Part 2: Ranger – Rehabilitation

Contents[1]

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1 List of papers grouped by Key Knowledge Need.

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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[1] School of Environmental & Life Sciences, The University of Newcastle, Callaghan, New South Wales 2308, Australia

(a)

(b)

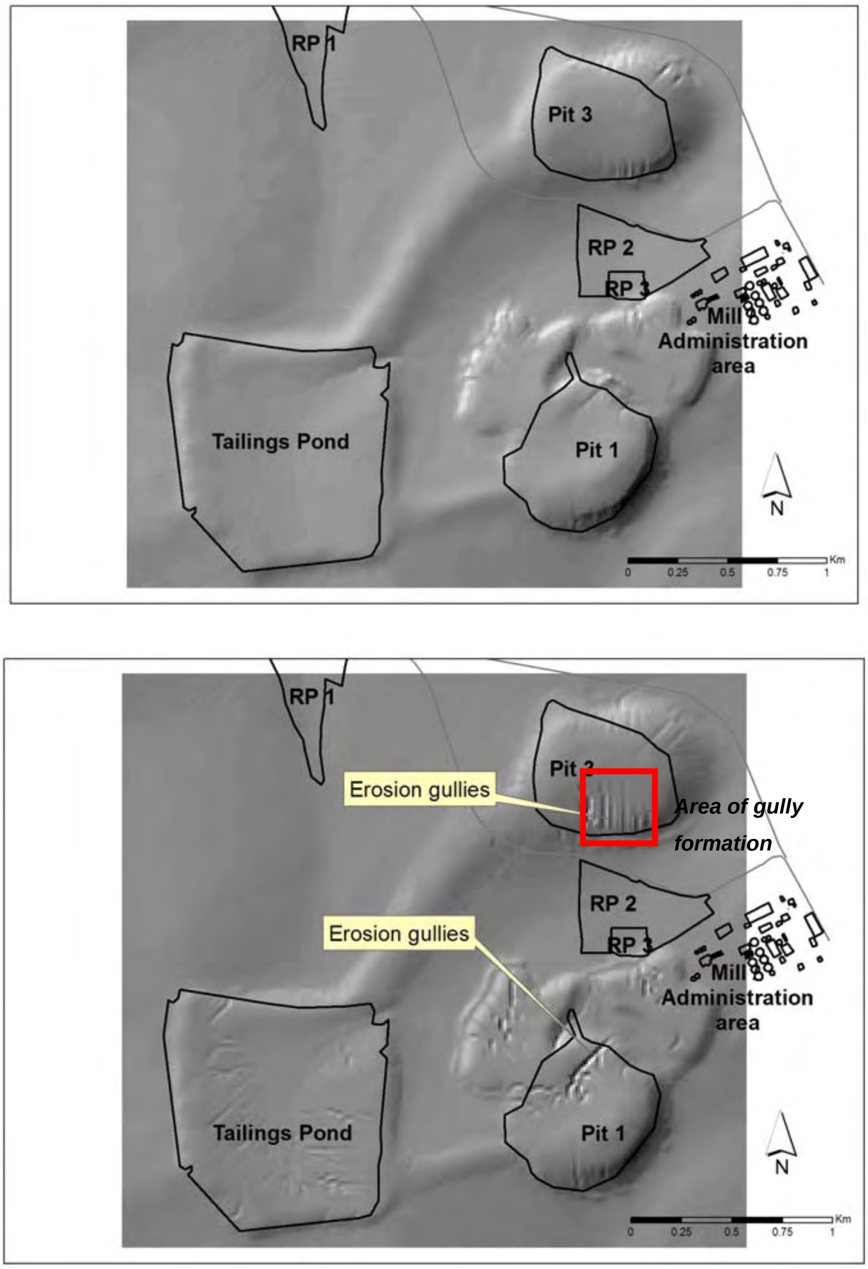

Figure 1 Areas of potential erosion / deposition on proposed 785-014 landform after 1000 years under (a) best case; and (b) 'worst case' scenario

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.

Reference

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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 ($t_{1/2}$= $4.5 \cdot 10^9$ yrs), ^{235}U ($t_{1/2}$= $0.7 \cdot 10^9$ yrs) and ^{232}Th ($t_{1/2}$= $14 \cdot 10^9$ 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.

[1] Charles Darwin University, Darwin

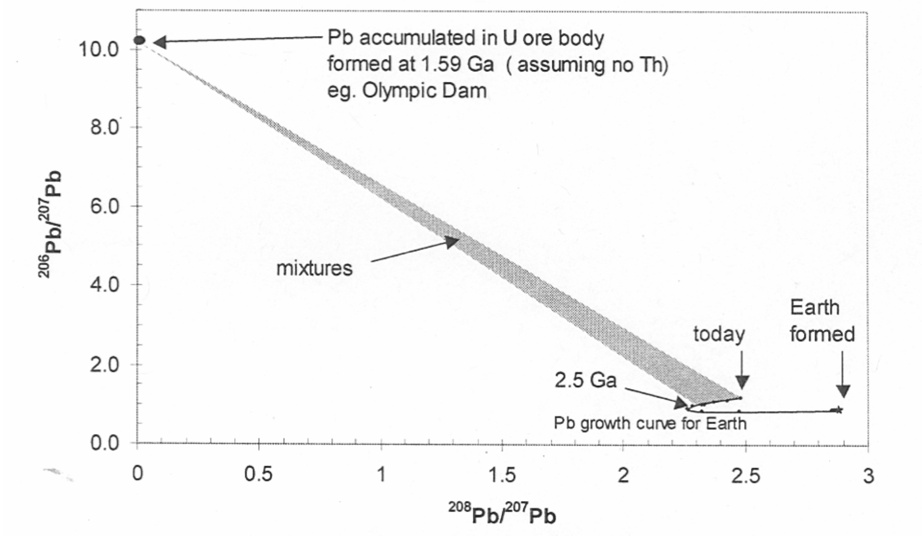

Figure 1 Origin of the isotopic composition of mixtures of radiogenic lead from uranium ores with common lead (from Bollhöfer et al 2005)

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.

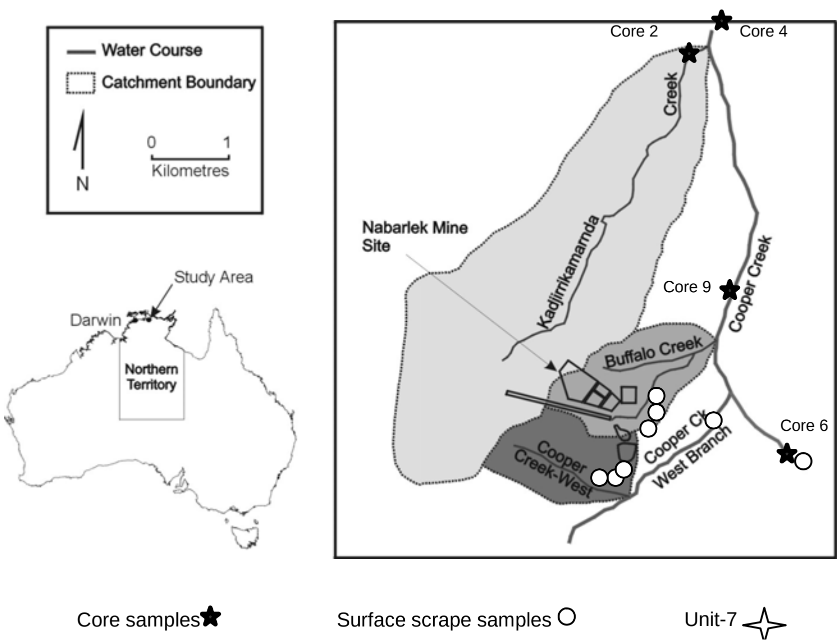

Figure 2 Location of the Nabarlek mineral lease and the sampling sites (modified from Hancock et al, 2006)

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.

