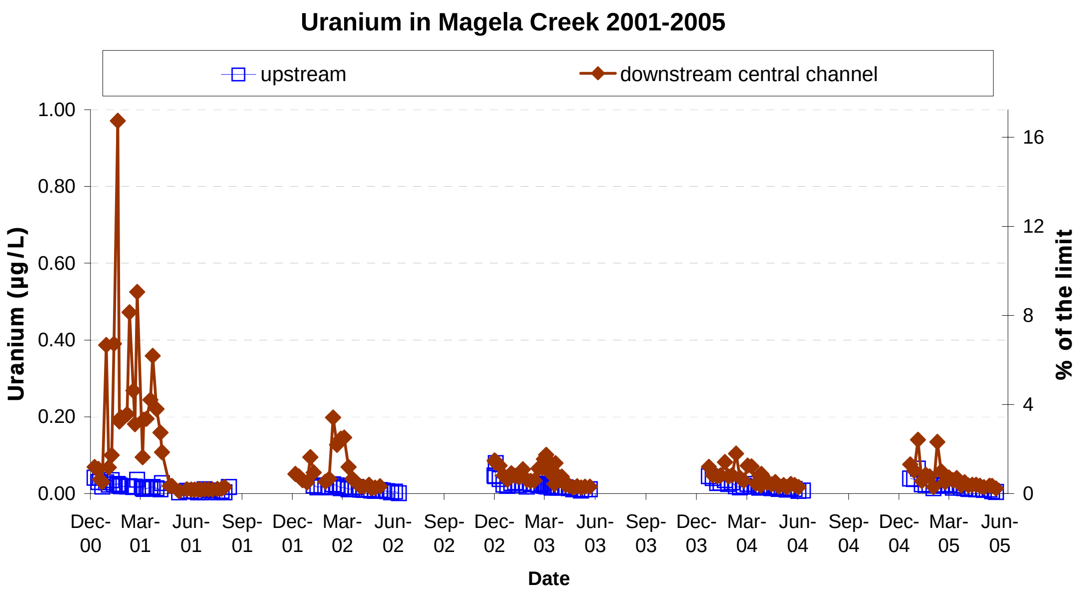

Figure 2 Uranium concentrations in Magela Creek since the 2000–01 wet season (SSD data)

Electrical conductivity (EC), whose guideline value provides a management tool for the control of magnesium and sulfate concentrations, was also slightly higher downstream but compared to the guideline value the difference was small. The manganese, pH, and turbidity medians are similar at both sites for the SSD and ERA datasets.

The water quality objectives set to protect the aquatic ecosystems downstream of the mine were achieved during the 2005–06 wet season. Available biological monitoring data (described later in this report) also indicate that the environment remained protected throughout the season.

Routine weekly sampling program in Gulungul Creek

The first water chemistry samples were collected from upstream and downstream sites in Gulungul Creek (Map 2) on 29 November 2005, during the first week after flow commenced in the creek. Weekly sampling was conducted throughout the wet season, and continued while the creek was flowing, except for the last week of April 2006 when sites became inaccessible after Tropical Cyclone Monica passed over Jabiru (on 25 April 2006). SSD collected its last sample on 15 August 2006 shortly before Gulungul Creek ceased to flow.

The upstream and downstream water quality data from both the SSD and ERA programs are summarised in Table 2, with uranium time series concentration data shown in Figure 3. There is good agreement between the datasets of both organisations and the overall water quality and seasonal trends for the 2005–06 wet season are comparable to those seen in previous years (Figure 4).

Although median values for most of the key variables were slightly higher downstream of the mine (Table 2), the concentrations were very low and not of environmental concern.

Table 2 Summary of Gulungul Creek 2005–06 wet season water quality upstream and downstream of Ranger

Parameter	Company	Median		Range	
		Upstream	Downstream	Upstream	Downstream
pH	SSD	6.3	6.5	5.4 – 6.7	5.7 – 6.7
	ERA	6.3	6.4	5.1 – 6.7	5.4 – 6.6
EC (µS/cm)	SSD	16	19	10 – 21	11 – 29
	ERA	13	15	8.7 – 24	8.4 – 26
Turbidity (NTU)	SSD	1.0	1.4	0.4 – 5.4	0.7 – 7.7
	ERA	1.	1.	<1 – 8.	<1 – 5.
Sulfate‡ (mg/L)	SSD	0.2	0.4	0.1 – 0.7	0.1 – 2.3
	ERA	0.2	0.5	0.1 – 1.2	0.1 – 1.8
Magnesium‡ (mg/L)	SSD	0.9	0.9	0.5 – 1.8	0.5 – 1.8
	ERA	0.8	0.8	0.3 – 1.6	0.4 – 1.3
Manganese‡ (µg/L)	SSD	2.1	3.6	1.2 – 8.5	2.0 – 18
	ERA	2.0	3.2	1.2 – 11	1.8 – 18
Uranium‡ * (µg/L)	SSD	0.054	0.095	0.030 – 0.169	0.058 – 0.393
	ERA	0.060	0.102	0.032 – 1.64	0.053 – 1.05

‡ dissolved (<0.45 µm), * limit = 6 µg/L

ERA measured elevated uranium on the first day of flow (Figure 3) when it sampled within hours of flow first occurring, resulting in considerably higher range maximum than SSD (Table 2). Uranium concentrations were below the limit and the concentration at the upstream site was higher than that at the downstream site. In mid-January 2006, SSD measured a higher than usual uranium concentration of 0.393 µg/L (less than 7% of the 6 µg/L limit determined for Magela Creek). None of these excursions is considered to be environmentally significant: Values this high experienced previously and for longer periods did not impact on the biodiversity (as assessed by the biological monitoring data at that time) of Gulungul Creek.

Available biological monitoring data (described later in this section) confirm that the environment remained protected throughout the 2005–06 season.

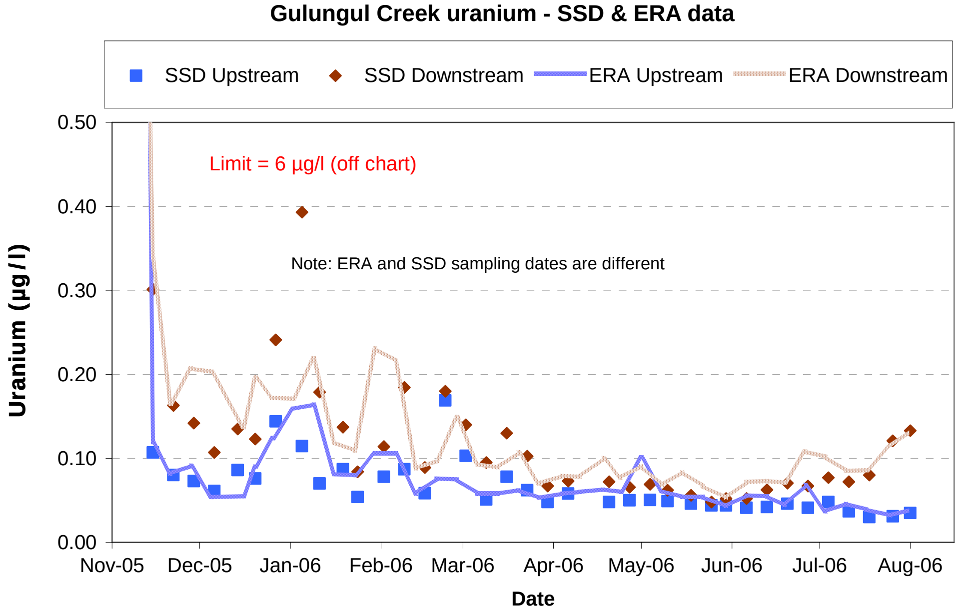

Figure 3 Uranium concentrations measured in Gulungul Creek by SSD and ERA during the 2005–06 wet season

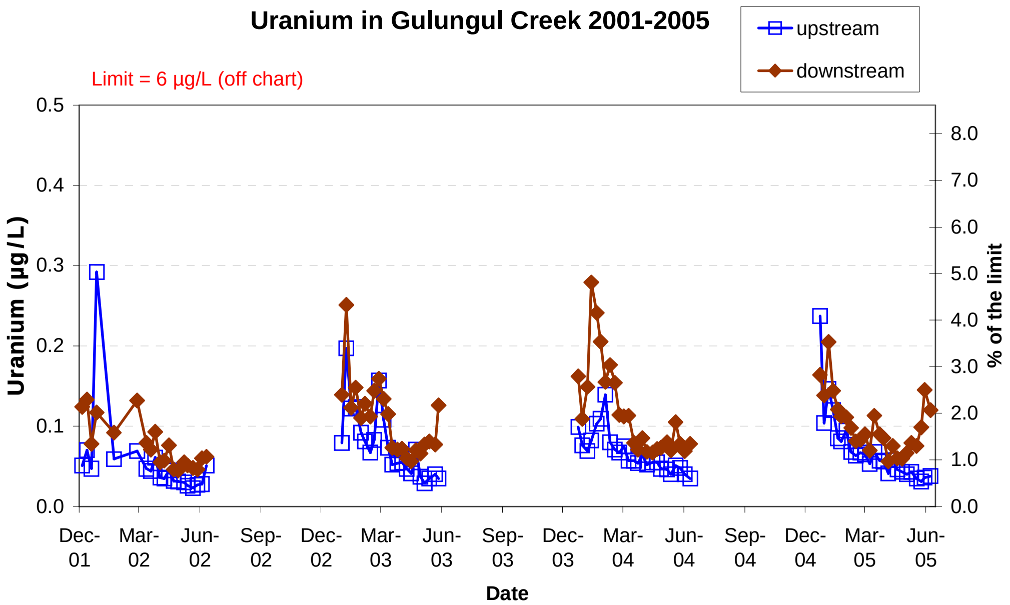

Figure 4 Uranium concentrations in Gulungul Creek between 2000 and 2005 (SSD data)

Reference

Iles M 2004. Water quality objectives for Magela Creek – revised November 2004. Internal Report 489, December, Supervising Scientist, Darwin. Unpublished paper.

Continuous monitoring of water quality

K Turner

For environmental protection and improved wastewater management associated with the Ranger mine site, there is a recognised requirement to track and quantify the movement of solutes originating from point and diffuse sources through the receiving Magela and Gulungul Creek systems. Continuous in situ measurement of key water quality variables using dataloggers placed at strategic locations on and off-site can meet these needs, particularly when linked to localised and catchment-wide rainfall and stream discharge data. Continuous monitoring will complement SSD's routine water quality monitoring program and enable detection of 'events' and exceedances that may be undetected by the weekly grab sampling regime of the routine program.

In addition to contributing to the current operational surveillance role, the implementation of continuous monitoring will enable the technology and data interpretation methods to be thoroughly tested for deployment during and beyond rehabilitation of the Ranger mine site.

Three loggers were deployed in Magela Creek at the start of the 2005–06 wet season – one located approximately 0.5 km downstream of the Magela Creek (upstream) control site (but still upstream of the mine surface-water influence) and another two located approximately 0.5 km downstream of the Magela Creek downstream compliance point (G8210009), on either side of the western-most channel (Map 2). The loggers were mounted on the pontoons housing the water intake lines for the creekside monitoring program. In situ water quality data (including electrical conductivity [EC], pH and turbidity) were collected at 15–20 minute intervals. Corresponding streamflow data were collected from upstream and downstream gauging stations on Magela Creek (by ERA and NRETA respectively).

Continuous EC, pH and flow data are measured by ERA at the RP1 discharge weir and in Corridor Creek at monitoring location GC2. Integration of these data with the ***eriss*** data from Magela Creek will enable a comprehensive real-time understanding of the link between site runoff and downstream water quality in Magela Creek.

Quality-control, spot check measurements were made using a calibrated portable field meter at the upstream and downstream Magela Creek sites and were very similar to the continuously measured values on both sampling occasions, indicating good calibration and performance of the in situ systems (Figure 1). The continuous data traces show that the difference between upstream and downstream EC values can be larger than indicated by grab sample data, such as the spot checks. This demonstrates how lower-frequency grab sampling methods, as used for the current routine water quality monitoring program, do not capture the full dynamic range of water quality behaviour.

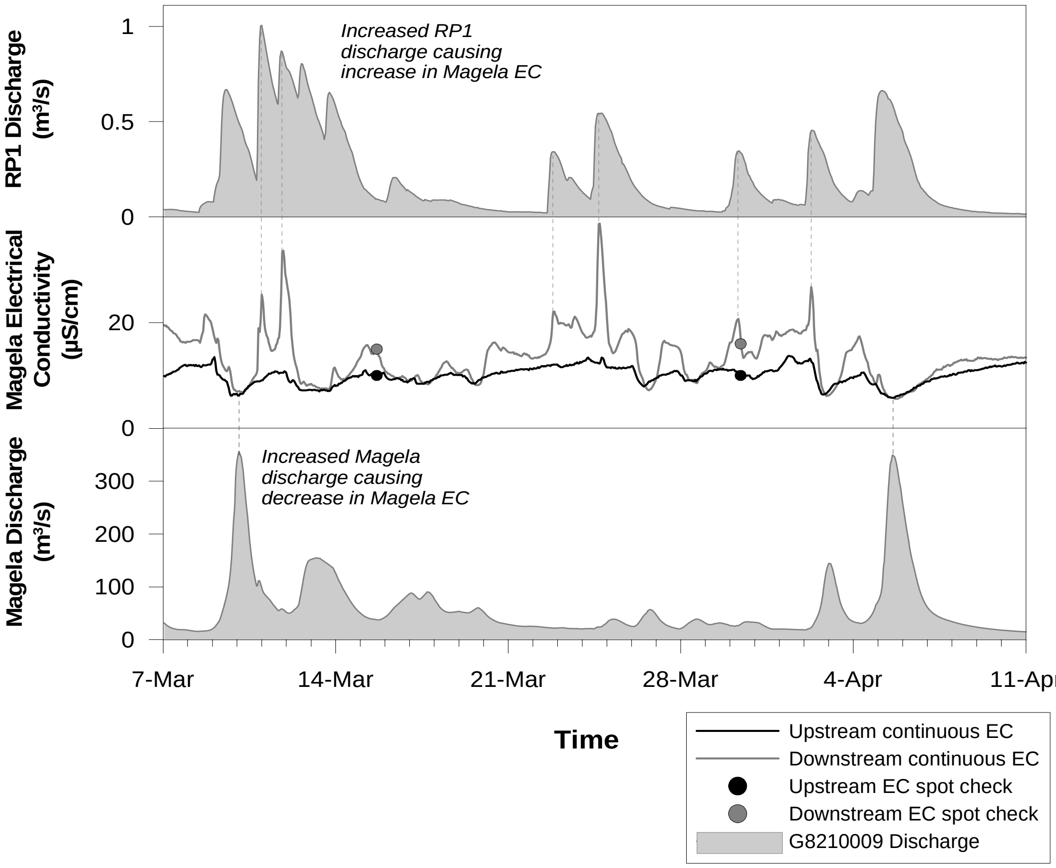

Figure 1 Continuous electrical conductivity (EC) at both the upstream and downstream sites on Magela Creek and quality-control spot checks measured using a calibrated portable field meter over mid-wet season months in 2006. The stream discharge measured at G8210009 and RP1 spillway is also shown.

Although the continuous monitoring data collected during 2005–06 have so far only undergone preliminary analysis, the interaction between inputs of RP1 water and variable dilution by flow in Magela Creek can be clearly seen (Figure 1). The EC downstream of the mine is generally higher and much more variable compared with upstream values. A number of peaks in downstream EC correspond to increased RP1 influence, caused by either an increase in RP1 discharge (due to localised rainfall over the mine site) or a decrease in Magela Creek discharge. Water samples analysed during some of these events provide evidence that elevated EC observed at the downstream site is attributed to elevated magnesium and sulfate concentrations (and to a lesser extent calcium concentrations), typically present in discharged mine wastewaters, particularly from RP1.

However, it should be noted that whilst short duration elevations in solute concentrations can now be detected by the continuous monitoring system, this does not imply that there are adverse effects upon the aquatic environment. The results from the creekside monitoring program, which integrates exposure of test organisms over a time period of one week, provide the assessment tool required to address this issue. The conclusion from the 2005–06 creekside monitoring program, the results from which are presented in detail below, showed no difference in response between the upstream (control) and downstream (impact) locations, indicating no adverse ecological effects arising from these transiently elevated solute concentrations.

The continuous monitoring data collected during the first year of deployment (2005–06) will be rigorously evaluated during 2006–07 in a whole-of-mine catchment context. Data analysis will include:

- accurate calculation of solute loads (previous estimates have required interpolation of the weekly grab sample results) to quantify and compare differences upstream and downstream of the mine and to investigate relative contributions from point (RP1 and GC2) and diffuse (Magela Land Application Area) sources;
- interpretation of observed spatial and temporal variation;
- identification of short-term trends; and
- derivation of more appropriate turbidity trigger values.

The data collected by the continuous loggers will aid interpretation of results from SSD's creekside and water quality monitoring programs. Following analysis and interpretation, the scope of the continuous monitoring program will be reviewed and refined, as required, for the next year of deployment.

Toxicity monitoring in Magela Creek

C Humphrey, D Buckle & R Luxon

Creekside monitoring

In this form of monitoring, effects of water released from the Ranger mine site are evaluated using responses of aquatic animals held in tanks on the creek side and exposed to creek waters. The responses of two test species are measured over a four-day period:

- reproduction (egg production) in the freshwater snail, *Amerianna cumingi* and
- survival of black-banded rainbowfish, *Melanotaenia nigrans* larvae.

Animals are exposed to a continuous flow of water pumped from upstream of the minesite (control site) and from the creek just below gauging station GS8210009 (Map 2), some 5 km downstream of the mine. At each of the two sites, duplicate pumps in the creek each feed water separately to: (i) in the case of snails, a container holding replicate (8) snail pairs (thus 16 pairs of snails exposed per site); and (ii) in the case of fish three containers, each container holding ten larval fish (thus 60 fish larvae exposed per site).

At the end of each four-day test, the mean number of eggs per snail pair and mean number of fish surviving per replicate are noted and compared for each of the upstream and downstream sites. Specifically, when data from the downstream site are subtracted from those at the upstream site, a set of 'difference' values can be derived. These 'difference' values may be compared statistically for different parts of the time-series. For example, 'difference' data for the wet season of interest may be compared with those from previous years. If they differ significantly, using a Student's *t* test, it may indicate a mine-related change. Since about 1996, creekside tests have been performed approximately every second week during the wet season. Tests usually commence in December and cease in early April, covering the period of significant creek flow in Magela Creek.

The results of the creekside trials are plotted as part of a continuous time series of actual and 'difference' data in Figure 1 for snail egg production, and in Figure 2 for larval fish survival. Descriptions of the sources of creekside data and data quality issues are provided in the Supervising Scientist's Annual Report for 2001–02 and web site (http://www.deh.gov.au/ssd/monitoring/magela-bio.html).

Seven creekside tests were conducted in the 2005–06 wet season. Significant pump failure occurred during the fourth test at the upstream site, to the extent that the test did not meet acceptance and validity criteria. The data for this test are displayed in the accompanying figures, however, they are not used in formal statistical analysis to detect and assess potential mining impact. (By convention, the upstream-downstream 'difference' value is omitted from the graphs of test organism responses to signify an invalid test.)

Amongst the snail tests, egg production at upstream and downstream sites was similar across all tests conducted for the wet season (Figure 1). The results also resemble the pattern of egg production observed in previous wet seasons with the possible exception of the relatively low egg production observed at the downstream site in the fifth test. This value was a consequence of significantly lower ($P<0.05$) egg production observed in the duplicate water drawn from the west bank of the creek at the downstream site (mean of 54 eggs per snail vial), relative to the corresponding duplicate water drawn from the east bank at this site (107 eggs per snail vial) and from the two duplicate waters drawn from the upstream site (117 and 123 eggs per snail vial). Corresponding spot water chemistry data collected during this test as part of the SSD's routine monitoring program did not indicate any significant elevation of analytes at this site. Additional water chemistry data, together with continuous datasonde records for key parameters including conductivity and pH, were also collected during this creekside test and the results did not show any significant issues with water quality. Thus the reduced snail egg production observed at the downstream west bank site during the fifth test does not appear to be mine-related.

Using the snail egg production data shown in Figure 1, 'difference' values for 2005–06 were compared with those from previous years. No significant difference was found (P>0.05).

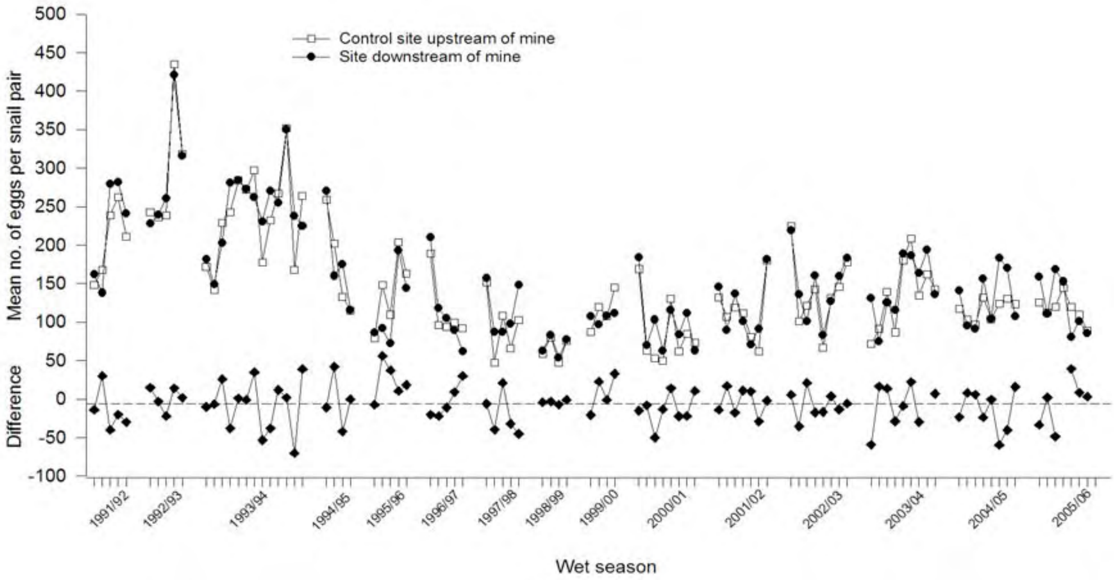

Figure 1 Creekside monitoring results for freshwater snail egg production for wet seasons between 1992 and 2006. (Snail egg production data for the first three tests of 1995/96, all tests for 1997/98, 1998/99 and 1999/00, and the last four tests in 2000/01, were provided by ERA.)

Across all fish tests, larval fish survival at upstream and downstream sites was consistent with the same relative survival rates observed in previous wet seasons with, typically, reduced survival at the upstream site relative to the downstream site (Figure 2). Possible causes for the lower survival at the upstream control site were discussed in the 2002–03 Supervising Scientist Annual Report.

From the collective creekside results, it was concluded that there were no adverse effects of discharged Ranger mine water on Magela Creek over the 2005–06 wet season.

In situ toxicity monitoring

While in situ testing has previously been investigated as a technique for biological monitoring in Magela Creek (Annual Research Summary 1987–88, 1988–89, 1989–90 and 1990–91), the method has remained undeveloped until now because of perceived occupational health and safety advantages of the creekside monitoring procedure (in particular, ready accessibility and safety of staff). However, the high resourcing demands of the existing creekside monitoring program coupled with refinement over the years of the protocols for the snail and fish tests, have led to a re-evaluation of the viability of in situ testing.

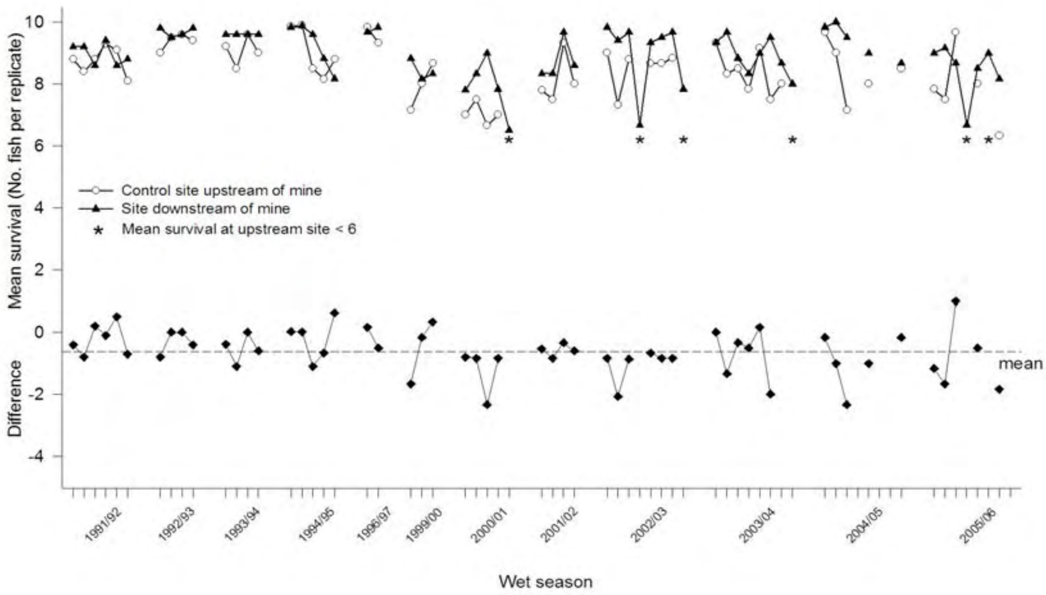

Figure 2 Creekside monitoring results for larval black-banded rainbowfish survival, for wet seasons between 1992 and 2006. (Larval fish survival data for the second test in 1999/00 were provided by ERA.)

Apart from substantially lower resource requirements, in situ testing has inherent technical advantages over the established creekside monitoring approach. These include removal of reliance on powered pumping systems in an area of high electrical storm activity, improved water flow-through and contact conditions for the test organisms, and portability. These advantages make the method appealing for future monitoring at Ranger and, potentially, also for use at other mine sites in the Northern Territory and elsewhere.

Accordingly, work commenced in the 2005–06 wet season to evaluate the potential for in situ deployment, inside floating cages in Magela Creek, of the same snail and fish tests currently used for the creekside monitoring program. This technique would provide a much more cost effective way of providing almost continuous biological monitoring of water quality in Magela Creek.

Preliminary studies involved developing a suitable design of holding vessels for test organisms, and assessing the reproduction response of freshwater snails to a number of holding conditions and feeding regimes. The 2005–06 wet season testwork also included a comparison between the in situ deployment and standard creekside tests of egg production by snails. This initial development work was done at the upstream creekside pump site (near the Magela upstream water quality monitoring site, Map 2).

Preliminary in situ tests were run in parallel with the creekside monitoring tests starting on the 17/02/06, 03/03/06 and 07/04/06 near the upstream creekside pump site. These trials investigated one of two possible feeding regimes: (i) daily feeding per current creekside monitoring protocol, and (ii) feeding only once, at the start of each four-day test. Daily feeding enabled direct comparison of results with those from the existing creekside monitoring program – an essential comparison for the initial stages of the test program. The inclusion of regime (ii) enabled parallel evaluation of a more streamlined protocol.

The results from the daily feeding in situ test are similar to those from the creekside monitoring control site and are almost exactly the same as those from the downstream creekside monitoring site for all three trials (Figure 3). The results obtained from the in situ tests in which food was provided only at the start of the test were encouraging, with close resemblance in egg production to that found for the daily feeding in situ test in the first two trials. If start-only feeding can be used for the in situ method, this will have substantial benefits for staff resourcing. It will also mean that this monitoring technique will be much more viable for extended deployment at less accessible (for example, Gulungul Creek) or more remote locations. Accordingly, both feeding regimes will be further evaluated during the 2006–07 wet season.

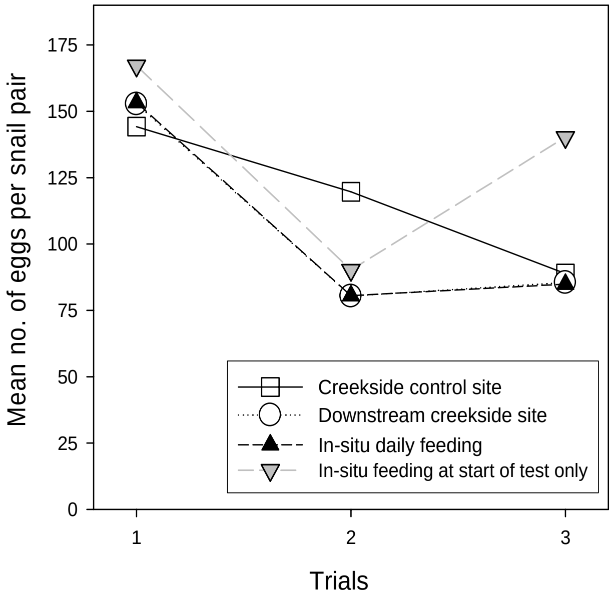

Figure 3 Comparison of freshwater snail egg production for routine creekside monitoring and two feeding regimes of in situ toxicity monitoring

Over a decade of baseline creekside monitoring test data has been obtained since 1991–92 (Figure 1) using the established creekside protocols and infrastructure. It is thus critical to ensure that the proposed in situ method yields comparable results before it can be phased in as the sole procedure in the future. To this end, further testing of the in situ deployment vessels and feeding regimes will be conducted in parallel with creekside monitoring over at least two wet seasons.

The testwork will be extended to the downstream site in the 2006–07 wet season. Future comparative tests will focus on the paired-site monitoring design employed for creekside monitoring (described above) and compare the 'differences' in responses between upstream and downstream sites for both test conditions and feeding regimes.

Bioaccumulation in fish and freshwater mussels from Mudginberri Billabong

K Turner, B Ryan, C Humphrey & A Bollhöfer

Mudginberri Billabong is the first major, permanent waterbody downstream (12 km) of the Ranger mine (Map 3). Local Aboriginal people harvest aquatic food items, in particular fish and mussels, from the billabong and hence it is essential that they are fit for human consumption. In this context, fitness for consumption refers to levels of metals and/or radionuclides, as related to potential impacts of solutes from the minesite. Microbiological indicators are not measured as part of the SSD's monitoring program.

Any significant increases in metal and radionuclide concentrations in aquatic biota measured through time (or compared to an appropriate reference site) would also provide the potential for early warning of a developing issue with bioavailability of mine-derived solutes. This provides an ecosystem protection role for the bioaccumulation monitoring program, in addition to the human health aspect.

Bioaccumulation data have been obtained from Mudginberri Billabong since 1980 and from a control site (Sandy Billabong, channel, Map 3) since 2002. The concentrations of radionuclides and metals in freshwater mussels from Mudginberri and/or Sandy Billabongs between 1983–2003 were reported and discussed by Ryan et al (2005). Uranium and radium data from this report have been included in the time series of data discussed below.

The metal and radionuclide data from mussels in Mudginberri span a long period, but are intermittent from the early period. In addition, metals data for mussels from the early to mid 1980s may suffer from QA/QC problems (specifically relating to adventitious contamination of samples by metals) arising from the outsourcing of chemical analyses or from within the laboratories of ERA.

Uranium concentrations in freshwater mussels from Mudginberri and Sandy Billabongs are shown in Figure 1. Uranium in mussels has been reported to have a short biological half-life (Allison & Simpson 1989). This published conclusion is supported by the data in Figure 1, with the uranium concentrations in mussel flesh being low and no evidence of an increasing trend in concentrations with mussel age (Ryan et al 2005). In particular, the concentrations of uranium in mussels from both the 'exposed' and control sites are very similar.

Also of note in the top panel of Figure 1 are the time series data for acid leachable uranium in sediment from Mudginerri Billabong. There is certainly no evidence of an increase through time, with essentially constant levels between 1989 and 2001, and lower levels from 2001 onwards. The decrease after 2001 may be an artefact of changes in the sampling regime or analysis method. A more detailed investigation of the concentrations of metals and radionuclides as a function of particle size class in control and exposed billabongs will be carried out in the second half of 2007.

Apart from uranium and radionuclides, metals data in fish from Mudginberri Billabong are sparse prior to 2000. A focused regular (two year frequency) sampling program was initiated by ***eriss*** in 2000 to measure metal levels. A summary of the work carried out by ***eriss*** since 1995 is provided in Table 1. The analytes chosen include key analytes that are likely to pose the highest risk to the environment and for human consumption in aquatic species that are common food items for traditional owners.

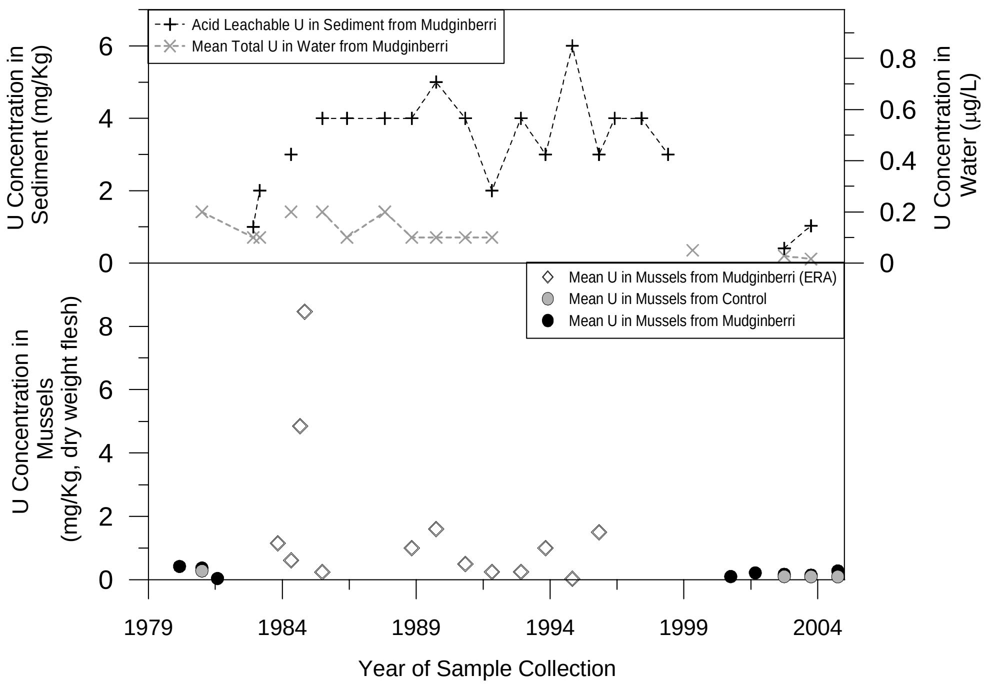

Figure 1 Mean concentrations of U measured in the mussel, sediment and water samples collected from Mudginberri billabong and control billabongs since 1979

Table 1 Summary of bioaccumulation sampling carried out by ***eriss*** in Mudginberri and Sandy Billabongs

Year	Species	Analytes	Tissues analysed
1984	AL	Cu, Zn	Flesh
1985	AL	Cd, Cu, Pb, Mn, Zn, U	Flesh
1988	AL	Cd, Cu, Pb, Mn, Zn, U	Flesh
1995	NE, AL, SJ, LC	Cd, Cu, Pb, Mn, Zn, U	Flesh, liver, kidney
1996	NE, AL, SJ, LC	Samples archived for future analysis	Flesh, liver, kidney
1997	NE, AL, SJ, LC	Samples archived for future analysis	Flesh, liver, kidney
1998	Various Catfish	Samples archived for future analysis	Bone, skin, gills, liver and kidney
2000	TA, AL	Ag, Al, As, Au, Ba, Bi, Ca, Cd, Co, Cr, Cu, Fe, Mg, Mn, Ni, Pb, Sr, U, Zn	Flesh, liver, kidney
2002	AL, TA, SJ, SB, LC	Al, Ba, Cd, Ca, Cr, Co, Cu, Fe, Pb, K, Mg, Mn, Na, Ni, Pb, Sr, U, Zn	Flesh, liver, bone, gill
2003	AD, AG, AL, NE, TA	Al, Sb, Ag, As, Ba, Ca, Cd, Co, Cr, Cu, Eu, Fe, Hg, K, Pb, Mg, Mn, Mo, Ni, Na, Re, Sb, Se, Sn, Sr, Zn, U, SO_4	Flesh, liver, bone, gill
2005	AL, TA, NH, NE, AG, SJ, AD, LC,	Cu, Pb, Mn, U, Zn	Flesh, liver, bone

AL – *Arius leptaspis* (forktail catfish); NE – *Nematalosa erebi* (boney bream); LC – *Lates calcarifer* (barramundi); SJ – *Scleropages jardini* (saratoga); TA – *Neosiluris ater* (eeltail catfish); AG – *Arius graeffei* (blue catfish); AD – *Anodontiglanis dahlia* (toothless catfish); SB – *Syncomistes butleri* (sharp-nosed grunter); NH – *Neosiluris hyrtlii* (Hyrtil's catfish).

After analysis and review of the available data, forktail catfish were identified as the most prospective species to monitor for uranium uptake, accumulating higher levels of metals than other common species inhabiting Mudginberri Billabong (Sauerland 2005). Thus, forktail catfish will continue to be monitored to provide early detection of mining impacts. Time series concentrations of uranium in the flesh of forktail catfish collected from Mudginberri and Sandy Billabongs are summarised in Figure 2, together with U concentrations measured in water and sediment.

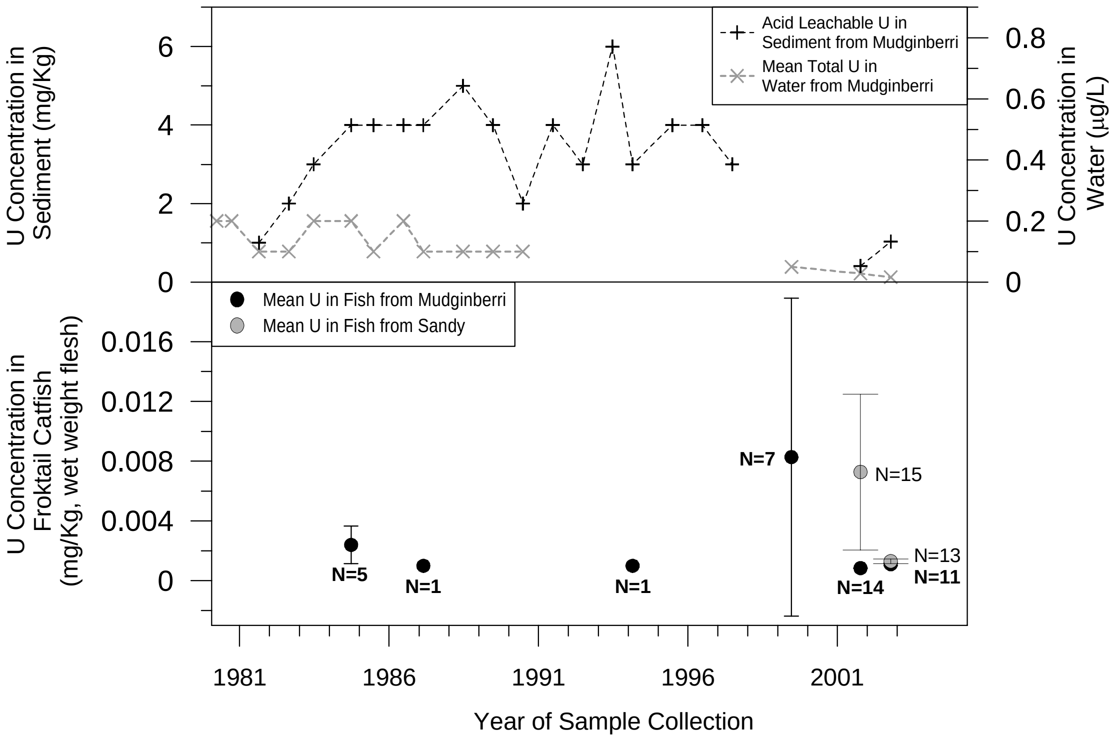

Figure 2 Mean concentrations of uranium measured in the flesh of forktail catfish, sediment and water samples collected from Mudginberri and Sandy Billabongs, since 1981. Error bars represent standard error.

Compared to uranium concentrations in the sediment, the concentrations in the flesh of forktail catfish are low (<0.02 mg/kg) with no significant variation over time (Figure 2). Error bars indicate that sample contamination was a significant issue in 1999 and 2001. Refinement of sample processing methods and analytical procedures reduced the amount of contamination in 2002.

Concentrations of Ra in mussels are age-dependent (Figure 3) and also appear to be related to growth rates and location within a billabong. Mudginberri sediments are finer where the mussels are currently collected, and hence have higher ^{226}Ra values than collections made earlier in the billabong, and as compared to the sandy, coarser sediments in Sandy Billabong (Ryan et al 2005). The need to better characterise sediment is now recognised and more extensive and refined sediment sampling and size fractionation protocols will be used for future sampling (starting end of 2006–07 wet season).

When comparing data from a particular season and a particular within-billabong location (Figure 3), concentrations of Ra in mussels from Mudginberri Billabong are seen to be higher, age-for-age, than in mussels from Sandy Billabong. Naturally higher catchment concentrations of Ra in Magela Creek compared with Nourlangie Creek catchment combined with lower concentrations of Ca (Ca can act as an antagonist to the uptake of Ra by aquatic organisms) in Mudginberri Billabong waters compared with Sandy (see explanation below) are the likely cause.

Earlier studies have shown that the presence of calcium in water reduces the rate of radium uptake and is inversely proportional to radium levels present in freshwater mussels in the region. There is more calcium in Sandy Billabong water, sediments and mussels than in the respective Mudginberri samples during the same period (Ryan et al 2005). This may contribute to the higher levels of ^{226}Ra in Mudginberri mussels when compared to Sandy Billabong mussels.

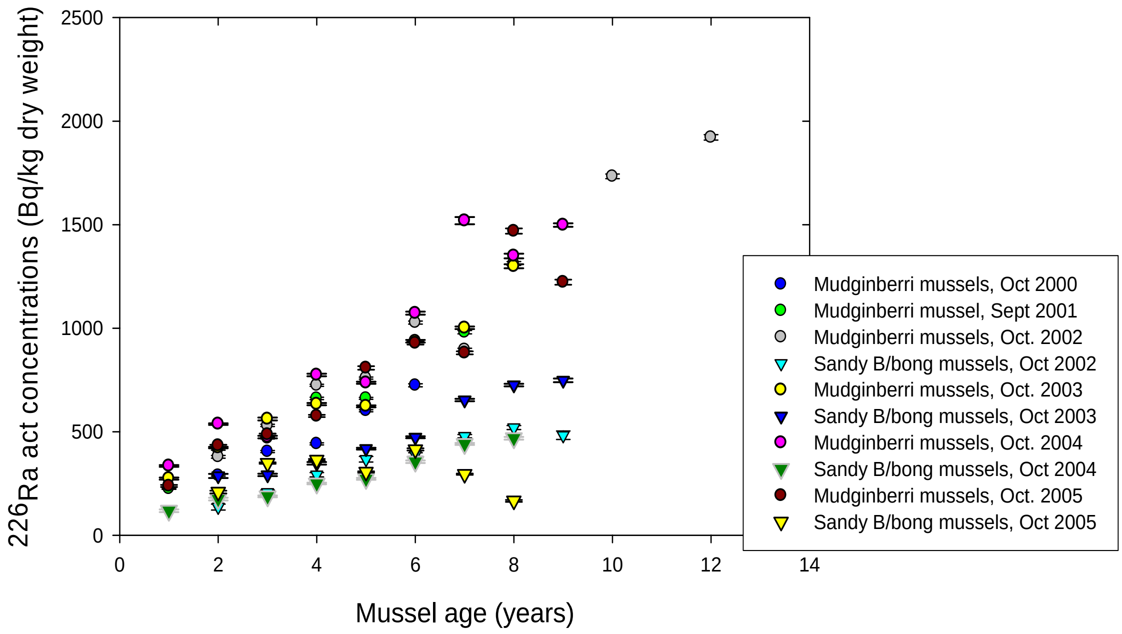

Figure 3 ^{226}Ra activity concentrations in the flesh of freshwater mussels collected from Mudginberri Billabong 2000-2005 and Sandy Billabong 2002–2005 (Ryan et al 2005)

Table 2 shows the current average committed effective doses calculated for a 10-year old child who eats 2 kg of mussel flesh, based upon average concentrations of ^{226}Ra and ^{210}Pb from Mudginberri and Sandy billabong mussels (2000–2005). Even if it was assumed that the difference in doses between the two billabongs was exclusively mine-related (most unlikely, see below), the mine contribution would still amount to only 10 per cent of the public dose guideline limit (ICRP 1996).

Table 2 Average committed effective dose for Mudginberri and Sandy billabong mussels 2000–2005 (Ryan et al 2005)

Sample	Committed effective dose (mSv)
Average all collections from Mudginberri Billabong	0.239
Average all collections from Sandy Billabong	0.133

Currently the extent of mine site influence on radionuclide concentrations in mussels in Mudginberri Billabong is inferred (based on comparison of Ra concentrations in water between MCUS and MG009) rather than being quantified by direct measurement. In this context it should be noted that the concentrations of radionuclides in the sediments of Mudginberri Billabong (and consequently the concentrations of Ra in mussels) may be an historic consequence of the weathering of surface exposed orebodies (#1 and #3) through time, rather than a consequence of the 'recent' mining operation. Sampling of mussels in Magela Creek upstream of Ranger coupled with measurements of radionuclide concentrations in suspended sediments will be used in 2006–07 to further investigate the extent to which the Ranger site contributes to the total concentrations of elements in Mudginberri mussels.

Notwithstanding the above, the generally consistent relationship between age and Ra concentration observed for mussels between years and for each billabong (Figure 3) currently provides a robust baseline against which any future mine-related change in Ra concentrations can be detected. The use of statistical methods to determine differences in regression relationships (from Figure 3) will be explored as a means for quantifying any such future change.

A review of the bioaccumulation study of metals and radionuclides at Ranger, described above, was undertaken in October 2005. A number of recommendations and outcomes arose from the review (Jones 2005), including:

- The need to stream-line the bioaccumulation sampling program for freshwater mussels and fishes, by having uniform sample preparation and analysis protocols for ecosystem and human health requirements (implemented);
- Undertake a risk assessment using ICPMS scans of waters from a variety of key locations to identify which metals (dilution and attenuation taken into account) need to be the focus of the future bioaccumulation analysis suite (completed and data interpretation underway);
- The need to quantify the relationship between Ra in mussels and the filter-feeder-relevant < 63 µm sediment fraction in Mudginberri Billabong. Only total sediments have been analysed to date so it has not been possible to properly account for differences in Ra concentrations for mussels collected from different parts of the billabongs and to directly compare measured concentrations with those in the coarser sediment from Sandy Billabong (implemented);
- As described above, the need to initiate a sampling program of mussels resident in Magela upstream and downstream (before Mudginberri Billabong) of Ranger to address the issue of whether mine is contributing higher Ra and U in Mudginberri Billabong mussels compared to Sandy Billabong mussels (to commence in May 2007).

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Monitoring using macroinvertebrate community structure

C Humphrey, J Hanley & C Camilleri

Macroinvertebrate communities have been sampled from a number of sites in Magela Creek at the end of significant wet season flows, each year from 1988 to the present. The design and methodology have been gradually refined over this period to both improve the ability to confidently attribute any observed changes to mining impact and to carry out the work more efficiently. The most significant refinement that took place in the study occurred in 1994 when there was a reduction from ten sites sampled in Magela Creek to just three, as well as commencement of sampling at reference sites in three additional streams not thought to be impacted by mining. Since 1994, there have also been three changes to sampling and sample processing methods (Humphrey & Pidgeon 1998).

As described in the previous Research Summary (2004–2005, SSR189), the refined (1994) design for this macroinvertebrate study is now based on the principle of gathering macroinvertebrate samples from sites in Magela and Gulungul Creeks upstream and downstream of Ranger (Gulungul Creek now no longer regarded as a reference stream), and also from similar paired upstream and downstream sites in two adjacent 'control' streams (Baroalba and Nourlangie Creeks) that are generally unaffected by any mining activity (Map 3). Thus the design of this study is a balanced one comprising two 'exposed' streams and two control streams.

Five replicate samples (each 0.31 m^2 in area) were collected from macrophyte-edge habitat at each site, using a Surber sampler, at the end of each wet season (between April and May, 2006). For each sampling occasion and for each pair of sites for a particular stream, a dissimilarity index is calculated. This index is a measure of the extent to which macroinvertebrate communities of the two sites differ from one another. A value of 'zero' indicates identical macroinvertebrate communities while a value of 'one' indicates totally dissimilar communities, sharing no common taxa.

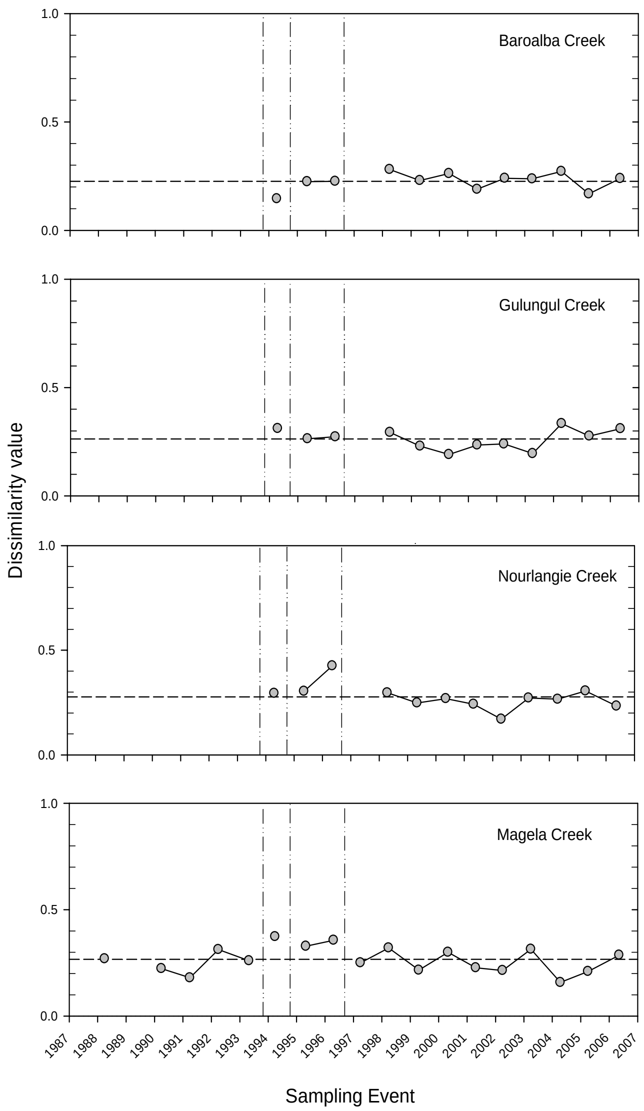
Research elsewhere in the Alligator Rivers Region (eg Faith et al 1995) has shown significantly 'higher' dissimilarity values for locations upstream and downstream of point sources of disturbance compared with values recorded in the pre-disturbance, baseline period in a stream prior to the start of an impact, and in still-undisturbed control streams. The higher dissimilarity is a consequence of the 'altered' (disturbed) macroinvertebrate community structure downstream of such point sources.

Analysis of the full macroinvertebrate data set from 1988 to 2006 has been completed and results are shown in Figure 1. This figure plots the paired-site dissimilarity values using family-level (log-transformed) data, for the two Magela catchment streams and two Nourlangie catchment (control) streams.

Inferences that may be drawn from the data shown in Figure 1 are weakened because there are no pre-mining (pre-1980) data for Magela and Gulungul Creeks upon which to assess whether or not significant changes have occurred as a consequence of mining. Notwithstanding this, the plots show that the mean dissimilarity value for each stream across all years is approximately the same (~0.3) and that the values are reasonably constant over time. Confirming this, single-factor ANOVA shows no significant difference in the mean dissimilarities between the two treatment groups, 'control' versus 'potentially disturbed' streams.

Dissimilarity indices such as those used in Figure 1 may also be 'mapped' using multivariate ordination techniques to depict the relationship of the community sampled at any one site and sampling occasion with all other possible samples. Samples close to one another in the ordination indicate a similar community structure. Figure 2 depicts the ordination derived using the same macroinvertebrate data that were used to construct the dissimilarity plot from Figure 1. Data points are displayed in terms of the sites sampled in Magela and Gulungul Creeks downstream of Ranger for each year of study (to 2006), together with all other control sites sampled for the same period. Because the data-points associated with these two sites are interspersed amongst the points representing the control sites, this indicates that these 'exposed' sites have macroinvertebrate communities that are not dissimilar to those occurring at control sites.

Figure 1
Paired upstream-downstream dissimilarity values (using the Bray-Curtis measure) calculated for community structure of macroinvertebrate families in several streams in the vicinity of the Ranger uranium mine for the period 1988 to 2006. The dashed vertical lines delineate periods for which a different sampling and/or sample processing method was used. Dashed horizontal lines indicate mean dissimilarity across years.



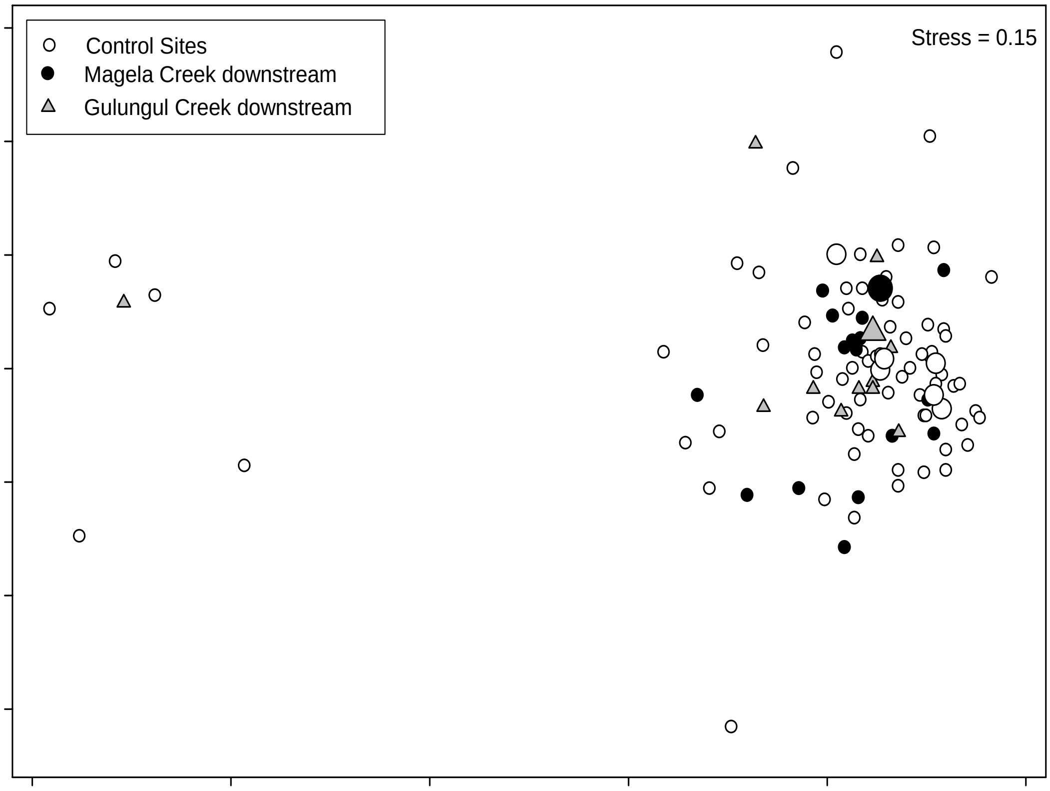


Figure 2 Ordination plot of macroinvertebrate communities sampled from sites in several streams in the vicinity of the Ranger mine for the period 1988 to 2006. Data from Magela and Gulungul Creeks for 2006 are indicated by the enlarged symbols.

Collectively, these results provide good evidence that changes to water quality downstream of Ranger as a consequence of mining in the period 1994 to 2006, have not adversely affected macroinvertebrate communities.

A related study of macroinvertebrate communities, sampled from shallow lowland billabongs in May 2006, is aimed at providing a biological basis for developing water quality closure criteria for the billabongs immediately adjacent to Ranger. The results from this billabong study and those acquired in future years from the same sites may also serve an important biological monitoring role.

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Monitoring using fish community structure

C Humphrey & D Buckle

Sampling of fish communities in billabongs is conducted between late April and the end of June each year. Two types of data are gathered, using non-destructive sampling methods:

1 Visual observation data from two deep channel billabongs: Mudginberri Billabong on Magela Creek about 12 km downstream of Ranger ('exposure' billabong, 1989–present); and Sandy Billabong on Nourlangie Creek (control billabong, independent catchment, 1994–present).

2 Data from 'pop-nets' set in shallow weedy lowland billabongs, in various combinations of billabong exposure types, located in Magela and Nourlangie Creek catchments, from 1994 to the present.

Shallow lowland billabongs

Fish in shallow billabongs were not sampled in 2006 given the extensive (annual) database already available and the results from power analysis which indicated that not sampling after the 2005-06 wet season would not significantly reduce the power of the historical data set.

This program of work was reviewed, along with the broader biological monitoring program, in early October 2006. The outcomes of this review will be reported in next year's Annual Research Summary.

Channel billabongs

The extent of similarity between fish communities in Mudginberri Billabong (impact site downstream of Ranger) and Sandy Billabong (control site in the Nourlangie catchment) (Map 3) was determined using multivariate dissimilarity indices. Calculated for each annual sampling occasion, the dissimilarity index is a measure of the extent to which fish communities of the two sites differ from one another. A value of 'zero' indicates identical fish communities while a value of 100% indicates totally dissimilar communities, sharing no common species. A significant change or trend in the dissimilarity values over time could imply mining impact. A plot of the dissimilarity values from 1994 to the present is shown in Figure 1.

Dissimilarity indices may also be mapped in an ordination to depict the relationship of the community sampled at any one site and sampling occasion with all other possible samples. Shifts in fish community structure have been observed in both billabongs over time (Figure 2). While the sites do not faithfully 'track' one another from year to year, the patterns and extent of 'meandering' are not too dissimilar. In the last four years, community structure in both sites has become more similar (annual data points in Figure 2 for the two sites are closer together), and this community structure has also become more similar to that found at the commencement of the paired-site study in 1994.

In the Supervising Scientist Annual Report for 2003–2004, a significant decline was noted in the paired-site dissimilarity measures over time. This decline has continued (Pearson's correlation R = -0.70, P<0.05) with the value reported in 2006 the lowest yet recorded (Figure 1). The decline is primarily attributed to the particularly high abundances in the early years of the study of chequered rainbowfish (*Melanotaenia splendida inornata*) and to a lesser extent glassfish (*Ambassis* spp) in Mudginberri Billabong, relative to Sandy Billabong. Chequered rainbowfish have declined in Mudginberri Billabong since sampling commenced in 1989. The decline in rainbowfish numbers, and by association, the paired billabong dissimilarity value, is not related to any change in water quality over time as a consequence of water management practices at Ranger. This issue was examined in more detail in the Supervising Scientist's 2004–05 Annual Report where the environmental correlates (1) wet season stream discharge, (2) natural, wet season stream solute concentration, (3) length of previous dry season, and (4) habitat conditions on Magela Creek floodplain, were identified as possible causes of the decline in rainbowfish.

Further work will be needed to elucidate the cause of the decreasing dissimilarity of fish communities between Sandy and Mudginberri Billabongs. The continued decline has been less influenced by chequered rainbowfish and glassfish in the latter years, suggesting more subtle changes in community structure are also occurring.

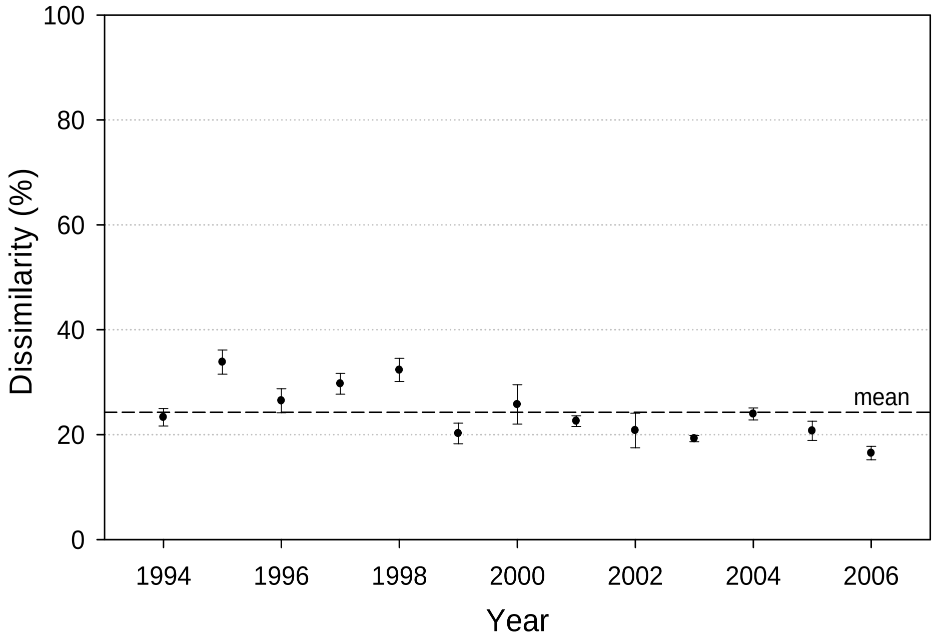

Figure 1 Paired control-exposed dissimilarity values (using the Bray-Curtis measure) calculated for community structure of fish in Mudginberri ('exposed') and Sandy ('control') billabongs in the vicinity of the Ranger uranium mine over time. Values are means (± standard error) of the 5 possible (randomly-selected) pairwise comparisons of transect data between the two billabongs. There has been a significant decline in paired-site dissimilarity over time but there is no evidence that this decline is mine-related (see text for further explanation).

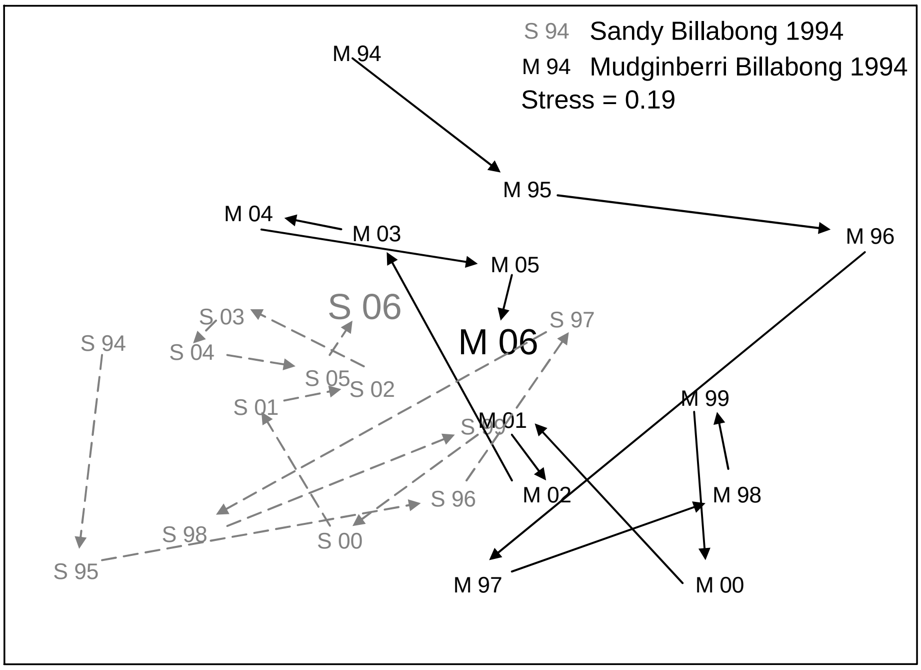

Figure 2 Ordination plot of fish communities sampled from two channel billabongs in the vicinity of the Ranger uranium mine for the period 1994 to 2006. Lines follow the trajectory of sites over time. The two-dimensional MDS was generated using Log(X+1) data. Data were averaged prior to generating Bray-Curtis dissimilarity matrix.

Monitoring support tasks

C Humphrey

Publication of protocols for the SSD's stream monitoring program in Magela Creek

Background and progress to date

Protocols for the SSD's stream monitoring program are being prepared for publication. Progress in preparing these protocols was reported to ARRTC in late February 2005. At that time, it was proposed to ARRTC that publication of the high-level protocols in the SSR series would be completed in 2006. Delays in publication have been experienced due to:

1 Competing priorities (including rehabilitation research); but most significantly

2 The need to document, as a priority, operational manuals pertaining to each of the protocols. This task was rated a high priority because of the risks associated with loss of corporate knowledge should critical staff leave the SSD. This task has diverted staff time away from completion of the high level protocols.

Work on the operational manuals and high-level protocols is well advanced and is anticipated that they will be completed in time for the commencement of the respective monitoring techniques in the upcoming 2006–07 wet season.

Internal review of the routine biological monitoring program

Background

In early October 2006, a workshop was held to internally review the SSD's routine biological monitoring program. The review took into account:

1 Possible reduced sampling (frequencies/effort) for components of the program, considering factors such as:

   a. sensitivity of monitoring organisms to mine-related, water quality changes;

   b. adequacy of current datasets as a basis for monitoring during the operational and rehabilitation phase; and

   c. competing resources in so far as possible increased intensity of new monitoring approaches and rehabilitation research

2 Optimisation of existing techniques (i.e. similar results with similar power, but with fewer samples/data); and

3 Wishes of stakeholders, including local landowners

Preliminary outcomes of the review were presented to the 18th meeting of ARRTC (October 2006) while the proceedings are currently being prepared as a Supervising Scientist Internal Report.

Surface water radiological monitoring in the vicinity of Ranger and Jabiluka

A Bollhöfer, P Medley & C Sauerland

Introduction

Since 2001 the monitoring techniques developed by SSD for environmental assessment of aquatic ecosystems have been implemented by way of a routine monitoring program. This includes the measurement of physical, chemical and radiological indicators in Magela and Gulungul Creeks, upstream and downstream of the Ranger mine (Supervising Scientist, 2004).

Surface water samples in the vicinity of the Ranger and Jabiluka project areas are regularly monitored for their ^{226}Ra activity concentrations to assess if there have been any changes in ^{226}Ra activity concentration downstream of the mine sites, and hence in the potential risk of increased exposure to radiation via the biophysical pathway due to mining-related activities. Water samples are collected weekly in Magela Creek and monthly in Ngarradj (Swift) Creek at sites both upstream and downstream of the project areas according to the ***eriss*** surface water monitoring protocol (Sauerland & Iles 2005).

Methods

All Ngarradj samples, and Magela Creek samples from every second week, are analysed for total ^{226}Ra (ie, combined filtered and particulate fractions) in ***eriss***'s radiochemical laboratories following a method described in Medley et al (2005).

The remaining fortnightly samples for Magela Creek are combined into '*wet season composite samples*', one for the upstream site and one for the downstream site.

Results

Magela Creek

Figure 1 shows the results of the ^{226}Ra monitoring from 2001–2005. The levels of ^{226}Ra are very low in Magela Creek. A paired two-tailed t-test indicates that the ^{226}Ra activity concentrations are not significantly different between the Magela creek downstream and upstream sites for the 4 wet seasons. The total ^{226}Ra activity concentrations at the upstream site can at times be higher than at the downstream site. However a ^{226}Ra activity concentration of 8.8 mBq/L^{-1} for the upstream site on the 15th of February 2005 was probably due to contamination along the sampling and processing chain of that particular sample.

Table 1 shows the median and standard deviations of the means for individual wet seasons for the entire study period. The '*wet season composite samples*' (not shown) for both the upstream and downstream locations compare well to the wet season median but have a lower variability due to the compositing. In 2004–05 the ^{226}Ra activity concentrations of the '*wet season composite sample*' from Magela Creek both upstream and downstream, was 2.4 mBq/L.

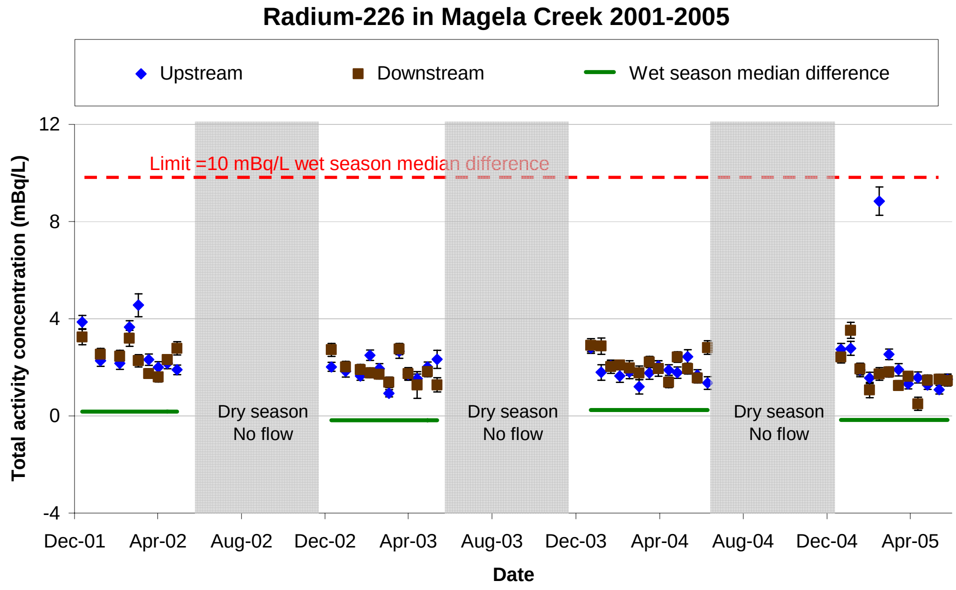

Figure 1 Time series of total radium-226 activity concentrations in Magela Creek (2001 to 2005)

A limit for ^{226}Ra concentration in surface waters downstream of Ranger has been defined for human radiological protection purposes (Klessa 2001) and is based on the potential dose received from the ingestion of ^{226}Ra in the freshwater mussel *Velesunio angasi* (Martin et al 1998). The upstream median value is subtracted from the median at the downstream site (Sauerland et al 2005) – the wet season median difference (shown in Figure 1) – and should not exceed10 mBq/L.

Table 1 Statistics for total ^{226}Ra activity concentrations [mBq/L]

Magela creek		All years	2001–02	2002–03	2003–04	2004–05
Median and standard deviation of the mean	upstream	1.9 (± 1.2)	2.3 (± 1.1)	2.0 (± 0.5)	1.8 (± 0.4)	1.7 (± 2.1)
	downstream	1.9 (± 0.6)	2.5 (± 0.6)	1.8 (± 0.5)	2.0 (± 0.5)	1.6 (± 0.7)
Wet season median difference		0.0	0.2	- 0.2	0.2	- 0.2
Ngarradj		All years	2001-02	2002-03	2003-04	2004-05
Median and standard deviation of the mean	upstream	1.2 (± 0.5)	1.2 (± 0.6)	1.4 (± 0.6)	1.1 (± 0.4)	1.3 (± 0.3)
	downstream	1.2 (± 2.0)	3.0 (± 2.8)	1.1 (± 1.5)	0.9 (± 0.9)	1.0 (± 0.6)
Wet season median difference		0.0	1.8*	- 0.3	- 0.2	-0.3

* note that the error of this number is greater than 1.8

The wet season median difference for the 2001–05 wet seasons is approximately zero. The available data for the four sampling seasons indicate that ^{226}Ra levels in Magela Creek are due to the natural occurance of radium in the environment and that mine origin radium has not caused any impact on human health.

Ngarradj Creek

The very low ^{226}Ra activity concentrations in Ngarradj Creek are shown in Figure 2 below. Although there were significant differences observed during the first two wet seasons between the upstream and the downstream monitoring site, Figure 2 shows that ^{226}Ra activity concentrations at the Ngarradj downstream site have been similar to those at the upstream site since December 2003, coinciding with the inception of the long-term care and maintenance phase at Jabiluka in the 2003 dry season. A paired two-tailed t-test of the data from the last two wet seasons indicates that there is no significant difference between upstream and downstream ^{226}Ra activity concentrations at the 95 % confidence level.

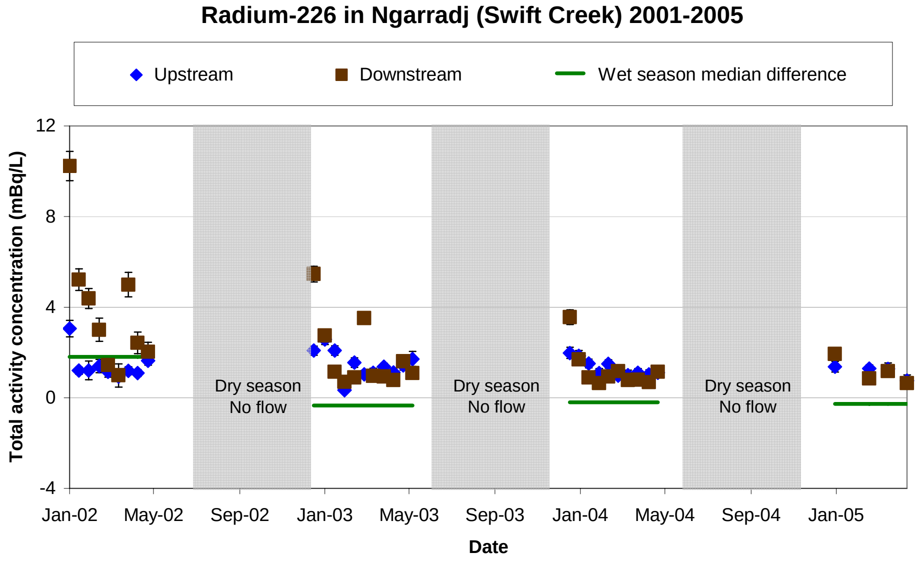

Figure 2 Radium-226 concentrations measured in Ngarradj from 2001 to 2005

Steps for completion

^{226}Ra activity concentration data for the 2005–06 wet season are currently being analysed and compiled and will be reported when complete. The monitoring of ^{226}Ra in Magela Creek and Ngarradj will continue in the 2006–07 wet season.

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Surface water transport of uranium in the Gulungul catchment

K Mellor[1], A Bollhöfer, C Sauerland & D Parry[1]

Introduction

Gulungul Creek lies to the west of Ranger mine and flows north to join Magela Creek, a tributary of the East Alligator River. Part of the mine's infrastructure, notably the tailings dam, lies partially within the Gulungul Creek catchment (Figure 1). Flow in the creek occurs mostly in the wet season, during which time it is made up of the main channel and numerous side channels and tributaries, three of which flow from areas possibly influenced by the Ranger mine.

Since 2001 the water quality monitoring program for Gulungul Creek upstream and downstream of the Ranger mine has included the measurement of physical and chemical indicators, including pH, electrical conductivity, suspended solids, sulphate and uranium concentration, (Supervising Scientist 2004).

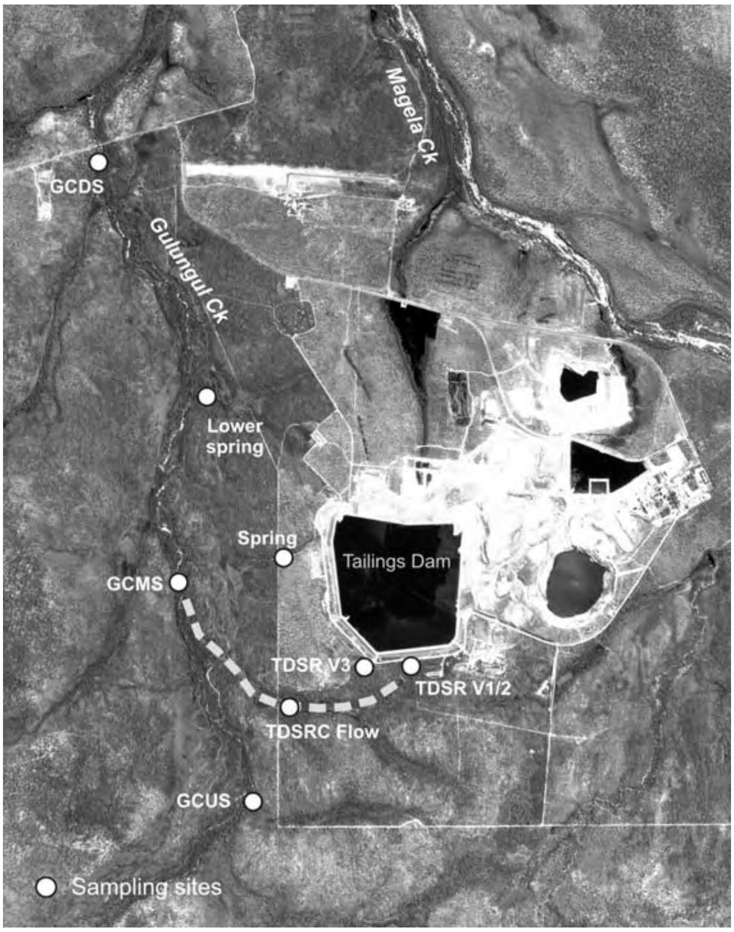

Figure 1 The Gulungul catchment and project sampling sites

[1] Charles Darwin University, Darwin

In January 2004, higher concentrations of uranium were found at Gulungul Creek downstream (GCDS) compared to Gulungul Creek upstream (GCUS). This difference in concentrations was greater than in previous years, and coincided with lower pH values, higher EC values and higher sulphate concentrations at the downstream site. Although the uranium concentrations were more than one order of magnitude less than the 99% ecosystem protection limit value of 6 µg/L established for Magela Creek, they were comparable to the focus trigger value for GS009 in Magela Creek. An investigation was therefore initiated to identify the source and mechanism of the increase.

Methods

In addition to the routine monitoring samples that were collected during the 2004–05 wet season, several field trips were conducted to collect surface water samples from elsewhere in the catchment for chemical and radionuclide analysis. Samples were collected from the upstream (GCUS), downstream (GCDS) and midstream (GCMS) sites and from several locations in the vicinity of GCMS, ie downstream at 'GCMS – 10 m', 'GCMS – 50 m' and upstream at 'GCMS + 50 m' and 'GCMS + 150 m'. Additional samples were taken from V-notches (TDSRV 1–3) located upstream of the tailings dam southern road culvert (TDSRC), the overland flow from TDSRC (TDSRC flow), a spring tributary flow (Spring) and from a swampy area produced by another suspected spring (Lower Spring) (Figure 1). Samples were collected in (i) February 2005, several days after a four day period of heavy rain that resulted in the flooding of the creek; (ii) in March 2005, towards the middle of the wet season when the creek was reasonably full; and (iii) in May 2005, towards the end of the wet season when water flow was much diminished and sampled tributaries had dried up.

Heavy metal and uranium concentrations were measured via ICPMS. Activity ratios of uranium isotopes were measured via alpha spectrometry to determine whether there was a difference in upstream and downstream activity ratios that may enable discrete contributing sources to be identified (Ivanovich & Harmon 1982). Uranium activities were extremely low and the standard chemical pre-concentration procedures needed to be modified to increase the chemical recovery of uranium from solution prior to isotope analysis.

Results

Uranium concentration

Figure 2 shows the routine weekly uranium monitoring results for GCUS and GCDS, the difference between downstream and upstream uranium concentrations, and the catchment rainfall measured at Jabiru Airport during the 2003–2004 and 2004–2005 wet seasons.

Differences between downstream and upstream uranium concentrations in Gulungul Creek during the first part of the 2004–05 wet season were less pronounced than in the previous wet season. Although there is no direct correlation between rainfall and uranium concentration over these wet seasons, it appears that the cumulative effect of heavy rain influences the difference in uranium concentration measured upstream and downstream of the mine. Rainfall was reasonable heavy and constant during December-January (582 mm in 25 days) leading up to the uranium increase at GCDS in the 2003–04 wet season. In the 2004–05 wet season rainfall was lower and less frequent, apart from two large rain events in early January and February.

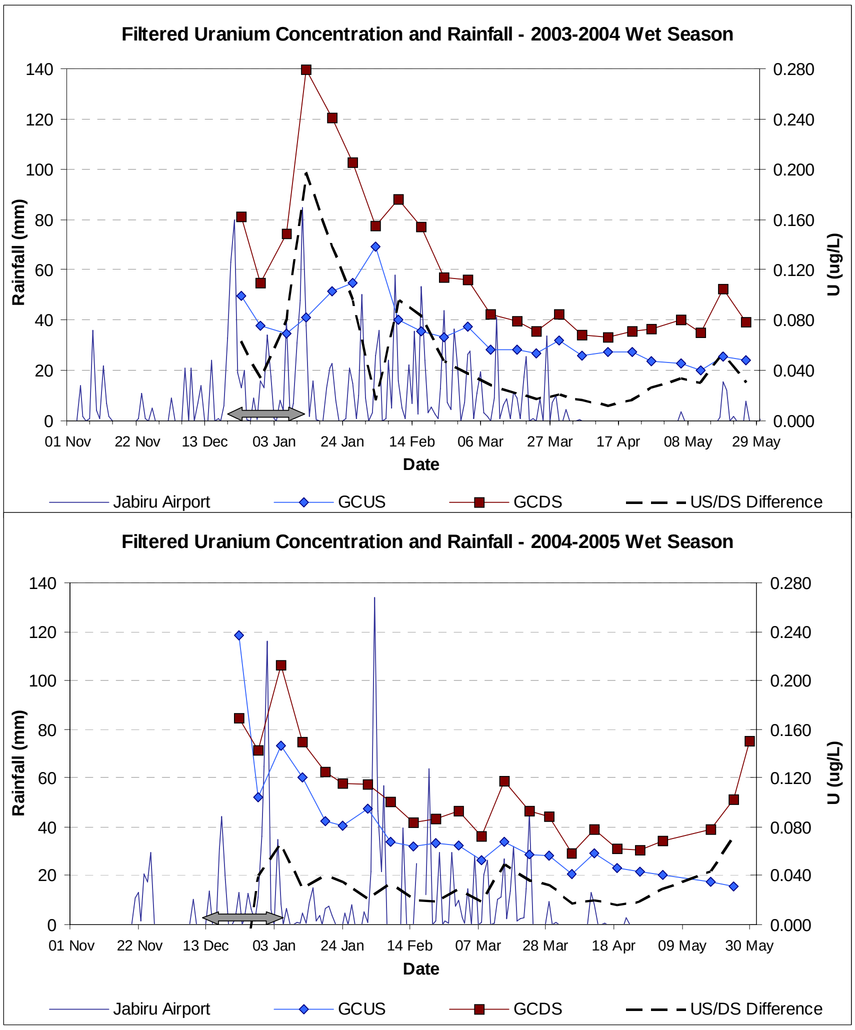

Figure 2 Uranium concentration and rainfall in the Gulungul Creek catchment

Table 1 shows the spatial distribution and the per cent increases in uranium concentration along Gulungul Creek measured in 2005. The data indicate that during the peak of the wet season (February, March), much of the increase in uranium concentration between GCUS and GCDS had already occurred at GCMS. The disparity in uranium input over time indicates that uranium input into the creek may be dependent on specific hydrological conditions. This is supported by the 2005–06 wet season data (Figure 3), which exhibit a uranium spike even higher than in 2003–04, and a similar rainfall pattern: the increase in uranium is preceeded by a period of relatively heavy, constant rain (515 mm in 25 days).