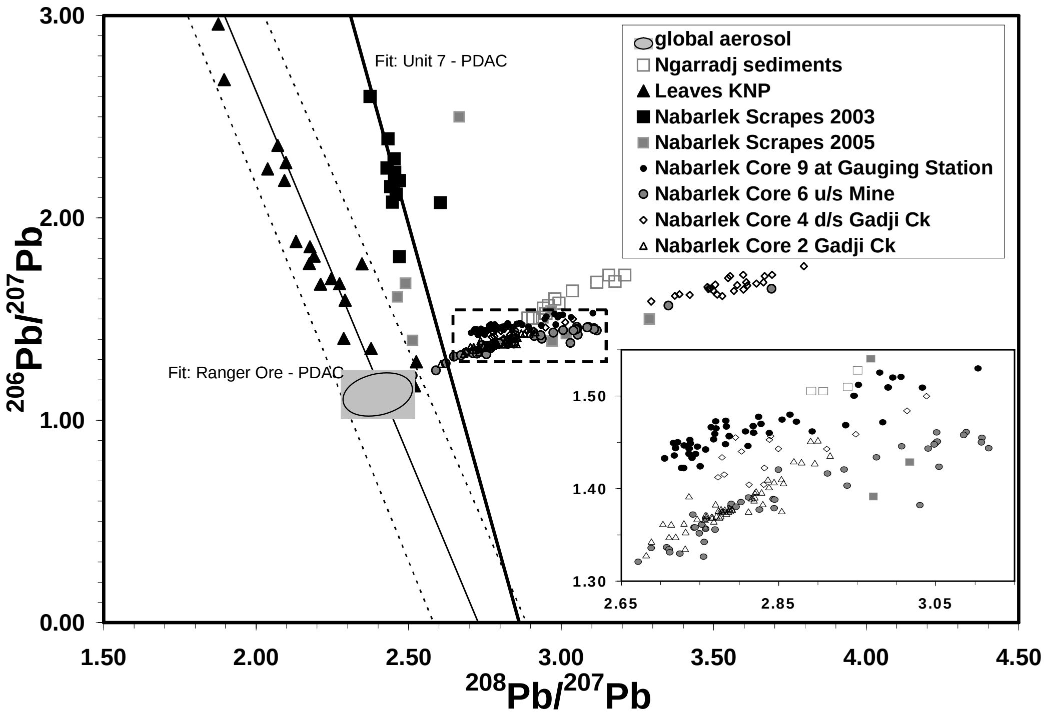

Figure 3 3-isotope plot of soil scrape and sediment samples taken at the rehabilitated Nabarlek mine

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.

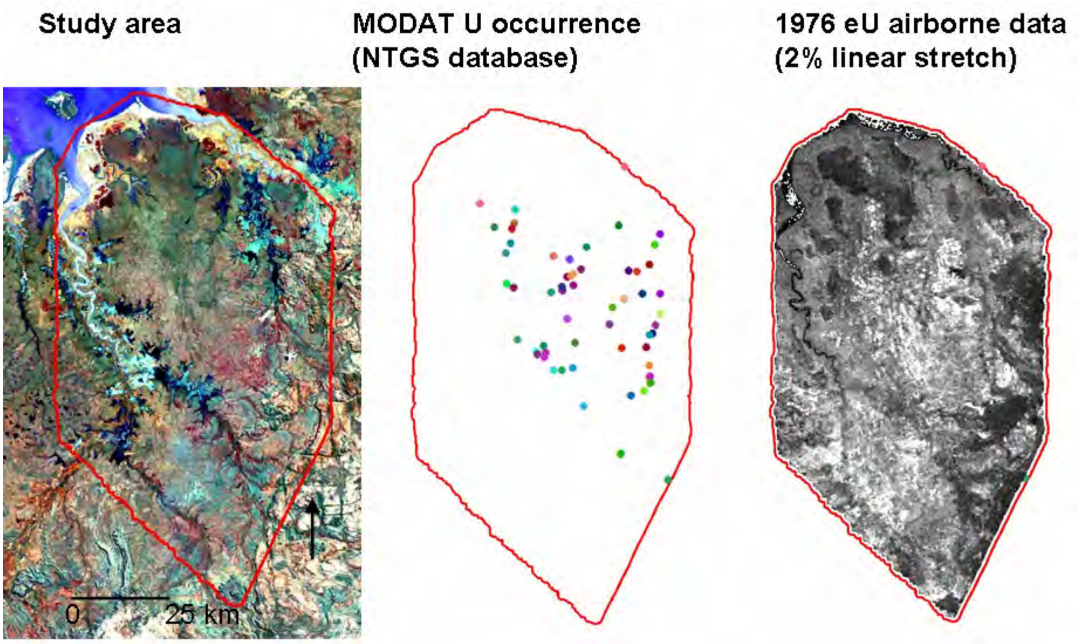

Figure 1 1976 study area, known uranium anomalies (sourced from the Northern Territory Geological Survey MODAT data base) and greyscale eU channel of the airborne gamma survey

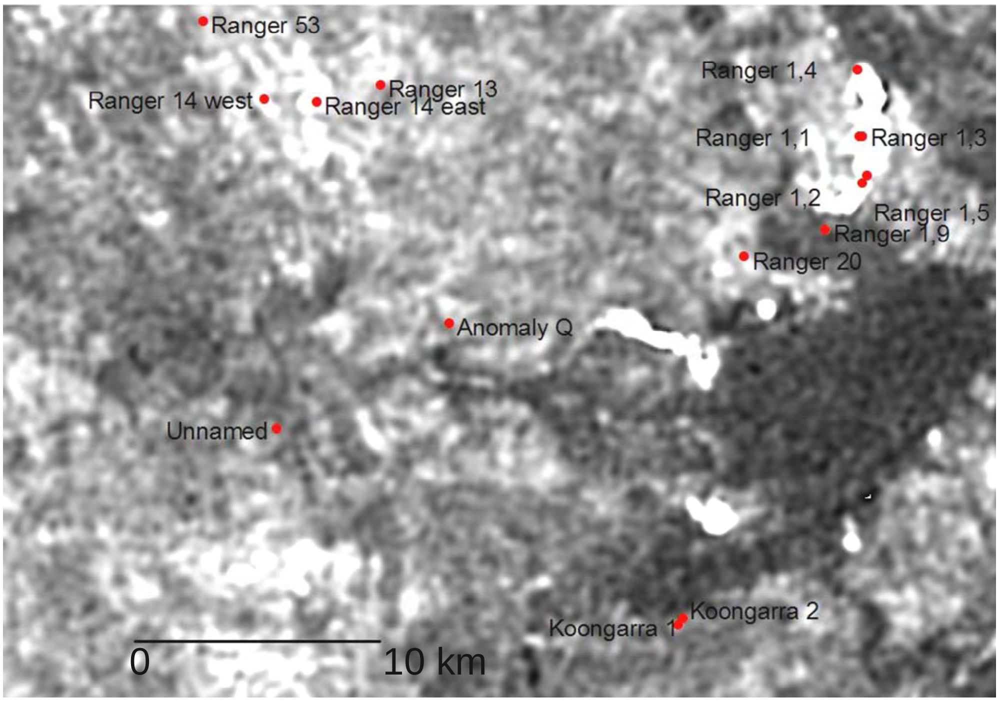

Figure 2 Subset of the 1976 eU data, white > grey > black. Known uranium anomalies overlaid from the Northern Territory Geological Survey MODAT database.

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.

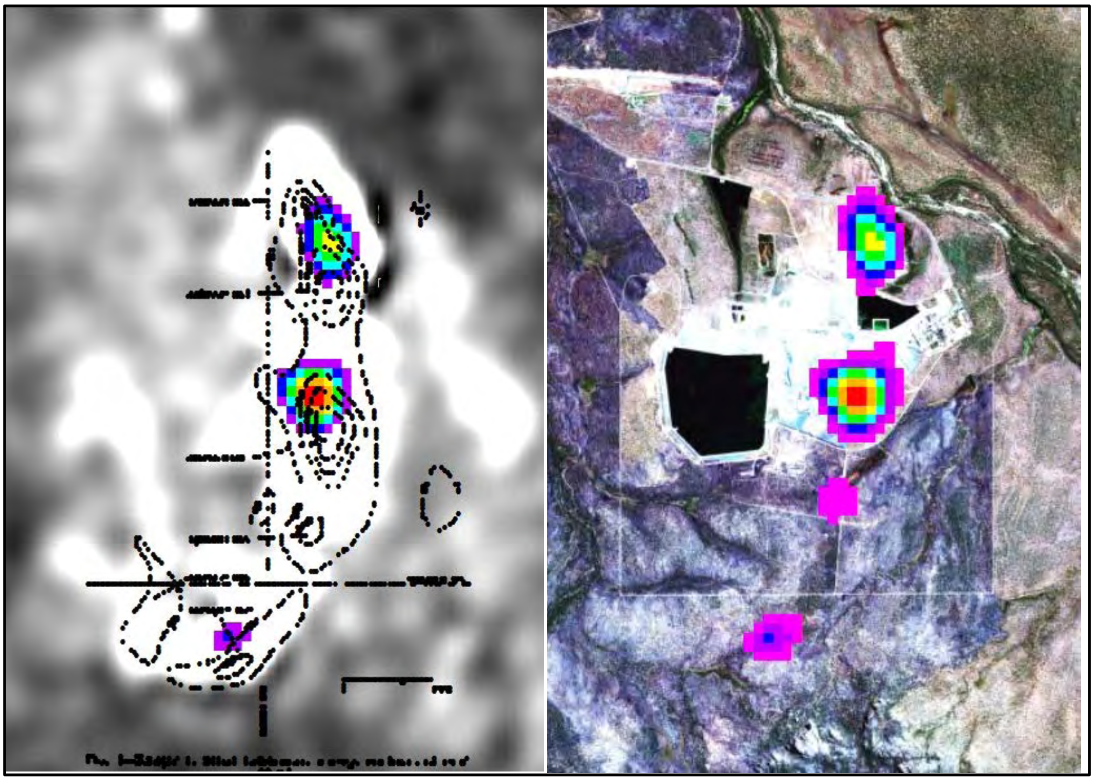

Figure 3 Eupene et al (1980) map of aerial radiometric contours of total count. Overlaid on airborne data (left) and IKONOS (2001) optical satellite data with eU 30–70% pixels mapped.