Table 1 Percent increase in filtered uranium concentration in Gulungul Creek in 2005 (dd/mm)

Site	Distance	Filtered U (µg/L)			Increase from GCUS to GCDS (%)			Increase above GCUS (%)		
	(m)	08/02	18/03	10/05	08/02	18/03	10/05	08/02	18/03	10/05
GCUS	0	0.068	0.060	0.045	0	0	0	0	0	0
GCMS +150m	1950	ns	ns	0.052	-	-	21	-	-	17
GCMS +50m	2050	0.087	0.093	0.053	58	74	23	28	56	19
GCMS -10m	2215	ns	0.105	0.054	-	100	26	-	76	22
GCMS -50m	2255	ns	ns	0.055	-	-	27	-	-	23
GCDS	6520	0.101	0.105	0.082	100	100	100	48	76	85

ns: not sampled

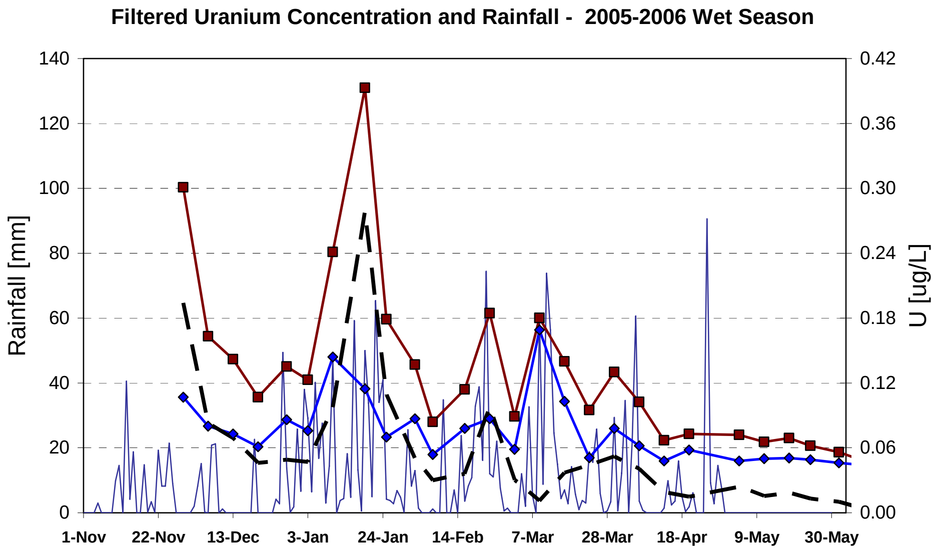

Figure 3 Uranium concentration and rainfall in Gulungul Creek, 2005–06 wet season

Uranium isotope activity ratios

The $^{234}U/^{238}U$ activity ratios measured in Gulungul Creek samples from 2004 and 2005 range from 1.26–1.69 for the upstream site, and from 1.12–1.45 for the downstream site. Although changes in upstream and downstream uranium concentrations do not appear to directly influence the magnitude of the ratios measured at each of these locations, the midstream ratios in samples collected in 2005 do exhibit such an influence. Figure 4 shows the inverse concentration plots for samples taken at GCUS and GCMS. Whereas GCUS uranium activity ratios are relatively constant at approximately 1.4, the midstream site exhibits a signature indicating mixing of two sources with endmembers represented by the upstream ratio and a ratio approaching 1. A $^{234}U/^{238}U$ activity ratio close to 1 is found for uranium in the flow from the tailings dam southern road culvert (TDSRC) that enters Gulungul Creek in the vicinity of GCMS, and represents a ratio typical for a mine-related source (Iles et al 2002).

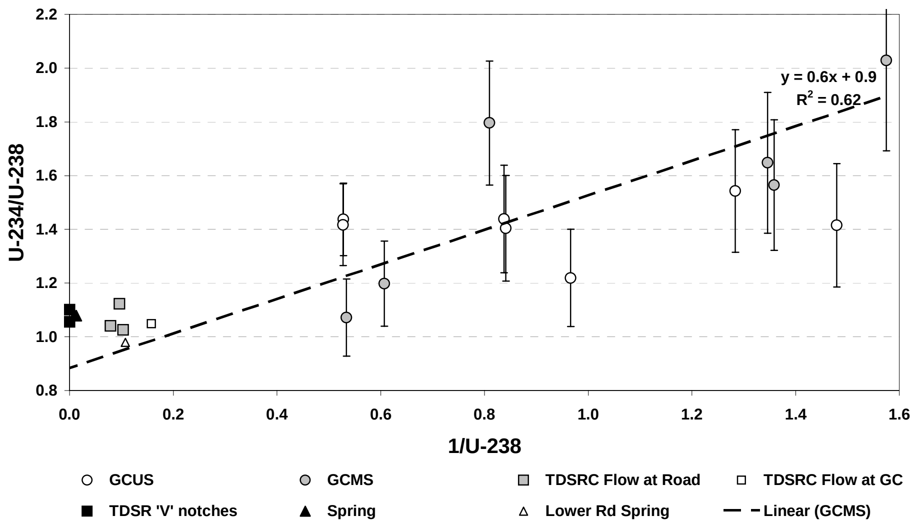

Figure 4 Uranium activity ratio data for 2005 plotted versus the inverse total uranium-238 activity concentration (L/mBq) measured at GCUS, GCMS and various possible sources in the catchment

Soil sampling

To further investigate the cause for the increase in uranium concentration measured in the creek, soil samples were taken in the dry season along the tributary indicated by the dashed line in Figure 1. Uranium concentrations in the soils decrease by almost 3 orders of magnitude from the tributary source close to the tailings dam, to where it enters Gulungul Creek, indicating significant attenuation of uranium, and other metals including manganese, copper and nickel. Leaching experiments show that much of this uranium and other heavy metals is able to be readily leached from the dry soils into water.

The previously identified large areas of black soils in the Gulungul catchment (Crossing 2002, Klessa & Welch 2003) thus appear to be acting as a sink and a source of contaminants from one season to the next. During the initial phase of the following wet season the metals leached out of the black soils in the vicinity of GCMS are flushed down into Gulungul Creek and cause elevated concentrations of uranium and other heavy metals, and a decrease in uranium isotope activity ratios in the vicinity of GCMS.

Summary

There is an input of U and other heavy metals into Gulungul Creek between the upstream and midstream sites, which produces consistently lower $^{234}U/^{238}U$ activity ratios at the downstream site. The contaminating uranium exhibits a $^{234}U/^{238}U$ activity ratio of ~1 and may originate from areas of black soils between the tailings dam and GCMS, which contain readily available metals. The metals are leached from dry soils at the start of the wet season, then accumulate and flush down into the creek under specific hydrological conditions. Uranium loads and discharges from this source required to shift uranium activity ratios in Gulungul Creek from a maximum of 1.40 at GCUS to 1.20 at GCDS (March 18, 2005) have been estimated at 665 µg/s and 1740 L/s, respectively, which is less than ¼ of the GCUS discharge, and is considered a realistic possibility. Future work will focus on event based sampling at GCMS and subsequent measurement of heavy metals, uranium and uranium activity ratios.

Acknowledgments

Thanks to Peter Medley, Jared Sellwood and Dene Moliere for their support of the laboratory and field work, and to Paul Martin and Arthur Johnston for initial discussion about formulating the project.

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Part 2: Ranger – Rehabilitation

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KKN 2.2.2 Characterisation of terrestrial and aquatic ecosystem types at analogue sites

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KKN 2.5.1 Monitoring of the rehabilitated landform

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Geomorphic stability of the currently proposed final landform at the Ranger mine using landform evolution modelling

J Lowry, KG Evans, D Moliere & G Hancock[1]

Introduction

The work reported here represents a continuation of the 2004–05 workplan. Co-operative work was conducted with EWLS assessing erosion on proposed rehabilitated landforms using the SIBERIA landform evolution model. In previous years proposed landform designs could only be modelled for surface conditions representing best and worst case scenarios as it was discovered that SIBERIA was unable to perform distributed hydrology modelling. That is, it was unable to implicitly address the different hydrology characteristics associated with the different surface conditions across the landform.

Consequently, in addition to assessing landforms developed by ERA/EWLS, an important aim of the work during the 2005–06 year was to ascertain whether current problems in incorporating hydrological parameters into the SIBERIA landform evolution model were a result of problems within the GIS interface (ArcEvolve), or the SIBERIA software itself.

Progress to date

During 2005–06, several landforms supplied by EWLS were modelled using the methodology described in Lowry et al (2004), in which the draft landform was modelled for a period of 1000 years, with hydrology parameters held constant for the entire landform and erosion parameters varied for each region of the landform representing different surface treatments. Through the GIS interface, it was possible to identify areas of potential erosion/deposition by subtracting the 1000-year modelled surface from the current surface (Fig 1).

SIBERIA simulations of erosion on the latest proposed landform (number 785-014) supplied by EWLS using the ArcEvolve interface (Boggs 2003) identified areas on the draft landform which needed to be redesigned in order to minimise erosion from the landform. A gully with a maximum depth of up to 8 metres was predicted to form on the left side of Pit 3 during the 1000 year simulation period (Fig 1), with the size and extent of the gully varying for the different scenarios. Whilst recognising limitations with the modelling process, ‘best case’ and ‘worst case’ simulation scenarios provided confidence in a range of predicted erosion and deposition rates.

The results of the modelling were presented at the 2005 NARGIS (North Australian Remote Sensing and GIS) conference (Hollingsworth & Lowry 2005), and at a workshop jointly run by SSD and EWLS (Moliere 2006). Outcomes of the workshop were presented to ARRTC at the February 2006 meeting. Further modelling results were presented at the 1st International Seminar on Mine Closure, in Perth (Lowry et al 2006).

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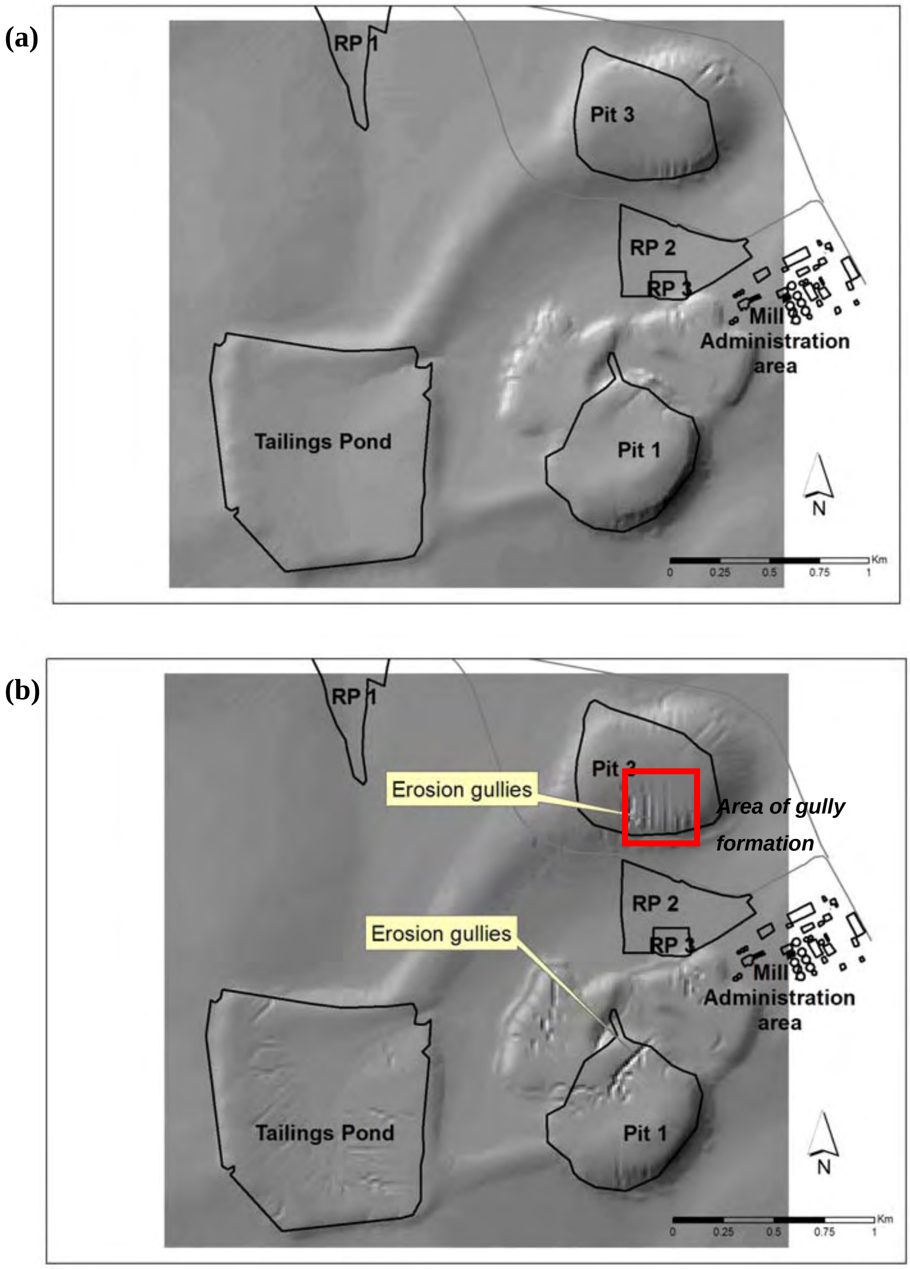

Figure 1 Areas of potential erosion / deposition on proposed 785-014 landform after 1000 years under (a) best case; and (b) 'worst case' scenario

Trial runs of the model indicated that the inability to perform distributed hydrology modelling was a problem of the GIS interface, rather than the Siberia modelling itself. To redress this situation the SIBERIA code has been modified by the University of Newcastle to perform distributed hydrology simulations independently of the interface. These indicate that under a 'worst case' scenario, erosion to a depth of 12 metres may occur. Conversely, the 'best case' scenario, which applied distributed hydrology parameters across the landform indicated erosion to a depth of 9 metres. This contrasts with the earlier trial runs, which indicated lower levels of erosion in both the 'best case' (3 metres) and 'worst case' (8 metres) scenarios. In both scenarios, and for both trials, erosion/deposition occurred in the same locations as predicted by the earlier modelling runs.

Steps for completion

SIBERIA will continue to be used to evaluate the erosion performance of future final landform designs proposed by ERA. However, it is recognised that the model needs to be upgraded to enable simulation of both short duration extreme rainfall events, and of continuous rainfall event records. The model currently operates using long-term average rainfall data. Further, as ERA proposes to incorporate a waste rock/laterite mix into the final landform, it will be necessary to incorporate parameters for these surfaces in order to assess the erosion performance of the final landform.

An important issue that needs to be addressed by ERA is ensuring the source digital elevation models (DEMs) supplied to ***eriss*** are at a resolution appropriate for the scale of the landform modelling. To date, the landforms have been supplied by EWLS as DEMs with a resolution of 25 metres. These have subsequently been resampled to a resolution of 12 metres. However, this resolution is poorer than required to track the evolution of erosion features, appropriate to the scale of the landform. A DEM with a resolution of 10 metres is regarded as optimal for the Ranger area.

'Stress testing' of the landform by incorporating extreme events into the modelling process is a critical component needed for final validation of the proposed design parameters. In part, it is proposed to use the palaeorecord to define the magnitude of the extreme events that need to be evaluated.

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Assessment of the significance of extreme events in the Alligator Rivers Region

KG Evans, MJ Saynor & DR Moliere

Introduction

The ARRTC14 (September 2004) breakout session on extreme flood event impact in the Alligator Rivers Region proposed:

- A comprehensive literature review of extreme rainfall and flood events in tropical Australia;
- Cross sectional analysis of flood hydrology model outputs to estimate flood peak heights and stream powers to assess erosion of containment structures during extreme events;
- Calibration of hydrology models for the Gulungul and Magela catchments to predict impacts of extreme storm events on the proposed rehabilitated landform at Ranger; and
- That should modelling of extreme events indicate a potential environmental risk, field studies should be undertaken to quantify peak discharges of extreme palaeofloods to accurately parameterise the hydrology models and confirm the level of risk.

This project addresses the literature review and the hydrology model for Gulungul and Magela Creek.

Progress to date

A CDU honours project (Ramsey 2006) calibrated a rainfall-runoff model for the Gulungul Creek catchment using observed large rainfall events and hypothetical 'extreme' events. However, the Magela flood hydraulic modelling component has not been started due to other priorities, in particular the need to concentrate resources on the upgrading and testing of the SIBERIA landform model for assessment of the effects of extreme rainfall events on the rehabilitated mine landform. Evaluating the geomorphic stability of the landform is of current highest priority given the requirement to finalise design criteria for the landform.

A comprehensive literature review is currently being undertaken on the subject of extreme event hydrology modelling. Finalisation of the review has been delayed due to the occurrence of Cyclone Monica in April 2006 and the extended 2005–06 wet season, requiring substantial additional field work by staff from the Hydrological and Geomorphic Processes Program.

A project on the investigation slackwater deposits as palaeoflood indicators is currently awaiting approval, depending on availability of staff resources, following the 2006/07 wet season.

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Radio- and lead isotopes in sediments of the Alligator Rivers Region (PhD project)

A Frostick[1], A Bollhöfer, D Parry[1], N Munksgaard[1] & KG Evans

Introduction

This project aims to develop an innovative, sensitive and cost-effective methodology to assess and monitor impacts of past, present and future uranium mining activities in and near Kakadu National Park, and is funded through the ARC Linkage-Projects scheme. A combination of stable lead isotopes, trace metals and radionuclide techniques is used. Concentrations are measured in both surface scrapes and sediment cores to determine the sediment deposition history and extent of erosion and deposition of mining-related contaminants in potentially mining influenced catchments. A pilot study conducted in the Ngarradj catchment, influenced by developments on the Jabiluka mineral lease, outlines the general approach (Bollhöfer & Martin 2003).

Lead has four stable isotopes three of which, ^{206}Pb, ^{207}Pb and ^{208}Pb, are endmembers of the ^{238}U ($t_{1/2}$= 4.5·10^{9} yrs), ^{235}U ($t_{1/2}$= 0.7·10^{9} yrs) and ^{232}Th ($t_{1/2}$= 14·10^{9} yrs) decay chains, respectively. Primordial lead was formed at an isotope abundance of 2% (^{204}Pb), 18.6% (^{206}Pb), 20.6% (^{207}Pb) and 58.9% (^{208}Pb) (Tatsumoto et al 1973). The radioactive decay of uranium and thorium in the Earth's crust results in radiogenic lead being formed, and hence changes in crustal lead isotope ratios with time. Present day average crustal (PDAC) $^{206}Pb/^{207}Pb$ and $^{208}Pb/^{207}Pb$ ratios are approximately 1.20 and 2.47, respectively.

In uranium and thorium rich minerals more radiogenic lead has formed over time. For example, monazites with high Th/U exhibit $^{208}Pb/^{207}Pb$ and $^{206}Pb/^{207}Pb$ ratios much higher than PDAC lead (Bosch et al 2002). On the other hand uranium ore bodies show elevated $^{206}Pb/^{207}Pb$ ratios but are low in $^{208}Pb/^{207}Pb$, as ^{208}Pb is formed by the radioactive decay of thorium. Gulson et al (1992) measured $^{206}Pb/^{207}Pb$ and $^{208}Pb/^{207}Pb$ ratios of 9.690 and 0.0494, respectively, in particulates from uranium tailings. Consequently, the $^{206}Pb/^{207}Pb$ and $^{208}Pb/^{207}Pb$ ratios of any mixtures between natural PDAC material and uranium rich sources fall within the grey area indicated in Figure 1.

Historically, lead isotopes have mainly been used as a source tracer in urban and developed areas (eg. Chow & Johnstone, 1965). However, conditions in the ARR provide an opportunity to develop the method as a monitoring tool for mining impacts in remote areas. As a relatively unpolluted environment is more susceptible to detect changes in the sources of lead via lead isotope ratios in various environmental compartments (aerosol, water, biota or soil), and due to the uniqueness of lead isotope ratios of the sources in the region (Gulson et al 1992, Munksgaard et al 2003, Bollhöfer et al 2006), this work provides a unique opportunity to study impacts of uranium mining on the environment in the Top End.

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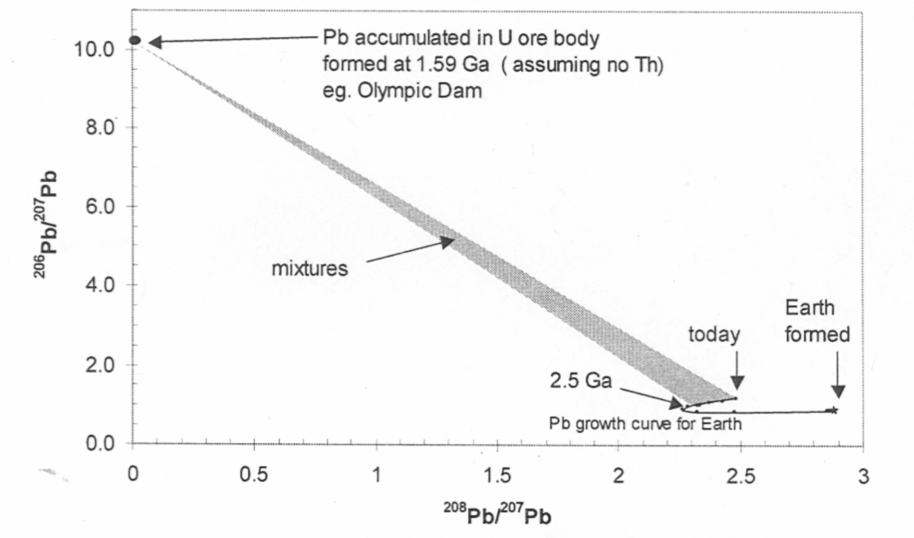

Figure 1 Origin of the isotopic composition of mixtures of radiogenic lead from uranium ores with common lead (from Bollhöfer et al 2005)

Methods

To determine the extent of erosion and deposition at the rehabilitated Nabarlek mine, surface scrape samples and 8 sediment cores were collected in 2005, in addition to samples that had been collected in 2003. The cores were taken in backflow deposition zones along Cooper Creek, upstream and downstream of Cooper Creek West, in the Kadjirrikamarnda catchment and downstream of its confluence with Cooper Creek (Figure 2). Cores were sliced into 1 cm increments along their lengths and each section prepared for measurement of metal content (ICPMS) and lead isotope ratios. Samples were then combined for gamma analyses for U and Th-series elements, ^{137}Cs and ^{40}K in an attempt to date the cores. Further samples for analysis were collected from the Gulungul and Magela catchments in the dry seasons of 2005 and 2006.

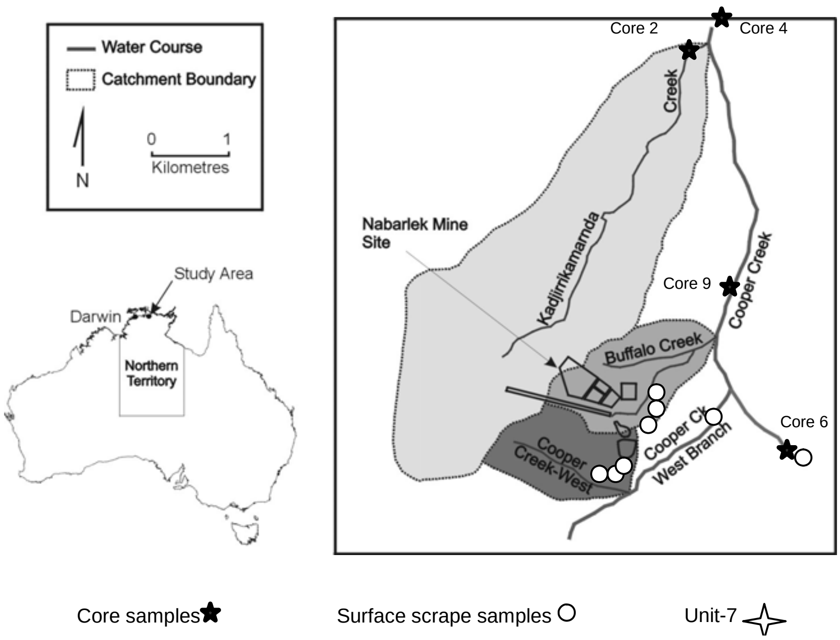

Figure 2 Location of the Nabarlek mineral lease and the sampling sites (modified from Hancock et al, 2006)

Pb isotope ratios and trace metal concentrations in the sediments were measured by ICPMS at Charles Darwin University (CDU). Samples were digested in a nitric/perchloric acid mixture and heated in a block digester at 180˚C. An aliquot was dried down and redissolved in 10% nitric acid, before being injected into the plasma torch of a Perkin Elmer Elan 6000 ICPMS. Details of the operating system and the sample preparation can be found in Munksgaard et al. (1998) and Munksgaard and Parry (2000). Typical uncertainties for the Pb isotope ratios are 0.5–1% relative standard deviation.

Sediments were analysed for elements of the natural uranium and thorium decay series, and potassium-40, using high resolution High Purity Germanium (HPGe) gamma detectors at the Environmental Research Institute of the Supervising Scientist (***eriss***). Procedures for sample collection, preparation and measurements of radionuclide activities via gamma spectrometry at ***eriss*** are described in Marten (1992). The counting system has been calibrated for the respective sample geometry, using certified uranium and thorium standards.

Results

Unit-7, a bare area on the rehabilitated Nabarlek mine, that has previously been identified as the source of three quarters of the uranium eroding off site (Hancock et al 2006), exhibits highly radiogenic $^{206}Pb/^{207}Pb$ ($^{208}Pb/^{207}Pb$) isotope ratios of 13.14 (0.448). This isotope ratio is more radiogenic, and is distinctively different from, lead isotope ratios previously measured in Ranger uranium ore. The ratio can be used as a source tracer for material eroding off site.

Some soil scrapes collected on site and from areas adjacent to the Nabarlek mine site exhibit elevated levels of trace metals, radionuclides and distinct lead isotope ratios indicating the presence of uranium rich material (Figure 3). $^{206}Pb/^{207}Pb$ ($^{208}Pb/^{207}Pb$) isotope ratios of the scrapes taken along major drainage lines on-site indicate that material is actively eroding and depositing in overflow areas in the vicinity of the mine.

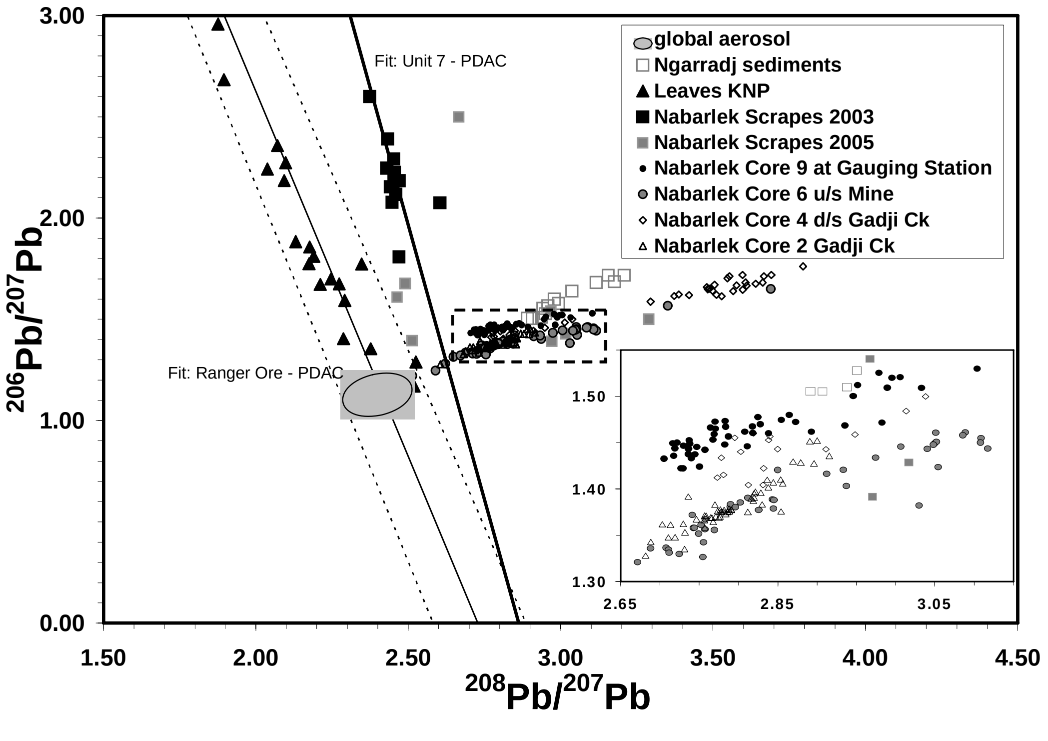

Figure 3 3-isotope plot of soil scrape and sediment samples taken at the rehabilitated Nabarlek mine

Although some of the radiogenic erosion products deposit outside the fenced area in a sediment settling pond and, since the breach of the settling pond wall, to the south of the rehabilitated waste rock dump retention pond, dispersion of this material is limited at this stage.

Cores 4 and 9 exhibit more radiogenic $^{206}Pb/^{207}Pb$ ratios as compared to the upstream core 6 and core 2 from the Kadjirrikamarnda catchment (see inset in Figure 3). This is most likely due to the higher radiogenic contribution from the catchment – the orebody (pre-mining) and the mine and rehabilitated site (post-mining) – upstream of these sites. The Kadjirrikamarnda catchment only delivers 3.3 % of the total ^{238}U flux from the Nabarlek mine site (Hancock et al 2006) and thus core 2 is relatively little influenced by radiogenic runoff.

Steps for completion

Sediment cores have been taken from Georgetown and Mudginberri Billabongs, from the Magela floodplain and the Gulungul catchment, to investigate pre-rehabilitation radionuclide and heavy metal concentration, sedimentation fluxes and lead isotope composition of the sediments in the Magela catchment. These sediments, and sediments from the Cooper Creek catchment at Nabarlek, are currently being investigated for their radionuclide activity concentrations and will be dated using a combination of ^{210}Pb, ^{137}Cs and Optically Stimulated Luminescence (OSL) dating techniques to investigate the history of regional sediment deposition. Additional scrape samples will be collected in the Magela and Gulungul Creek catchments, at Ngarradj and in the Nourlangie catchment in the dry seasons of 2006 and 2007. It is envisaged that Nourlangie Creek will act a a natural analogue for the study.

Acknowledgments

David Klessa from EWLS is greatly acknowledged for providing three sediment cores from Georgetown Billabong.

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Use of a natural analogue to determine Ranger pre-mining radiological conditions

A Bollhöfer & K Pfitzner

Introduction

From a radiation protection point of view it is essential that pre-mining baseline conditions are known so as to be able to place into perspective the residual radiological conditions after a mine is rehabilitated. Such pre-mining data also provides the basis for developing technically defensible radiological closure criteria for a mine site.

Annual radiation doses above pre-mining background received by members of the general public and summed over all exposure pathways should not exceed one milli Sievert (ICRP, 1991). However, the relevance of this target for a location does need to be considerd in the context of both the local pre-mining condition and the regional radiological background.

In the case of the Ranger site it is difficult to assess the pre-mining condition, both because information is scarce, and because of the uncertain quality of the data that are available. To redress these issues it was planned to combine historic pre mining airborne gamma-ray data with recent ground truthed data at undisturbed sites to estimate the pre-mining radiological conditions at Ranger.

Airborne gamma surveys (AGS), coupled with ground truthing surveys, can be an ideal tool for an area wide assessment of radiological conditions (Martin et al 2006). Nabarlek, Ranger and Koongarra had strong airborne and ground radiometric responses, which were the basis for their discovery (Giblin 2004). Groundtruthing airbone data obtained from an undisturbed site may assist with estimating area wide pre-mining radiological conditions at the disturbed site (for which non-groundtruthed aerial radiometric data do exist).

In the original proposal put forward at ARRTC 15, it was suggested that airborne gamma data from the Koongarra and Ranger uranium deposits acquired in 1976 be used to infer the pre-mining radiological condition at Ranger.

Methods and results

In 1976 a geophysical survey was conducted in the Alligator Rivers Region covering both Ranger and Koongarra (Figure 1). The data were acquired by the NT Government, and are available in the public domain (the *Alligator River Geophysical Survey*). Data were re-processed in 2000 by the Northern Territory Geological Survey and then resampled at a pixel size of 70 m in 2003.

A closer inspection of the airborne gamma data revealed that the airborne signal from Koongarra appeared very weak with little elevation in count rates above background (Figure 2). This finding contrasts sharply with Giblin (2004) who stated that Nabarlek, Ranger and Koongarra had strong airborne and ground radiometric responses. It is possible that inappropriate post-processing of the raw data may have altered the output significantly. Unfortunately the source data are not available to test this assertion.

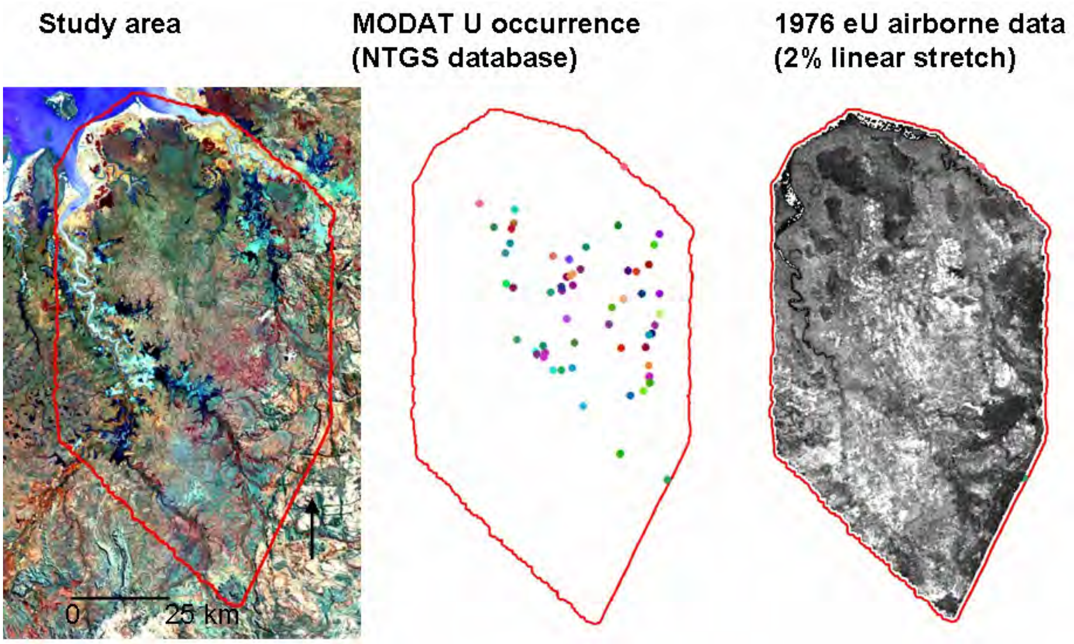

Figure 1 1976 study area, known uranium anomalies (sourced from the Northern Territory Geological Survey MODAT data base) and greyscale eU channel of the airborne gamma survey

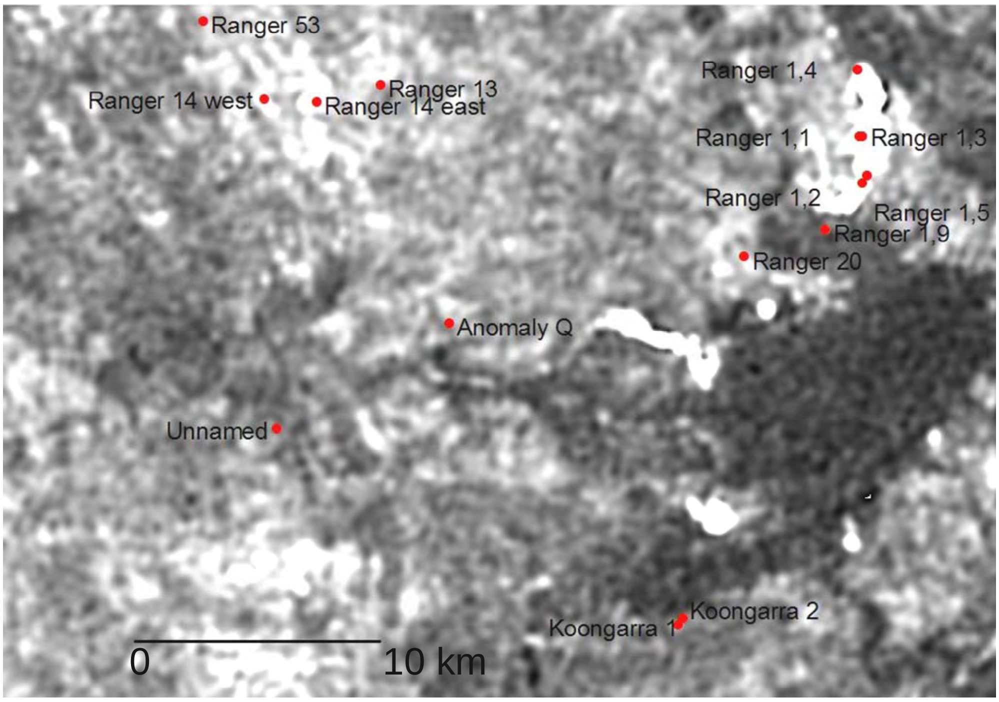

Figure 2 Subset of the 1976 eU data, white > grey > black. Known uranium anomalies overlaid from the Northern Territory Geological Survey MODAT database.

Due to the above issues and the current political sensitivity of Koongarra it has been decided to postpone initial groundtruthing surveys.

Anomaly 2 at Ranger may prove more suitable as an analogue site for pre mining radiological conditions. Figure 3 shows the pre-mining airborne signal in the Ranger vicinity by extent and intensity (top 70% of values found in Ranger subset) and the signal related to land cover using optical satellite data acquired by IKONOS satellite in 2001. Also shown in Figure 3 is a contour map by Eupene et al (1980) that shows the total counts acquired during an airborne survey of Ranger, which is overlaid on the airborne gamma data from 1976.

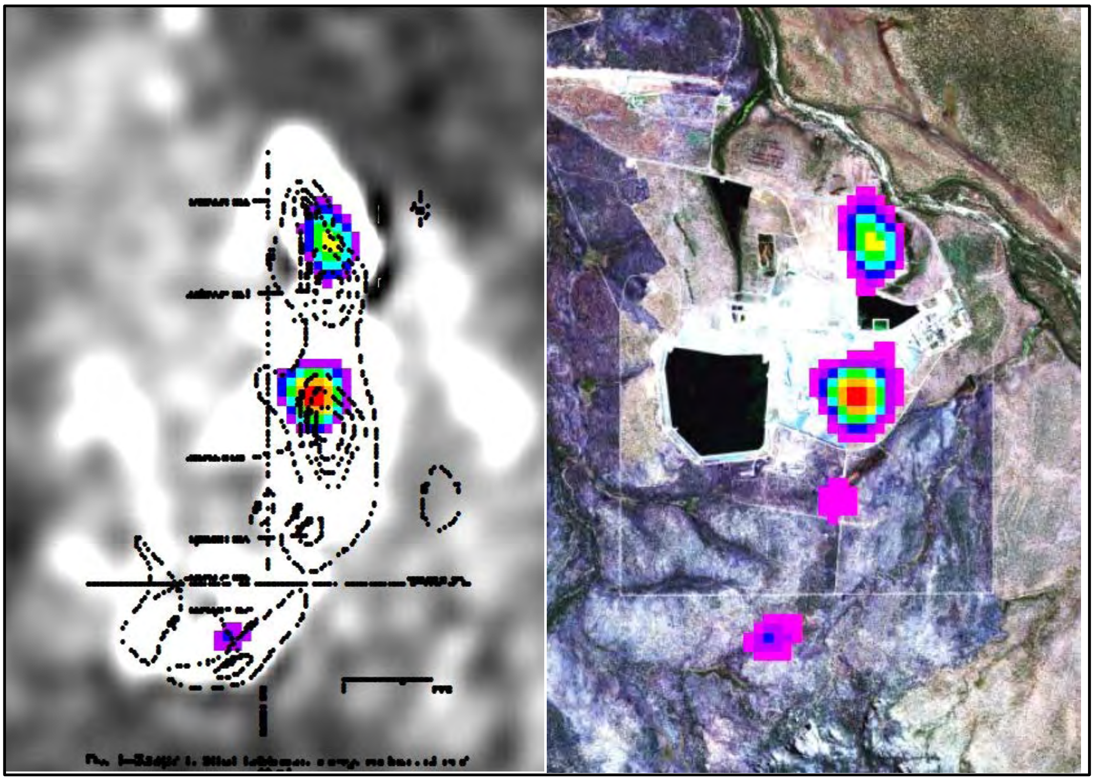

Figure 3 Eupene et al (1980) map of aerial radiometric contours of total count. Overlaid on airborne data (left) and IKONOS (2001) optical satellite data with eU 30–70% pixels mapped.

Pits 1 and 3 show up distinctively in this data set. A further comparison of signal intensity with known uranium occurrences in the MODAT database illustrates that Anomaly 2 to the south of the Ranger lease may be a more suitable site to determine the Ranger pre-mining radiological conditions, as the airborne gamma signal appears much stronger as compared to the Koongarra signal. However, access to this is difficult due to its proximity to a site (Mt Brockman) of extreme cultural significance to the local Mirrar people. Furthermore, anomaly 2 is very small compared to Koongarra. Distinct mineralogical and geomorphological differences between Ranger and the Koongarra or Anomaly 2 sites may not allow the use of either site as a radiological analogue for Ranger.

Summary

Airborne gamma data revealed that Koongarra may not be the ideal site to use as a natural analogue for Ranger pre-mining conditions. Groundtruthing exercises are costly and need to be carefully planned and thus the most appropriate site indentified before fieldwork commences. Radiological anomalous areas in the vicinity of the Ranger lease may prove more valuable analogue sites to determine Ranger pre-mining conditions.

Steps for completion

A radiological analogue for Ranger pre mining conditions needs to be identified for groundtruthing. Raw data are needed for the 1976 radiological survey, in order to exclude shortcomings in data evaluation leading to the apparently anomalous signal pattern observed for Koongarra. Due to the political and cultural sensitivity of the areas in discussion, appropriate permits will need to obtained once appropriate targets are identified.

Due to other work priorities, this project has not been included in the 2006–07 workplan. However, it is anticipated that work will be resumed in 2007–08.

Acknowledgments

The NT Geological Survey and Mark Foy are thanked for discussion and data provision for the project.

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Developing water quality closure criteria for Ranger billabongs using macroinvertebrate community data

C Humphrey & D Jones

Introduction

The approach to deriving water quality criteria from local biological response data outlined in the Australian and New Zealand Water Quality Guidelines (ANZECC & ARMCANZ 2000) is being applied to the derivation of water quality closure criteria for waterbodies such as Georgetown Billabong, located immediately adjacent to the mine site. Specifically, if the post-closure condition in Georgetown Billabong is to be consistent with similar undisturbed (reference) billabong environments of Kakadu, then the range of water quality data from the billabong over time that supports such an ecological condition in Georgetown Billabong (as measured by suitable surrogate, biological indicators) may be used for this purpose.

For shallow lowland billabongs such as Georgetown Billabong, distinctive wet season and dry season water quality regimes can be recognised. This is a consequence of flushing of the billabongs during the wet season, followed by contraction in surface area and substantial evaporative concentration of solutes during the six months of the subsequent dry season. If water quality closure criteria were derived from the annual-average water quality record, then the resultant values would be too conservative for the dry season and too lenient for the wet season. For this reason, two sets of water quality criteria are required – one for the wet season and one for the dry season.

Data derived from macroinvertebrates are regarded as most useful for setting water quality criteria because of the enhanced sensitivity of this group of organisms to water quality generally. Hence monitoring of macroinvertebrate communities is being used to develop closure criteria for relevant water quality indicators in the local Ranger billabongs.

Sampling for macroinvertebrates in most of the Ranger and relevant reference water bodies has been conducted previously in 1995 and 1996 and provides a basis for time series comparison. For the 1995 and 1996 surveys, the macroinvertebrate communities of Georgetown Billabong resembled those of reference waterbodies in the Alligator Rivers Region.

Given the changes that have occurred on the mine site since 1996 – in particular the increased wet season loads of solutes entering Georgetown Billabong – a contemporary survey was needed to determine if the macroinvertebrate communities in the billabong were still comparable to reference waterbodies in the region. Accordingly, macroinvertebrates were sampled in May 2006 from Coonjimba, Georgetown and Gulungul Billabongs and Ranger Retention Pond 1 and Retention Pond 2 (mine-water exposed sites) and Baralil, Corndorl, Wirnmuyurr, Malabanjbanjdju, Anbangbang, Buba and Sandy Billabongs and Jabiru Lake (reference sites, not exposed to Ranger mine waters) (see Maps 2 & 3).

Progress to date

At the time of writing this report, the samples collected in May 2006 were still being sorted and the organisms identified and counted. Interim water quality criteria will be derived in March 2007 based on the findings from the three sets of macroinvertebrate and associated water quality monitoring data from Georgetown Billabong in 1995, 1996 and 2006.

Post-closure water quality criteria for Georgetown Billabong – consistent with maintaining the billabong in a condition similar to undisturbed reference waterbodies in Kakadu – will be based on the range of water quality data measured in the billabong over the preceding wet (wet season criteria) and dry (dry season criteria) seasons for each of the three years of macroinvertebrate data. Wet season criteria will be produced from summary statistics of the water quality measured over the period January to May and dry season criteria produced from the worst water quality observed in the preceding dry season, typically for the months September to December.

Macroinvertebrate and associated water quality data gathered from sampling in future years will be used to further revise the criteria current at the time of the new sampling. This adaptive approach to revising criteria to accommodate new findings is consistent with the Australian Water Quality Guidelines (2000) and the stakeholder agreed strategy to periodically update water quality compliance trigger values at G8210009 in Magela Creek.

Progress results for this study were presented at the ARRTC18 meeting (October 2006).

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Use of analogue plant communities as a guide to revegetation and associated monitoring of the post-mine landform at Ranger

C Humphrey, I Hollingsworth[1] M Gardener[1] & G Fox

Background

Suitable plant communities must be identified and characterised for the final, post-mine landform following Ranger mine-site rehabilitation. Plant communities from these natural analogue sites will assist in selection of species for re-establishment and also may act as targets in monitoring programs designed to assess the extent to which revegetation is being successfully sustained and achieved.

For a range of key vegetation community types that span the range of environments likely to be found across the rehabilitated footprint, relationships with key geomorphic features (parent material, slope, effective soil depth etc) have been derived using multivariate procedures (Hollingsworth et al 2003). By identifying the key environmental features that are associated with particular vegetation community types, the conditions required to support these communities may then be specified for the final, post-mine landform at Ranger (Reddell & Meek 2004).

Reddell and Meek (2004) noted that the work of Hollingsworth and co-workers may need to be extended by way of additional surveys, to 'refine some of the target vegetation types once the design features of the final landform are finalised (eg for drainage lines, or for potentially waterlogged areas such as the former tailings dam floor)'. Dr Carl Grant (ARRTC independent scientific member) also recommended that: (i) the study of Hollingsworth et al (2003) be expanded beyond the current geographic extent to the broader environment of Kakadu National Park; and (ii) the vegetation classification incorporate species abundance data (hence, better aligned to the broader rehabilitation objectives set for Ranger for which plant density must be considered).

Progress to date

Work to date has involved (1) classification of analogue vegetation communities, and (2) gathering of environmental data associated with existing plant analogue sites as well as new plant data associated with *Melaleuca* communities.

(1) Analogue vegetation classification

The original analogue classification of Hollingsworth et al (2003) was extended to include an additional 20 sites and associated species abundance data gathered by Brennan (2005) in the mid 1990s. Brennan's sites included additional Koolpinya lowland sites (the dominant vegetation type surveyed by EWLS) as well as hill sites encompassing quartzite, sandstone and schist mineralogies from a variety of ARR locations, extending from the upper South

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Alligator River valley (Fisher) to Tin Camp Ck (near Nabarlek). Only the data for trees and shrubs have been analysed to date. Herb data are available but have not yet been examined. Using PRIMER multivariate software, initial classification, ordination, ANOSIM (~multivariate ANOVA) and SIMPER (plant association) analyses were conducted. The results of this analysis were reported to ARRTC 16 and are summarised in Humphrey et al (2006).

In their ordination and classification, Humphrey et al (2006) identified three main vegetation communities. These three community groups concorded and were consistent with those from existing classifications of the region's vegetation units, published by Schodde et al (1987). The three groups are described as dry mixed woodland, mixed woodland and *Melaleuca* woodland, according with Schodde et al's (1987) open forest, woodland and myrtle-pandanus savannah vegetation units respectively – see Table 1. In the analysis by Humphrey et al (2006), it was noted that the dominant, mixed eucalypt communities from the Georgetown analogue sites surveyed by Hollingsworth and co-workers, were represented in the two main classification groups (mixed eucalypt communities) identified by multivariate analysis of the broader regional group of sites. This indicated that the Georgetown analogue sites adequately described the eucalypt community types found in the region. *Melaleuca* woodland sites, however, were not well represented in the dataset which was analysed and hence in the subsequent classification – see below.

Table 1 Descriptions of three broad analogue communities and the matching vegetation units according to Schodde et al (1987)

Broad vegetation community	Dominant tree species	Vegetation units used by Schodde et al (1987)
Dry Mixed Eucalypt Woodland	*Xanthostemon paradoxus* *Erythrophleum chlorostachys* *Corymbia foelscheana* *Eucalyptus tectifica*	Open forest
Mixed Eucalypt Woodland	*Eucalyptus tetrodonta* *Xanthostemon paradoxus* *Corymbia porrecta* *Eucalyptus miniata*	Woodland
Melaleuca Woodland	*Melaleuca viridiflora*	Myrtle-Pandanus Savannah

Gardener (EWLS, unpublished report) has subsequently described ecological attributes of each of the three community groups using species phenology, including growth form, life history, time to maturity, response to fire, type of re-sprouting and deciduousness. In general, all three communities have similar attributes, ie an even mix of tree and shrub species, comprising mostly long lived perennials and able to re-sprout after fire. The only attribute that differed was deciduousness, with the drier community having a greater proportion of deciduous species.

A plant location database of all known records of vascular plants on the Ranger Lease has been developed by EWLS. At least 500 species have been recorded on the lease, of which 140 species are shrub or tree species with the remainder being grasses, herb, sub-shrubs and climbers.

(2) Gathering of soil and additional plant survey data

Phase 1 of the project described above revealed two knowledge gaps: (i) additional vegetation plots are needed to characterise the *Melaleuca* community group (only three plots were represented in the original survey and subsequent classification); and (ii) the need for a soil characterisation survey to define the range of environmentally relevant (physical and chemical) characteristics of the soils at all of the analogue locations.

At the time of writing this paper, field sampling for the soil characterisation component was near completion. This study has described soil physical properties and measured in situ water infiltration rates at various profile depths. Profile samples have been collected for analysis of metals and nutrients. It is proposed that the original vegetation survey data be re-modelled together with the new soils and additional environmental data to provide additional information about the relationship between vegetation type and soil profile condition. These data have the potential to be used for both design of the surface growth medium of the landform and well as being used to specify target closure attributes for the landform.

Melaleuca survey work will be carried out in the early 2006–07 dry season, to match survey timing in the year that the original Georgetown analogue work was conducted.

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Establishing demonstration landform-vegetation plots at Ranger

P Bayliss & M Gardener[1]

Introduction

The aim of this project is to determine the influence of capping type and waste rock mix on the success of vegetation development, particularly in relation to species mix, propagation method, water balance and disturbances caused by fire and weeds. One of the key outcomes of the Ecosystem Establishment (EE) Workshop in December 2005 (Bayliss & Gardener 2006) was unanimous agreement amongst participants that experimental landform-vegetation plots (Demonstration Plots) were required to close key knowledge gaps in closure criteria definition, vegetation establishment, development and sustainability. A focus group to be chaired by ERA was formed at the EE workshop to progress the development of 'Demonstration Plots'. The time frame for milestones flagged at the workshop were: a scoping document produced with key stakeholders by December 2006 addressing design issues and benefits and costs; construction of the trial by December 2007; and planting carried out in the 2007–08 wet season.

Progress

At the EE Workshop all stakeholders agreed that it was necessary, for purposes of Best Practice, to establish large-scale landform-vegetation experimental plots by December 2007 at the latest (herein referred to as Demonstration Plots or DPs). Workshop participants agreed also that a working group chaired by ERA would be established to advance this recommendation and that the first meeting of this group should be convened in April 2006.

An initial meeting was held on 19 April 2006 between scientific collaborators from ERA-EWLS, CDU and ***eriss*** to ascertain whether or not an experimental design approach will be accepted in principle by ERA and, if so, what were the key high level technical issues that had to be resolved with all stakeholders in subsequent meetings. Hence, the key objectives of the initial meeting were to commence development of technical terms of reference for construction of the DPs, and to clarify technical stakeholder expectations of DPs. This scope includes all experimental design issues such as the number of priority revegetation treatments, treatment plot size and number of replicates.

Major outcomes of the initial meeting were that: ERA/EWLS endorsed, in principle, the need to establish a DP area to close critical key knowledge gaps for successful rehabilitation; the area of the DP was to be increased from 3ha to 7ha; and that the establishment time would be brought forward to December 2006 from December 2007 owing to the availability of mine fleet equipment in the immediate vicinity whilst construction of the pad for the Western waste rock stockpile was in progress. Key actions from the meeting are summarised below.

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Planning and communication

- ERA/EWLS to prepare a scoping document outlining terms of reference and proposed design of Demonstration plots (DPs), with review and technical input to be provided by ***eriss*** by end of May 2006.
- Broader stakeholder meetings (involving NLC-GAC, NTG & PAN) to be arranged as high priority for the last week of May 2006 (by ERA/EWLS) in order to discuss the content of the scoping document and to obtain critical inputs to the design process.
- Refine technical design details of the DP area with reference to final landform characteristics.
- Present final plan to stakeholders (via the Ranger Minesite Technical Committee Meeting & ARRTC18) for acceptance.

Critical technical tasks

- Draft a map of the proposed DP area with vertical cross-section.
- In consultation with engineers, ERA to conduct a risk assessment for developing the project that addresses cost and feasibility issues associated with the proposed design.
- Conduct pilot tests outside the assigned plot area to assess the feasibility and costs of mixing laterite with waste rock, and use as a key input into the risk assessment for selection of cover composition(s) to be used for the DP area.
- EWLS to provide, as soon as possible, Kakadu Native Plants and Seeds (KNPS) with a plant species list for establishment of primary cover on the DP area because key species will soon be setting seed and ready for harvest.
- Within the constraints of the proposed DP area, develop a rehabilitation monitoring program that targets key attributes needed to demonstrate successful and sustainable rehabilitation.

By July 2006 it had become apparent that the originally proposed construction timeline for the DPs could not be met owing to pressing process water management issues on site as a result of delays in the commissioning of the process water treatment plant. To address this issue required a major lift to the tailings dam in the second half of 2006 to reduce the potential environmental risk posed by process water in the event of another above average wet season. The component of the mining fleet that would have been used to build the demonstration landform area was required for this task. In addition, the damage inflicted by cyclone Monica reduced the availability of native seed, hence compromising the ability of KNPS to produce sufficient stock for the trial areas.

Two meetings were held with EWLS in July/August 2006 to ascertain the new timelines for production of the scoping document, review by stakeholders and eventual establishment of the DP area and monitoring programs. A draft scoping document outlining purpose and experimental design of the DP area was going to be presented to stakeholders at ARRTC18 for review, but this has been further delayed pending feedback from the Ranger Closure Team (see below).

ERA/EWLS update (Mark Gardener): Demonstration plots

ERA/EWLS are currently developing a scope for this project. Initial plans for a 7 ha landform with physical characteristics in the range of those proposed by Ian Hollingsworth have been submitted to the Department of Primary Industry, Fisheries and Mines. Currently, we are waiting for an assessment by an engineer. This demonstration landform would sit adjacent to the main access road in front of the Western Stockpile. It is proposed to use this demonstration area to build stakeholder confidence in ERA's ability to rehabilitate the final landform and to fill key knowledge gaps. This project will solicit contribution from all main stakeholders. Currently, it is proposed by ERA to construct the demonstration area in the 2007 dry season and revegetate it in the 2007–2008 wet season. The development of the demonstration plots is being driven by ERA's closure team.

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Hydrochemical and ecological processes of constructed sentinel wetlands and reconstructed wetlands in the Magela Creek catchment

P Bayliss, D Jones, C Humphrey & J Boyden

Introduction

The aim of this project is to address existing knowledge gaps in hydrochemical and ecological processes of perennial and ephemeral wetlands, in order to specify design and management criteria of constructed wetland filters and, if required, to reconstruct Djalkmara Billabong. A key closure objective is that surface water arising or discharging from the Ranger Project Area (RPA) following rehabilitation must not compromise primary environmental objectives.

The proposed project addresses three critical knowledge gaps with respect to the design and management of wetland filters: (i) hydrochemical – what is the composition of runoff and the flow duration of seepage; (2) ecophysiological – what is the maximum load of solutes that can effectively be treated during the wet season by ephemeral and perennial wetlands?; and (3) ecological – how can we rapidly establish sustainable perennial and ephemeral wetland ecosystems.

The original project outline suggested the following three phases and associated time lines:

1 For remainder of the 2005–06 financial year, develop conceptual models for sentinel and reconstructed wetlands and, undertake a literature review of existing knowledge (including unpubl CSIRO data) and a gap analysis. Characterise all existing ephemeral and perennial analogue wetlands in the Magela catchment using existing knowledge;

2 From (i) above and, if necessary, design field projects to commence in the early dry season of 2006 or the late wet season of 2006–07. Undertake field sampling over full seasonal wetting and drying cycles of selected analogue wetlands (eg Mt Brockman Bund, Corridor Ck, RP1/Coonjimba Billabong) and encompassing riparian feeder creek systems. Closely monitor key hydrochemical and ecological processes, particularly the trophic transport of contaminants, and develop predictive ecosystem models; and

3 If necessary, design and commence experimental constructed wetland work in 2007–08 that both integrates and runs in tandem with the experimental terrestrial landform plots proposed in the above project.

However, owing to staff shortages, the additional workload arising from the extended 2005–06 wet season and higher priority being given to assessing impacts from Cyclone Monica, the above time lines have been put back by one year.

Nevertheless, some progress has been made such as: presentations were given by ***eriss*** staff at the Ecosystem Establishment Workshop in December 2005 (Bayliss & Gardener 2006) on (i) Conceptual models for sentinel wetlands (D Jones) and (ii) Vegetation aspects of constructed wetlands (P Bayliss); a comprehensive literature review has commenced; and D Jones participated in the Constructed wetlands session at the Society of Wetland Scientists 27th International 'Catchment to Coasts' conference (Cairns, July 2006).

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Seed biology of native grasses: BSc (Honours) project by Kathryn Sangster

K Sangster[1], S Bellairs[1], P Bayliss & M Gardener[2]

Introduction

The aim of this project was to investigate the seed biology of five grass species native to Kakadu National Park that occur on the Ranger mine lease. A secondary aim was to carry out a literature review to investigate traditional grass use by Aboriginal people in the tropical and arid areas of Australia.

Grasses are a feature of most Australian landscapes and are a major component of the understorey on the Ranger mine lease area. They provide food and shelter for a range of native fauna and have a number of vital roles for mining rehabilitation projects, especially for erosion protection in the initial stages when the framework tree species are becoming established. Grasses are fast growing and can quickly cover bare ground, stabilising the soil, and helping to retain nutrients. They can also assist in preventing the soil surface from heating and drying. The vegetation cover that grasses provide can also assist with providing a favourable micro-environment for nutrient cycling.

Exotic grasses are often used for rehabilitation projects, as seeds are readily available and their establishment requirements are well understood. However some exotic species can become weeds, and spread into high conservation value areas. Native grasses are also adapted to local conditions and are therefore more likely to establish, spread and persist. However, despite the potential benefits, native grasses are often not used in revegetation projects, partly due to lack of information on their germination requirements. Without knowing the germination requirements, germination of native grasses can be poor and unreliable, even when good quality seed is used.

Aboriginal people have a long history of use of native grasses and some of these aspects may be important for rehabilitation of a site that will be useful for Aboriginal people. They also have considerable knowledge about native grasses that will be useful for successfully rehabilitating mine sites in the Northern Territory. It was beyond the scope of this study to comprehensively explore this aspect, however, an initial literature review was carried out to highlight information that could be followed up.

Progress

The Honours project was submitted in 2005 and passed. Major outcomes associated with this work include: greater knowledge about the seed biology and germination behaviour of five native grass species that have potential for rehabilitation of the Ranger mine; and information on potential cultural issues associated with native grasses to be discussed with local Traditional Owners. The major research outputs are outlined below.

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Native grass seed biology

Seeds of five native grasses were collected from the Ranger mine lease area: *Alloteropsis semialata, Eragrostis rigidiuscula, Eragrostis schultzii, Eriachne schultziana* and *Heteropogon triticeus*. Viability of the seeds of these grasses was moderate with between 30% and 80% of the filled seeds being viable. However without treatment only one of the species achieved 12% germination and the others did not germinate. Scarification was required to break the husk imposed dormancy for all these species. This increased germination to 20% for *Alloteropsis semialata* and up to 80% for *Heteropogon triticeus*. Other dormancy breaking treatments were effective but not to the same extent as physical scarification. This study showed that treatment of native grass seeds is vital to achieving effective germination.

Aboriginal native grass use

Native grasses are used for a variety of purposes. It is important to recognise that Aboriginal people have their own specific classifications and names for grasses. Some grasses that are recognised as separate species are not distinguished but are recognised as a broader category depending on their use. If a grass species has a traditional name this is likely to indicate that it was, at some stage, notable or useful. Whether or not a grass has a specific name can vary between language groups. This study also found that traditional use of grasses could vary depending on changes within, and demands of, the society. At least 14 species of native grass are recorded as being used for food but this has declined as flour has become widely available. Grasses, however, remain important for associations with game, as calendar plants, for utility purposes, for maintaining the integrity of the landscape and for maintaining ethno-botanical knowledge. Consultation would be important to assess to what extent these different aspects will impact on rehabilitation success of disturbed land.

Bioaccumulation of radionuclides in terrestrial plants on rehabilitated landforms

B Ryan, A Bollhöfer & R Bartolo

Introduction

Over the last 25 years the Supervising Scientist Division (SSD) has gathered radiological data on bush foods throughout the Alligator Rivers Region (ARR) in the Northern Territory (Martin & Ryan 2004). Early studies were focused on aquatic animal and plant species due to the identified importance of the aquatic transport pathway for bioaccumulation of radionuclides in bush foods, particularly during the operational phase of uranium mining operations in the region (Johnston et al 1987, Petterson et al 1993).

Following rehabilitation of the Ranger uranium mine site there may be a shift towards food sources that are growing in the vicinity of the former mine. It can reasonably be assumed that the highest dose rates to humans will be received from the consumption of foods that grow in the vicinity of the contamination source and this aspect needs to be addressed as a component of the radiological protection issues associated with land use by local Aboriginal people.

The issue of radiological content of bush foods also needs to be addressed and assessed for the rehabilitated Nabarlek mine and the abandoned mines in the South Alligator River Valley. The dose assessment needs to be site specific with the radiation dose model including local habits, human land use and land use expectations for the site (Bollhöfer et al 2002). Information on the uptake factors of radionuclides in terrestrial plants is also needed to enable a radiological risk assessment to be carried out for the rehabilitated site at Ranger. This information needs to be coupled with the data being collected on estimates of terrestrial bush food consumption and site occupancy estimates by local Aboriginal people to develop a robust dose assessment model.

Results

An earlier investigation of uranium series radionuclides in native fruits and vegetables (Ryan et al 2005) has shown that the highest percentage contribution to committed effective dose from the ingestion of long lived members of the uranium decay series in fruits and yams is from ^{226}Ra and ^{210}Po (Table 1). This is primarily due to the relatively high dose conversion factors of these two radionuclides. Consequently, research efforts have focused on determining concentration factors in terrestrial plants for ^{226}Ra and ^{210}Po.

Table 1 Estimated percentage contribution to committed effective dose from the ingestion of fruits and yams for long-lived members of the uranium decay series (from Ryan et al 2005)

Species	^{238}U	^{234}U	^{230}Th	^{226}Ra	^{210}Pb	^{210}Po
Fruits	0.5	0.5	1.9	37	17	42
Yams	0.1	0.1	0.3	50	17	33

A new method has been developed which allows measurent of ^{228}Ra in samples prepared via the Sills method (Medley et al 2005). Figure 1 shows an example of the method validation. In this figure ^{228}Ra activity concentrations in mussels from Mudginberri Billabong measured using the new method are compared with activity concentrations previously determined via standard gamma spectrometry techniques. Differences between individual sample activity concentrations may be due to non-homogeneity in the sample, as sample size used for the Sills method was much smaller. The radium concentrations and ^{226}Ra/^{228}Ra activity ratios in samples of different types of bushfood and associated soils (and sediments) are currently being measured to determine radium uptake factors.

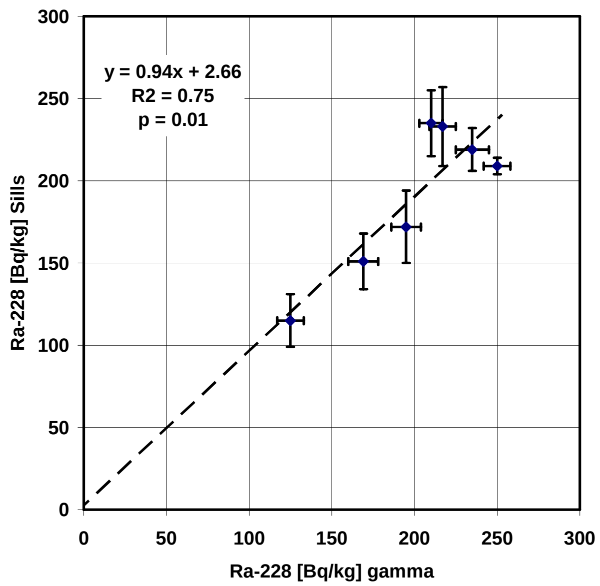

Figure 1 ^{228}Ra activity concentrations determined in mussel samples with the new method

The newly developed method also makes it possible to measure low levels of ^{228}Ra in archived samples, such as bushtucker, surface or ground water samples, so that radium activity ratios can be retrospectively calculated.

As part of the development of a dose assessment model a knowledge management tool called the Bushtucker Spatial Information System (SIS) has been developed further to collate and integrate the historical radiological data. To date, over 1500 records exist in the Bushtucker SIS. The results can be graphically displayed together with contextual data such as satellite imagery, photographs and maps (Figure 2). The system has facilitated a quality assessment of the available radionuclide data, recent and historic, aquatic and terrestrial, and has assisted in identifying gaps in knowledge about radionuclide uptake in flora and fauna. It is also highlighting the lack of terrestrial bush food radionuclide information currently available.

The Bushtucker SIS is of particular interest and importance to the local Aboriginal people who rely on traditional bush food sources, as it provides reassurances to people that bush food sources are safe to eat or whether there may be locations where it might not be advisable to gather food. It is also being used as a communication tool to graphically display in an easier to understand format the complex results of radionuclide analyses of food and other associated items in the Region.

The bushfood data gathered over the years from the ARR has made it possible to replace some published International Atomic Energy Agency (IAEA) default radionuclide concentration factors for temperate environments with locally derived radionuclide concentration factors, allowing a more accurate dose assessment. For example, applying IAEA reference values for fish concentration factors overestimates thorium and ^{210}Pb uptake by up to one order of magnitude (Martin et al 1998) and thus the effective dose to people from the consumption of fish in the ARR. Locally derived values give a more reliable estimate.

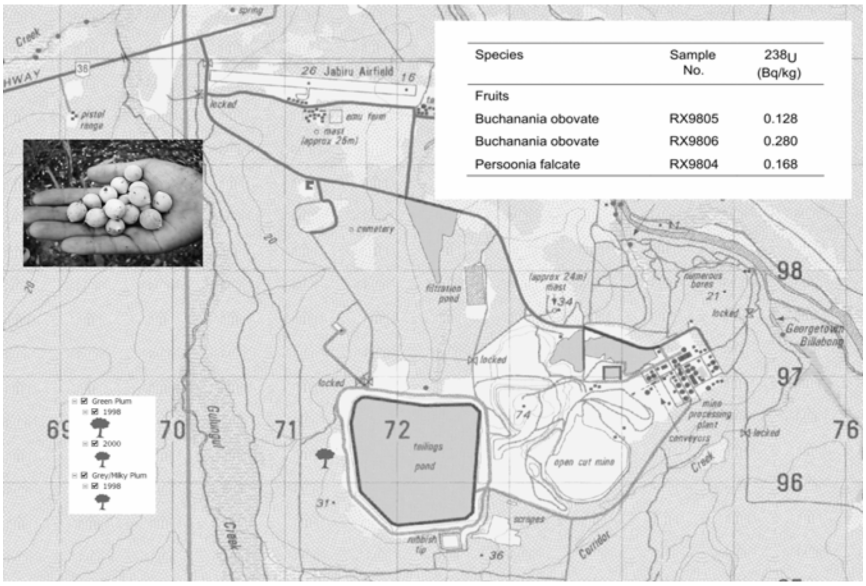

Figure 2 Screen shot of the bushtucker SIS showing uranium activity concentrations in terrestrial bush food samples collected in 1998 around the Ranger mine site

Gaps identified in our knowledge of radionuclide uptake in terrestrial flora and fauna have resulted in the implementation of a strategic sampling design that focuses future research effort on better defining radionuclide uptake pathways for terrestrial food items. Terrestrial bushtucker samples will continue to be collected and analysed from the Ranger mine site, the rehabilitated Nabarlek mine and the South Alligator Valley.

Steps for completion

Collection of bushfood samples in the ARR, in particular near rehabilitated and working mine sites, will continue and radium and other radionuclide activity concentrations will be determined. A recently developed more specific sequential leaching method will be employed to determine radionuclide, specifically radium, activities and heavy metal concentrations in various soil fractions. The aim of this work is to identify and quantify the bioavaible fraction of the total radionuclide and metal content of soils or sediments that is most important for radionuclide and metal uptake by plants.

Dietary information from local ARR Aboriginal people continues to be collected. This will be incorporated into an updated radiological dose assessment model for rehabilitated mine sites.

Acknowledgments

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Development of a spectral library for minesite rehabilitation assessment

K Pfitzner, A Bollhöfer & G Carr

Introduction

Research is being conducted into the application of remotely sensed data for mine site monitoring and rehabilitation assessment. An important component includes an analysis of those factors that can be used as quantitative indicators of revegetation success. For this purpose high resolution data are required because of the variability and short range variation in surface cover, typical of the disturbed environment. Very high spatial resolution satellite data have been used contextually to identify temporal changes in vegetation cover, however, individual species identification has been limited owing to the limited resolving capability of broad multispectral bands (Pfitzner 2005a, b). One-off remote sensing feasibility studies utilising hyperspectral data from the CASI, HyMap and DeBeers Hyperspectral Mapper platforms, have not provided generically useful information because results are sensor specific and spatially and temporally dependent.

This work aims to define the spectral responses of vegetation species which are important for mine site rehabilitation assessment, including introduced weeds and natives, in order to identify the most appropriate (remote sensing?) monitoring method. To achieve this, fortnightly measurements of key species have been made to establish a time series of high resolution spectral reflectance measurements. The project aims are addressed by the following research questions.

- What are the fortnightly spectral responses of ground cover vegetative species?
- Can ground-cover vegetative species be distinguished using ground-based reflectance spectra, and if so, what spectral resolution is required?
- At what phenological stage is maximum separability detected and is there a phenological stage when species are confounding?
- What are the implications of seasonal variability for using hyperspectral imaging throughout the year to track changes in groundcover?

To answer these questions, the research design needed to ensure that the spectral response is not confounded by extraneous factors such as localised changes in atmospheric conditions. The hypothesis is that with a well designed approach to collecting field spectral measurements and metadata, extraneous factors can be accounted for, accurate processing of spectra can be performed and the first database of Top End spectra relevant to the mine environment can be developed.

Method

A challenge in the project design phase was to locate sites with homogenous dense cover that were unlikely to be disturbed from threats such as fire, development or mowing. Replicate plots were established with support from Commonwealth and Northern Territory Government Departments and private industry. Priority species were identified with stakeholders. Dense and homogenous stands of plants addressed include pasture species such as Para grass (*Urochloa mutica*), Guinea grass (*Urochloa maxima*), Pangola grass (*Digitaria eriantha*), Jarrah grass (*Digitaria milanjiana*), Tully grass (*Urochloa humidicola*) and Stylo species (*Stylosanthes* spp*)*. Introduced weeds include Snakeweeds (*Stachytarpheta* spp.), Hyptis (*Hyptis sauveolens*), Mission grasses (*Pennisetum* spp), wild passionfruit (*Passiflora foetida*), Calopo (*Calopogonium mucunoide*), Gamba grass (*Andropogon gayanus*), Couch grass (*Cynodon dactylon*), purple top grass (*Chloris* sp*)*, Gambia Pea (*Crotalaria goreensis*), Sicklepod (*Senna obtusfolia*), and native grasses (*Heteropogan* spp. *Sorghum stipodeum, Panicum mindanese* and *Schizachyrium fragile*). Suitable sites for additional species are continually being sourced to further investigate potentially confounding spectral responses as well as including other weeds of national significance that threaten rehabilitation success in the mine environment.

Because spectral signatures represent complex physical and biophysical relationships, an initial focus was to review and conceptualise the factors that influence field-based spectra. The concept of collecting consistent and accurate spectral data while minimising the influence of potential extraneous variation is relevant to field spectrometry in all environments, but these methods are rarely reported. The development of protocols for collecting field spectra is necessary because there are no national or international standards on in situ reflectance measurement or management of such data.

SSD has designed and implemented standards for the collection, documentation and storage of spectral data and metadata. The standards described were developed to enable a consistent and repeatable method that minimises the influence of extraneous factors in spectral measurement. Reflectance characteristics over the visible to shortwave infrared (350-2500 nm) using a FieldSpec-FR (ASD Inc 2004) of weed and native ground covers were sampled fortnightly from permanent plots around the greater Darwin region. The spectral data were supported by metadata describing the viewing and illumination geometries, environmental conditions and state of the target measured. These fortnightly measurements are continuing.

Results

The factors that affect spectral measurements and the issues to be considered when designing a spectral library database were reviewed and reported (Pfitzner et al 2005). It was found that the quality of ground-based reflectance spectra are dependent on a number of complex variables including the physical and chemical properties of the target of interest, the interaction between the target with electromagnetic radiation (EMR), illumination and viewing geometry and the localised environmental conditions. Spectral quality can also vary depending on the operator and calibration of the instrument and standard panel. Consideration and documentation of each of these variables are essential in obtaining meaningful reflectance spectra in the field.

A presentation by Pfitzner et al (2005) to the Spatial Sciences Institute (SSI) Biennial Conference, Melbourne (2005) initiated a discussion and decision to establish a ‘SSI Working Group on field spectroscopy and in situ measurements’. The Working Group acknowledges the importance of standardised spectral collection methodologies, outlined by Pfitzner and Carr (2006) and Pfitzner et al (2006a, b).

The factors that affect standardised measurements were summarised to include: environmental (eg wind speed and direction, cloud cover and type, temperature, humidity, aerosols), viewing geometry (field-of-view, height above target and ground, instantaneous-field-of-view), illumination geometry (time and sun altitude, azimuth and orientation, smoke and haze), properties of the target (physical and bidirectional distribution function) and calibration of the instrument and reference standard. As a result, spectral measurement standards were developed to include: adequate spectrometer warm-up time, laboratory verification of the spectrometer and reference panel calibration; images of the target at nadir, scaled set-up, horizon photographs and hemispherical photographs; subject information (classification, condition, appearance, physical state); subject background (scene background information similar to subject data); measurement information (instrument mode, date, local time, data collector(s), fore optics, number of integrations, reference material, height of measurement from target and ground, viewing and illumination geometry); environmental conditions (general site description, specific site location, geophysical location, sun azimuth and altitude, ambient temperature, relative humidity, wind speed and direction, weather instrument and sky conditions); and, of course, reflectance spectra.

Figure 1 conceptualises the interrelationship of metadata with spectral reflectance measurements. The metadata recorded with each spectral measurement are shown in Figure 2.

Apart from obtaining meaningful spectra at the time of in situ data collection, considering the optical, local environmental, scalar and physical variables, aids in temporal measurement analysis. Figure 3 illustrates selected ground cover reflectance spectra, accompanied by selected metadata, for *Stylosanthes humilis* over time. The depth and width of absorption features and the magnitude of reflectance change as the sample senesces over time. The intensity of water absorption features also change over time. Whether or not these changes are a result of biophysical changes of the target or attributable to the illumination conditions can only be assessed by a temporal sampling record combined with accurate metadata. For example, a decrease in water absorption features (at ~ 1400 and 1900 nm) are evident on the spectra recorded on the 12-06-2006 (Figure 3). The relative humidity, cloud cover and atmospheric metadata recorded with these samples supports that the decrease in water absorption can be attributed to comparatively low humidty (RH 18%) and 0% cloud cover. The humidity variable is not expected to be less in September compared to June–Aug. It is only with accurate spectral and metadata collection that both averaged ‘reference’ spectra and any significant temporal change in spectral response can be identified both within and between species.

Summary

Many remote sensing applications will remain in the research realm since they lack a knowledge base that quantifies spectral signatures through time, including the variation that occurs within and between vegetation species in the localised environment. Ground-based temporal measurements of high resolution spectra can provide a defined expectation for separability likeliness. The spectra expected for plant mixtures and vegetation-soil mixtures can thus be modelled. This information will be useful not only in the mine rehabilitation context , but also for weed management in the areas of Kakadu National Park surrounding the Ranger mine, assessing introduced ‘weedy’ pastures in nearby Arnhem Land, and any remote sensing feasibility study involving weed and native covers. These data will also provide insight into subtle phenological spectral changes between and within species. It is envisaged that, over time, a knowledge base will be be developed to provide the basis for undertaking cost/benefit analyses of proposed remote sensing studies. With this knowledge base, it may become possible to schedule airborne overpasses at times of greatest expected separability (chance provides highest cost effectiveness) between the spectral reflectance of targets of interest.

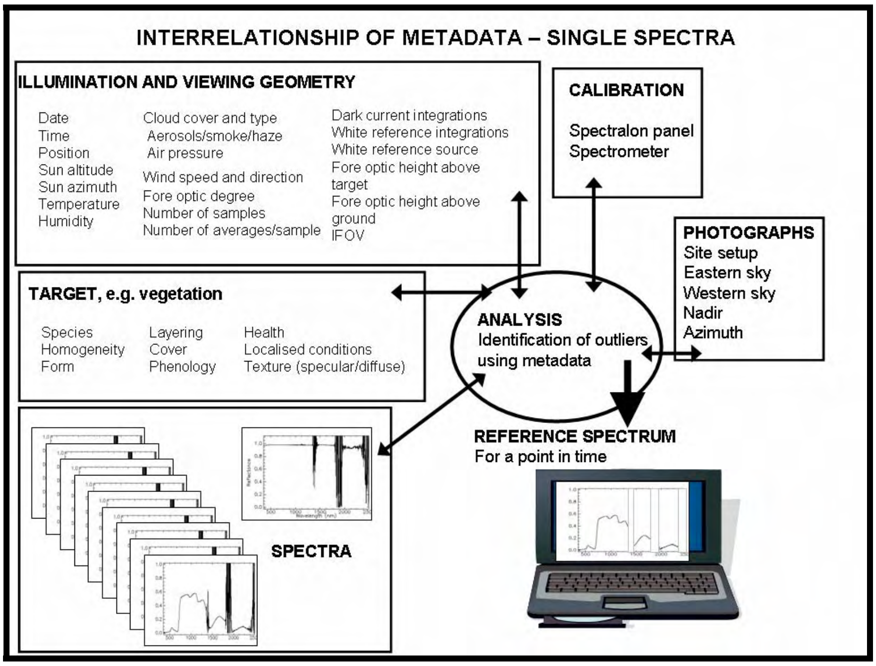

Figure 1 The interrelationship between metadata and spectra

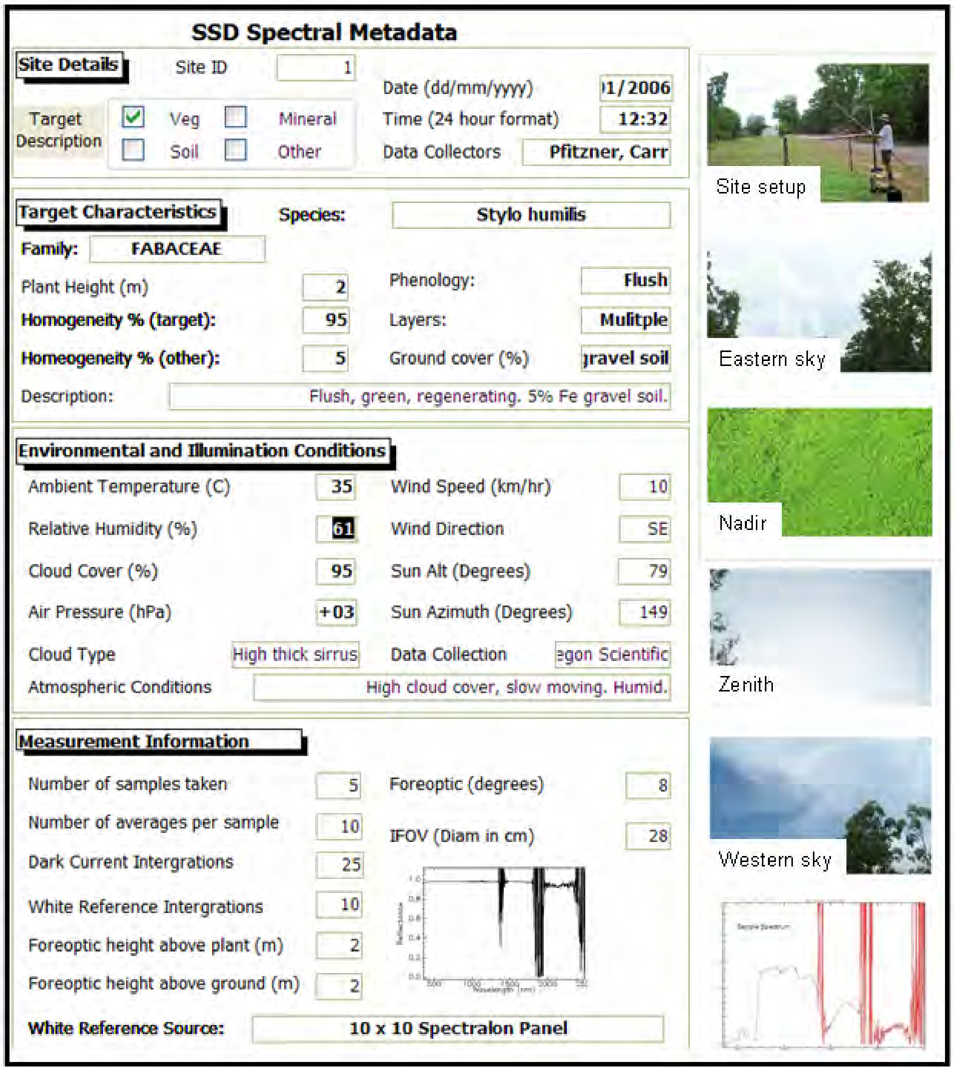

Figure 2 SSD's Spectral Database concept – spectral data and metadata records

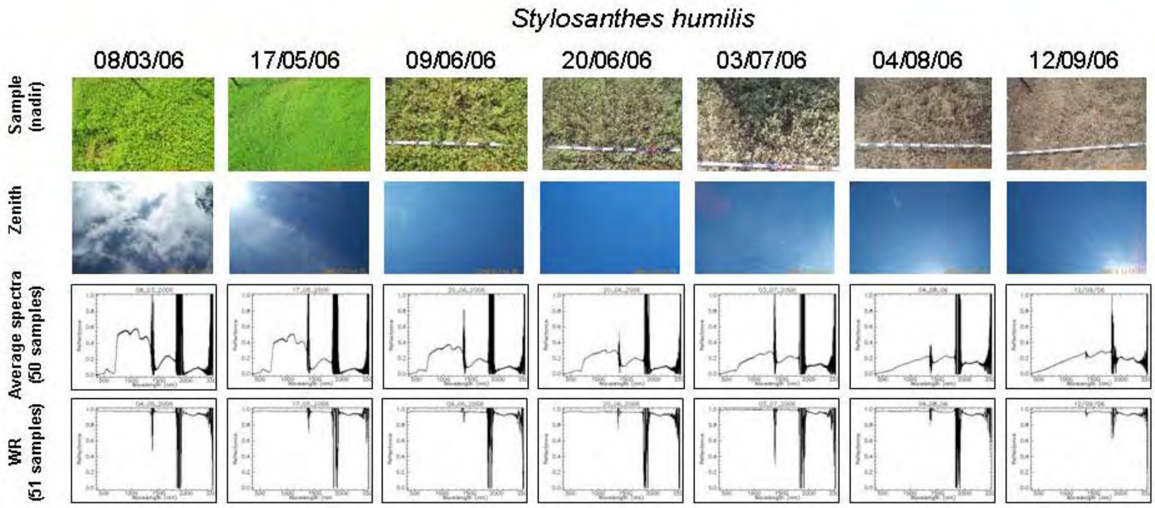

Figure 3 Selected ground cover reflectance spectra for *Stylosanthes humilis*, accompanied by selected metadata

Steps for completion

Fortnightly measurements of ground covers will continue. Suitable sampling sites for potentially confounding species or species of significance need to be continually sourced. An appropriate database to store and retrieve ground-based spectral information and metadata needs to be established. To account for within species variability, it is envisaged that spatio-temporal spectra will be measured along environmental gradients incorporating different densities and environmental backgrounds in the late wet season (during maximum phenological difference). Method to sample framework shrub and tree species and spectra of waste rock, soil and rock outcrop also needs to be developed. Once the database is established, the data needs will be analysed for both between and within species similarity and dissimilarity. Feasibility studies will be performed to determine the spectral separability of ground and canopy covers for a variety of remotely sensed platforms and recommendations on the most appropriate datasets for minesite rehabilitation assessment made.