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

[1] Earth Water Life Sciences, PO Box 39443, Winnellie NT 0821

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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[1] Earth Water Life Sciences, PO Box 39443, Winnellie NT 0821

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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[1] Charles Darwin University, Darwin NT 0909

[2] Earth Water Life Sciences, PO Box 39443, Winnellie NT 0821

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.

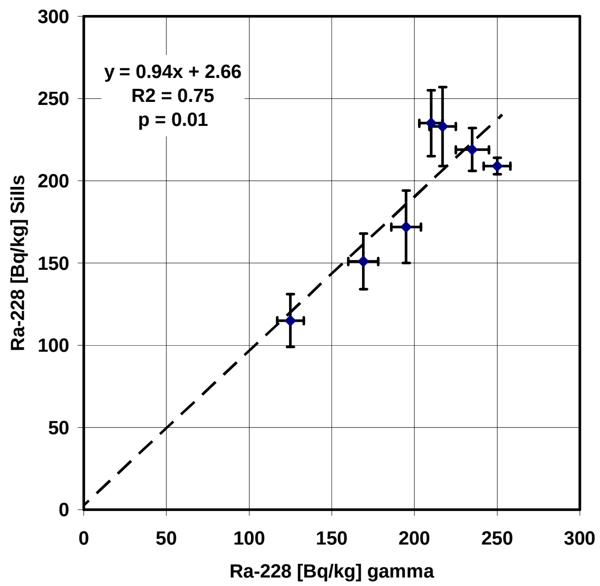

Figure 1 ^{228}Ra activity concentrations determined in mussel samples with the new method

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.

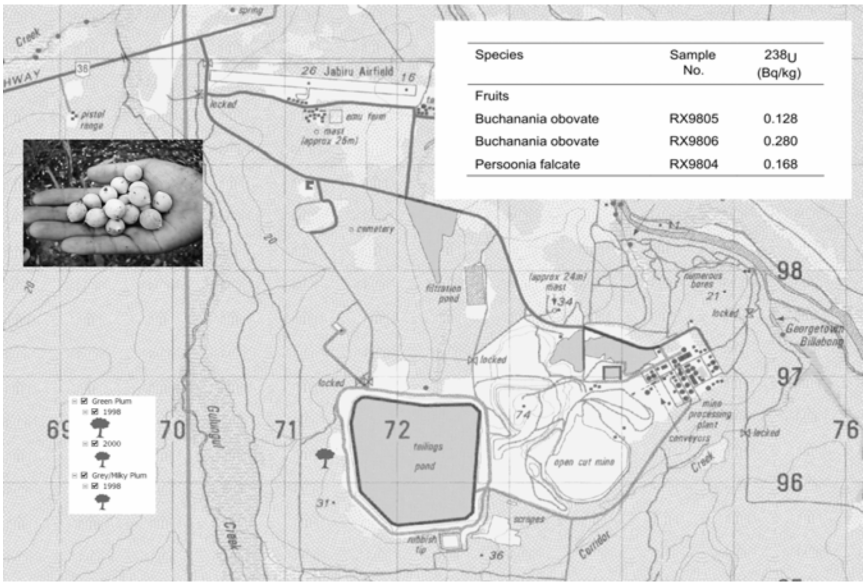

Figure 2 Screen shot of the bushtucker SIS showing uranium activity concentrations in terrestrial bush food samples collected in 1998 around the Ranger mine site

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

We would like to acknowledge Anthony Sullivan and Sally Atkins from SSD and the Mudginberri residents of Kakadu for their help in sample collection and advice.

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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.

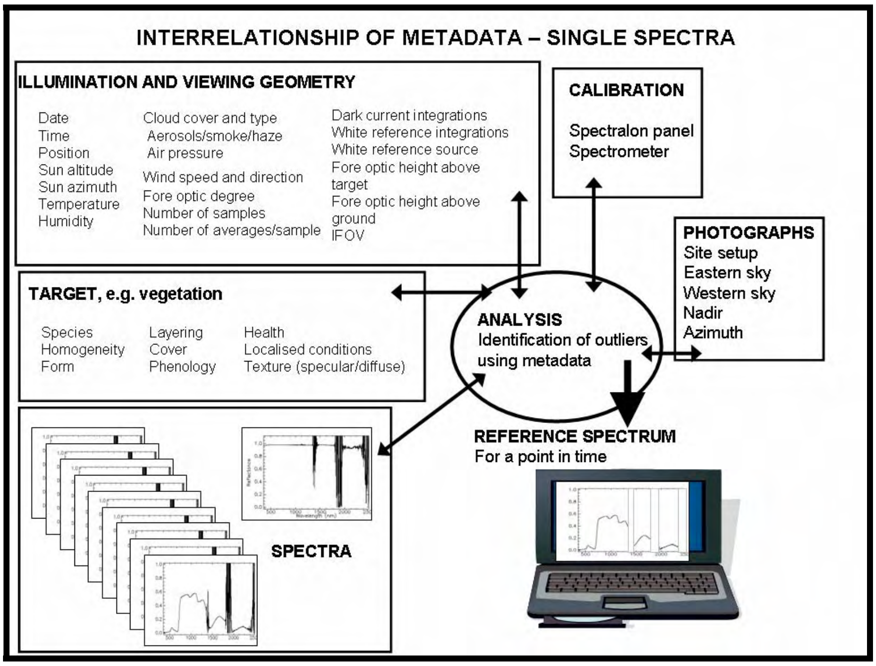

Figure 1 The interrelationship between metadata and spectra

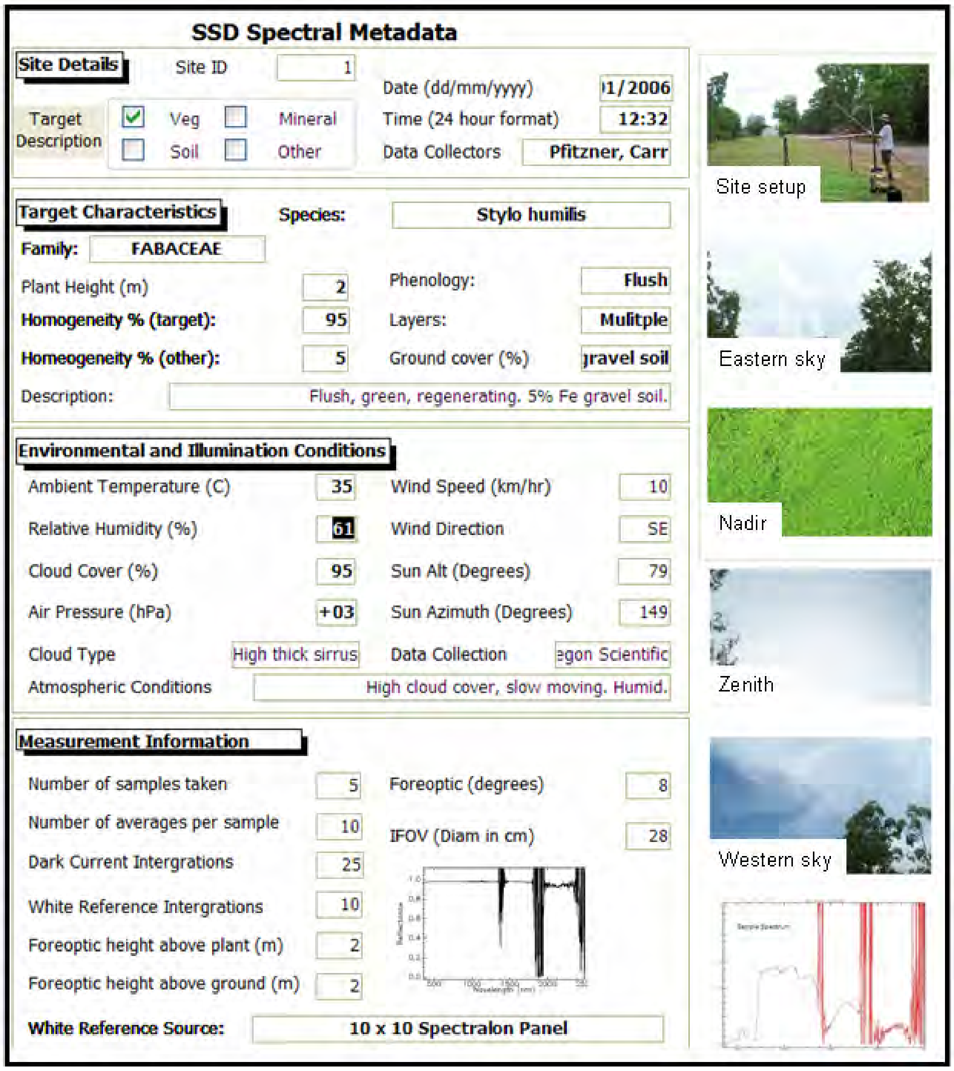

Figure 2 SSD's Spectral Database concept – spectral data and metadata records

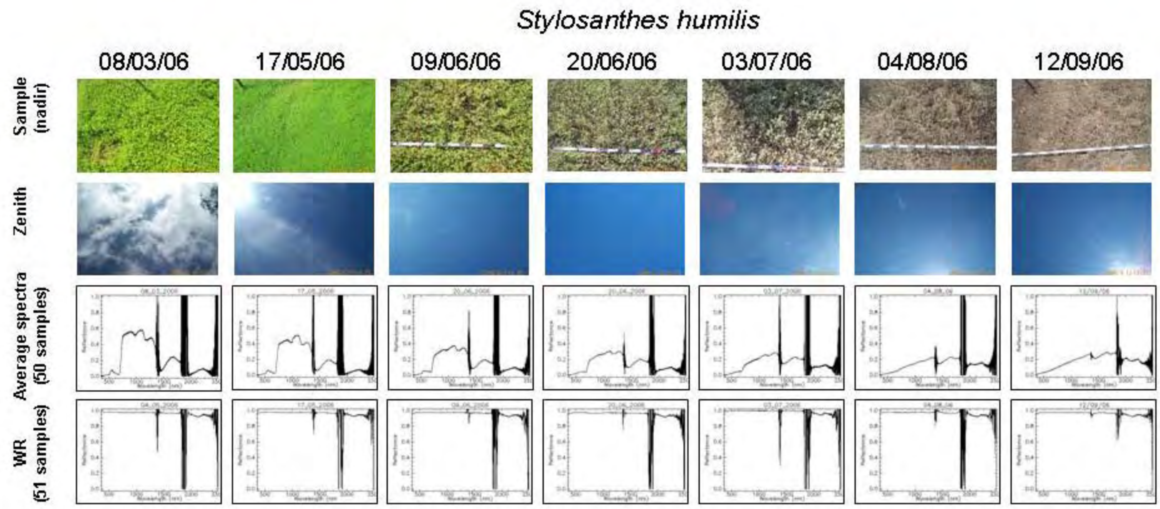

Figure 3 Selected ground cover reflectance spectra for *Stylosanthes humilis,* accompanied by selected metadata

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).

[1] Earth, Water Life Sciences, PO Box 39443, Winnellie NT 0821

[2] Charles Darwin University, Darwin NT 0909

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).

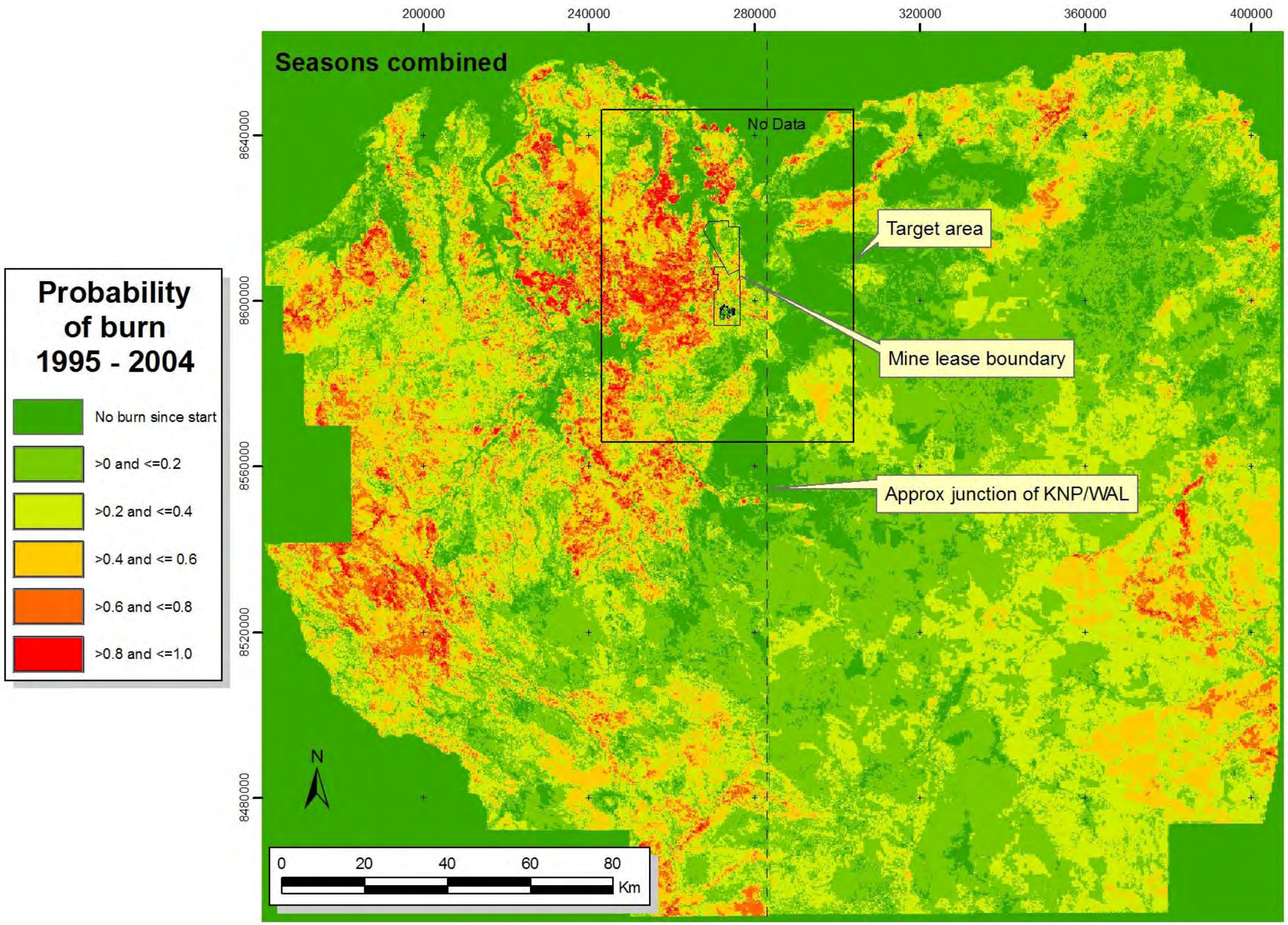

Figure 1 Kakadu National Park and western Arnhem Land merged fire datasets showing the relative location of the target are