Acknowledgments

Thanks to Dr Grahame Webb, Charlie Manolis and John Pomeroy (Crocodylus Park), Dr Gary Cook and Rob Eager (CSIRO) and Rob Kelley and Arthur Cameron (Berrimah Farm) for continued support and access to vegetation plots suitable for spectral sampling. Thanks also to Peter Bayliss, Mark Gardener, Jane Addison, Sean Bellairs, Bronwyn Bidoli, Dave Walden and James Boyden for initial discussion of the project.

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Development of key indicators and indices of ecosystem ‘health’ to monitor and assess rehabilitation success

C Humphrey, G Fox & J Boyden

Project status report

This project aims to develop and assess key indices of ecosystem ‘health’ to monitor and assess rehabilitation success, including faunal recolonisation. (See ARRTC 17 for one-page description of the project.) Progress with this study is contingent upon, and follows logically from, the results of the vegetation analogue study reported above (KKN 2.2.2). The study was proposed for 2006–07 and will commence later in this reporting year, as the analogue study is further advanced.

Incorporation of disturbance effects in predictive vegetation succession models

P Bayliss, D Walden, J Boyden, M Gardener[1] & S Bellairs[2]

Background

The aim of this project is to develop a predictive vegetation succession model that incorporates the effects of fire and weed disturbances at the landscape scale, in order to monitor and assess revegetation performance within a risk management framework. The project is in two phases. Phase 1 will draw on existing knowledge and data to: (i) characterise fire and weed disturbances with respect to frequency, intensity, duration, spatial extent and possible interactions; (ii) develop a conceptual model for vegetation succession that incorporates disturbance effects; and (iii) using the conceptual model commence development of a spatially explicit vegetation succession model. The model will incorporate current knowledge on landscape-vegetation relationships and vegetation dynamics, the starting conditions with respect to agreed establishment species and methods, the desired vegetation end point, and undesirable states that deviate from the desired trajectory pathway. The second phase of the project, due to commence in 2007–08, will use the model to: (iv) examine the resilience of vegetation along the successional trajectory by simulating temporal and spatial responses to disturbances; (v) identify gaps in knowledge that may require additional more focused monitoring studies, and/or data from landform-vegetation plots (see proposal for demonstration landform-vegetation plots); (vi) develop an ecological risk assessment and adaptive management framework for management of fire and weed disturbances during the rehabilitation phase.

Preliminary results for (i) above with respect to fire and weeds on the Ranger Project Area (RPA) and surrounds are reported below. Modelling work has commenced on sections (ii) and (iii) and, operationally, aspects of fire and weed research have been embedded into EWLS and ***eriss*** work plans as a key outcome of the Ecosystem Establishment Workshop held in December 2005 (Bayliss & Gardener 2006).

Fire

Progress to date

The following fire statistics for the RPA and surrounds (Fig 1) were determined: frequency of burns (F) over the time series, probability of burn (or proportion of years burnt, P), time since last burnt (TSLB, as an index of current fire risk), mean interval between burns (MeanIBB) and the minimum interval between burns (MinIBB). Statistics were derived for early dry season (EDS) and late dry season (LDS) fires. Two ‘fire scar’ data sets were obtained from the Fire Research Unit of the NT Bushfires Council (BFC, NRETA).

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The KNP data set covers the entire Park from years 1980 to 2004, whilst the Western Arnhem Land (WAL) data set covers the region east of the park boundary to approximately 125 km out, but only for the years 1995 to 2004. The WAL data set was required because the KNP data set only extends 6 km east of the RPA. For KNP Landsat satellite imagery was used to derive fire history, whilst that for WAL was derived from a combination of Landsat™, MODIS and NOAA–AVHRR. Early dry season fires are defined as those from late April/early May to the end of July. Imagery is captured at least twice to address potential problems of 'under-sampling', where fire-scars can be missed after rapid regrowth of vegetation (Oliver 1992, Russell-Smith et al 1997). Late dry season burns are defined as those from August onwards and are also derived from at least two captures (Russell-Smith et al 1997). Ten years of data from 1995 to 2004 are available for both of the above data sets and updates are currently being sought. Other data sets obtained for spatial pattern analyses include: land systems and vegetation (Story et al 1969 & 1976, Schodde et al 1987, Lynch & Wilson 1998); land units (soils, Wells 1979); roads, infrastructure, waterways and wetlands (AUSLIG 1999).

Data processing and future analyses

The fire-scar GIS shape files of each EDS and LDS KNP and WAL data sets were merged and then converted to a 250 m x 250 m raster grid. For a representative 'off-lease' fire history, a target area of 4880 km^2 (61 km x 80 km) surrounding the RPA was included in the data sets, and encompasses comparable landscapes found on the lease. Text files were produced from the raster grids and imported into Microsoft Excel™ where a customised Visual Basic program calculated the fire statistics listed above as outputs, which were then imported back into a GIS for mapping (see Figs 2–5).

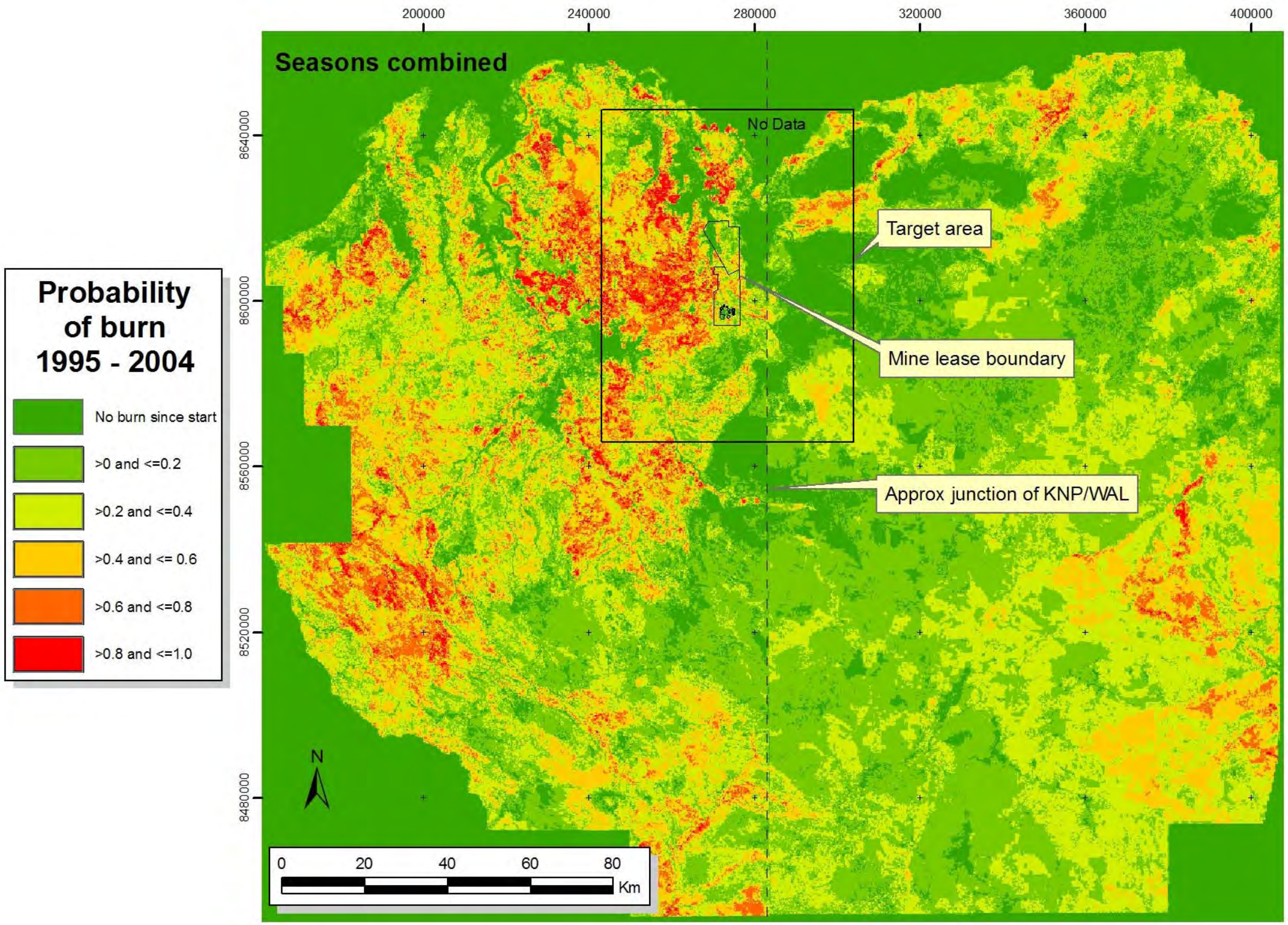

Figure 1 Kakadu National Park and western Arnhem Land merged fire datasets showing the relative location of the target are

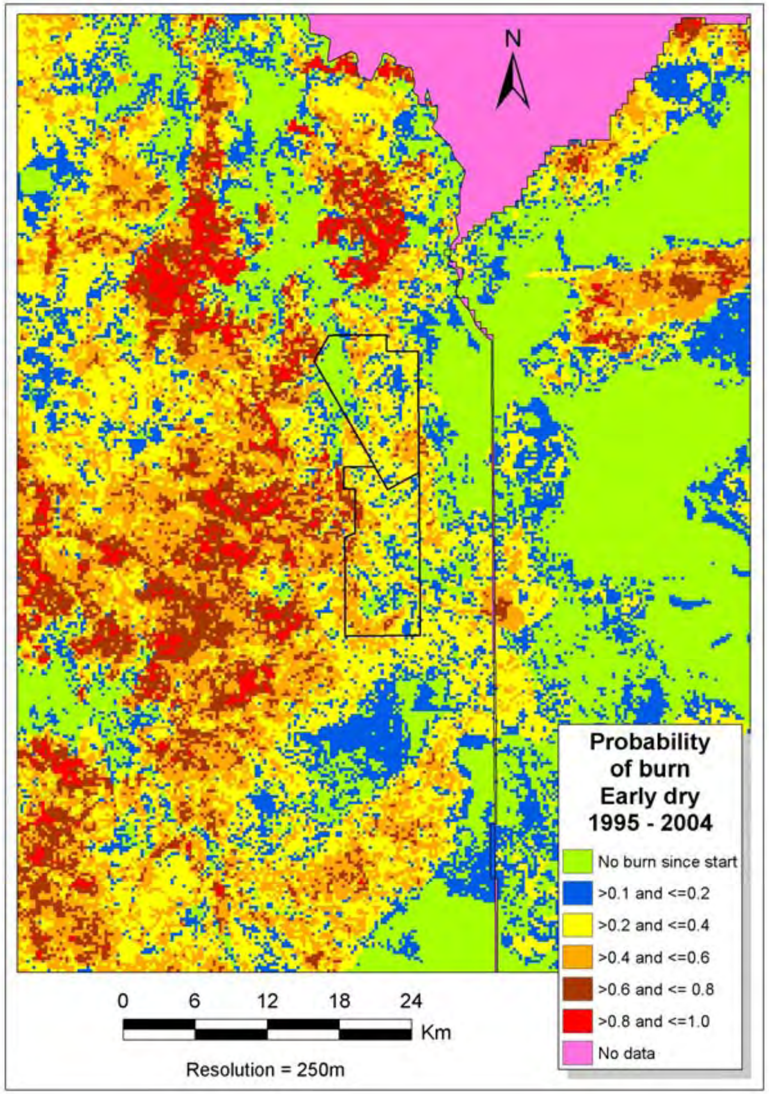

Figure 2 Early dry season burn probability for the target area

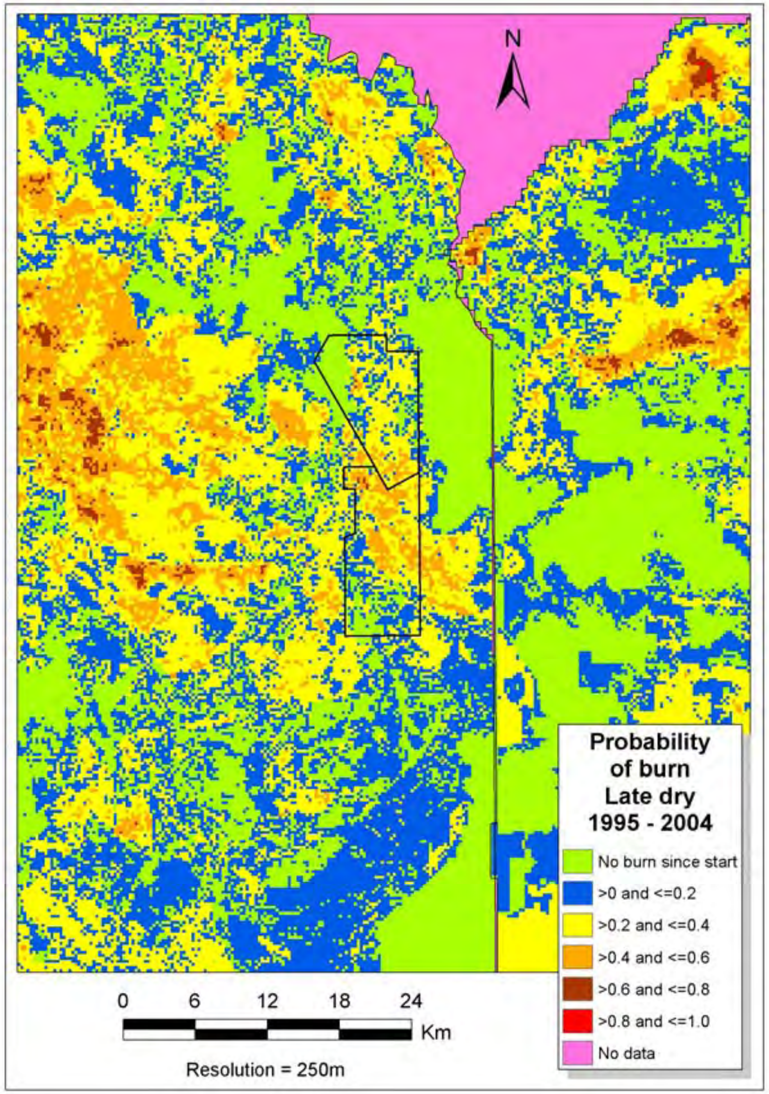

Figure 3 Late dry season burn probability for the target area

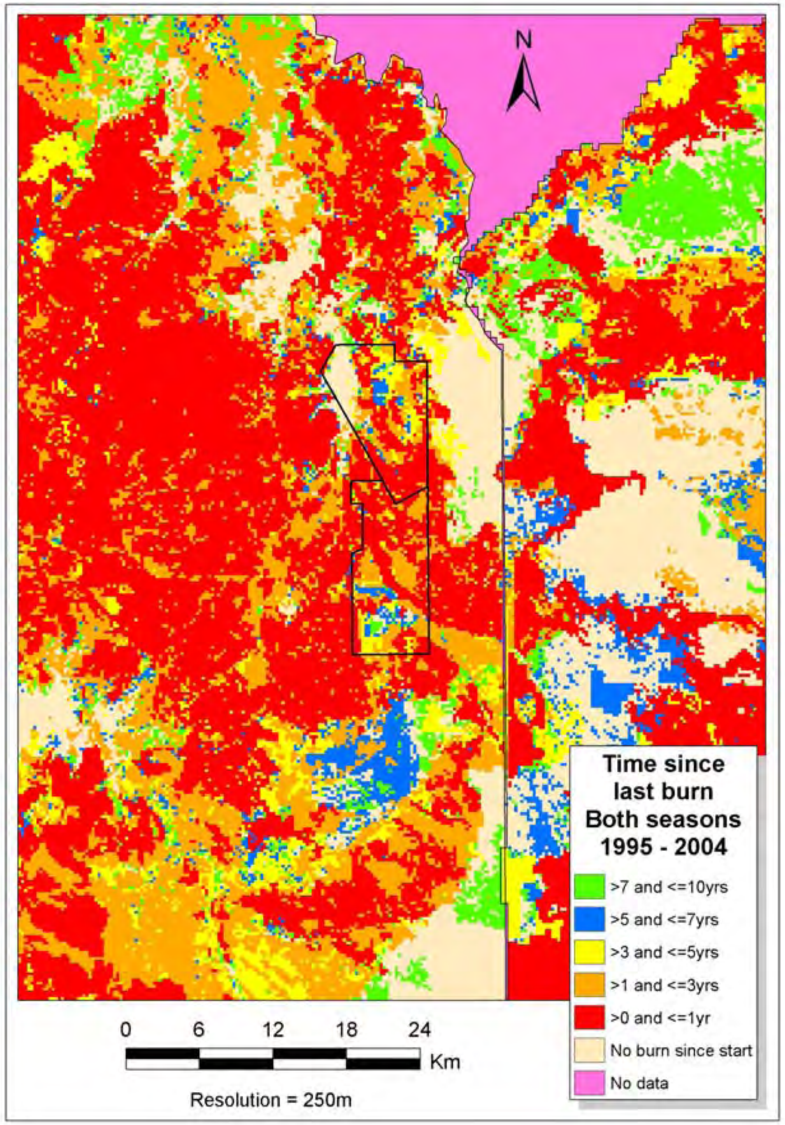

Figure 4 Time since last burn for the target area

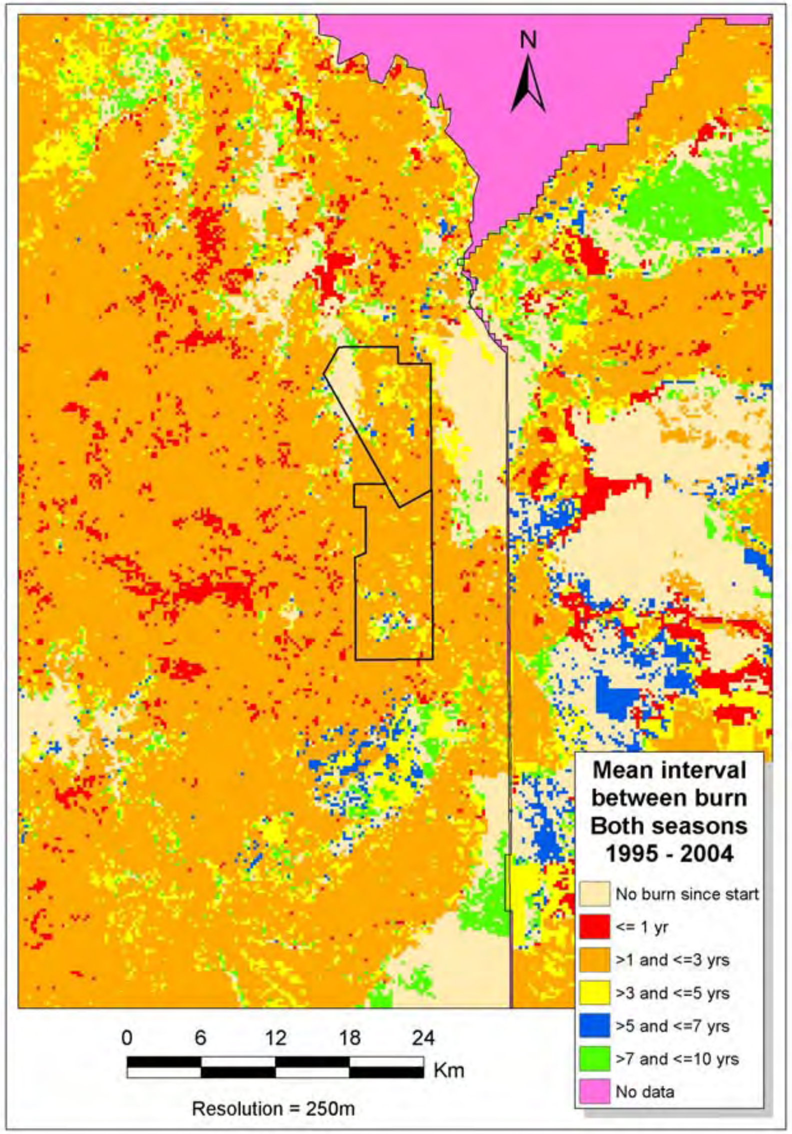

Figure 5 Mean interval between burn for the target area

Table 1 Summary of fire statistics on the Ranger Project Area (RPA – Ranger & Jabiluka mineral leases), Kakadu National Park (KNP) and western Arnhem Land (WAL). Spatial data on a 250 m grid were derived from Landsat fire scar maps (NT BFC) between 1995 and 2004 (n=10 yrs). % Area is the percentage of the total study extent of each location as defined in Fig 1, TSLB is time since last burnt (years), MIBB is the mean interval between burns (yrs), Fburn is the mean frequency of burns (yrs) over 10 years, and Pburn is the probability of fire over the 10 year interval (or the proportion of years burnt).

Regions	% of target area	TSLB	MIBB	Fburn	Pburn
WAL	34.2	1.48	2.23	2.28	0.11
Jabiluka	1.6	1.59	1.88	3.68	0.18
Ranger	1.6	1.46	1.94	4.73	0.24
RPA	3.2	1.52	1.91	4.20	0.21
KNP	62.5	1.28	1.79	4.52	0.23

A comparison of fire history statistics between different locations in the study area is summarised in Table 1. The contrasts are based on the mean occurrence of a fire history attribute on a 250 m grid cell within each location. Although these contrasts may provide a rough picture of what is happening they do not account for spatial autocorrelations and scale effects, and hence are not quantitative. Hence, a CDU PhD student will be contracted in January 2007 to undertake more appropriate spatial analysis of the fire history data set using a Classification and Regression Tree (CART) approach.

The analysis will contrast fire statistics on the spatial grid between locations (RPA vs. KNP & WAL, Ranger vs. Jabiluka mineral leases), infrastructure (roads, fences), landscapes, broad vegetation communities and nested combinations of the former. Additionally, availability of the finer spatial resolution fire history data will allow previous multivariate analyses of all analogue data (***eriss***–Brennan + EWLS–Hollingsworth) to be re-examined with fire included as a major ecological factor or component, and this will be undertaken by collaborators from ***eriss***, EWLS and CDU.

ERA/EWLS update (Mark Gardener): aligning fire management of Ranger and Jabiluka leases with the surrounding KNP

The collaborative fire project described above is the first of three phases of the technical component of this study (driven by ***eriss***), and uses long-term LANDSAT satellite imagery to detect and map fire scars. Fire history on the RPA and areas of adjacent KNP over the last 25 years have been described. The project also has a social component (driven by EWLS) where land managers in the region have been interviewed. These data will be used to paint a picture of past and present fire management, and will be used to inform the development of a 5 year fire management plan for the lease. This fire management plan will attempt to align fire management on the lease to that of the surrounding national park. Also other uses of fire, such as for rehabilitation and weed management, will be developed. A collaboration with Gundjeihmi Aboriginal Corporation to incorporate traditional fire management on the lease is also being developed.

Weeds

Progress to date

The GIS mapping and monitoring of weeds on the RPA commenced by Michael Welch/EWLS in 2005 has been continued and improved by Mark Gardener/EWLS (see below). Additionally, the GIS weeds database for Kakadu has been updated by PAN staff. Characterisation of the potential disturbance effects of weeds to successful revegetation on Ranger will be undertaken using GIS data from the RPA and surrounding Kakadu. Potential interactions between weeds and fire will be investigated using all available temporal and spatial data.

(a) **(b)**

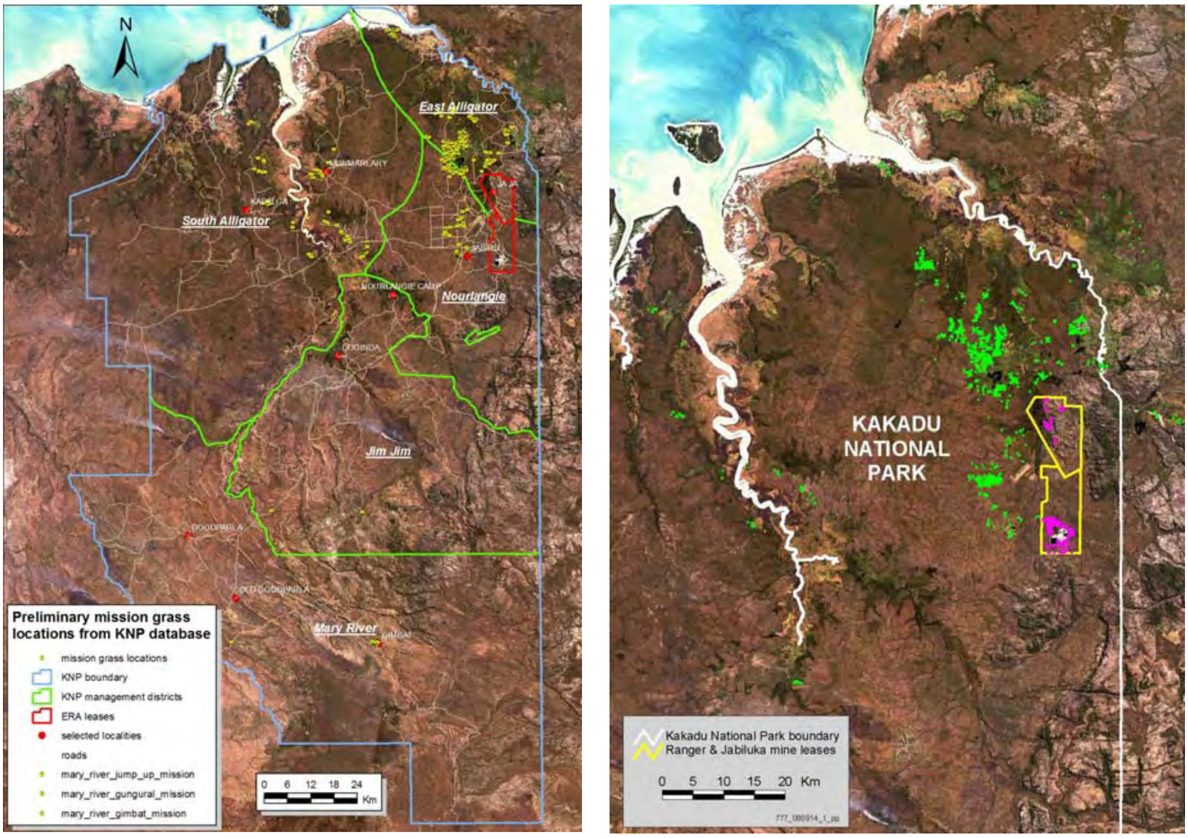

Figure 6 a & b Maps showing locations of perennial and annual mission grass (*Pennisetum polystachion & P. pedicellatum*, respectively) across (a) Kakadu National Park (derived from surveys conducted by PAN rangers), and (b) the RPA (derived from ERA-EWLS surveys, showing additional locations on the Oenpelli floodplain just north of the E Alligator River, & in western Arnhem Land just off the park).

A Weeds Closure workshop was held in November 2005. The outcomes were reported in detail by EWLS–ERA/***eriss*** at ARRTC 17 (February 2006) and in an EWLS report (EWLS 2005). A follow-through weeds closure workshop was planned for March/April in 2006 but has been re-scheduled to accommodate a planned workshop series in 2007 on landscape change and fire and grassy weed management, to be facilitated by PAN, ***eriss*** and CDU.

At the November 2005 Weeds Closure workshop both perennial and annual mission grass species (*Pennisetum polystachion & P. pedicellatum*, respectively) were identified as possibly the greatest weeds risk to revegetation success at Ranger and possibly one of the most important environmental risks to rehabilitation in general. A preliminary distribution map

(Figure 6) of both species of mission grass in KNP has been derived from survey and control information provided by Parks, and indicates that the RPA is currently at risk of invasion from the Magela catchment and, conversely, KNP is also at risk of invasion from infestations on the RPA. The extent of mission grass on the RPA is not indicated in detail on Figure 6b. This aspect will be reported separately by EWLS.

Hence, a well coordinated control effort involving all stakeholders is required, and the first Weeds Closure workshop in late 2005 was a significant step in that direction. A project proposal is currently being drafted for PAN to determine the extent of mission grass across KNP, and to undertake an ecological risk assessment. The project will review also strategic management goals and operational procedures. The outcomes of this new project proposal have direct relevance to developing acceptable closure criteria for mission grass on rehabilitated areas of Ranger, and for the risk management of weeds and fire on the RPA in general.

ERA/EWLS update (Mark Gardener): developing closure criteria for weeds on Ranger lease

Weeds are one of the most serious environmental problems on the Ranger mining lease (Ranger) and the surrounding KNP. When mining and milling ceases, rehabilitation will happen in a staged fashion. Weeds have a significant potential to impact rehabilitation and successful mine closure, and must be addressed at the regional scale. One legislative requirement of the Ranger Authorisation states that the goal is to 'rehabilitate the Ranger project area to establish an environment similar to adjacent areas of Kakadu National Park such that, in the opinion of the Commonwealth Minister with the advice of the Supervising Scientist, the rehabilitated area could be incorporated into Kakadu National Park'. Interpretation of the above legislative requirement into that which is applicable and technically meaningful with respect to weeds is necessary. Currently closure criteria for weeds on the Ranger lease are being developed through a system of stakeholder consultation, weed risk assessment and mapping of weeds at Ranger and in KNP.

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Monitoring sediment movement along Gulungul Creek during mining operations and following rehabilitation

D Moliere, M Saynor & K Evans

Introduction

As part of the data required to assess the success of rehabilitation of the Energy Resources of Australia (ERA) Ranger mine, it is proposed to determine the baseline loads of stream suspended sediment in the catchment of Magela Creek. The first stage of this work will involve the measurement of fine suspended sediment loads in Gulungul Creek, a small left bank tributary of Magela Creek that is likely to receive sediment generated from the rehabilitated mine site (Erskine & Saynor 2000). Given the location of Gulungul creek and the potential for erosion and transport of sediment into Magela Creek, the hydrology and sediment transport characteristics in Gulungul Creek are being investigated before rehabilitation at the mine site occurs (Moliere et al 2006).

Two gauging stations were installed in the Gulungul Creek catchment, one station upstream (GCUS) and one downstream (GCDS) of the Ranger mine (Fig 1). These stations were installed in November 2003 and February 2005 respectively. Fine suspended-sediment[1] (mud) transport is monitored at these stations using turbidimeters. Mud concentration data, derived from in situ continuous turbidity measured over several years, will be used to derive mud concentration (and turbidity) trigger values in accordance with The Australian and New Zealand water quality guidelines (WQG) (ANZECC & ARMCANZ 2000) using a Before-After-Control-Impact, paired difference design (BACIP) (Stewart-Oaten et al 1986, 1992, Humphrey et al 1995) approach. These trigger values will provide the basis for assessing mine impact through the operations and rehabilitation phases.

Flow data collected at the two stations will be used to determine long-term hydrological characteristics and assess flood risk both upstream and downstream of the Ranger mine. The long-term runoff record at station G8210012 (Fig 1) (a station operated between 1971 and 1993 along Gulungul Creek that is neither entirely upstream nor downstream of the Ranger mine site influence and now re-instumented) will be used to extrapolate the record at the relatively new station locations. The flow data collected at GCUS and GCDS will also be combined with mud concentration data to derive event mud loads at the stations (discussed below).

Progress to date

Continuous rainfall, runoff and mud concentration data were collected during 2005–06. Water samples were collected at GCUS (Gulungul Creek upstream of Ranger) to validate the turbidity-mud concentration relationship previously fitted using 2003–2005 data (Moliere et al 2005). Water samples collected at GCDS (Gulungul Creek downstream of Ranger) were used to derive a turbidity-mud concentration relationship for that site.

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[1] Fine suspended-sediment is the mud (silt+clay) component of sediment transported in the water column ie. that portion < 63 μm, > 0.45 μm diameter.

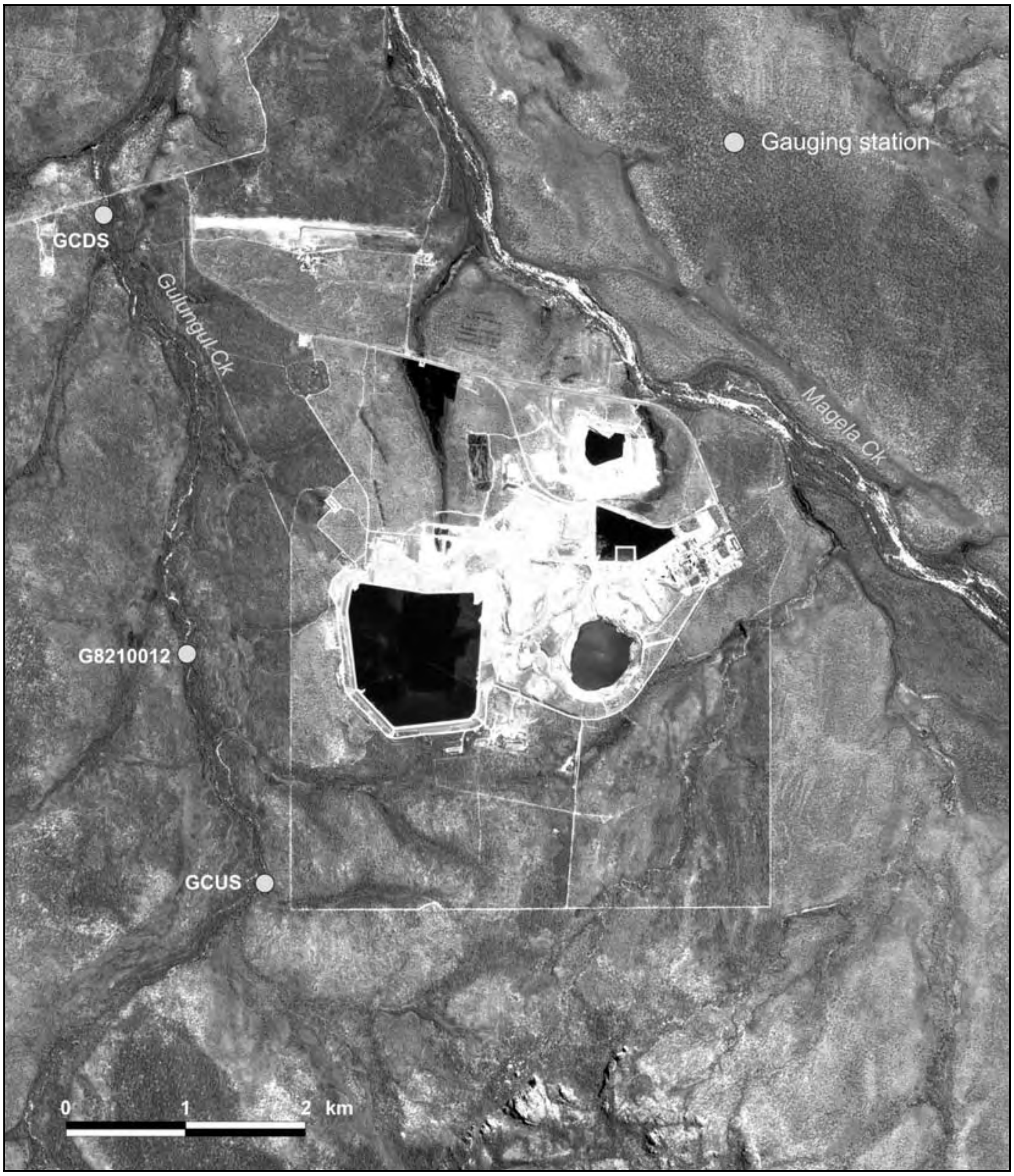

Figure 1 Location of gauging stations along Gulungul Creek

During the 2005–06 wet season several high-flow velocity-area gaugings were taken at GCUS and GCDS to refine the 'higher end' of the rating curve for GCUS and to fit a rating curve for GCDS. Since both stations have now been gauged to approximately 80% of the maximum flow for the 2005–06 wet season, it is considered that the rating curves for GCUS and GCDS are reliable for most flow conditions. Using three years of runoff data at GCUS and one year at GCDS, significant relationships were fitted between observed event peak discharges at the two stations with corresponding peak discharges at G8210012. This indicates that the historical long-term runoff record at station G8210012 (1971 to 1993) can be used to extrapolate the record at GCUS and GCDS. Using the extended runoff record at the two stations, flood frequency curves were established for GCUS and GCDS (Moliere et al 2007).

Mud loads were determined for 11 runoff events at the stations upstream and downstream of Ranger during the 2005–06 wet season. These upstream and downstream event load data were compared using an event-based Before-After-Control-Impact, paired difference design (BACIP). This comparison of event mud loads observed upstream and downstream of the mine under non-mine impacted conditions will be used to provide the basis for future impact assessment during operations and following closure.

The mean ratio of event mud load measured downstream to event mud load measured upstream along Gulungul Creek for the one-year monitoring period is approximately 1.8 (Fig 2). Larger catchments have higher sediment loads than smaller catchments because of higher discharges.

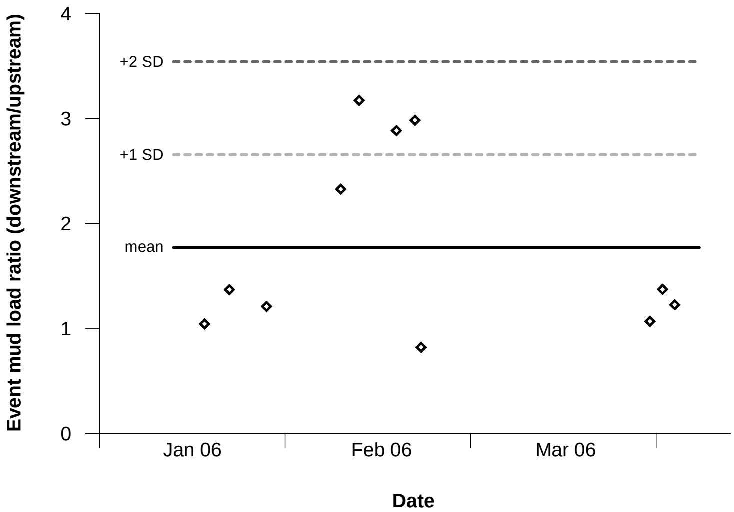

Figure 2 Control chart showing temporal variation of the ratio of event mud loads measured downstream to that upstream along Gulungul Creek during 2005–06 (indicated as◇). The mean ratio and associated standard deviations are also shown.

Events that lie greater than two standard deviations above the mean ratio (ie > +2 SD) indicate that the event mud load observed downstream of the mine is significantly elevated above that observed upstream (compared to other events), which may indicate a possible mine-related impact. During 2005–06 no events were considered to be ‘outliers’, although there were three successive events above the +1 SD line (Fig 2) that occurred during a 10-day period in February. This behaviour indicated that event mud load measured downstream was relatively high compared to the event load measured upstream during this period. It is recommended that event load data are collected for at least two more years within the Gulungul Creek catchment to provide a larger database from which to establish the pre-closure baseline using BACIP analysis before rehabilitation commences at Ranger.

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Monitoring sediment movement along Magela Creek up and downstream of Ranger

D Moliere & K Turner

Introduction

It is important to quantify the annual loads of suspended sediment (and associated contaminants) and the dynamic range of turbidity in Magela Creek upstream and downstream of the mine before rehabilitation is started (Moliere & Saynor 2006). This information will enable derivation of both operational management guidelines for turbidity as well as closure criteria for tubidity and annual suspended sediment load. Prior to the 2005–06 wet season, only limited suspended sediment concentration data had been collected within the Magela Creek catchment (upstream of G8210009). Moreover, grab samples collected for turbidity measurement did not adequately cover periods of high flow.

During December 2005, Hydrolab datasondes equipped with turbidity probes and telemetry instrumentation were installed at three locations along Magela Creek - one site upstream of the Ranger minesite influence (Magela Creek upstream - MCUS) (fig 1) and two sites downstream of the mine (009 east channel – 009esond and 009 west channel – 009wsond) (fig 1) – see KKN 1.3.1 for additional information on this deployment. This paper is an initial assessment of the continuous stream turbidity data collected at all three sites for the 2005-06 wet season.

Results

Flow data along the main Magela Creek channel were measured at stations upstream (Magela01) and downstream (G8210009) of the mine (Fig 1) by ERA and NRETA, respectively. Flow data were also collected at the discharge weir of Retention Pond 1 (RP1) by ERA. The flow time series data are shown in Figures 2 to 4.

The turbidity data collected at the two downstream stations (009esond and 009wsond) are very similar throughout the wet season. It should be noted that, despite the similarity in turbidity data between the two stations, electrical conductivity between the two stations is significantly different, which suggests that, in this case, solute and fine suspended sediment transport is dominated by different processes (D Jones pers comm. 2006). Figure 2 shows how strongly the two sets of downstream turbidity data correspond with each other during a five-week, high runoff period in March–April.

Upstream and downstream differences

In general, turbidity spikes observed upstream at MCUS as a result of a catchment runoff event are also observed downstream (a few hours later) (Fig 3). However, Figure 3 also highlights a period in mid-March where three spikes in turbidity were observed downstream of the mine that were not observed upstream. These are the only events of the 2005–06 wet season where this has occurred. Figure 4 shows the turbidity data collected at 009wsond and MCUS during this period in mid-March.

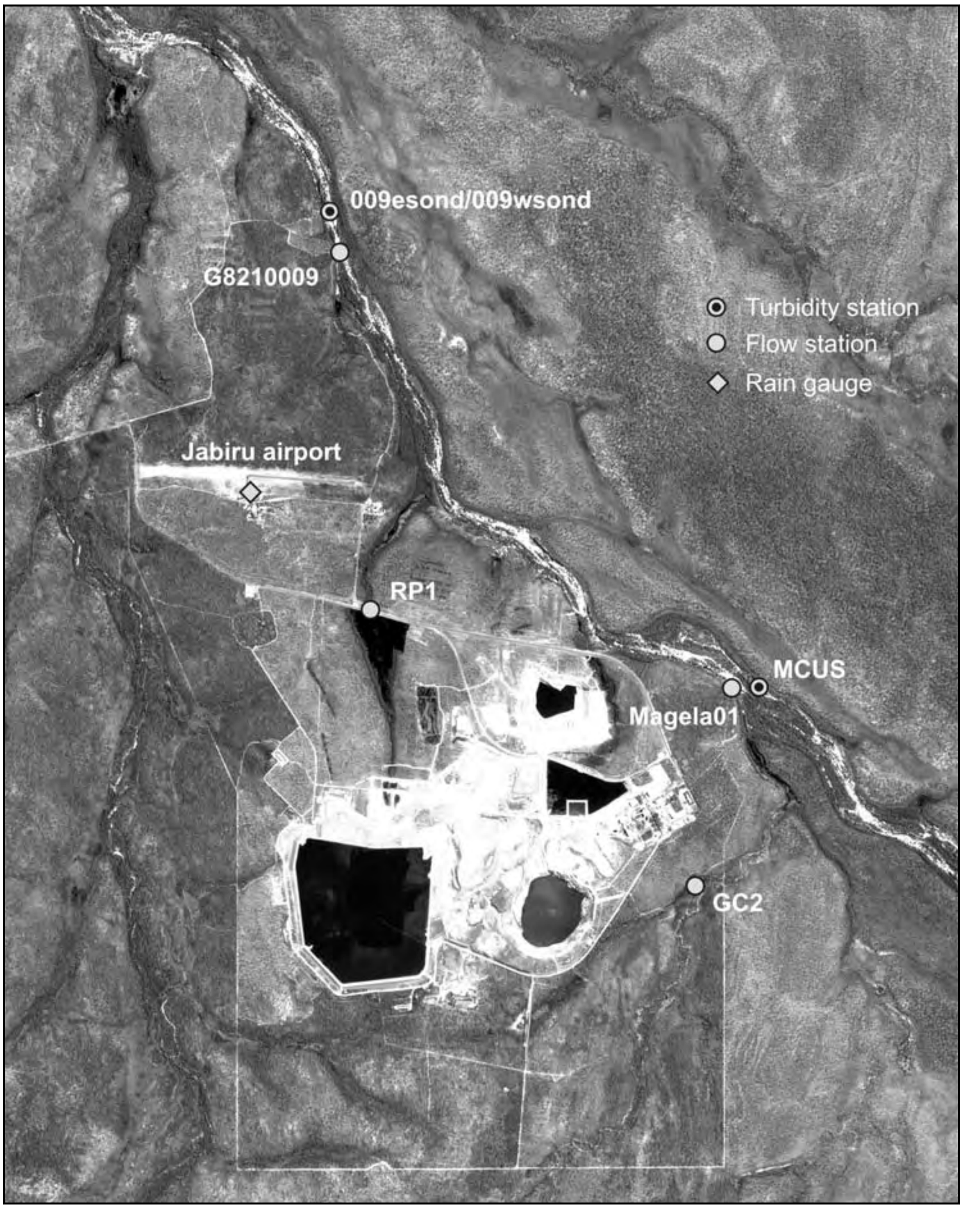

Figure 1 Location of stations along Magela Creek and mine site tributaries

Turbidity spikes 1 and 2 occur at both stations and can be attributed to a rainfall-runoff event which occurred within the Magela Creek catchment (as indicated by the G8210009 hydrograph). Turbidity spikes A, B and C, which occur at 009wsond (and 009esond as indicated in Figure 2) but not at MCUS, are not associated with a runoff event observed at G8210009. However, these spikes (A, B and C) are associated with runoff events observed at RP1. The corresponding rainfall data collected at Jabiru airport indicate localised storms may have occurred within the mine site catchment (but not further upstream) which contributed to these three runoff events observed at RP1. It is likely that suspended sediment was flushed from the RP1 catchment during these three runoff events and subsequently observed as a relatively minor spike in turbidity at the downstream stations. Given the small size of the RP1 catchment compared to the catchment area upstream of G8210009, these runoff events at RP1 have almost no effect on the G8210009 hydrograph.

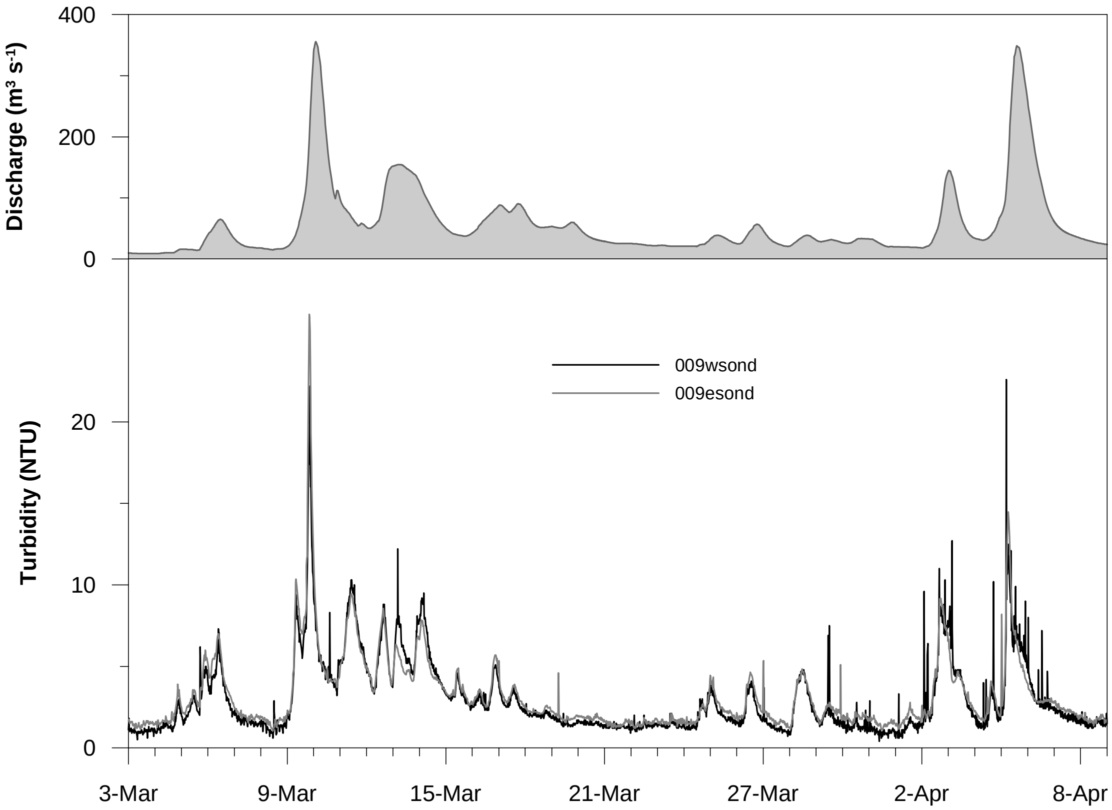

Figure 2 Turbidity data collected at the two downstream sites during a 5-week period of 2005–06. Discharge data observed at G8210009 are also shown.

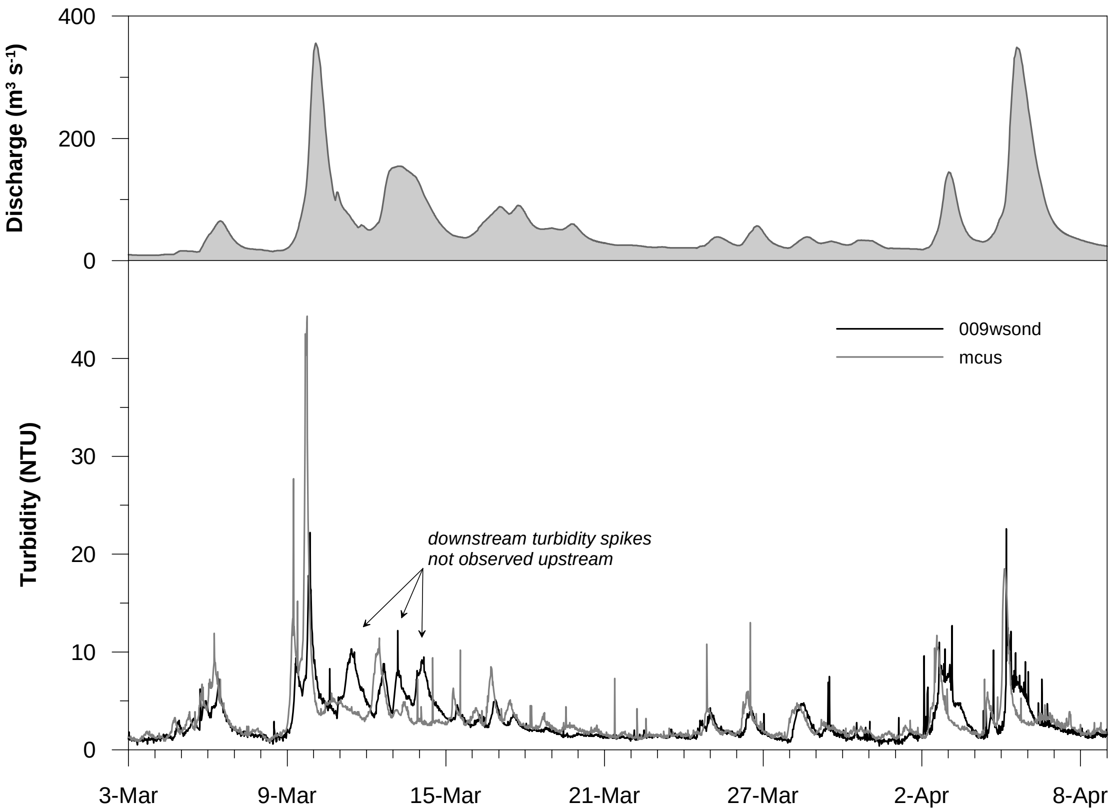

Figure 3 Comparison between upstream and downstream turbidity probes. Discharge data observed at G8210009 are also shown.

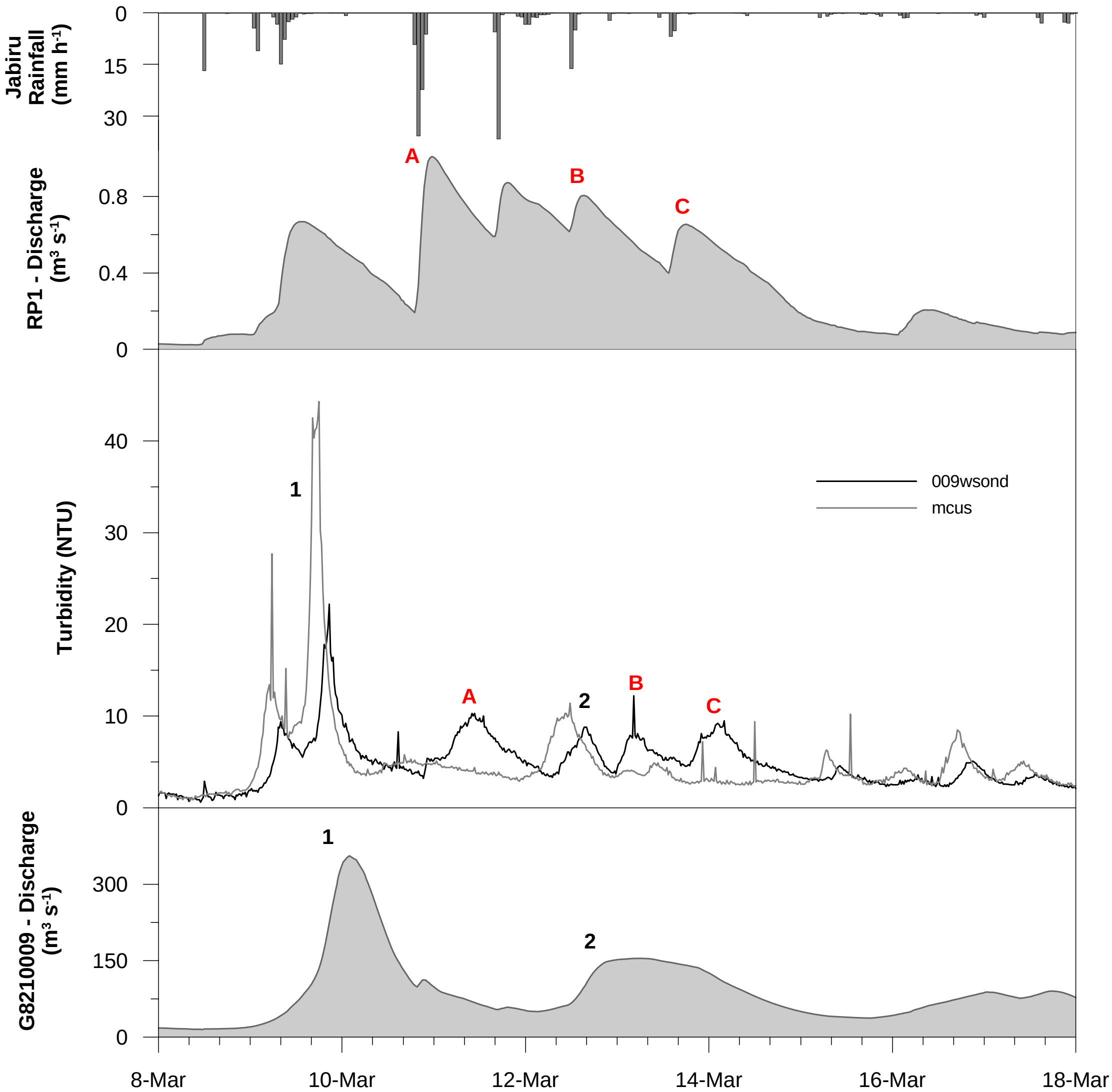

Figure 4 Turbidity data collected at MCUS and 009wsond during mid-March 2006. Discharge data observed at G8210009 and RP1 and rainfall data from Jabiru airport are also shown.

Moliere et al (2005) showed that turbidimeters are a robust and efficient method for monitoring the stream transport of fine suspended-sediment[1] within the Kakadu region. However, a turbidity-fine suspended sediment (mud) concentration relationship was not able to be fitted for the sites along Magela Creek owing to an insufficient number of samples spanning the dynamic range of turbidity having been collected for suspended solids analysis during the 2005–06 wet season.

Water samples will be collected during 2006–07 by automatic pump samplers installed at the upstream station and the downstream station to provide additional data to define the fine suspended sediment versus turbidity relationship. These data will be used to derive upstream and downstream site-specific turbidity-mud concentration relationships for Magela Creek.

[1] Fine suspended-sediment is the mud (silt+clay) component of sediment transported in the water column, ie. that portion < 63 µm, > 0.45 µm diameter.

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Part 3: Jabiluka

Contents[1]

3.1 Monitoring

KKN 3.1.1 Monitoring during the care and maintenance phase

3.2 Research

KKN 3.2.1 Research required prior to any development

[1] List of papers grouped by Key Knowledge Need.

Monitoring sediment movement at Jabiluka

D Moliere, M Saynor & K Evans

Introduction

The Jabiluka uranium deposit is located in the catchment of Ngarradj (Swift) Creek in the wet-dry tropics of the Northern Territory, Australia (Fig 1). Ngarradj is a major downstream right-bank tributary of Magela Creek, which flows directly into the Magela Creek floodplain. The Ngarradj catchment will be the first to be affected should any impact occur as a result of mining operations at Jabiluka. In 1998 a stream gauging network was established to determine the pre-mining hydrological and suspended sediment transport characteristics of the Ngarradj catchment. Stream gauging stations were installed upstream (Upper Main – UM; East Tributary – ET) and downstream (Swift Creek – SC) (Fig 1) of Jabiluka (Erskine et al 2001).

Fine suspended-sediment[1] transport is monitored at the stations using field-calibrated turbidimeters. Moliere et al (2005, 2006a) has used an event-based Before-After-Control-Impact, paired difference design (BACIP) (Stewart-Oaten et al 1986, 1992, Humphrey et al 1995) approach for impact assessment using event mud loads derived from mud concentration data collected by the turbidimeter during 2003–04 and 2004–05. In this case, an event-based BACIP design where SC and the combination of UM and ET are treated as paired sites and the comparison of ratios is used to assess impact. Event load data collected during 2005–06 have now been added to the previous pool (Moliere et al 2005, 2006a) of BACIP analyses.

Progress to date

During the three year monitoring period (2003–06) there were 34 events with complete event load data collected at all three (SC, UM, ET) stations. The ratio of SC mud load to UM + ET mud load for these 34 events is not normally distributed and, therefore, we have used percentiles to assess the data. The events of 'interest' are those that lie greater than the 95th percentile of the mud load ratios because these are events where significantly elevated mud loads are measured at SC relative to the combined load at UM and ET. The event-based BACIP analysis indicates that only one such event has occurred throughout the three-year period (Fig 2).

The event that lies above the 95th percentile of the mud load ratios on Figure 2 occurred on 10 March 2006. Peak runoff associated with this event was the highest for 2005–06 at SC and UM (and fourth largest at ET) (Moliere et al 2006b). The total mud load for this event was 15% of the total annual load at SC and only 9% and 4% of the total annual load at UM and ET respectively. Hence, it is possible that the contribution of mud load at SC from the ungauged tributaries within the western part of the Ngarradj catchment may have been relatively high during this runoff event. This highlights the need to monitor flow and mud concentration on these western tributaries to better able to attribute source of elevated mud loads observed downstream of Jabiluka compared to the upstream stations, particularly if mining should proceed at Jabiluka.

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[1] Fine suspended-sediment is the mud (silt+clay) component of sediment transported in the water column, ie. that portion < 63 μm, > 0.45 μm diameter.

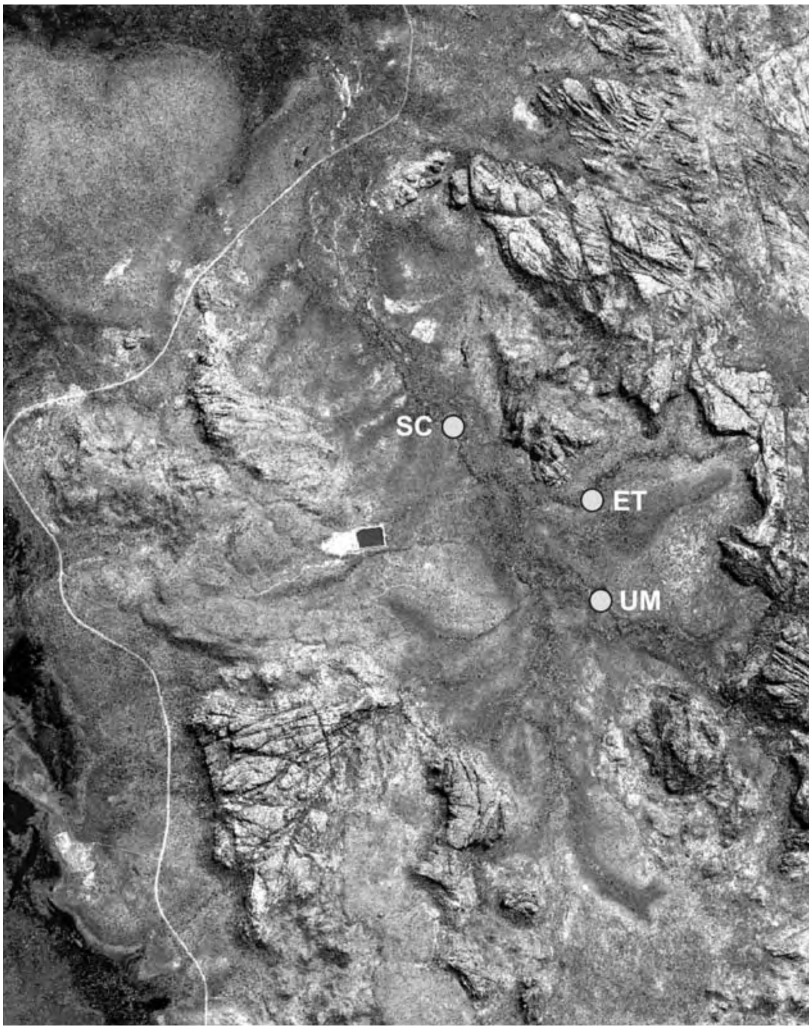

Figure 1 Location of gauging stations along Ngarradj

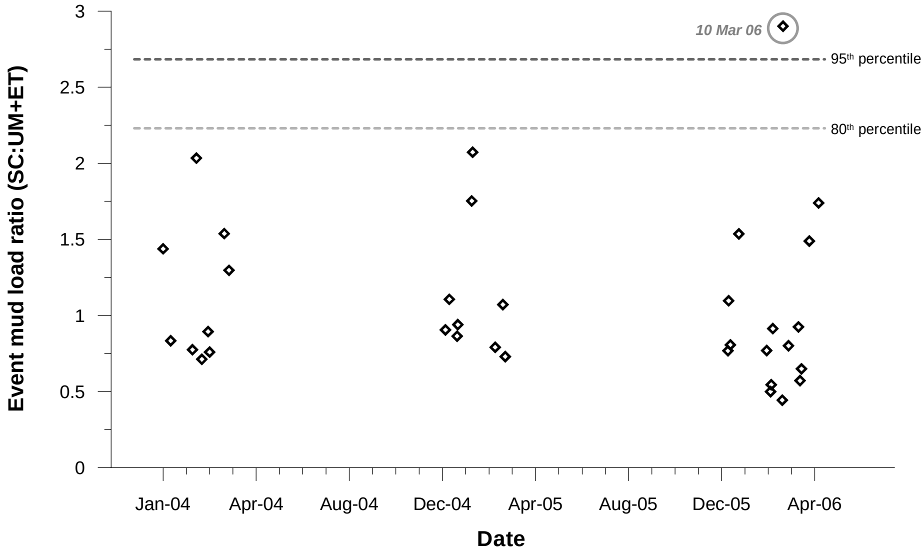

Figure 2 Temporal variation of the ratio of event mud loads measured at SC to that at UM and ET during 2003–04, 2004–05 and 2005–06 (indicated as ◇). The 80th and 95th percentiles of the event mud load ratios are also shown.

Cyclone Monica

Cyclone Monica moved through the Ngarradj catchment early on 25 April 2006 (by this time it had reduced to a category 3 cyclone). Substantial tree fall occurred throughout the catchment as a result of this event, particularly the riparian vegetation along the Ngarradj channel (Moliere et al 2006b). As a result of the treefall, significant changes could occur to the hydrology, sediment transport and channel stability characteristics within the Ngarradj catchment compared with pre-cyclone conditions. These changes would occur as a result of (1) increased availability of sediment for erosion throughout the catchment as a result of treefall, and (2) a change in channel alignment and channel cross section as erosion around fallen trees occurs (particularly around root balls). It is essential that hydrology and sediment transport data are collected during the 2006-07 wet season to be in a better position to assess the changes to the catchment conditions as a result of the cyclone. If significant changes have occurred to the hydrology, sediment transport and channel stability characteristics, several more years of post-cyclone data may need to be collected within the catchment to revise the pre-mining catchment conditions.

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Stewart-Oaten A, Bence, JR & Osenberg CW 1992. Assessing effects of unreplicated perturbations: No simple solutions. *Ecology* 73, 1396–1404.

Stream bedload characterisation: Ngarradj catchment

MJ Saynor, WD Erskine[1], DR Moliere & KG Evans

Introduction

A stream-monitoring program was implemented in the Ngarradj catchment in the late dry season of 1998 and prior to the 1998–1999 wet season (Erskine et al 2001). Rainfall, stream suspended mud concentration, suspended bedload, solutes, EC, turbidity and stream discharge data were collected for the wet seasons 1998–1999 to 2004–2005, inclusive. Transported bedload samples were collected for the wet seasons 1998–1999 to 2001–2002, inclusive. The data have allowed (1) determination of baseline characteristics for the measured sediment parameters in the catchment and (2) assessment of impact on water quality resulting from construction of the Jabiluka project site site. The work discussed here focuses on water, solute and sediment yields for the East Tributary catchment (Figure 1).

Progress to date

East Tributary is a small sand-bed stream which is a right bank tributary of Ngarradj Creek. The total catchment area of East Tributary is 10.3 km^2, of which 8.5 km^2 drains to the gauging station. The gauging station is located in the Forested Meandering Reach (Erskine et al 2001), of the Tributary. This is characterised by a sinuous planform (sinuosity > 1.5) and by steep, well-vegetated banks (monsoonal vine forest dominated by *Allosyncarpia ternata*). The East Tributary gauging station is fitted with a stilling well, an optical shaft encoder and pressure transducer, data logger, stage-activated automatic pump sampler (APS) with a fixed level inlet, rain gauge and gauging wire. Data have been collected for the 7 wet seasons between late 1998 and mid-2005.

Water samples collected by the APS were downloaded on a weekly or fortnightly basis. The water samples were processed in the ***eriss*** laboratory using standard sediment filtering and water chemistry techniques after Eaton et al (1995) and described in Evans et al. (2004). Parameters measured included concentration of sand (> 63 µm diameter); mud or silt and clay (< 63 µm and > 0.45 µm diameter) and solutes (< 0.45 µm diameter). The lower limit of detection for mud concentration was 3 mg/L (Evans et al 2004). Bed-load transport samples were collected by a Helley-Smith bedload sampler for most of the times the site was visited to download data.

Rainfall is highly seasonal in the East Tributary catchment with monthly totals greater than 150 mm being recorded at the peak of the wet season between December and March. During the period of this study rainfall normally commenced in October and persisted until April/May (Table 1). Mean and median monthly values are generally similar for the 7 years of data reported here. As a consequence of the distinct wet season period, streamflow is also highly seasonal.

[1] Centre for Sustainable Use of Coasts & Catchments, School of Environmental and Life Sciences, University of Newcastle, Ourimbah Campus, PO Box 127, Ourimbah NSW 2258.

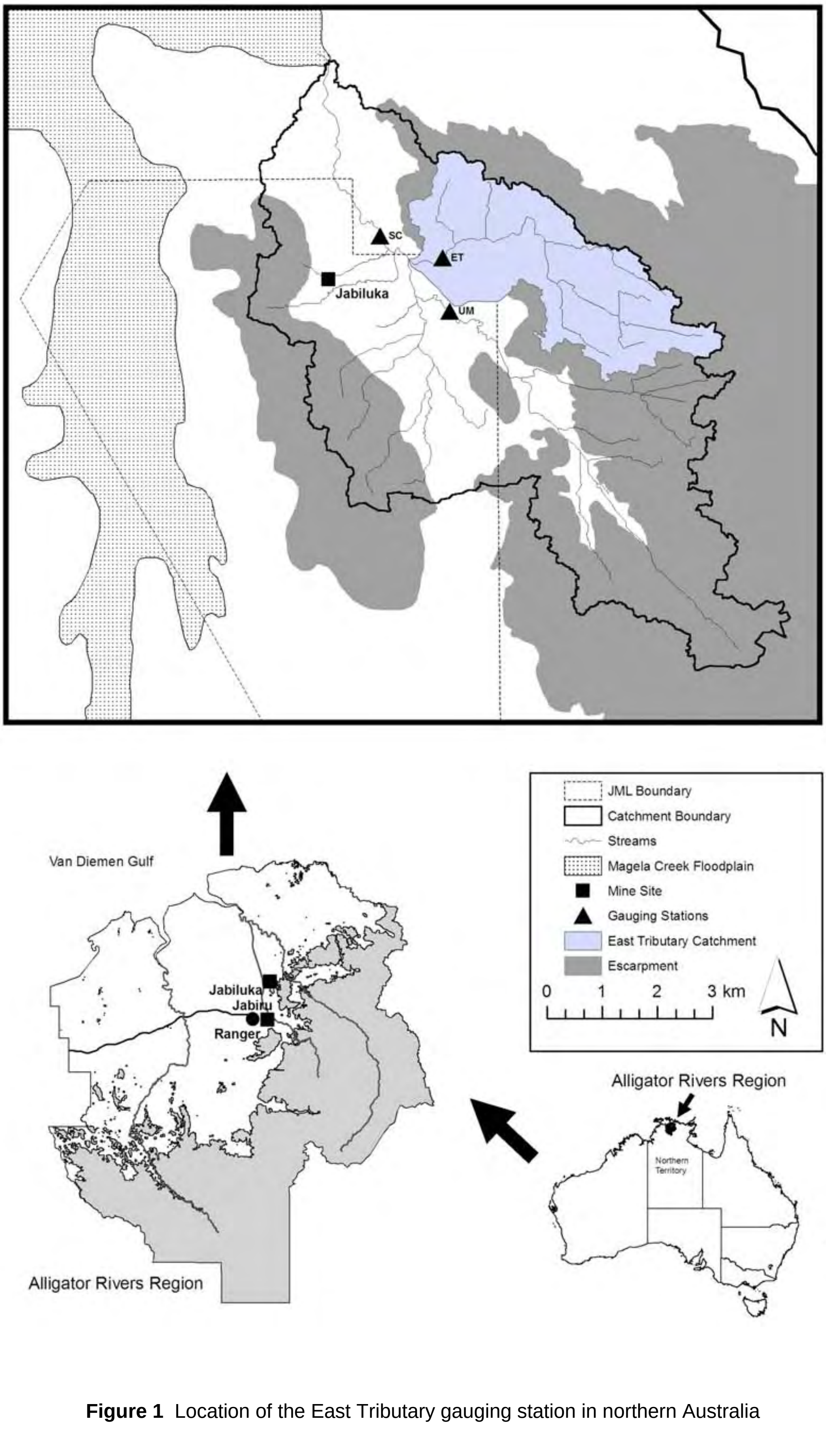

Figure 1 Location of the East Tributary gauging station in northern Australia

On average, flow occurs for approximately 6 months of the year (December to May). Mean annual rainfall (Sept to Aug) was 1662.9 ± 106.2 mm and varied between 1352.8 (2004–05) and 2069.6 mm (1999–2000). Additional rain gauges could not be installed in the upper catchment because the traditional owners valued its cultural significance and did not want any disturbance associated with site visits.

Table 1 Rainfall and runoff from East Tributary catchment for the 7-year study period (1998 to 2005)

Year	Total rainfall (mm) [ARI (y)]	Rainfall period	Antecedent rainfall (mm)	Runoff period	Total runoff (ML) [Peak discharge (m^3s^{-1})]
1998/99	1733.6 [7.5]	20 Sep – 28 Apr	415	9 Dec – 27 May	7621 [8.5]
1999/00	2069.6 [83.3]	14 Oct – 24 May	280	20 Nov – 25 Jun	8532 [8.1]
2000/01	1891.4 [20.4]	14 Oct – 27 Apr	245	28 Nov – 21 May	8275 [8.2]
2001/02	1372.2 [1.8]	17 Oct – 14 Apr	330	28 Dec – 25 Apr	3963 [8.3]
2002/03	1789.8 [10.4]	13 Sep – 1 May	355	1 Jan – 7 May	7249 [8.2]
2003/04	1430.8 [2.1}	7 Oct – 31 May	190	21 Dec – 8 May	5605 [7.8]
2004/05	1352.8 [1.7]	20 Nov – 22 Apr	239	23 Dec – 10 May	4712 [9.0]

Mean annual runoff was 6565 ± 681 ML or 776 ± 81 mm for the 7-year study period. Annual runoff was significantly related to annual rainfall, with, on average, 46.0 ± 0.02% of rainfall being converted to runoff each wet season. Given that there were no rain gauges on the higher elevation Arnhem Land plateau, it is likely that the single rain gauge at the gauging station underestimates catchment rainfall. Therefore, it is likely that no more than 46% of rainfall is converted to runoff. The actual value may be slightly less because rainfall is likely to be greater over the Arnhem Land plateau.

Bankfull discharge occurred at least once during each wet season (Moliere et al 2002). Table 1 shows the peak instantaneous discharge during each wet season and the range (7.8–9.0 m^3/s) is clearly small by southern Australian standards. During the dry season, all channels ceased flowing and the water table dropped to at least 0.5 m below the river bed (Saynor et al 2004).

Solute concentrations were only determined for 2000–01 and 2001–02 wet seasons when a total of 463 water samples were analysed (Evans et al 2004). Mean annual solute yield for 2000 to 2002 was calculated as 118 ± 39 t/yr using method 14 of Phillips et al (1999).

Concentrations of mud (silt and clay) were relatively low between 1998 and 2002 with 339 samples being less than the lower limit of detection of 3 mg/L (Evans et al 2004). The total number of suspended sediment samples analysed for mud concentration was 1340. For the first two wet seasons (1998–99 and 1999–2000), mud concentrations remained constant, decreased in 2000–01 and increased in 2001–02.

Erskine et al (2006) calculated bedload yields by nine different methods for the period 1998–2005. The most reliable bedload rating (based on data from for 52 double traverses)was found to be produced by a least squares linear regression equation of mean bedload flux (Qs) against the mean stream discharge (Q) occurring when the bedload gauging was being done:

$$Qs = 119.38\ Q - 26.604 \qquad (1)$$

The F ratio was 137.11 which has a $\rho < 0.0001$, an adjusted $R^2 = 0.727$ and a standard error = 38.33 g/s. The most reliable estimate of mean annual bedload yield obtained using the above rating was 550 ± 60 t/yr (Erskine et al 2006).

The total terrigenous yield is the sum of the solute, suspended mud, suspended sand and bedload yields and equals 1282 t/yr or 151 t/km^2.yr. The dominant fraction (80.8%) is sand (suspended sand and bedload). Using a bulk density of 1.43 t/m^3 for the Koolpinyah Surface the yield translates to a denudation rate of 0.11 mm/yr. Erskine and Saynor (2000) reported a range of denudation rates for natural or rehabilitated sites in the region of 0.01–1.25 mm/yr and in more recent studies at Tin Camp Creek near Nabarlek, Hancock (pers comm 2007) measured a hillslope denudation rate of 0.46–0.58 mm/yr using ^{137}Cs and 0.98 mm/yr using erosion pins. If a sediment delivery factor of 0.25 is applied to East Tributary then hillslope denudation is 0.42 mm/yr. There is good comparison between the stream sediment transport methods for determining catchment yield presented in this study and hillslope studies in the region which provides good validation of the stream sediment transport methods.

Additional work

Data have been analysed for each of the three gauging stations and two papers (both on East Tributary) prepared for presentation at the 30th Hydrology and Water Resources Symposium, 4–7 December 2006 Launceston, Tasmania.

- Bedload transport, yield and grain size in a seasonal tropical river in northern Australia, WD Erskine, MJ Saynor, DR Moliere & KG Evans
- Water, solute and sediment yields for a seasonal tropical river in northern Australia, MJ Saynor, WD Erskine, DR Moliere & KG Evans

The written papers are independently refereed prior to publication in the conference proceedings.

Analysis is continuing on the data obtained from the other two ***eriss*** gauging stations in the catchment of Ngarradj Creek. It is expected that findings from all three gauging stations will be produced as a Supervising Scientist report and a journal paper.

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Part 4: Nabarlek

Contents[1]

[1] List of papers grouped by Key Knowledge Need.

Quantitative use of remotely sensed data for minesite revegetation assessment

K Pfitzner & P Bayliss

Introduction

An important component of minesite monitoring and rehabilitation assessment includes an analysis of revegetation success. The disadvantage of traditional ecological-based assessments are that they are very labour intensive at broad scale and so can only sample a small proportion of the area affected by mining (eg at field point locations, along transects or within quadrants). The qualitative nature of many methods may also cause problems with consistency when used by different assessors (Corbett 1999).

The challenge in monitoring minesite environments using remotely sensed data is to differentiate cover types with wide spectral variation across an inherently variable land surface, and over different capture times. Differentiation between introduced weeds, native ground and tree canopy cover and exposed soil is required as these index local environmental conditions in addition to rehabilitation success. Remotely sensed data that combines small pixel size and/or high spectral resolution with the capability to capture new images soon after disturbances provides such continuous coverage and, in contrast to intensive ground-based methods over much smaller sample areas, may be more cost-effective.

The rehabilitated Nabarlek minesite is being used as a test site. Very high resolution (VHR) satellite data are being utilised for revegetation assessment at the Nabarlek minesite. The major aims of the study are to help assess whether or not vegetation communities on the Nabarlek minesite blend with the undisturbed surrounding landscape and to contribute to a quantitative description of the plant communities in the region. Further, the data are being used to assess the impact of threats such as fire and to develop methods applicable to the future rehabilitation assessment of the Ranger mine.

Method – Nabarlek

A ground-based monitoring program was initiated by SSD in the late dry season of 2003 and repeated in the late wet season of 2004 to quantitatively assess revegetation performance and to develop survey methodologies applicable to the future rehabilitation of the Ranger uranium mine. Details of the ground-based method and results of sampling can be found in Bayliss et al (2004a & b). Because only 0.51% of the total rehabilitated area was able to sampled across the variable minesite VHR satellite (Quickbird) captures were commissioned to coincide with the ground-based sampling to facilitate scale up from the transect-based data. In addition to the transect-based fieldwork, hundreds of point data and regional data of ground covers were sampled using a GPS across the minesite. The 4-band (B G R IR) Quickbird data were pan-sharpened (PS) to 60 cm pixel size using the University of New Brunswick (UNB) algorithm and data were orthorectified.

During June 2004 and November 2005, the Northern Land Council reported that fires occurred on the minesite. Quickbird image captures were tasked and data obtained in August 2004 and November 2005 to map the extent of fire impact. Another image capture was tasked in December 2005 to assess the impact of vegetation recovery as a result of onset of wet season rains. In April 2006, Cyclone Monica crossed Nabarlek. A flyover the following week showed that the site had been severely impacted, with 90% of trees defoliated and/or fallen. Unfortunately a fire occurred on the minesite prior to acquisition of the post cyclone Quickbird data in July 2006.

Native four band data and transformations, including ratios (B4/B3, B3/B2, B4/B1) and Principal Components Analysis (PCA) were assessed for their suitability in extracting land cover features. Regions characterized by the field surveys were used to obtain spectral regions of interest from the remotely sensed data, including introduced ground covers (such as *Urochloa mutica*, *Pennisetum* spp*, Hyptis sauveolens, Passiflora foetida, Cynodon dactylon, Chloris* spp*),* native ground covers (*Heteropogan* spp *Sorghum stipodeum, Schizachyrium fragile)* and bare surfaces (exposed soils and rocks and infrastructure). Spectral separability of these regions were assessed using the Transformed Divergence separability statistic (Research Systems 2005).

A contextual classification approach using image objects rather than pixels was required to identify and map meaningful objects from within a highly variable data set (Pfitzner 2005). However, a contextual approach is limited by the number of image objects that can be used, and therefore prevented an analysis of the entire image scene. For this reason a buffer of 300 m was created from the minesite perimeter to create a tractable subset of the image data.

The surrounding country (vegetation, landform and soils) are well described by detailed Land Units mapping (Day and Czachorowski 1982). For the minesite subset, different data layers (bands 1–4, ratios and PCA bands) were assessed for their usefulness in creating image objects. Bands 1–4 were input for image segmentation using an object-orientated method (www.definiens-imaging.com). The segmentation was a bottom-up region merging approach starting with single pixel objects. In an optimisation pair-wise clustering process, smaller objects were merged into larger objects based on heterogeneity criteria of colour (spectral response) and shape. The pair of adjacent objects with the smallest growth (deviation) from the defined heterogeneity criteria were merged with each iteration. The process stopped when the smallest growth for merging of adjacent objects exceeded a predefined scale parameter. The heterogeneity criteria weighted gave a higher weighting of colour over shape. Spectrally similar objects were merged based on a scale parameter analysis.

Results

Figure 1 shows selected false colour composites of Quickbird subsets covering the minesite (May 2004, November 2005, December 2005 and July 2006).

In May 2004, much of the minesite was covered by introduced ground cover species. Tree cover is dominated by *Melaleuca* spp on Evaporation Ponds 1 and 2 and *Acacia* spp on the pit. The November 2005 image shows the effect of a fire on the minesite, with much of the minesite characterised by a fire scar (burnt canopies are indicated by a yellowy-brown colour). One month later (December 2005) introduced species were regenerating with the onset of wet season rains. The July 2006 image illustrates the loss of vegetation cover as a result of both cyclone Monica and an intense dry season fire. In May 2004, 71% of the minesite was covered by vegetation, compared to just 15% of the minesite in July 2006.

Separability statistics showed high separability (>1.9) for like pairs of ground covers, including *Urochloa mutica*, *Heteropogan* spp, *Cynodon dactylon* and schist rocks (ie two regions representing the same cover type had a separability score of > 1.9 with the 4 band Quickbird data). These results confirmed the high spectral variability for surface cover, even for like species, and showed that there was limited ability to discriminate species using a spectral-based approach. A contextual method was then assessed and implemented (Pfitzner and Bayliss 2006) to enable spectrally similar but contextually different ground covers to be extracted.

The buffered mine region from the Quickbird scene and Land Unit data are illustrated in Figure 2. Image objects were created from the pixel level, and spectrally like neighbours merged at increasing scale factors (levels). The scale parameter modal statistic provided an appropriate scale factor for increasing levels. The segmentation parameters were not transferable across temporal images, but the methodology was. The contextual approach maintained individual tree canopies, while the high variability within like surface covers was simplified (averaged), making a four band spectral analysis appropriate at the Quickbird mapping scale (Figure 3).

A binary classification to broadly separate vegetated surfaces from non-vegetated surfaces was possible with the transformed Normalised Difference Vegetation Index (NDVI) data. The membership function used for discriminating vegetated land cover was a NDVI threshold based on larger than values. Tree canopy was further classified by shape (compactness) and also indicated by non-vegetated cover, such as shadow. Non-vegetated cover was separated using an inverted similarity to green vegetation.

Membership functions to distinguish different non-vegetated surfaces included: mean band 1 (painted surfaces such as concrete and tanks and airstrip guidelines), mean band 3 (sediments) and pca2 (fire scar). The PCA transformed data applied to image segments was required to separate the fire scar from the bitumen of road surfaces and the airstrip.

The approach described above is being implemented for assessing revegetation progress on the Nabarlek minesite over time and shows promise as a monitoring and assessment tool for rehabilitated minesites in general (Pfitzner & Bayliss 2005).

Summary

Revegetation success at Nabarlek is under pressure from threats such as weeds and fire. While ground-based measurements provide necessary information on species abundance, broad scale use of this method is limited due to small sample sizes and the effort required for monitoring changes in abundance due to disturbance. Remotely sensed data provides the potential to monitor broad landscape changes. Due to the short range variation in surface cover types at the Nabarlek minesite, VHR data are required to resolve the land cover features required for revegetation assessment. Four-band data are of limited use for spectral separation of land cover features. Pending further developments (substantially increased numbers of spectral bands) of remote sensing technologies, a contextual approach for separating cover components shows considerable promise as a monitoring tool for rehabilitated sites in general. This involves indexing local environmental condition using VHR satellite data.

Steps for completion

The analysis of the multitemporal data (including detailed ground and canopy cover maps) and accuracy assessment using ground-based data need to be finalised. The results are to be written up and published. Vegetation recovery from the effects of the cyclone and fire in 2006 will be assessed with a late wet season Quickbird capture in 2007. To separate the effects of the cyclone and the fire, three captures of Landsat 5 data were acquired, including data pre-cyclone, post-cyclone (pre-fire) and post-cyclone post-fire. These data will be analysed and published.