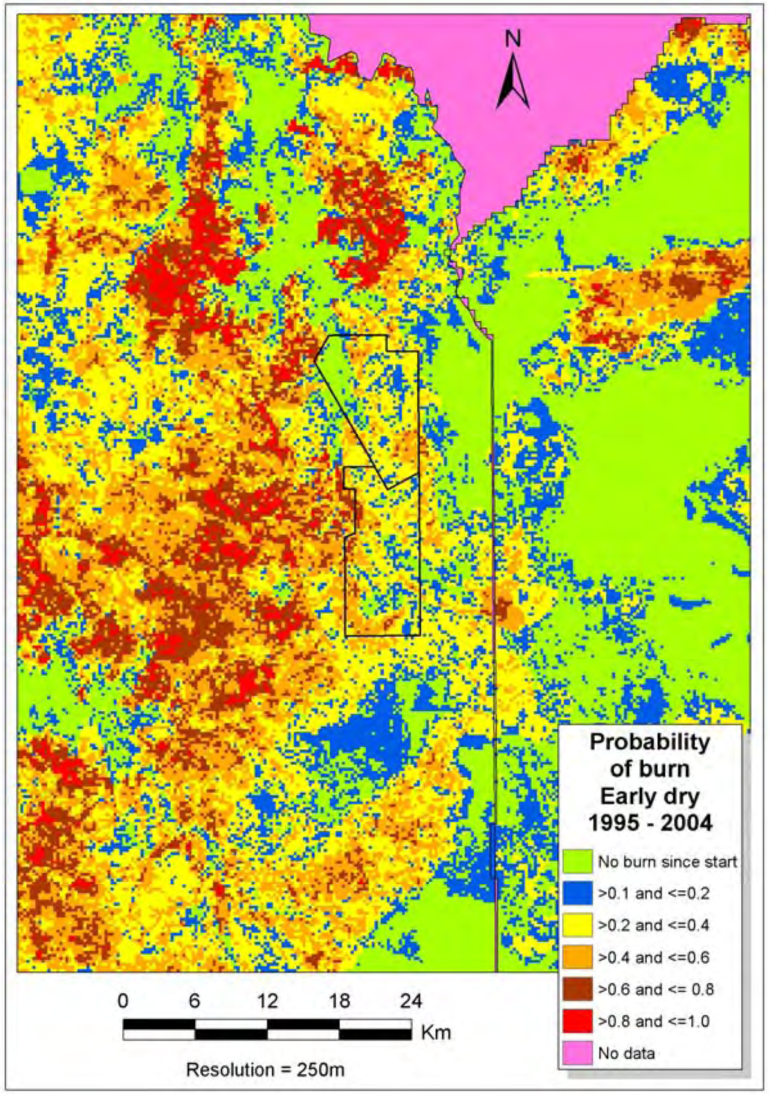

Figure 2 Early dry season burn probability for the target area

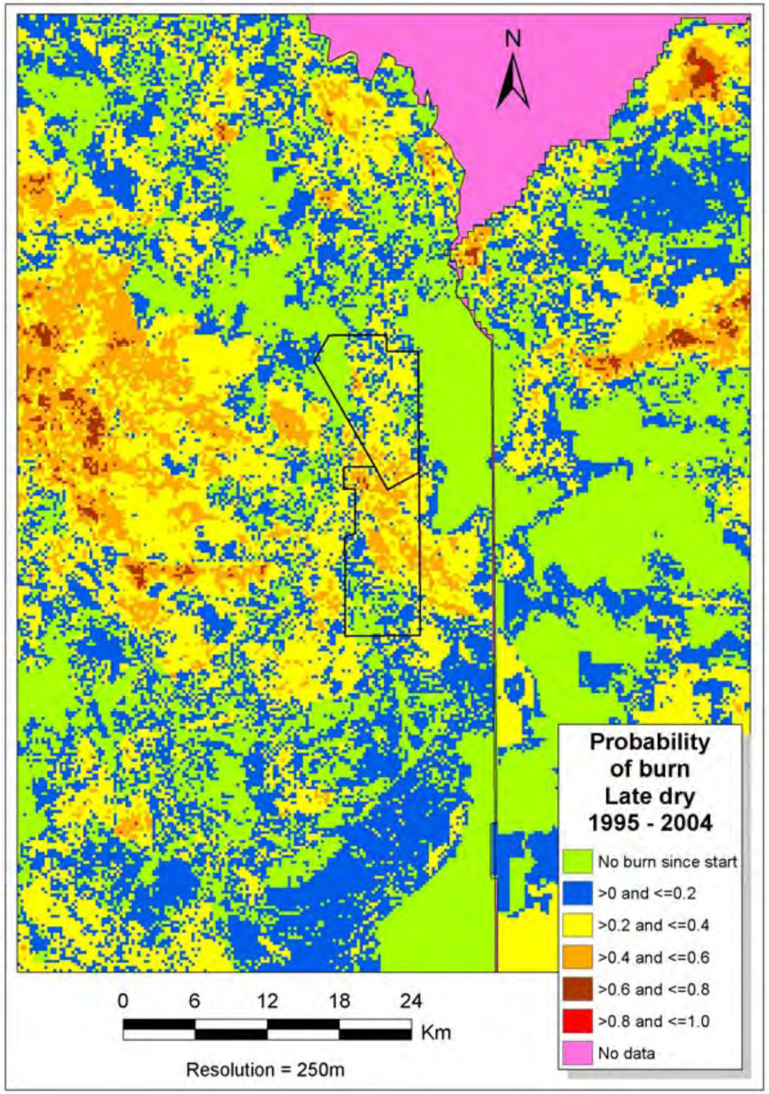

Figure 3 Late dry season burn probability for the target area

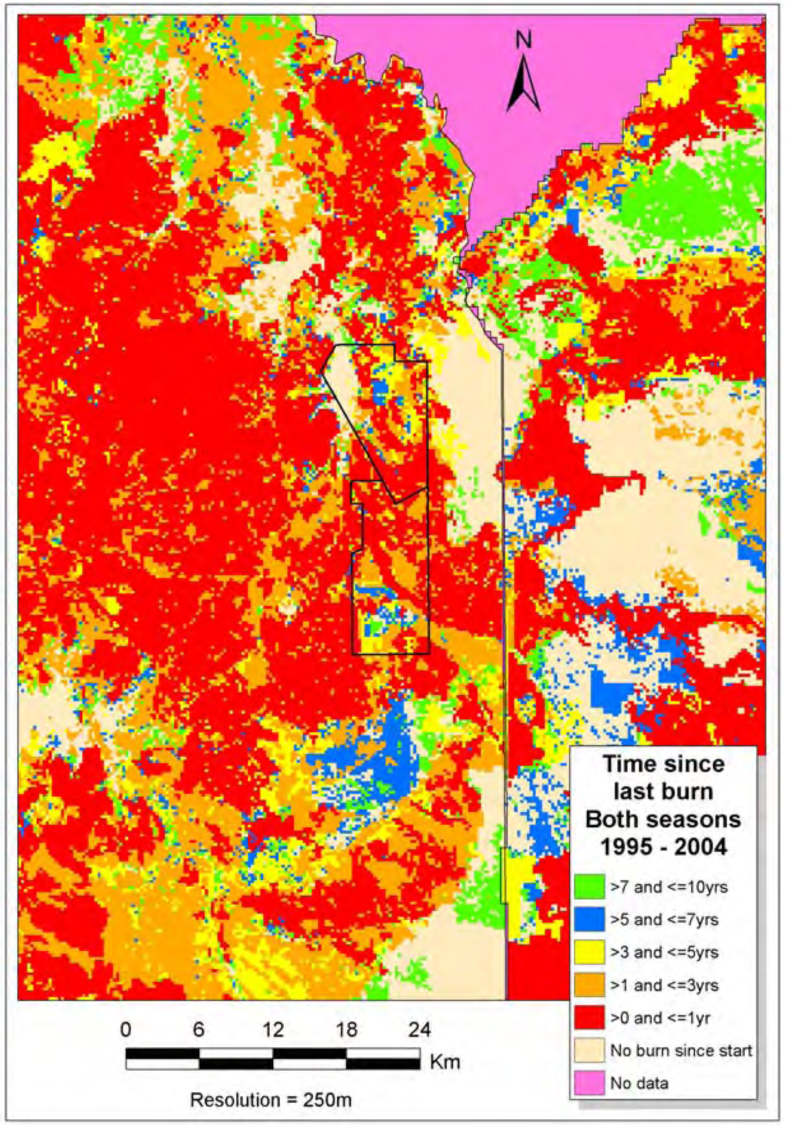

Figure 4 Time since last burn for the target area

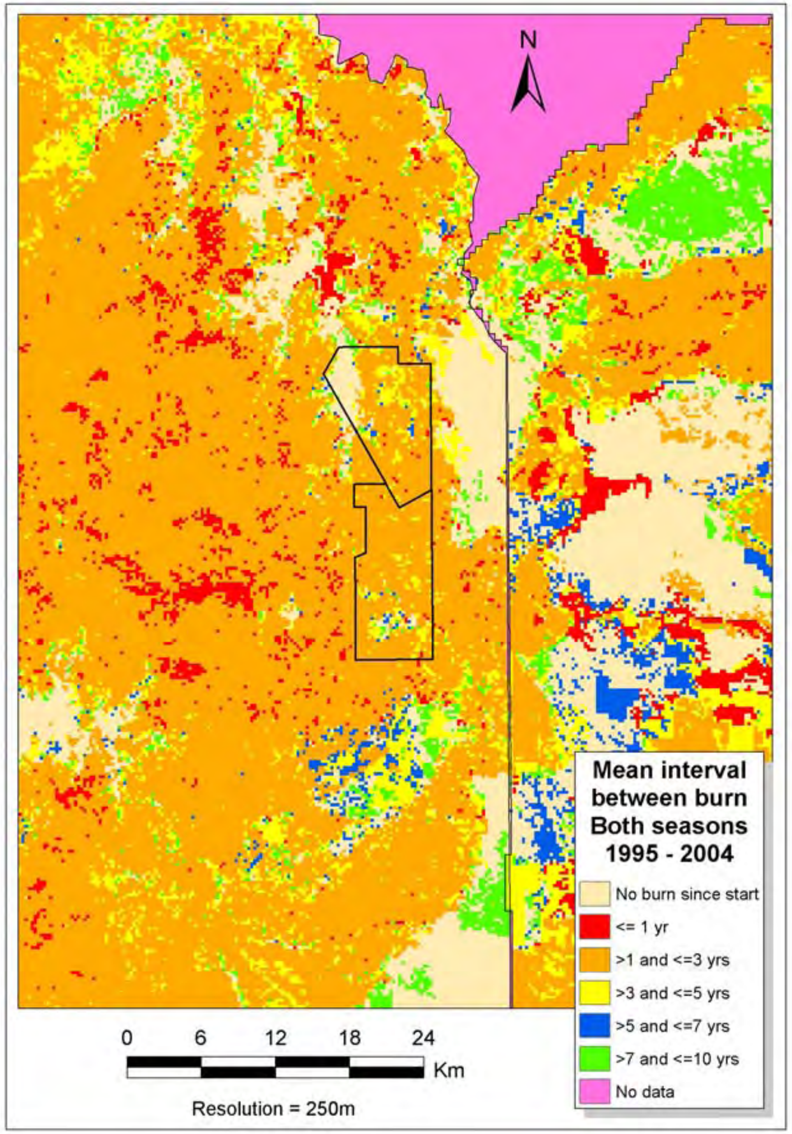

Figure 5 Mean interval between burn for the target area