Acknowledgments

A team of collaborators contributed to the fieldwork, particularly staff from ***eriss*** (Peter Bayliss, Gary Fox, Bruce Ryan, Andreas Bollhöfer & James Boyden) and from Charles Darwin University (Sean Bellairs, Stephanie Vink & Judy Manning).

Future work – Ranger/Jabiluka

Ranger/Jabiluka – satellite data

Cyclone Monica passed through Jabiru during April 2006, causing changes in vegetation cover, fire impact, soil exposure and implications for sediment transport. To research the extent and intensity of change due to the storm effects, VHR Quickbird data, covering 14 km x 45 km was acquired in July 2006. Figure 4 illustrates the extent of data capture. Because fire disturbed the landscape prior to the capture of Quickbird data, multi-temporal Landsat data were acquired to separate the cyclone effects from fire. Landsat data were acquired pre-fire and cyclone, post cyclone (pre-fire) and post cyclone/fire. It is envisaged that Landsat data will also be acquired in the late wet season of 2007 to assess revegetation recovery.

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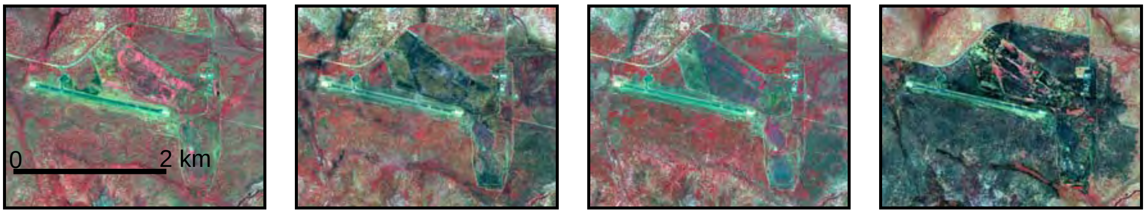


May 2004 | November 2005 | December 2005 | July 2006

Figure 1 Multitemporal Quickbird subsets of the Nabarlek minesite. IR R G (R G B). Vegetation is reflective in the IR (shown as red colours for native vegetation and pink colours for grassy weeds). Fire impacts are shown in shades of blue-grey.

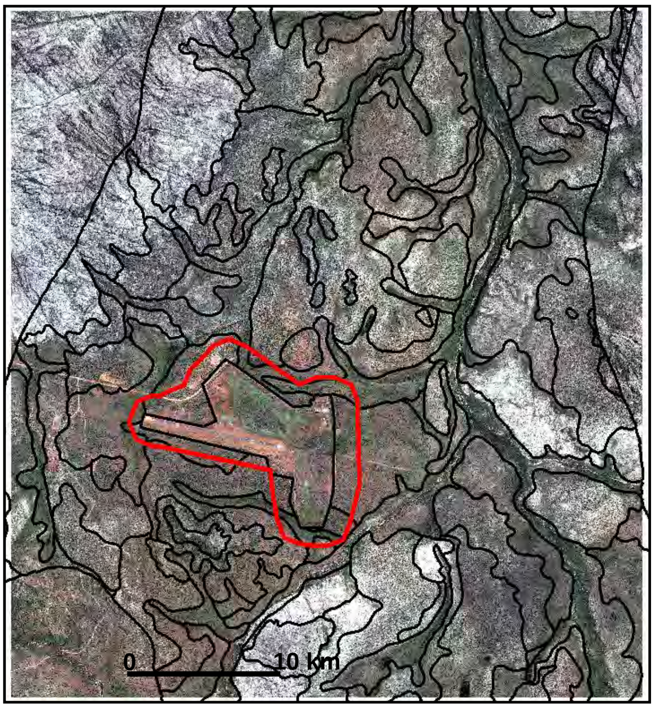
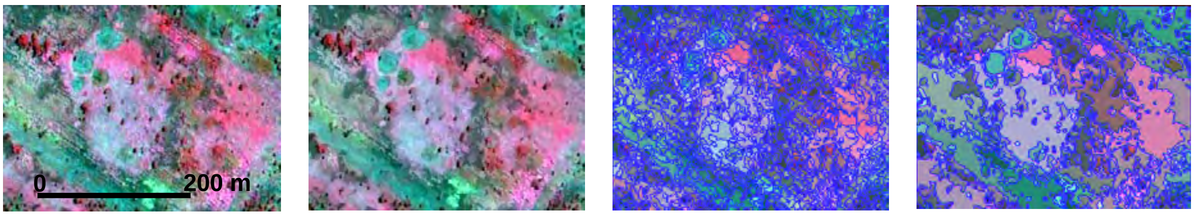


Figure 2 (left) Quickbird data capture May 2006 – full extent (65 km^2) (R G B). Land units overlaid (black lines) and buffer subset (red polygon).



Pixel based | Level 2 | Level 4 | Level 7

Figure 3 (above) Small sub-samples of Quickbird data (May 2004), IR R G (R G B) using the multi-level segmentation approach. Image objects boundaries are depicted in blue for levels 4 and 7.

Figure 4 (right) Extent of June 2006 Quickbird data. Ranger – Jabiluka surrounds.

Radiological impact assessment of the rehabilitated Nabarlek site

A Bollhöfer & B Ryan

Introduction

There is no permanent habitation close to the rehabilitated Nabarlek uranium mine site at present, but future occupancy of the site (on a part or full time basis) cannot be ruled out. Radiological risk assessment, including all exposure pathways, is needed to assist planning for any future changes to land use.. Such an assessment requires integration of data from: 1) gamma dose rate surveys; 2) radon flux densities and airborne radon concentration surveys; 3) radionuclide concentration in surface soils and erosion/stability assessment; 4) bore water uranium isotope and radium concentration measurement; and 5) measurement of radionuclide uptake into edible plants growing on and off site.

Fieldwork, data analysis and interpretation for tasks 1, 2 and 3 above are mostly complete. In 2005–06 the spatial variability of the airborne radon concentration at the site was determined using track etch detectors. Particular emphasis was given to evaluating groundwater radionuclide activity and metal concentration data, and assessing the potential impact on off-site groundwater quality.

Reference should also be made to the paper under KKN 2.1.6 ('Radio- and lead isotopes in sediments of the Alligator Rivers Region') that describes the potential for use of radionuclides and Pb isotopes as tracers of mine impact. A substantial component of this paper describes results from the Nabarlek site.

Methods and results

Radon concentrations in air

78 passive radon monitors (PRM) were distributed across the site, at a height of 1 m above ground, at 37 individual sites. Two detectors were deployed at each site, covering various areas on the mine. These areas included the evaporation ponds (EP1 and 2), the plant run-off pond (PROP), the stockpile run-off pond (SPROP), the pit including a radiological anomalous area (unit-7), the waste rock dump (WRD), the waste rock dump run-off pond (WRDRP) and an environmental control site (ENV).

Radon concentrations measured at individual sites ranged from a minmum of 25±9 Bq·m^{-3} at the environmental control site close to the Myra camp turn-off up to a maximum of 500±100 Bq·m^{-3} at evaporation pond 2. Radon concentration were also high at unit-7 (maximum 380±50 Bq·m^{-3}), a relatively bare area, which has previously been identified as an area of high soil radium activity concentration (Hancock et al 2006) and radon flux densities (Bollhöfer et al 2005). Table 1 summarises the results of the radon concentration survey.

Area-averaged concentrations of radon in air at Nabarlek were compared with average gamma dose rates determined from groundtruthing of an airborne gamma survey (Martin et al 2006), from a detailed survey of unit-7 in 2005, and with radon flux densities determined across the site (Bollhöfer et al 2005). As expected from first principles, higher soil radium concentrations lead to elevated average radon concentrations. This was observed at the pit, WRD, WRDRP, unit-7, EP1 and PROP.

Table 1 Average airborne radon concentrations measured at Nabarlek and a comparison with dose rates (Martin et al 2006) and radon flux densities (Bollhöfer et al 2005) at Nabarlek

	Radon concentration [Bq·m^{-3}]	Gamma dose rate [uGy·hr^{-1}]	Radon exhalation [mBq·m^{-2}·s^{-1}]
EP-2	**361 ± 162**	**0.37**	**105 ± 102**
Unit 7	**296 ± 83**	**0.98**	**6508 ± 6831**
PROP	**66 ± 18**	**0.36**	**278 ± 203**
SPROP	**249 ± 78**	**0.36**	**137 ± 120**
EP-1	**152 ± 88**	**0.48**	**169 ± 86**
PIT	**137 ± 76**	**0.51**	**971 ± 739**
WRD	**113 ± 18**	**0.46**	**335 ± 318**
WRDROP	**138 ± 92**	**0.47**	**335 ± 318**
ENV	**41 ± 15**	**0.09**	**31 ± 15**

However, both EP2 and SPROP stand out in this comparison with the highest and third highest radon concentrations, respectively. Compared to the other sites these locations had a significantly denser vegetation cover at the time of deployment. Track etch detectors were deployed amongst dense stands of weeds (red natal grass, and para and mission grasses). This condition may have inhibited air flow and hence promoted a build up of radon and its progeny during the night and in the early morning hours, and inhibited an effective convective air exchange during the day.

This accumulation of radon in 'dead zones' has potentially important implications for assessing human exposure routes on rehabilitated mines landforms. In particular, measurements made in well flushed open environments may underestimate exposure that would occur in an area with denser mid-story or canopy development. Moreover, humans are typically much closer to the ground (sleeping) during the night and early morning hours when the potential for radon accumulation will be the greatest. Addditional work was planned to investigate near ground surface concentration of radon in vegetated areas at Nabarlek during the 2006 dry season. However, the occurrence of Cyclone Monica and subsequent fires meant that this followup work could not be done.

Groundwater

Radionuclide activity and dissolved metal concentrations in borewaters from the decommissioned and rehabilitated Nabarlek uranium mine have been analysed by ***eriss*** in samples collected from 1996 to 2005. The standing water levels for all bores for the collection dates were acquired from Northern Territory Department of Business, Industry and Resource Development. Bore logs were obtained to aid in the interpretation of the data.

The standing water levels (SWL) at Nabarlek from the deep aquifer tend to reflect the local topography. Groundwater flow directions are generally eastwards towards Cooper Creek in agreement with the regional groundwater flow patterns calculated by Salama (1986).

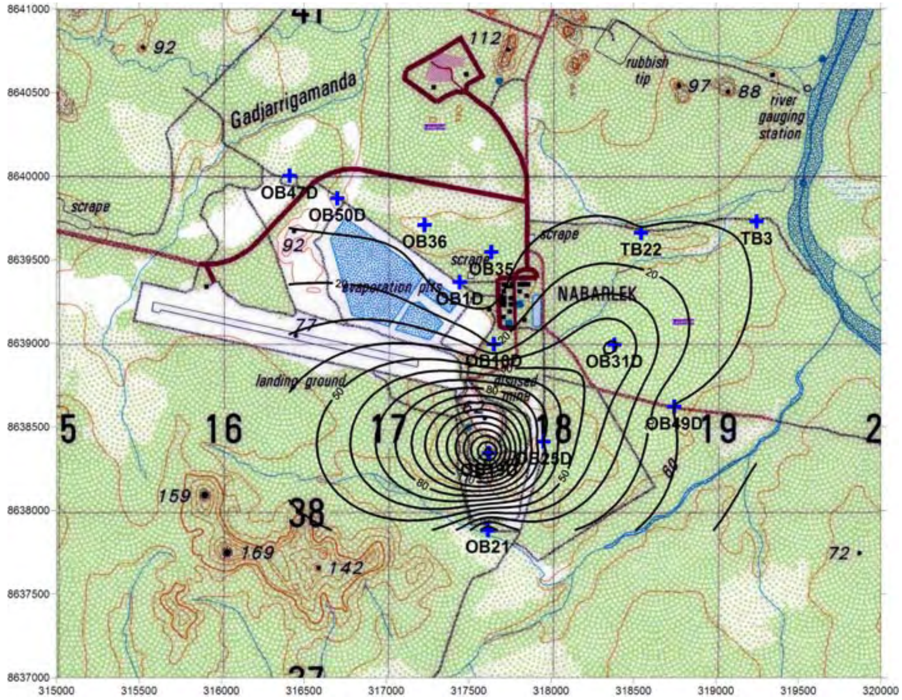


Figure 1 ^{238}U activity concentration [mBq·l^{-1}]contours for Nabarlek groundwater 2004

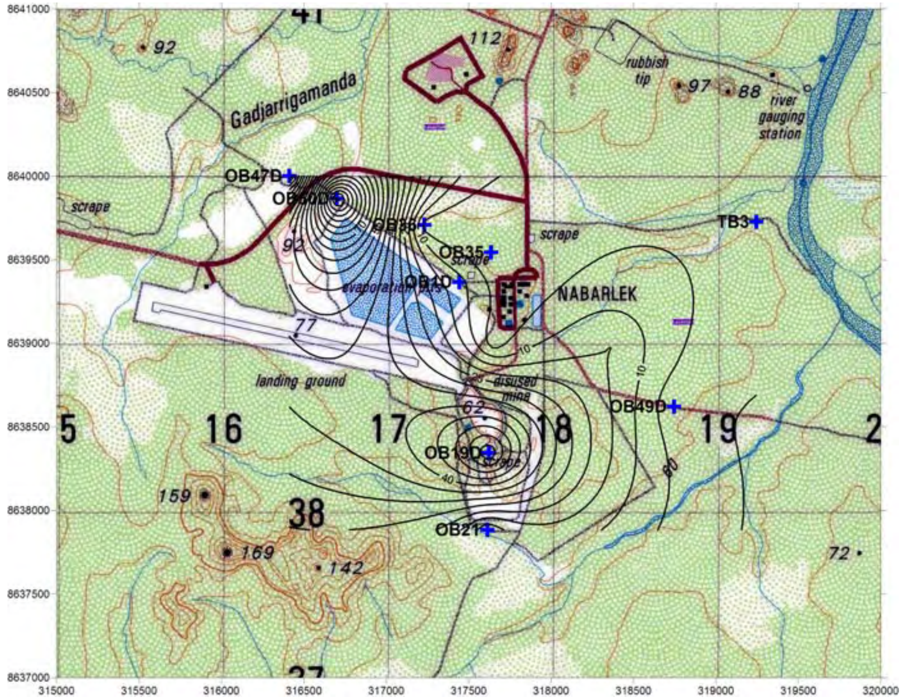


Figure2 ^{226}Ra activity concentration [mBq·l^{-1}] contours for Nabarlek groundwater 2004

Uranium activity concentration data collected from 1996 to 2005 range from < 1 mBq·l^{-1} in OB1D to the north-east of the mine to 179 mBq·l^{-1} in OB19D, which is situated down gradient from, and closest to, the former pit where the tailings were deposited. Borewaters from OB25D and OB31D also exhibit significant uranium activity concentrations of 124 mBq·l^{-1} and 94.9 mBq·l^{-1}, respectively. All the other bores analysed since 2003 have uranium levels of ≤ 20 mBq·l^{-1}. OB25 is closest to the eastern edge of the former pit and uranium activity concentrations have decreased over the past 10 years, whereas levels have increased in OB19. Uranium levels in OB31 did initially increase but have displayed a decrease in the past two years.

Uranium and radium contour lines shown in Figures 1 and 2 suggest a plume moving from the pit and waste rock dump areas to the northeast of the Nabarlek area towards Cooper Creek. Bores OB25, OB31 and TB22 exhibit endmember $^{234}U/^{238}U$ activity ratios of ~ 1. A ratio close to 1 can indicate a mining-related source of uranium in groundwater as shown previously by Iles et al (2002).

The remnants of spray irrigation may be the reason for the higher ^{226}Ra activity concentration measured in bores situated at the northern end of the mine (Figure 2). OB1D, SP29, OB47D and OB50D have relatively high ^{226}Ra activity concentrations and $^{238}U/^{226}Ra$ ratios well below 1, which may suggest that ^{226}Ra, which was deposited by spray irrigation between 1984-87, is being leached and mobilised into the groundwater from the soil profile in the vicinity of the bores. This has also been observed by Martin and Murray (1991).

Steps for completion

Further statistical analysis of all Nabarlek groundwater data, including metal and trace metal concentrations, needs to be conducted. Future work at Nabarlek will focus on bushtucker collection and analysis, and the determination of plant radionuclide uptake factors for the site. This will enable a comprehensive dose model to be developed for Nabarlek that will include all relevant exposure pathways.

Acknowledgments

All bore samples collected between 1996 and 2005 and associated field data were supplied by the Minerals and Energy Group of the Department of Primary Industry and Fisheries and Mines.

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Part 5: General Alligator Rivers Region

Contents[1]

5.1 Landscape scale analysis of impact

[1] List of papers grouped by Key Knowledge Need.

Changes in Melaleuca distribution on the Magela floodplain 1950–2004

G Staben, J Lowry & G Boggs[1]

Background

In September 2001, concerns were raised by the media that the spread of *Melaleuca* spp observed in Papua New Guinea and the Mary River Floodplain in the Northern Territory may be occurring in the wetlands of Kakadu National Park. It was suggested that the spread of *Melaleuca* spp could displace herbaceous vegetation communities in the wetlands of Kakadu. An initial desktop study was undertaken using GIS software to map changes in Melaleuca distribution on a section of the Magela floodplain between 1975 and 1996 (Riley & Lowry 2002). This found that while there had been an overall decline (21%) in tree density on a 41 km^2 section of the Magela floodplain, the spatial distribution of woody vegetation had increased. However, there were recognised problems with the accuracy of some of the analysis, owing to limitations in image pre-processing techniques and human error using manual classification methods. The conclusions from this initial study emphasised that future technological developments in image analysis and classification software may help to overcome these problems.

The report by Riley and Lowry (2002) formed the basis for further research, which was undertaken as a Bachelor of Science Honours project at Charles Darwin University during 2005. This project has applied both remote sensing and GIS technology to investigate the change in *Melaleuca* spp canopy cover for a 4.9 km^2 section of the Magela floodplain.

The Honours project had two primary aims:

1 To assess the use of object-based classification for distinguishing between *Melaleuca* spp. cover and other floodplain communities using aerial photographs.

2 To track changes in the spatial and temporal distribution of *Melaleuca* spp. cover over the period 1950–2004, for a representative portion (4.9 km^2) of the Magela Creek floodplain.

Progress to date

Current advances in multi-scaled object-based classification techniques have enabled the successful classification of very high resolution satellite data (Laliberte et al 2004). The use of a multi-scaled approach has enabled the development of classification methods resembling the way humans interpret an image (Baatz et al 2004). It was found that environmental conditions at the time of acquisition of the photographs influenced the success of the classification. In particular, the 1975 image was significantly easier to classify due to the absence of other vegetation, allowing greater contrast between water and *Melaleuca* spp Typically, vegetation studies using automated classification techniques rely heavily on areas of the electromagnetic spectrum such as the infrared region, as it able to best discriminate between different vegetation species (Ahmad et al 1998, Harvey & Hill 2001). However, the

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spectral properties of panchromatic and true colour aerial photographs (as used in this study) are derived from the visible range of the electromagnetic spectrum (0.30–0.72 um). Consequently, these are unable to differentiate between different vegetation types as well as the infrared spectrum (Campbell 1996). This limitation of the visible range of the electromagnetic spectrum was found to affect the quality of the segmentation process, as extraction of meaningful objects (at the scale used in this project) still relies heavily on the spectral properties of an image. Specifically,this study found that the reduced spectral properties of the visible part of the electromagnetic spectrum were not able to discriminate well between *Melaleuca* spp and other vegetation.

It should be noted that the scale and quality of the 1950 aerial photograph may have led to a bias in the classification process. Specifically, small individual examples of *Melaleuca* spp may have been omitted, whilst tree shadow may have been classified as *Melaleuca* spp.

Applying a low-pass filter over the 1996 image greatly reduced the heterogeneity of the pixels in the image, and increased the contrast between *Melaleuca* spp and other vegetation types. The combination of smoothing the image and incorporating a scale level classified on the different brightness levels across the image helped to increase the accuracy of the automated classification process. The ability to incorporate objects at different scale levels into a single classification knowledge base helped to compensate for the limited spectral properties of aerial photographs and enhance the overall classification process.

Accuracy assessment was undertaken using reference datasets generated from digitised manual interpretation of 250 random points across each aerial photograph; additionally ground truthing data was collected to assess the 2004 classification. The final 1950 and 1975 classified images recorded an overall accuracy estimated at 89%, and 90% respectively. The overall accuracy of the final 1996 classification was estimated to be 82%. Estimated accuracy of the final 2004 classification using the digitised referenced data was 85% and for the ground truthing data 81%.

Change analysis

Change analysis was undertaken using a GIS platform. The extent of *Melaleuca* spp estimated to cover the 4.9 km^2 study area in 1950 was 118.9 ha; by 1975 the extent had increased by 14.4 ha to 133.4 ha. In 1996 *Melaleuca* spp. cover again increased slightly by 2 ha to 135.4 ha and in 2004 there was a slight decline in cover of 15.4 ha to 120.4 ha (Fig 1). Taking into account the error margins present in each classified datasets, these results indicate that the overall canopy cover of *Melaleuca* spp has not varied greatly over the 54 year period.

To identify spatial change in canopy cover over the 54 year time period, datasets representing percent of canopy cover for 392 m^2 areas across the whole image were produced using the block statistics function and the raster calculator in ArcMap. This was done to compensate for geometric distortions and misregistration between the different aerial photographs which would over estimate the level of change. Image differencing was then performed to produce data revealing levels of ± % cover change. Although the estimated percentage of canopy cover datasets indicate large variations in spatial distribution of *Melaleuca* spp. cover across the study area as a whole, coverage has been consistently expanding in the lower eastern region of the study area over the 54 year period. While this study shows there has been little overall change in canopy cover in the study area, the change in spatial distribution appears to have been large. The use of historical aerial photographs has enabled the floodplain to be studied at a scale not available in other forms of historical imagery.

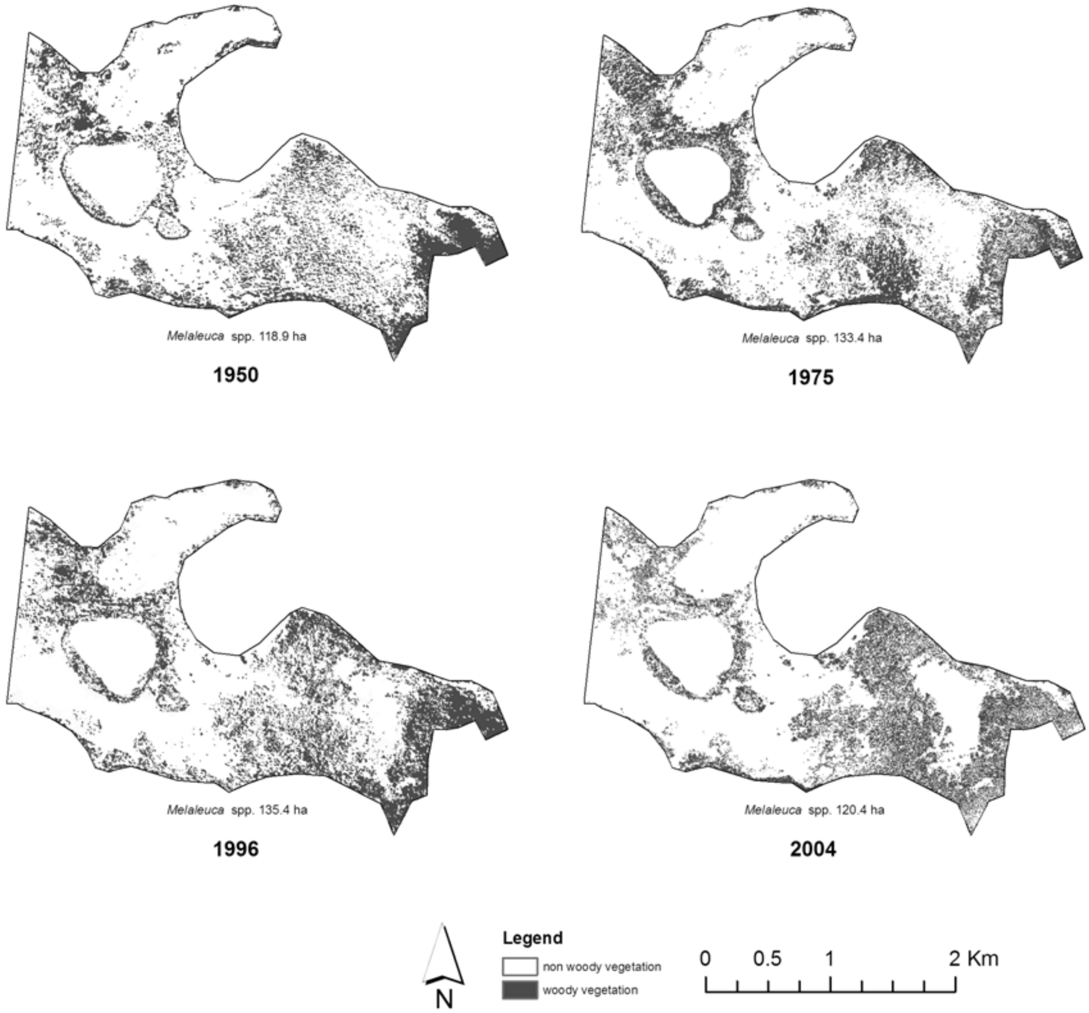

Figure 1 Classified images showing the spatial extent of *Melaleuca* spp. cover for the study area for each time period, with darker colours indicating increasing density of woody vegetation

Identifying the reasons for this change was beyond the scope of this study. However, the impact of fire and feral pigs was very apparent during the collection of ground truthing data in August 2005. Fire occurs regularly throughout the region, and mature *Melaleuca* stands have been identified as fire sensitive communities (Gill et al 2000, Russell-Smith et al 1997). While *Melaleuca* spp are generally a fast growing pioneer species (Morris, 1996) and their seedlings regenerate well in the ash bed of fires (Cowie et al 2000, Roberts 1997), new forests may take between ten and twenty years to develop (Morris 1996). Areas of juvenile regrowth of *Melaleuca* spp, and burnt out patches of *Melaleuca* spp were both observed along the margins of the study area. The observed impact of fire on *Melaleuca* spp may account for the spatial changes in distribution found in this study.

There was also significant soil disturbance (as a result of pig rooting) along the margins of the floodplain within the study area. In south-eastern Australia, pig rooting can change the species composition of native vegetation (Hone 1995). Outside of Australia they have been shown to modify soil nutrients, reduce plant cover, alter plant species composition, and effect soil erosion (Mitchell & Mayer 1997). Research on the effect of native pigs (*Sus scrofa*) on woody understory vegetation in a lowland rain forest in Malaysia has shown that native pigs play an important role in plant dynamics at the understory level (Ickes et al 2001). It is also possible that changes identified in this study could be representing intra species changes in distribution of *Melaleuca* spp., due to changes in rainfall patterns or succession due to sediment accumulation. Identifying and understanding the complex relationships between the various causal factors driving vegetation change is complex and requires further research (Banfai & Bowman 2005).

The honours thesis (Staben 2005) written for this project was submitted on schedule in November 2005. A poster was also presented at NARGIS 2005. An important output of the project is a number of datasets which would be invaluable for further analysis of woody vegetation communities on the Magela floodplain.

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Significant habitats and species in the Alligator Rivers Region

C Humphrey

Background

This project is being conducted in response to a specific recommendation of the IUCN and the World Heritage Committee. Their concern was that there might be endemic species of animals that, while not at risk from direct contaminant pathways associated with any development at Jabiluka, could be affected by indirect secondary pathways.

Surveys have been conducted on the aquatic fauna of seeps and springs in the stone country of KNP including in the vicinity of Jabiluka. Particular attention is being paid to the crustacean groups, the isopods (family Amphisopodidae), freshwater crabs (family Parathelphusidae) and prawns and shrimps (families Atyidae and Kakaducarididae) that occur in these habitats. The results obtained in these surveys are being provided to taxonomists to distinguish and describe new species collected from the sites. If species are identified that are only found in the vicinity of Jabiluka, consideration will be given to pathways for potential impact and possible monitoring programs.

This work could be of direct relevance to any possible mining developments in Western Arnhem Land. In addition, these endemic species may be vulnerable to the invasion of cane toads and their life stages, through either toxicity (direct contact or from consumption) or competition with tadpoles for food and space.

Progress to date

Current work is taxonomic, with southern collaborators from Griffith University, BioAccess Australia and The Australian Museum conducting morphological and molecular genetic studies on the samples. Work to date is confirming that the macro-crustacean groups from seeps and springs are very diverse, with very localised endemism.

One of these crustacean groups is an endemic genus of phreatoicidean isopod (*Eophreatoicus*) that has exceptional species-level diversity. Dr George Wilson from the Australian Museum and ***eriss*** received a research grant from the Australian Biological Resources Study (ABRS) in 2004 to describe isopods of KNP and western Arnhem Land. Dr Wilson has made particular note about the results he has recently acquired from the Jabiluka region – collected from Catfish, North Magela and 7-J creeks, Ngarradj and 3 small tributaries draining the Jabiluka outlier itself. It appears that there is a 'species flock' around the Jabiluka region with a number of these small creeks returning 2 or 3 co-occurring species, restricted just to these streams.

It has been postulated that this diversity and endemism is a consequence of the extreme age and persistence of the stone country and its associated fresh waters, and isolating mechanisms including fragmentation of habitat (long-term climate changes, erosion) and the generally poor dispersal characteristics of the crustacean groups. One model being proposed is that climatic variation over the Neogene (broad period of geologic time starting 23 million years ago to the present) has promoted speciation during both periods of aridity (when populations become isolated) and wetter periods (when animals are able to disperse). This ‘species pump’ model has also been used to explain diversity of vertebrates in the wet tropics of Australia.

To complete the isopod work and publish the findings, some additional sampling is required in 2006-07 from Jabiluka sites from which there is presently too little material. The results have profound implications for the conservation values of the sites and resident faunas. The extent of connectivity between surface and deep aquifers will need to be well understood to be able to predict the near surface effects of mine dewatering operations, in the event that mining does proceed. If significant lowering of the near surface groundwater table did occur in the habitat locations of these ispopods then their dry season habitat (sub-surface groundwater) would be compromised.

Ecological risk assessment of Magela floodplain to differentiate mining and non-mining impacts

P Bayliss, R van Dam, D Walden & J Boyden

Background

The Ecological Risk Assessment (ERA) project is the final project of the 'Landscape-scale analysis of impacts' Program established in 2002 to help differentiate mining and non-mining impacts on the World Heritage and Ramsar listed Magela Creek wetlands downstream of the Ranger mine. Ecological risk assessment allows the level of risk to the 'health' of ecosystems exposed to multiple stressors to be quantified in a coherent, robust and transparent manner. A high protection level for the biodiversity of aquatic ecosystems was used as the assessment endpoint, so conclusions here can be regarded as being appropriately conservative.

Two key results from the initial ERA of the Magela floodplain reported at ARRTC17 (February 2006) were that: (i) diffuse landscape-scale risks were several orders of magnitude greater than point source risks to Magela surface waters from the Ranger mine; and that (ii) of the landscape-scale risks, damage from pigs > para grass > unmanaged fire. However, the current huge difference between non-mining and mining related risks may reduce when on-site water management systems and some of the potential exposure pathways at Ranger change in the transition between mine production and mine closure and rehabilitation. For this reason the decommissioning and closure periods will require their own detailed and explicit risk assessment.

Progress

Whilst the Landscape Program has basically concluded more advanced risk analysis and modelling is still underway in the lead up to publication of results. For example, use of recently revised estimates of para grass (*Urochloa mutica*) cover and distribution across Magela floodplain shows that it is currently the major ecological risk because of its extent, adverse effects and rapid spread rate (see below). However, damage to biodiversity values from pigs in the initial ERA was assumed to be 100% (i.e. effects probability = 1.0) because they are declared a Threatening Process under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act). The influence of this 'maximum' assumption on the overall landscape ecological risk value and, hence, on the importance rank of each landscape threat, was examined by sensitivity analysis where the ecological effect of pigs was varied between 0.25 and 1.00. Results (Table 1) show that: the overall landscape risk value does not reduce significantly over a wide range of assumed pig effects. Para grass still ranks first in importance regardless of the effect of pigs; and, not surprisingly, fire became the second ranking risk when the effect of pigs was reduced. Since para grass contributes most to the overall landscape risk value (now para grass > pigs > unmanaged fire) it has been examined in greater detail by further study as outlined below.

In the early 1980s para grass was present in very small areas of the Magela Creek floodplain, and by the mid 1990s it had spread from 132 to 422 ha in five years (1991–1996, Knerr 1998). This core patch of para grass occupies the centre of the floodplain (see Figs 2 & 3) and is expanding on average at 14% p.a. (Fig 1a), or doubling in extent on average every 5 years (Bayliss & Walden 2003). The increase in area of para grass between 1991 and 1996 showed a corresponding decrease in area of a community of wild rice and *Eleocharis* spp sedge, important food resources for pre-fledging magpie geese and nesting material for adults, respectively. Para grass currently occupies about 1250 ha or 10% of the floodplain with 100% cover, and new outbreaks are occurring in inaccessible dense Melaleuca woodland.

Table 1 Summary of sensitivity analysis undertaken to examine the influence of variable pig effects on the overall ecological risk assessment value for landscape threats, and how this influenced the importance rank of each threat

Pig effects	Landscape ERA	Rank importance		
		Para grass	Pig damage	Unmanaged fire
0.25	0.18	1	3	2
0.50	0.19	1	3	2
0.75	0.20	1	2	3
1.00	0.21	1	2	3

Data obtained from sample plots in 2003 show that the percentage of native vegetation (eg wild rice, *Eleocharis*, *Hymenachne*, open water/lilies & *Leersia*) 'lost' to para grass rapidly increased with increasing weed cover and, importantly, that there was a 'threshold' effect for each plant group (Fig 1b, minus *Leersia*). Hence, for most floodplain plants measurable impacts did not occur until para grass reached 15–20% cover, suggesting that this extent may represent a pragmatic, cost-effective and justifiable control target.

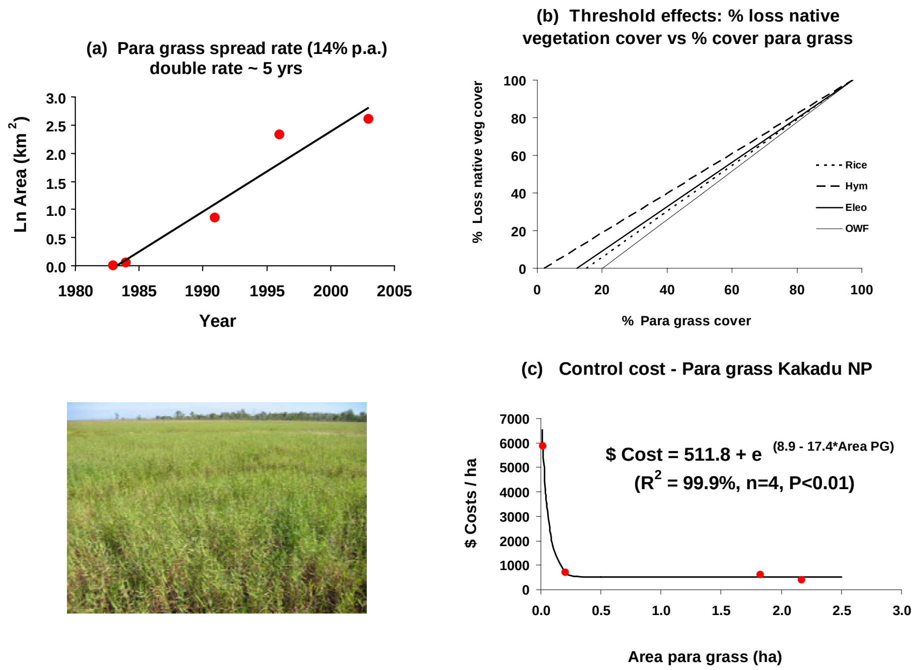

Figure 1a–c (a) Linear regression between Log_e extent (km^2) of para grass and time (years) (R^2 = 69%, P<0.04), (b) Relationship between loss of native vegetation cover (%) of four key wetland plants and increasing cover of para grass, (c) Negative exponential control-cost curve for para grass (Noulangie floodplain, Kakadu National Park)

Cost-of-control functions have been derived for mimosa and para grass (Fig 1c), and are critical for evaluating the benefits and costs of any invasive species management program using a risk management framework. The cost-curve for para grass shows that a 15-20% control target would avoid exponentially increasing control costs generally associated with unachievable eradication objectives, or cost-prohibitive 'trace level' objectives. However, this reasoning may not apply to mimosa because of its massive seed set.

A Bayesian Habitat Suitability Model (HSM) was developed in collaboration with Charles Darwin University to predict current and future distribution (or exposure, see Ferdinands 2006) of para grass and, hence, potential impacts on native wetland vegetation. The methodology has been successfully applied to the Mary River floodplain (Ferdinands et al 2001). The risk-based exposure map (Fig 2) incorporates test data from high resolution QuickBird™ satellite imagery (validated by helicopter & airboat surveys) to provide more reliable information on para grass extent over different temporal and spatial scales. The methodology developed to date in the core para grass area of central Magela provides a cost-effective monitoring and assessment tool for Park managers.

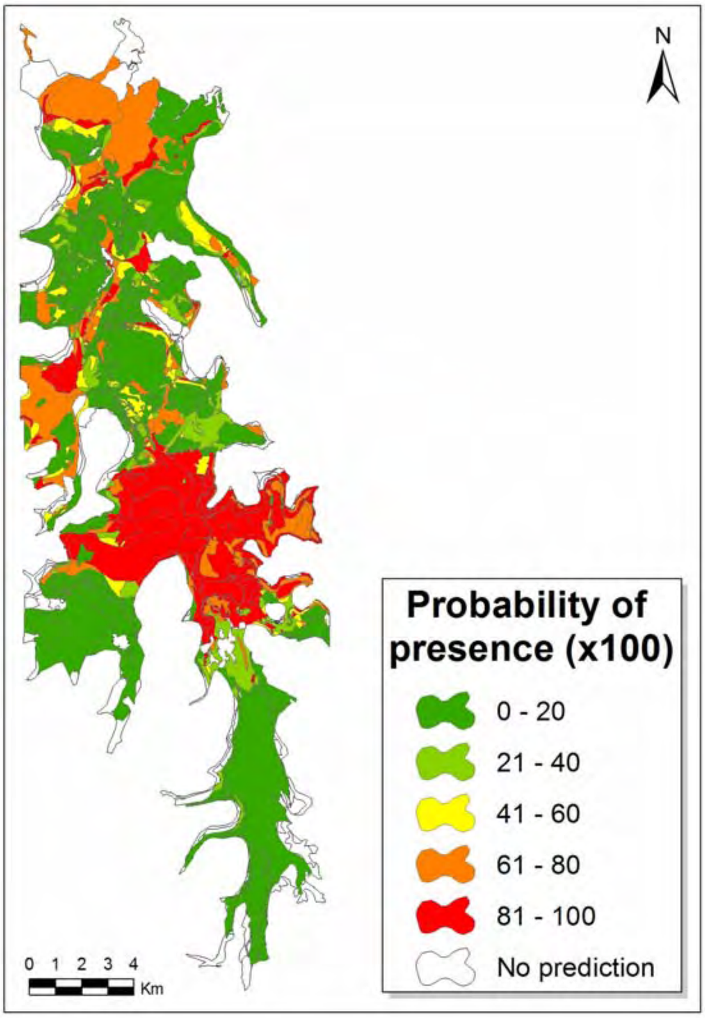

Figure 2 Bayesian habitat suitability model for para grass showing exposure probabilities (dark area is high exposure risk or present, dark grey is low exposure, light grey is absent). The exposure risk map was derived from a QuickBird™ satellite data capture, helicopter and airboat validation surveys and GPS observations by park staff.

Additionally, a spread rate model was developed to predict para grass extent and, hence, potential ecological impacts over time. Management scenario simulations were undertaken ranging from 'do nothing' to a range of initial and maintenance control investments. Initial simulation results suggest that with no control 50% or more of the floodplain will be lost within 20 y (Fig 3). However, this time frame may be the 'best case scenario' because satellite patches of para grass are now spreading along the entire length of the Magela floodplain, representing nascent foci for expansion.

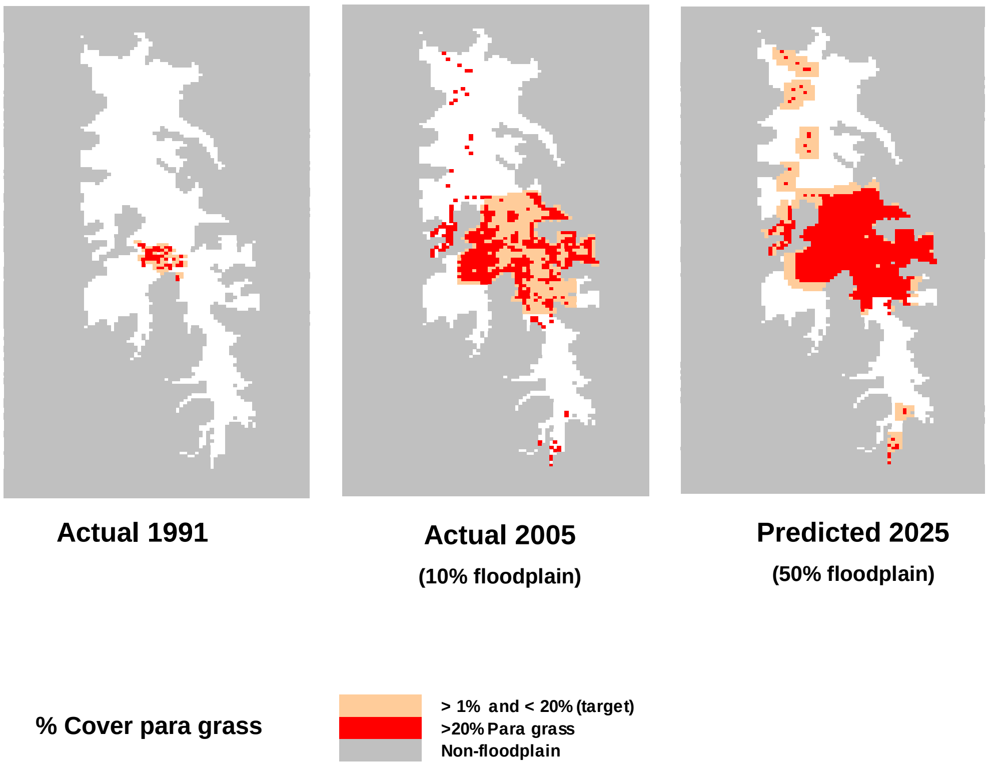

Figure 3 The extent of para grass on Magela floodplain in 1991 and 2005, and the predicted extent in 2025 based on habitat suitability, spread rates and location of known infestations

Future work

In June 2006 additional QuickBird™ multispectral satellite imagery over the entire Magela floodplain was obtained opportunistically as part of a broader assessment by ***eriss*** of damage caused to native vegetation by Cyclone Monica. At the same time intensive helicopter and airboat surveys of native vegetation and para grass communities were undertaken in order to calibrate spectral information from the QuickBird™ captures. Standard pixel-based spectral analysis combined with object-based image analysis (eg using pattern recognition software such as Ecognition) will be used to assess the capability of QuickBird™ imagery to map and monitor para grass distribution across the Magela, and to determine the condition of native wetland vegetation. Additionally, the 2004 and 2006 time series will be used in conjunction with future captures to provide Park managers with key information such as: what habitats are more susceptible to para grass colonisation; habitat-specific spread rates; and the cost-effectiveness of future control programs.

Para grass is currently the key threat to the World Heritage and Ramsar values of Magela floodplain and, hence, further work will be undertaken in collaboration with Parks Australia

North-Kakadu to finalise a more comprehensive risk assessment, and to help initiate an active control program. Additional field work has been completed this wet season, and detailed analysis and reporting is expected by December 2007.

More comprehensive risk assessment analyses have commenced on both minesite and landscape threats in the lead up to publication of results (eg Bayesian Nets & Influence Diagrams, sensitivity analyses, distance to target concepts), and this will involve collaboration with Dr Keith Hayes (CSIRO Marine & Atmospheric Research).

Major conclusion

The overall findings of the landscape ERA to date suggest strongly that non-mining landscape-scale risks to Magela floodplain should be receiving a level of scrutiny commensurate with their dominant risk ranking including an assessment of what appropriate level of investment would be needed to manage these risks.

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Research consultancies

This section contains a summary of non-uranium mining related external projects carried out by ***eriss*** during 2005–2006.

The Tropical Rivers inventory and assessment project (TRIAP)

R van Dam, R Bartolo, P Bayliss & J Lowry

The tropical rivers inventory and assessment project (TRIAP)

R van Dam, R Bartolo, P Bayliss & J Lowry

Background

'Australia's tropical rivers – an integrated data assessment and analysis' is more commonly known as the 'Tropical rivers inventory and assessment project' (TRIAP). The TRIAP, funded by Land & Water Australia and the Natural Heritage Trust 2, is a collaborative effort between ***eriss***, James Cook University and the University of Western Australia, with additional involvement of the University of Wageningen in the Netherlands. The project aims to provide an information base to support the management of Australia's tropical rivers and consists of three sub-projects: (i) mapping and inventory; (ii) risk assessment of key threats; and (iii) development of a framework for evaluating ecosystem services. The project focus during 2005–06 was on sub-projects 1 and 2. The summary below was drawn from the Milestone 5 Project Progress Report (NCTWR 2006), the full details of which are available from the TRIAP web site (http://www.environment.gov.au/ssd/tropical-rivers/publications-reports.html).

Study area

The TRIAP is operating primarily at two spatial scales: (i) the tropical rivers study area, comprising the 51 river/drainage basins for the Gulf of Carpentaria, Arafura Sea and Timor Sea; and (ii) focus catchments, namely the Fitzroy River (WA), Daly River (NT) and Flinders River (Qld) (see Figure 1).

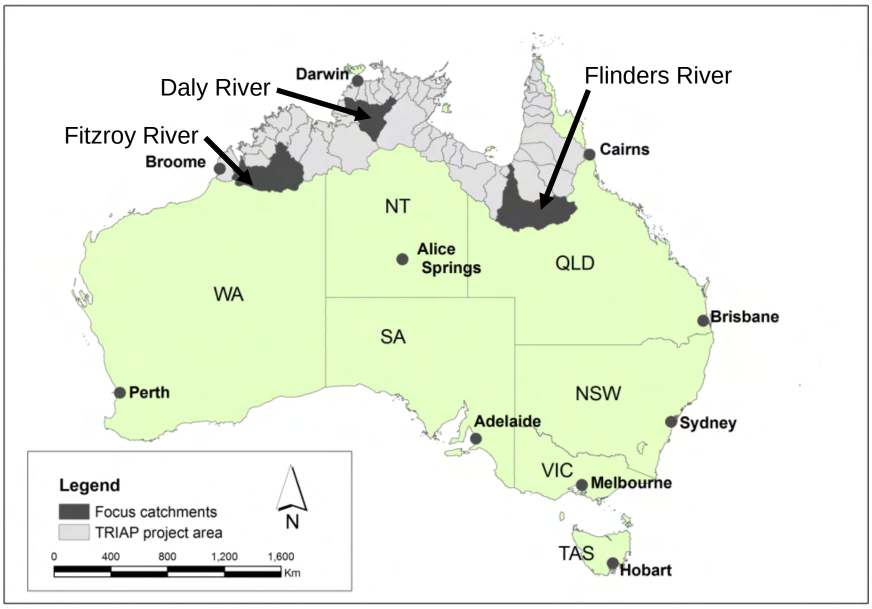

Figure 1 Delineation of the two scales at which the Tropical Rivers Inventory and Assessment Project is focusing: (i) the tropical rivers study area (catchments shaded light and dark grey); and (ii) focus catchments (shaded dark grey)

Sub-project 1 – Inventory of the biological, chemical and physical features of aquatic ecosystems

Description

The major purpose of sub-project 1 is to undertake a multiple-scale inventory of the habitats and biota of the rivers, floodplains and estuaries within Land & Water Australia's program area for the Tropical Rivers funding program. The project is integrating information from the previous Land & Water Australia (LWA) data collation project and additional published sources to make an initial assessment of the diversity, status and ecological value of aquatic ecosystems across the region. This is being undertaken using the multiple-scale model for inventory supported by the Ramsar Wetlands Convention and being applied in the Alligators Rivers Region. The core data cover information necessary for describing the biological, chemical and physical character of an aquatic ecosystem.

Status

A summary is provided in Table 1 of progress against the key activities that occurred, and/or were scheduled to occur, during 2005–06. The major activities during the reporting period involved (i) ongoing data gathering and analysis for the biophysical attributes, and (ii) construction of the GIS and associated standardisation of the datasets and metadata records. Two key components that were significantly progressed were the geomorphic and initial hydrological classifications of the TRIAP study area.

Sub-project 2 – Assessment of the major pressures on aquatic ecosystems

Description

The objective of sub-project 2 is to develop a risk assessment framework applicable across multiple scales, which meets stakeholder needs, within the tropical rivers study area. In developing the risk assessment framework, semi-quantitative and quantitative risk analyses are being undertaken where possible, for selected threats. The scope of TRIAP has only allowed the detailed quantitative risk analysis methology to be developed and trialled in the Daly catchment, although it will have broader application to issues in other catchments. In contrast, semi-quantitative risk analyses will be applied to the tropical rivers study area as well as at least one of the focus catchments, based on data gathered during this sub-project and sub-project 1 (see below).

Status

A summary is provided in Table 2 of progress against the key activities that occurred, and/or were scheduled to occur, during 2005–06. Through discussions with LWA, the scope of this sub-project was formally broadened to include a northern Australian overview of threats to aquatic ecosystems. The aim of this component is to identify and describe the key threats, and their relative risks, to the aquatic ecosystems of the tropical rivers. This will be done using a comparatively coarse level, catchment scale relative risk model (RRM), the same tool being applied at the focus catchment scale, as described in more detail by van Dam et al (2006). Progress has been steady, but slower than initially anticipated, mostly due to staff resource constraints.

Table 1 Summary of progress to June 2006 for key activities for Sub-project 1 (Inventory and mapping)

Data and metadata standards	A hierarchical directory structure was applied for the storage and management of spatial datasets. All spatial datasets are maintained in a geographic projection, using the Geocentric Datum of Australia 1994. Following a review of procedures for the creation and management of metadata within the Department of Environment and Heritage, metadata for databases / datasets was progressively created / updated to the ISO19115 standard. Significantly, all datasets now have a metadata record attached to them. It should be noted that the level and availability of metadata varies considerably.
Compile existing GIS datasets at 2.5M, 250K and other scales	Collation and compilation of data for the inventory component of the project was completed, with data compiled at two broad scales (continental – 1:2,500,000; and catchment scale – 1:250,000). In addition, data were collated for the 'focus' catchments at the catchment scale, or better. Data collation continued at a reduced level to support risk assessment activities within the three focus catchment, focussing on the collation of datasets representing the distribution of feral animals, weeds, rare and threatened species, and temporal variations in land use and landcover. A license for cadastral /land tenure data for the Kimberley region in Western Australia was being sought, and will complete the coverage of this type of data across the project area. Existing collated datasets were reviewed and updated to ensure that the latest versions of key datasets (geology, topography, hydrology) are held by the project database.
Identify, collate and analyse additional data for reach attributes	Additional national (eg. AUSRIVAS, OZCAM, BirdsAtlas) and State/Territory faunal and floral databases were accessed and data extracted to identify the distribution of specific species at catchment and focus catchment scale. Additionally, new spatial datasets were created for hydrological, geomorphic and water quality attributes. Analyses were undertaken to look for patterns/relationships of biophysical attributes across the tropical rivers.
Develop geomorphic classification/typology	Both the continental scale and focus catchment scale geomorphic classifications were completed. These classifications will be used by other Theme Leaders in the analyses of their data.
Trial and apply skeletal typology	Given the dependency of this activity on the finalisation of the data analyses for the key biophysical attributes, there was little progress. However, the project timeline was extended to reflect this delay (see *Variations to Milestones*).
Estuary classification review	Data collection included information on tidal character and non-tidal processes, cyclone paths and land crossing, climate change and variability projections and estuarine classification systems. Classification systems were reviewed. This component was approaching completion.

Nevertheless, numerous key activities have been undertaken, including: stakeholder workshops in two of the focus catchments (Fitzroy and Flinders); the completion and distribution of a risk assessment framework and methodology paper (van Dam et al 2006); and the development of several conceptual models for the focus catchments, depicting the inter-relationships between the ecological assets and threats. In addition, a large amount of information on ecological assets and threats for the tropical rivers study area and the three focus catchments was collated.

Table 2 Summary of progress to June 2006 for key activities for Sub-project 2 (Assessment of pressures)

Activity	Progress/status
Risk assessment framework and methodology	A paper describing the risk assessment framework and methodology was completed and distributed to stakeholders.
Identify key stakeholders	Stakeholder identification has been an ongoing task. The key stakeholders for the Fitzroy and Flinders Rivers were identified.
	Stakeholder liaison/consultation was active and ongoing, and will continue. This process helped refine and improve the information on assets and threats
Liaise with stakeholders on assets and threats	A stakeholder workshop was conducted in Derby, WA for the Fitzroy catchment, and in Richmond, Qld for the Flinders catchment. The Daly River, NT stakeholders will be consulted during 2006–07.
Identify, acquire data for, and describe key assets & threats	Data acquisition was occurring during the latter half of the period, for all three focus catchments and the tropical rivers study area as a whole. Information from spatial datasets and key synthesis documents will continue to be extracted and synthesised.
Compile new GIS layers/ datasets & maintain metadata	Where possible, spatial data for key assets and threats were acquired through the relevant State, Territory or Commonwealth agencies. This activity was advanced for the Daly River and in ongoing discussions with CALM and WWF for the Fitzroy River.
Develop conceptual models	Draft conceptual models were developed for the Fitzroy catchment and a conceptual model for land clearing was drafted for the Daly River. The conceptual models will be completed in 2006-07.
Semi-quantitative risk analyses	A model for conducting semi-quantitative risk analysis at the catchment and regional scale was selected: the Relative Risk Model. Application of the model will commence upon completion of the conceptual model and effects/consequence analysis.
Quantitative risk analyses	Data are being sourced for the specific requirements of quantitative risk assessments. In addition, software (Netica) was purchased to undertake Bayesian Network development.

Communications achievements

Communication and consultation activities continued to take place during 2005–06. Two major stakeholder communication activities were the workshops held in Derby, WA, for the Fitzroy catchment, and Richmond, Qld for the Flinders catchment. These workshops were designed as a forum to elicit stakeholder views on ecological assets and threats in their focus catchment. Another important communication activity was the commencement of cross-project collaboration meetings in December 2005. Meeting participants include representatives from the TRIAP, Charles Darwin University, Northern Territory Department of Natural Resources, Environment and the Arts, and the Northern Australia Irrigation Futures Project. The regular meetings are designed to share knowledge, ensure relevant linkages between projects are built through regular communication and minimise duplication. One key aspect that the meetings address, is the coordinated approach by the various projects in engaging stakeholders.

The third and fourth editions of the TRIAP Newsletter were distributed to all stakeholders in November 2005 and April 2006, respectively. Distribution of the newsletter to stakeholders is an important tool to identify stakeholders who have not been engaged previously.

Numerous presentations on the TRIAP were given during 2005–06, including:

Lowry J & Alewijnse M 2005. Integration of data for inventory and assessment of Australia's northern rivers, *Proceedings of the North Australian Remote Sensing and GIS Conference*, Darwin, 4–7 July, 2005.

Moliere D, Boggs G & Lowry J 2005. Spatial analysis of stream runoff response in the Tropical Rivers Region, *Proceedings of the North Australian Remote Sensing and GIS Conference*, Darwin, 4–7 July, 2005.

Lowry J, Bartolo R. & Alewijnse M 2005. Integration of data for inventory and assessment of Australia's northern rivers, Proceedings of SSC 2005 Spatial Intelligence Innovation and Praxis: The National Biennial Conference of the Spatial Sciences Institute, September 2005, Spatial Sciences Institute, Melbourne, 953–962.

Finlayson M, Lukacs G, Lowry J, van Dam R, Bartolo R & De Groot R 2005. Benchmarking Northern Australia's rivers before further degradation – practical approaches and constraints. *International Riversymposium*, Brisbane, 6–9 September, 2005.

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Appendix 1 SSD publications for 2005–06

Published[1]

Bollhöfer A, Honeybun R, Rosman KJR & Martin P 2006. The lead isotopic composition of dust in the vicinity of a uranium mine in northern Australia and its use for radiation dose assessment. *Science of the Total Environment* 366, 579–589.

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Bollhöfer A, Storm J, Martin P & Tims S 2006. Geographic variability in radon exhalation at a rehabilitated uranium mine in the Northern Territory, Australia. *Environmental Monitoring and Assessment* 114. 313–330.

Evans KG, Rovis-Hermann J, Webb A & Jones DR (eds) 2006. ***eriss** research summary 2004–2005*. Supervising Scientist Report 189, Supervising Scientist, Darwin NT.

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Hancock GR & Evans KG 2006. Channel head location and characterisitics using digital elevation models. *Earth Surface Processes and Landforms* 30, 809–826.

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Hogan AC, van Dam RA, Markich SJ & Camilleri C 2005. Chronic toxicity of uranium to a tropical green alga (*Chlorella* sp.) in natural waters and the influence of dissolved organic carbon. *Aquatic Toxicology* 75, 343–353.

Hollingsworth I & Lowry J 2005. Landscape reconstruction at Ranger mine. In *Proceedings of the North Australian Remote Sensing and GIS Conference,* Darwin, 4–7 July 2005, Applications in Tropical Spatial Science (CD-ROM).

Iles M 2005. Application of national water quality guidelines in mine regulation at Ranger mine, Australia. In *Proceedings of the 9th International Mine Water Association Congress*, eds Loredo J & Pendás F, 5–7 September 2005, Oviedo, Spain, Departmento de Explotación y Prospección de Minas, University of Orviedo, 533–541.

Larson HK & Buckle D 2005. A new species of the circumtropical goby genus *Gnatholepis* Bleeker (Teleostei: Gobiidae Gobionellinae) from northern Australia. *The Beagle, Records of the Museums and Art Galleries of the Northern Territory* 21, 67–72.

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[1] Includes presentations to conferences and symposia that have been externally published in 2005–06.

Lowry J & Alewijnse M 2005. Integration of data for the inventory and assessment of Australia's northern rivers. In *Proceedings of the North Australian Remote Sensing and GIS Conference,* Darwin, 4–7 July 2005*,* Applications in Tropical Spatial Science (CD-ROM).

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Martin P, Tims S, McGill A, Ryan B & Pfitzner K 2006. Use of airborne γ-ray spectrometry for environmental assessment of the rehabilitated Nabarlek uranium mine, northern Australia. *Environmental Monitoring and Assessment* 115, 531–553.

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Appendix 2 ARRTC Key Knowledge Needs 2005–2006

Overall objective

To undertake relevant research that will generate knowledge leading to improved management and protection of the ARR and monitoring that will be sufficiently sensitive to assess whether or not the environment is protected to the high standard demanded by the Australian government and community.

Background

In assessing the Key Knowledge Needs for research and monitoring in the Alligator Rivers Region, ARRTC has taken into account current mining plans in the region and the standards for environmental protection and rehabilitation determined by the Australian Government.

The assumptions made for uranium mining operations in the region are:

- Mining of uranium at Ranger is expected to cease in about 2008. This will be followed by milling until about 2011 and final rehabilitation expected to be completed by about 2016.
- Nabarlek is decommissioned but has not reached a status where the NT Government will agree to issue a Revegetation Certificate to the mine operator. Assessment of the success of rehabilitation at Nabarlek is ongoing and is being used as an analogue for rehabilitation at Ranger.
- Jabiluka will remain in a care and maintenance condition for some years, at least until mining ceases at Ranger.
- It is unlikely that any proposal will be brought forward for mining at Koongarra in the foreseeable future.

This scenario is considered to be a reasonable basis on which to base plans for research and monitoring, but such plans may need to be amended if mining plans change in the future. ARRTC will develop a series of possible future scenarios regarding uranium mining in the ARR, and will ensure the research and monitoring strategy is flexible enough to accommodate any new knowledge needs.

The Commonwealth Government has specified Primary and Secondary environmental objectives for mining at Ranger in the Ranger Environmental Requirements. Similar standards would be expected for any future mining development at Jabiluka or Koongarra.

Specifically, under the Ranger Environmental Requirements (ERs):

The company must ensure that operations at Ranger are undertaken in such a way as to be consistent with the following primary environmental objectives:

3 maintain the attributes for which Kakadu National Park was inscribed on the World Heritage list;

4 maintain the ecosystem health of the wetlands listed under the Ramsar Convention on Wetlands (ie the wetlands within Stages I and II of Kakadu National Park);

5 protect the health of Aboriginals and other members of the regional community; and

6 maintain the natural biological diversity of aquatic and terrestrial ecosystems of the Alligator Rivers Region, including ecological processes.

With respect to rehabilitation at Ranger, the ERs state that:

The company must rehabilitate the Ranger Project Area to establish an environment similar to the adjacent areas of Kakadu National Park such that, in the opinion of the Minister with the advice of the Supervising Scientist, the rehabilitated area could be incorporated into the Kakadu National Park.

The ERs go on to specify the major objectives of rehabilitation at Ranger as follows:

7 revegetation of the disturbed sites of the Ranger Project Area using local native plant species similar in density and abundance to those existing in adjacent areas of Kakadu National Park, to form an ecosystem the long term viability of which would not require a maintenance regime significantly different from that appropriate to adjacent areas of the park;

8 stable radiological conditions on areas impacted by mining so that, the health risk to members of the public, including Traditional Owners, is as low as reasonably achievable; members of the public do not receive a radiation dose which exceeds applicable limits recommended by the most recently published and relevant Australian standards, codes of practice, and guidelines; and there is a minimum of restrictions on the use of the area;

9 erosion characteristics which, as far as can reasonably be achieved, do not vary significantly from those of comparable landforms in surrounding undisturbed areas.

While there are many possible different structures that could be used to specify the Key Knowledge needs, ARRTC has chosen to list the knowledge needs under the following headings:

- Ranger – current operations
- Ranger – rehabilitation
- Jabiluka
- Nabarlek
- General Alligator Rivers Region
- Knowledge management and communication.

1 RANGER – CURRENT OPERATIONS

ARRTC believes that the knowledge (research) needs relating to the current management of the uranium mining operations in the ARR would be best organised within a risk management framework. Such a framework would permit the various risks to the ARR to be assessed using a consistent, quantitative methodology and to be placed in priority order. Risk management is built on the use of quantitative predictive models to link threats or stressors with potential adverse ecological effects.

eriss is undertaking some ecological risk assessment work, but we believe this needs to be upgraded and made the central focus of the research program. Proposals for research should then be assessed in terms of how the knowledge generated will contribute to the management of risk from the mining operations.

1.1 Reassess existing threats

KKN 1.1.1 Surface water transport of radionuclides

Using existing data, assess the present and future risks of health problems to the Aboriginal population eating bush tucker potentially contaminated by the mining operations bearing in mind that the current Traditional Owners derive a significant proportion of their food from bush tucker.

KKN 1.1.2 Atmospheric transport of radionuclides

Using existing data and atmospheric transport models, review and summarise, within a risk framework, dose rates for members of the general public arising from operations at the Ranger mine.

1.2 Ongoing operational issues

KKN 1.2.1 Ecological risks via the surface water pathway

In order to place the off-site contaminant issues at Ranger in a risk management context, a conceptual model of transport/exposure pathways should be developed. This process should include a review and assessment of the existing information on the risks of the bioaccumulation and trophic transfer (ie biomagnification) of uranium and other Ranger mining-related contaminants from all exposure pathways and including the identification of key information gaps.

KKN 1.2.2 Land irrigation

Investigations are required on shallow groundwaters in the land irrigation areas adjacent to Magela Creek as a diffuse source of contaminants. Contaminants of interest/concern in addition to radionuclides are magnesium, sulfate and manganese. Further, the status of the irrigation areas in relation to decommissioning requirements (including radiological risk) needs to be assessed. Water quality models will be linked to knowledge of ecological effects.

KKN 1.2.3 Wetland filters

The key research issue associated with wetland filters in relation to ongoing operations is to determine whether their capacity to remove metals (principally uranium) from the water column will continue to meet the needs of the water management system in order to ensure protection of the downstream environment. Related to this is a reconciliation of the solute mass balance particularly for the Corridor Creek System.

KKN 1.2.4 Ecotoxicology

Although a great deal of ecotoxicological research and assessment has been undertaken, there are still a number of key issues that remain to be addressed including uranium toxicity measurements for two additional local native species, completion of research on the toxicity of magnesium including the ameliorative effects of calcium, and an assessment of the toxicity of manganese. Other issues that should be considered could include the relationship between dissolved organic matter and uranium toxicity and the effects of suspended sediment on aquatic biota.

KKN 1.2.5 Assurance program for radionuclide surface water transport

Further research on surface water dispersion of radionuclides is not considered necessary on the basis of risk. However, a continuing program of monitoring of radionuclides in surface water and in aquatic biota is considered necessary to provide assurance for Aboriginal people who source food items from the Magela Creek system downstream of Ranger.

KKN 1.2.6 Radiation exposure of workers

Further work should be considered in three areas: (a) a more robust examination of radon loss from dust particles, (b) development of a system which measures the concentration of radioactive dust and radon progeny in the breathing zone of a worker whilst wearing respiratory protection, and (c) measurement of the AMAD (activity Median Aerodynamic Diameter) and solubility of ore and product dusts in a range of exposure scenarios.

1.3 Monitoring

KKN 1.3.1 Surface water, groundwater, chemical, biological, sediment, radiological monitoring

Routine and project-based chemical, biological, radiological and sediment monitoring should continue. There is very little research required for the continued implementation of these programs although there is scope for some specific research and analysis in relation to the review of the occupational radiological monitoring program. More specifically, ARRTC supports the design and implementation of a new risk-based radiological monitoring program based on a robust statistical analysis of the data collected over the life of Ranger.

2 RANGER – REHABILITATION

Mining and milling at Ranger is likely to cease by about 2011. Closure of the Ranger mine requires a large number of decisions, many of which will be dependent upon high quality scientific and technical information. The generation of this information will be the major focus of Ranger over the next five years. It will also be necessary to develop a holistic monitoring strategy, based on the risk assessments (and the associated models) recommended above, that aims to quantify changes in the identified high risk areas or test outcomes predicted by the models.

2.1 Landform design

KKN 2.1.1 Development and agreement of closure criteria from the landform perspective

Closure criteria from the landform perspective need to be established at both the broad scale and the specific. At the broad scale, agreement is needed, particularly with the Traditional Owners and within the context of the objectives for rehabilitation incorporated within the ERs, on the general strategy to be adopted in constructing the final landform. These considerations would include issues such as maximum height of the landform, the maximum slope gradient (from the aesthetic perspective), and the presence or absence of lakes or open water. At the specific scale, some criteria could usefully be developed as guidance for the initial landform design such as slope length and angle (from the erosion perspective), the minimum cover required over low grade ore, and the minimum distance of low grade ore from batter slopes. Specific criteria are needed that will be used to assess the success of landform construction. These would include, for example, maximum radon exhalation and gamma dose rates, maximum sediment delivery rates, maximum constituent concentration rates in runoff and maximum settling rates over tailings repositories.

KKN 2.1.2 Initial landform design

An initial design is required for the proposed final landform. This would be based upon the optimum mine plan from the operational point of view and it would take into account the broad closure criteria, engineering considerations and the specific criteria developed for guidance in the design of the landform. This initial landform would need to be optimised using the information obtained in detailed water quality, geomorphic, hydrological and radiological programs listed below.

KKN 2.1.3 Water quality in seepage and runoff from the final landform

Existing water quality monitoring and research data on surface runoff and subsurface flow need to be analysed to develop models for the quality of water, and its time dependence, that would enter major drainage lines from the initial landform design. Options for adjusting the design to minimise solute concentrations and loads leaving the landform need to be assessed.

KKN 2.1.4 Groundwater modelling

In addition to the seepage and runoff issues discussed above, there is a specific need to address the existence of mounds under the tailings dam and waste rock stockpiles. Models are needed to predict the behaviour of groundwater and solute transport in the vicinity of these mounds and options developed for their remediation to ensure that on-site revegetation can be achieved and that off-site solute transport from the mounds will meet environmental protection objectives.

KKN 2.1.5 Geomorphic behaviour and evolution of the landscape

The existing data set used in determination of the key parameters for geomorphological modelling of the proposed final landform should be reviewed after consideration of the near-surface characteristics of the initial proposed landform. Further measurements of erosion characteristics should be carried out if considered necessary. The current site-specific landform evolution models should be applied to the initial proposed landform to develop predictions for long term erosion rates, incision and gullying rates, and sediment delivery rates to the surrounding catchments. Options for adjusting the design to minimise erosion of the landform need to be assessed. In addition, an assessment is needed of the geomorphic stability of the Ranger mine site with respect to the erosional effects of extreme events.

KKN 2.1.6 Radiological characteristics of the final landform

The characteristics of the final landform from the radiological exposure perspective need to be determined and methods need to be developed to minimise radiation exposure to ensure that restrictions on access to the land are minimised. Radon emanation rates, gamma dose rates and radionuclide concentrations in dust need to be determined and models developed for both near-field and far-field exposure. The pre-mining radiological conditions should also be assessed so that estimates can be made of the likely change in exposure rates compared to pre-mining conditions.

KKN 2.1.7 Testing of ‘trial’ landforms

Current landforms at Ranger and at other sites such as Nabarlek should be used to test the various models and predictions for water quality, geomorphic behaviour and radiological characteristics at Ranger.

KKN 2.1.8 Final landform design

The detailed design for the final landform at Ranger should be determined taking into account the results of the above research programs on surface and ground water, geomorphic modelling and radiological characteristics.

2.2 Ecosystem establishment

KKN 2.2.1 Development and agreement of closure criteria from ecosystem establishment perspective

Closure criteria for ecosystem establishment need to be established at both the broad scale and the specific. At the broad scale, agreement is needed, particularly with the Traditional Owners and within the context of the objectives for rehabilitation incorporated within the ERs, on the general strategy to be adopted on habitat types to be incorporated and the species composition of trees, shrubs and grasses to be established on the landform. At the specific scale, criteria are needed that will be used to assess the success of ecosystem establishment. These would include, for example, targets for species density and abundance and measures of faunal return.

KKN 2.2.2 Characterisation of terrestrial and aquatic ecosystem types at analogue sites

To implement the revegetation strategy for Ranger mine, an understanding of the relationships between vegetation communities and key geomorphic features (parent material, slope, effective soil depth, internal drainage characteristics) in surrounding areas of Kakadu National Park is essential in identifying sustainable and achievable ‘landscape’ analogues (or target habitats) for the final, post-mine landform at Ranger. Identification and description of these landscape analogues is also the first step in developing robust, measurable, ecologically-based criteria for assessing revegetation performance, function and success.

KKN 2.2.3 Establishment and sustainability of ecosystems on mine landform

Research on how the landform, vegetation, fauna habitat, hydrology and geochemistry will be reconstructed at Ranger is essential. Noting that there are no good examples in the wet-dry tropics of successful reclamation of hard rock mines, priority needs to be given to this research. Research sites should be established that demonstrate an ability to reconstruct an ecosystem, even if this is at a relatively small scale. Issues that need to be addressed include species selection, seed collection germination and storage, propagation of recalcitrant species, nursery production of seedlings, fertiliser strategies including application methods and direct seeding techniques. Other issues requiring investigation include the return of fauna habitat, potential plant toxicity problems from waste rock, the exclusion of weeds and the effects of fire, hydrology and erosion on the rehabilitation strategy.

KKN 2.2.4 Radiation exposure pathways associated with ecosystem re-establishment

Bioaccumulation studies conducted to date have focused on aquatic animal and plant species because of their importance of the aquatic transport pathway, particularly during the operational phase of uranium mining operations. Information on radionuclide uptake by terrestrial animals and plants is required to enable a radiological risk assessment to be carried out for the revegetation program. This needs to be coupled with estimates of terrestrial bushfood consumption by local Aboriginal people. Another radiological issue that requires assessment is the potential for tree roots to penetrate any radon barriers that form part of the rehabilitated landscape.

2.3 Groundwater dispersion

KKN 2.3.1 Containment of tailings and other mine wastes

The primary method for protection of the environment from dispersion of contaminants from tailings and other wastes will be containment. For this purpose, investigations are required on the hydrogeological integrity of the pits, the long-term geotechnical properties of tailings and waste rock fill in mine voids, tailings deposition methods, geochemical and geotechnical assessment of potential barrier materials, and strategies and technologies to access and 'seal' the surface of the tailings mass, drain and dispose of tailings porewater, backfill and cap the remaining pit void.

KKN 2.3.2 Geochemical characterisation of source terms

Investigations are needed to characterise the source term for transport of contaminants from the tailings mass in groundwater. These will include determination of the permeability of the tailings and its variation through the tailings mass, strategies and technologies to enhance settled density and accelerate consolidation of tailings, and pore water concentrations of key constituents. Assessment is also needed of the effectiveness (cost and environmental significance) of paste and cementation technologies for increasing tailings density and reducing the solubility of chemical constituents in tailings.

KKN 2.3.3 Aquifer characterisation and whole-of-site model

The aquifers surrounding the tailings repositories (Pits 1 & 3) need to be characterised to enable modelling of the dispersion of contaminants from the repositories. This will involve geophysics surveys, geotechnical drilling and groundwater monitoring and investigations on the interactions between the deep and shallow aquifers.

KKN 2.3.4 Hydrological/hydrogeochemical modelling

Predictive hydrological/hydrogeological models need to be developed, tested and applied to assess the dispersion of contaminants from the tailings repositories over a period of 10 000 years. These models will be used to assess whether all relevant and appropriate factors have been considered in designing and constructing an in-pit tailings containment system that will prevent environmental detriment in the long term.

2.4 Water treatment

KKN 2.4.1 Active treatment technologies for specific mine waters

Substantial volumes of process water retained at Ranger in the tailings dam and Pit 1 must be disposed of by a combination of water treatment and evaporation during the mining and milling phases of the operation and during the rehabilitation phase. Research priorities include treatment technologies and enhanced evaporation technologies that can be implemented for very high salinity process water.

KKN 2.4.2 Passive treatment of waters from the rehabilitated landform

Sentinel wetlands may form part of the final landform at Ranger. Research on wetland filters during the operational phase of mining will provide information relevant to this issue. However, there is a need to assess the long-term behaviour of physical and biotic components of wetlands and the ecological health of wetlands which are used to treat runoff from the proposed rehabilitated landform.

2.5 Monitoring

A monitoring program to assess the success of rehabilitation at Ranger will be essential. Prior to its design and implementation, clear and agreed closure criteria will be needed as indicated above. These criteria should be used to determine the design of the monitoring program.

KKN 2.5.1 Monitoring of the rehabilitated landform

A new management and monitoring regime for the rehabilitated Ranger landform needs to be developed and implemented. It needs to address all relevant aspects of the rehabilitated landform including ground and surface water quality, radiological issues, erosion, flora, fauna, weeds, and fire.

KKN 2.5.2 Off-site monitoring during and following rehabilitation

A monitoring regime for the downstream environment is also required to assess rehabilitation success with respect to protection of the downstream environment. This program should address the dispersion of contaminants by surface water, ground water and via the atmosphere.

3 JABILUKA

The Jabiluka project has now entered a long-term care and maintenance phase. It is ARRTC's view that ongoing monitoring will be required throughout this period. In addition, a review is needed of knowledge that would be required prior to any proposal to develop Jabiluka. In particular, it will be necessary to identify and implement any projects considered essential in providing this knowledge well in advance of any development plans.

3.1 Monitoring

KKN 3.1.1 Monitoring during the care and maintenance phase

The monitoring regime for Jabiluka during the care and maintenance phase needs to be determined, implemented and regularly reviewed. The monitoring program (addressing chemical, biological, sediment and radiological issues) should be commensurate with the environmental risks posed by the site, but should also serve as a component of any program to collect baseline data required before development such as meteorological and sedimentary data.

3.2 Research

KKN 3.2.1 Research required prior to any development

A review of knowledge needs is required to assess minimum requirements in advance of any development. This review would include the groundwater regime (permeabilities, aquifer connectivity etc), hydrometeorological data, waste rock erosion, assess site-specific ecotoxicology for uranium, additional baseline for flora and fauna surveys.

4 NABARLEK

Nabarlek is decommissioned but has not reached a status where the NT Government will agree to issue a Revegetation Certificate to the mine operator. Since Nabarlek is the first Australian uranium mine of the modern era to complete operations and be rehabilitated, ARRTC believes that Australia needs to ensure that an overall assessment of the success of rehabilitation at Nabarlek is carried out. The Nabarlek site should also be used as an analogue for rehabilitation at Ranger and projects at Nabarlek should be designed to address specific issues of concern at Ranger.

4.1 Success of revegetation

KKN 4.1.1 Revegetation assessment

The principal ongoing issue at Nabarlek is the poor revegetation. Assessment of the adequacy of revegetation at the site should continue and, following its completion, management options should be developed and submitted to the mine-site technical committee for its consideration.

KKN 4.1.2 Development of revegetation monitoring method

A methodology and monitoring regime for the assessment of revegetation success at Nabarlek needs to be developed and implemented. Currently, resource intensive detailed vegetation and soil characterisation assessments along transects located randomly within characteristic areas of the rehabilitated landform are being undertaken. Whilst statistically valid, these assessments cover only a very small proportion of the site. Remote sensing (satellite) data are also being collected and the efficacy of remote sensing techniques for vegetation assessment should continue. The outcomes of this research will be very relevant to Ranger.

4.2 Assessment of radiological, chemical and geomorphic success of rehabilitation

KKN 4.2.1 Overall assessment of rehabilitation success at Nabarlek

The current program on erosion, surface water chemistry, groundwater chemistry and radiological issues should be continued to the extent required to carry out an overall assessment of the success of rehabilitation at Nabarlek. In particular, all radiological exposure pathways should be evaluated and a comprehensive radiation dose model for Nabarlek should be developed.

5 GENERAL ALLIGATOR RIVERS REGION

5.1 Landscape scale analysis of impact

Apart from regular refinement of procedures for the current monitoring programs, a potential major future research area is the possible development of broader, landscape scale programs that would enable possible effects of mining to be distinguished from those arising from other causes. Such a program was recommended by the Independent Science Panel of the World Heritage Committee. Initial studies have been undertaken. However, ARRTC believes that, before committing further resources to this program, a review of the program to assist in determining future priorities needs to be undertaken.

KKN 5.1.1 Re-assess and prioritise the landscape program

A review is required, within a modelling conceptual and risk assessment framework, of the landscape wide program to determine options and priorities for the future development of this program.

5.2 South Alligator River valley rehabilitation

The focus of work to develop and implement a rehabilitation strategy for historic uranium mining related sites in the South Alligator Valley is the identification of a suitable site for the burial of radiologically active mining residues such as uranium ores or sediments contaminated with tailings. Parks Australia is responsible for this program. Once potential sites have been identified based upon hydrology, access, stability, cultural and other considerations, groundwater investigations will be required to ensure that the site meets requirements for minimum separation between the base of the repository and top of the water table.

KKN 5.2.1 Assessment of mine sites in the South Alligator River valley

SSD conducts regular assessments of the status of mine sites in the SAR valley, provides advice to Parks Australia on technical issues associated with its rehabilitation program and occasionally conducts a low level radiological monitoring program, primarily for assurance purposes. ARRTC believes these should continue.

5.3 Develop monitoring program related to West Arnhem Land exploration activities

Mining exploration is proceeding in the eastern area of the ARR in Arnhem Land outside the Kakadu National Park. In order to overcome the common problem of inadequate baseline data for correctly identifying the cause of environmental change, the SSD and NLC have jointly advocated the strategic collection of regional baseline information on aquatic ecosystems in areas adjacent to mining exploration sites in the ARR.

KKN 5.3.1 Baseline studies for biological assessment in West Arnhem Land

In areas adjacent to mining exploration sites, ARRTC believes there is a need to determine a baseline for (a) rare, threatened and endemic biota and (b) indicator species or groups such as macroinvertebrates.

5.4 Koongarra

There are currently no plans for the development of the Koongarra uranium prospect. However, it is ARRTC's view that, subject to the prioritisation of available resources, an ongoing base-line data collection program could be established and the value of Koongarra as an analogue for pre-mining radiological conditions at Ranger could be investigated.

KKN 5.4.1 Baseline monitoring program for Koongarra

A low level monitoring program should be developed for Koongarra to provide baseline data in advance of any possible future development at the site. Data from this program may also have some relevance as a control system for comparison to Ranger, Jabiluka and Nabarlek.

KKN 5.4.2 Analogue information for pre-mining conditions at Ranger

The value of Koongarra as an analogue site for pre-mining radiological conditions at Ranger should be investigated. There are some pre-mining radiological data for Ranger but the value of these data could be greatly enhanced if it could be extrapolated, through the use of an undisturbed analogue site such as Koongarra, to provide further information on parameters such as pre-mining gamma dose rates, radon exhalation, and radioactivity concentrations in dust.

6 KNOWLEDGE MANAGEMENT AND COMMUNICATION

The Alligator Rivers Region is one of the most studied regions in Australia. Consequently, a very large amount of knowledge has been accumulated over the years on this system. The stimulus for the research is that knowledge-based management of the uranium mines is the best approach to ensuring minimal risk to the ARR.

ARRTC believes that additional emphasis needs to be put on knowledge management and exchange in the next five years. Key aspects that will need to be addressed include the following.

6.1 Integrated framework

KKN 6.1.1 Development of an integrated framework

This has already commenced within a landscape analysis framework and is linked with the development of conceptual models of the ARR recommended above. Such an integrated framework will assist with the communication where the scientific information is relevant, and how it informs on the various risks to the system and its people from the uranium mines.

6.2 Uncertainty analysis

KKN 6.2.1 Uncertainty analysis of data and communication

People involved in the management of natural resources rarely have all the information they need. Even in the ARR, where a very large amount of research has been undertaken on the possible impacts of uranium mining, there is still much not known about the risks. ARRTC believes that management of the mining operations would be improved if the uncertainties in the risk assessment were explicitly identified and communicated. Additionally, those high risk areas where the uncertainty is great would be targeted for more research. It is expected that current work on the development of conceptual models of the ARR will clarify many of these uncertainties.

6.3 Effective communication channels between research providers

KKN 6.3.1 Establishing effective communication channels between and within research providers

There are a large number of organisations undertaking research in the ARR including SSD, EWLS, ERA, Parks Australia North and CSIRO. Given limited resources, it is critical that research is not being duplicated or previous studies repeated. ARRTC believes that communication between the various research providers could be improved and become more formalised to ensure better outcomes for all parties.

6.4 Effective communication to stakeholders

KKN 6.4.1 Effective communication of science to stakeholders

There are a large number of stakeholders with direct and indirect interests in uranium mining in the ARR. It is critical that the results of the high quality research being undertaken in the ARR is communicated to all stakeholders in the most relevant format. ARRTC believes that the various research providers need to target their communication strategies more specifically to the various stakeholder groups.

Appendix 3 ARRTC membership and functions

The Alligator Rivers Region Technical Committee (ARRTC) was established in 1993 following amendments to the Commonwealth *Environment Protection (Alligator Rivers Region) Act 1978*. The membership structure and functions of ARRTC were revised in 2001 in response to a recommendation by an Independent Science Panel established by the World Heritage Committee calling for the establishment of an independent scientific advisory panel to review research activities in the Alligator Rivers Region and the scientific basis for assessing mining operations.

ARRTC membership

ARRTC membership comprises:

- an independent Chairperson;
- seven independent scientific members nominated by the Federation of Australian Scientists and Technological Societies (FASTS) with expertise in the following disciplines:
  - Hydrology and hydrogeology
  - Radiation protection and health physics
  - Plant ecology of minesite revegetation
  - Freshwater ecology
  - Ecotoxicology
  - Geomorphology
  - Chemistry and ecological risk assessment; and
- six members representing key stakeholder organisations.

ARRTC functions

The primary functions of ARRTC are:

a to consider programs for research into, and programs for the collection and assessment of information relating to, the effects on the environment in the Alligator Rivers Region of uranium mining operations in the Region;

b to keep under review programs and the carrying out of programs, referred to in paragraph (a);

c to make recommendations to the Minister [for the Environment and Water Resources] on:

  i the nature and extent of research necessary to protect and restore the environment in the Alligator Rivers Region, and

  ii the most appropriate organisations to undertake the research referred to in subparagraph (i); and

d to refer to the [Alligator Rivers Region] Advisory Committee matters relating to programs, and the carrying out of programs, referred to in paragraph (a).