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)**

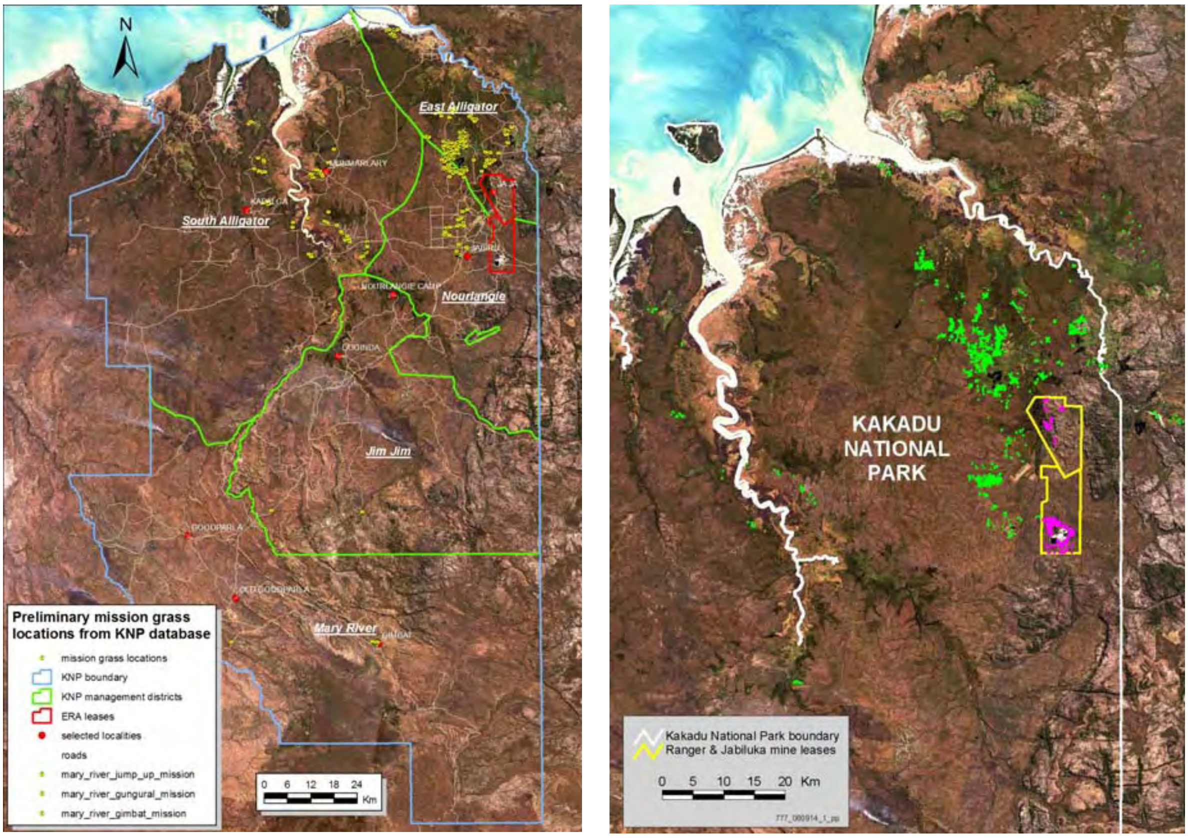

Figure 6 a & b Maps showing locations of perennial and annual mission grass (*Pennisetum polystachion & P. pedicellatum*, respectively) across (a) Kakadu National Park (derived from surveys conducted by PAN rangers), and (b) the RPA (derived from ERA-EWLS surveys, showing additional locations on the 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.

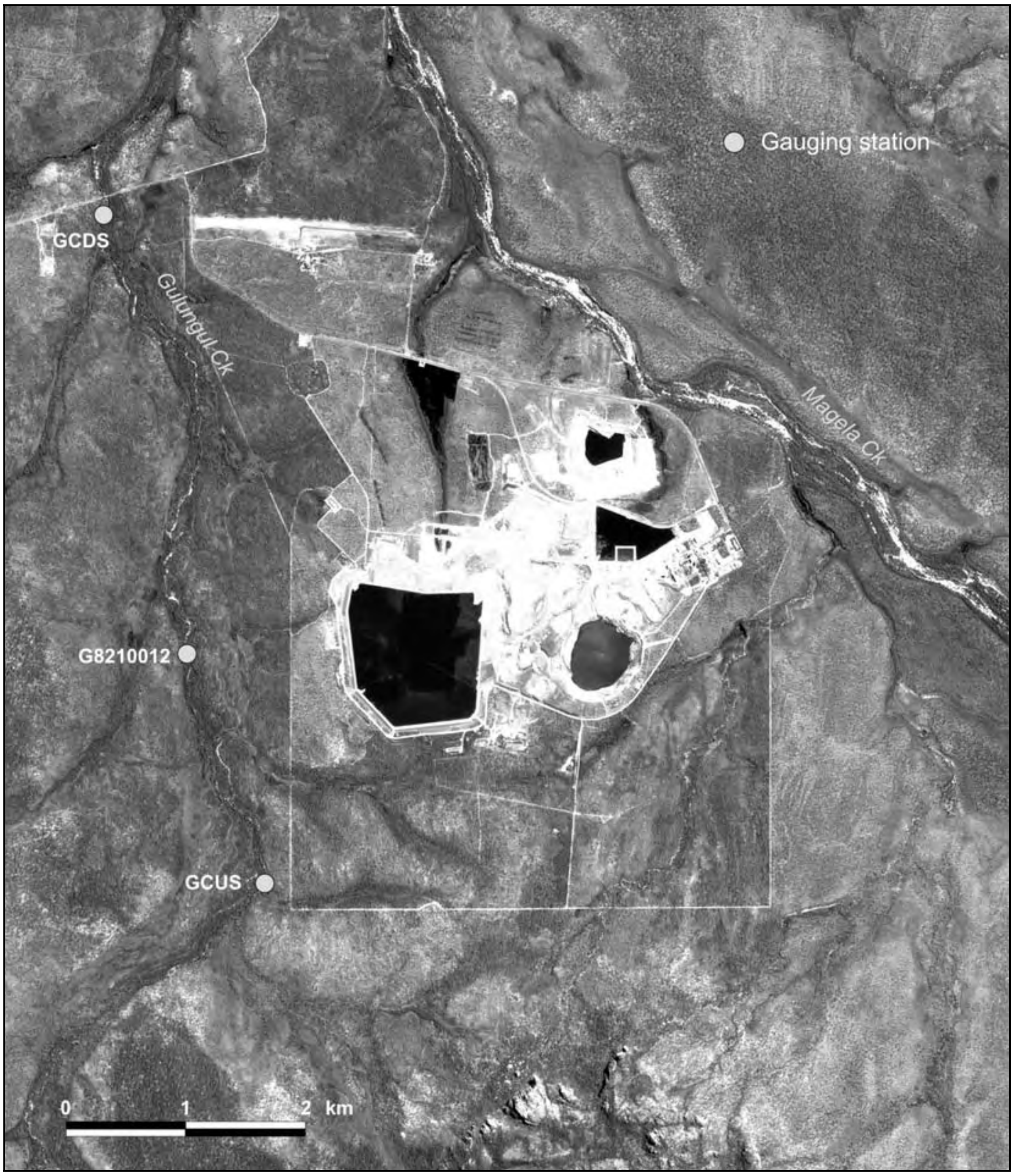

Figure 1 Location of gauging stations along Gulungul Creek

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.

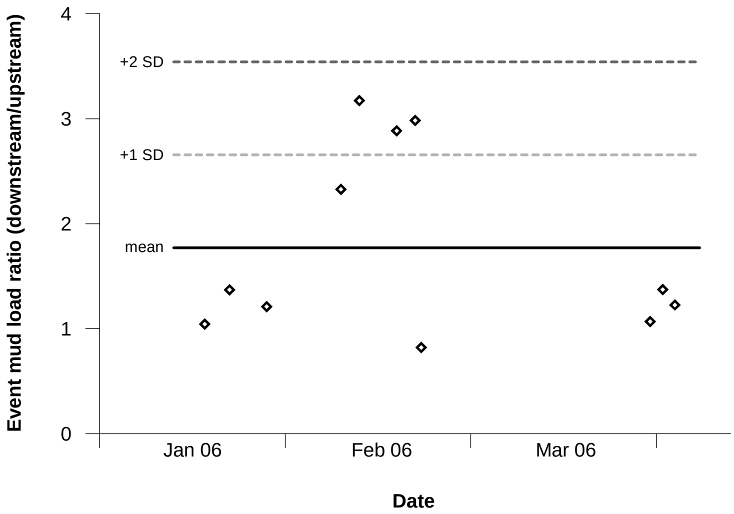

Figure 2 Control chart showing temporal variation of the ratio of event mud loads measured downstream to that upstream along Gulungul Creek during 2005–06 (indicated as ◇). The mean ratio and associated standard deviations are also shown.

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.

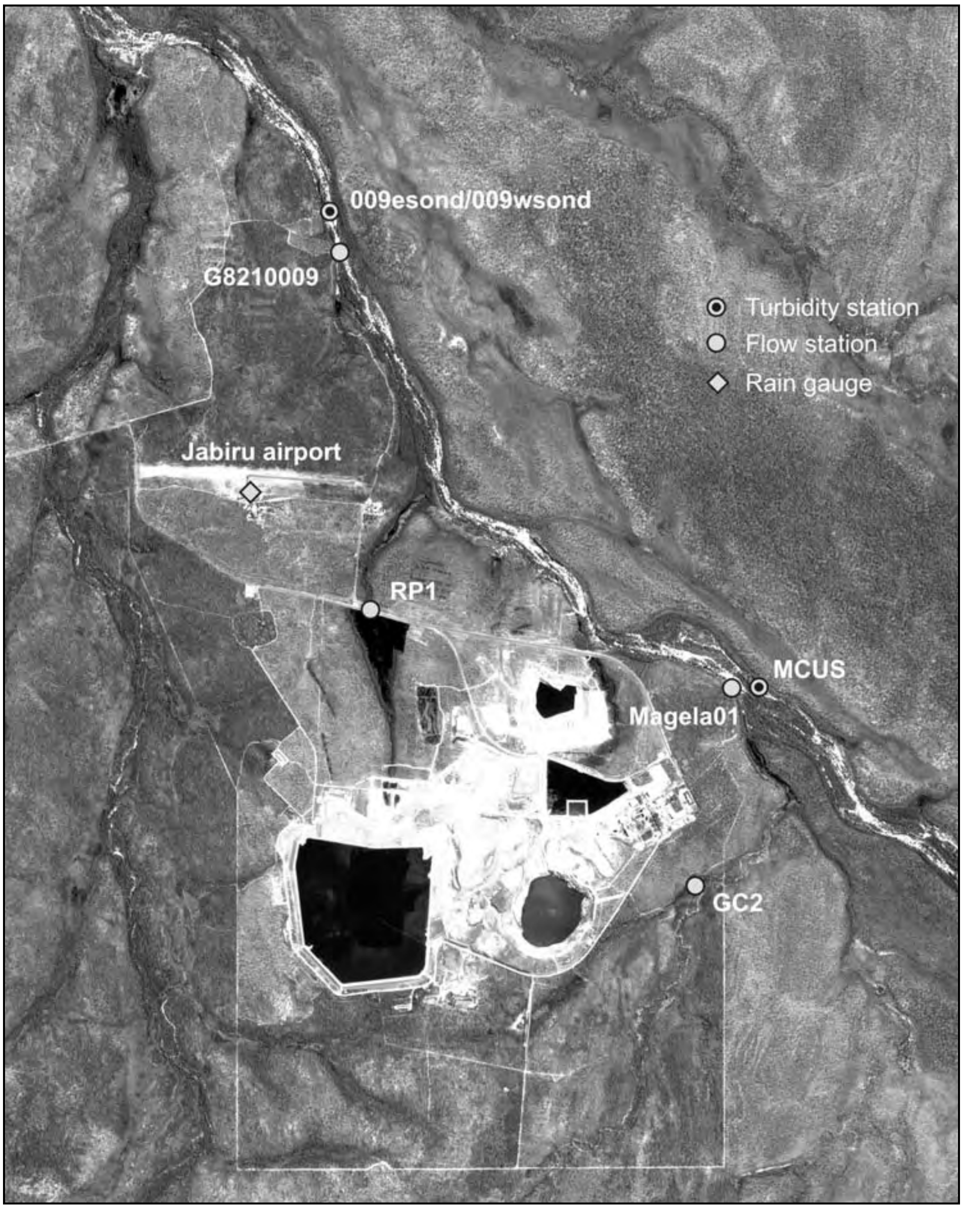

Figure 1 Location of stations along Magela Creek and mine site tributaries

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.

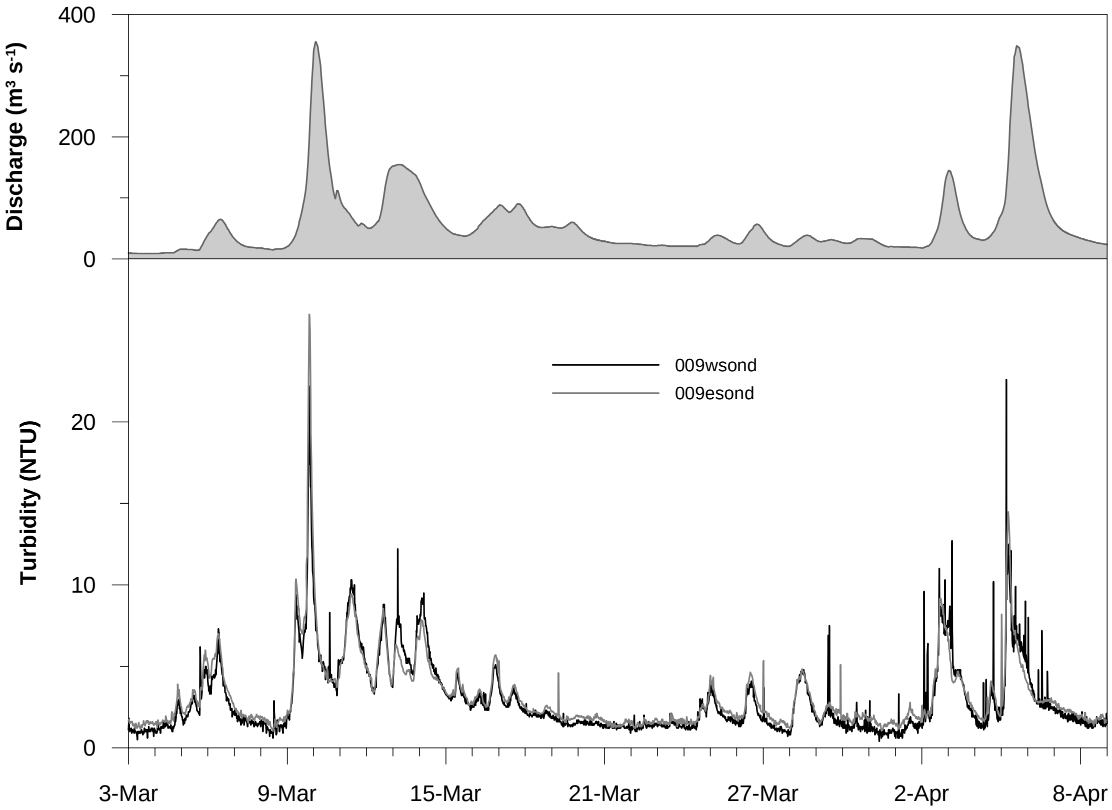

Figure 2 Turbidity data collected at the two downstream sites during a 5-week period of 2005–06. Discharge data observed at G8210009 are also shown.

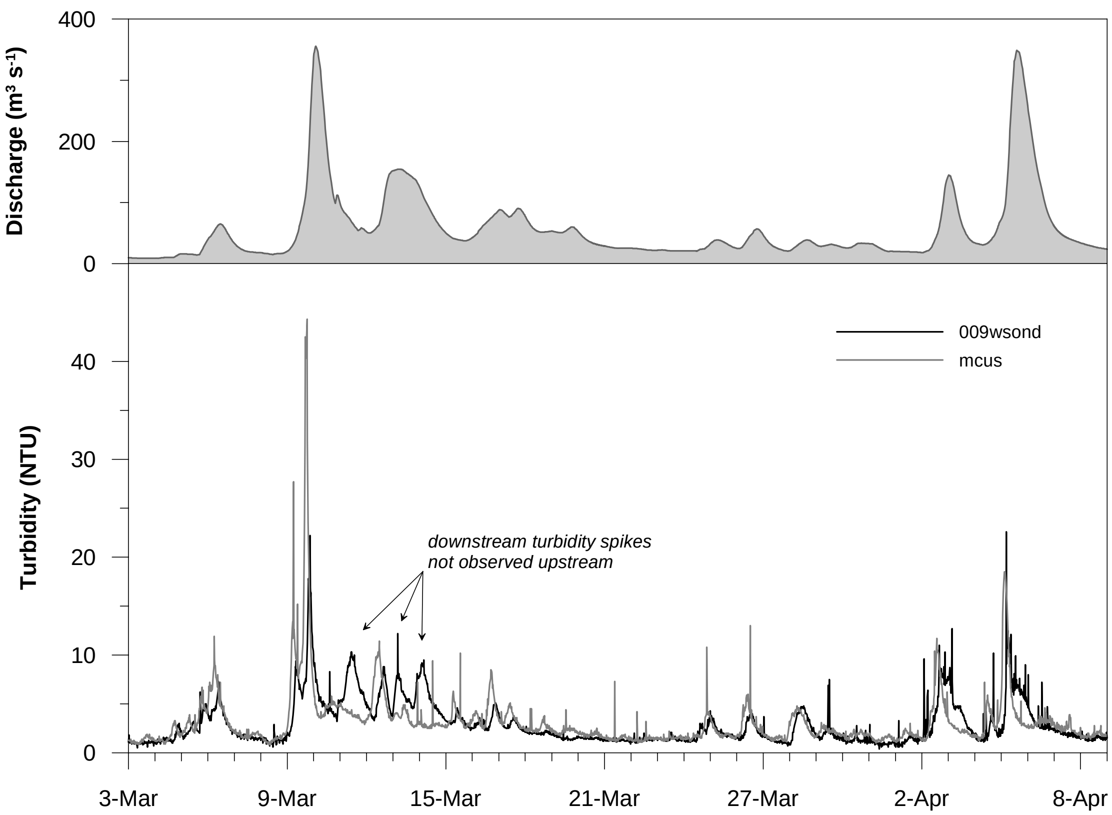

Figure 3 Comparison between upstream and downstream turbidity probes. Discharge data observed at G8210009 are also shown.

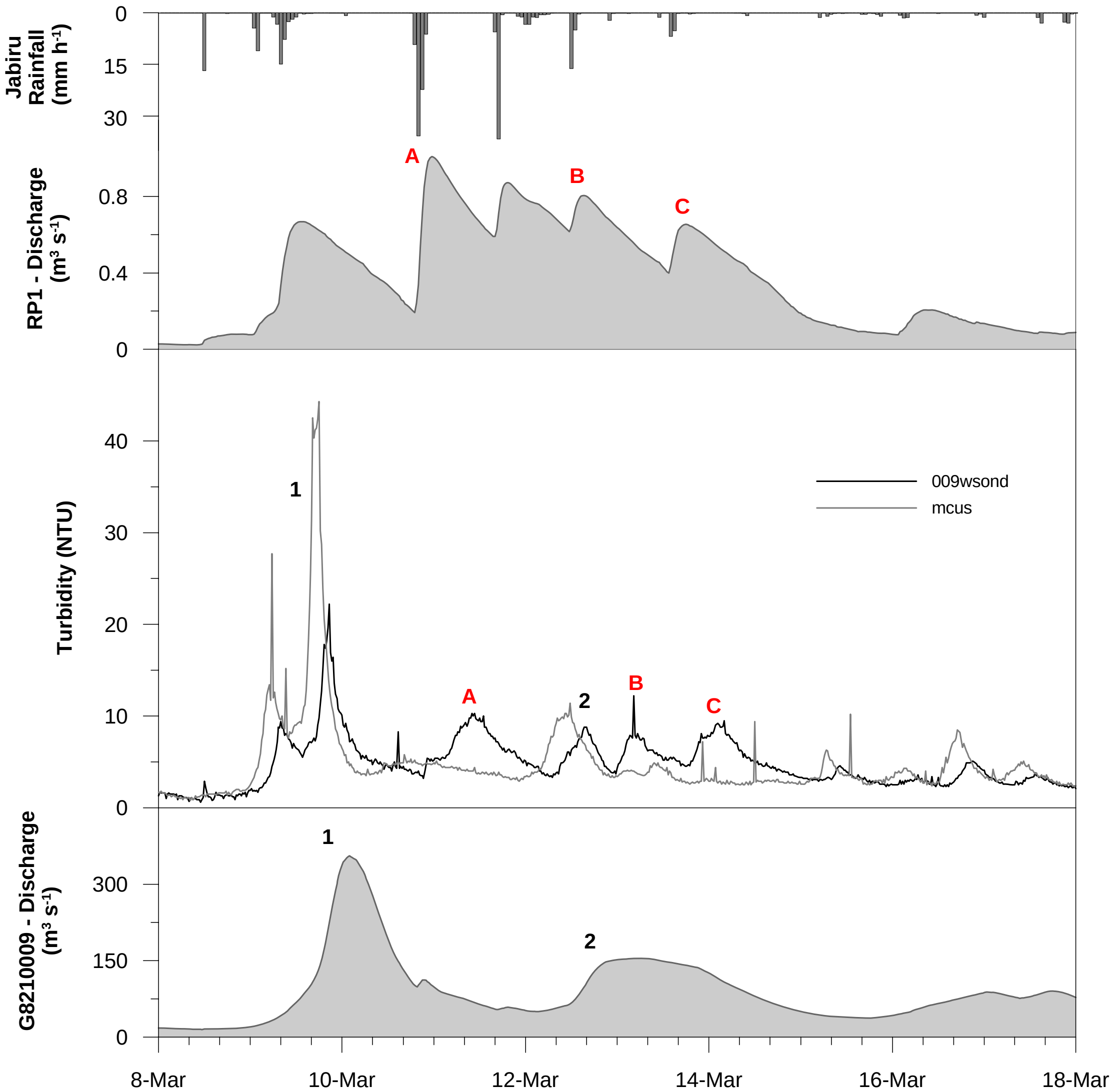

Figure 4 Turbidity data collected at MCUS and 009wsond during mid-March 2006. Discharge data observed at G8210009 and RP1 and rainfall data from Jabiru airport are also shown.

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.

References

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Moliere DR, Saynor MJ & Evans KG 2005. Suspended sediment concentration-turbidity relationships for Ngarradj – a seasonal stream in the wet-dry tropics. *Australian Journal of Water Resources* 9(1), 37–48.