Part 2: Ranger – Rehabilitation

Assess the impact of extreme rainfall events on Ranger rehabilitated landform geomorphic stability using the CAESAR landform evolution model

KG Evans, GR Hancock[1], JBC Lowry & TJ Coulthard[2]

Introduction

The bulk of this project, as it relates to Ranger landform evolution simulations, was reported at the 20th ARRTC meeting in October 2007. During 2007–08 a report was completed describing the progress of the co-operative study conducted with Professor Tom Coulthard and the University of Hull to utilise the CAESAR (Cellular Automaton Evolutionary Slope and River model; Coulthard 2001, Van de Wiel et al 2007) landscape evolution model to assess the impact of extreme rainfall events on the proposed Ranger rehabilitated landform.

In addition, during 2007–08 further work was undertaken in collaboration with Dr Greg Hancock (University of Newcastle, NSW) using the CAESAR model to assess the impact of extreme rainfall events on a natural sub-catchment of Tin Camp Creek (TCC) in western Arnhem Land. The catchment of TCC has a similar geology (ie schist-based) to that of the pre-mining land surface at the Ranger uranium mine and it may provide a suitable analogue for specifying the long-term (closure critertia) erosion rates to be expected following rehabilitation of the site (Uren 1992) and Moliere et al (2002) showed that erosion rates and landform morphology at TCC were a good estimate of what the Ranger landform may evolve towards for slopes where channels have developed where flow has concentrated.

The Siberia landform evolution model has been used to provide average long-term erosion and gully incision rates of rehabilitated mine landforms within a catchment with varied surface treatments (Evans & Willgoose 2000, Hancock et al 2008, Lowry et al 2006). However, the average long-term erosion assessments conducted prior to these studies have not implicitly addressed the impact of an extreme rainfall event or a series of events comprising an 'extreme' wet season. It is therefore important to assess what the impact of extreme rainfall events on a rehabilitated landform will be and to assess the possibility of buried contaminants becoming exposed.

CAESAR uses individual rainfall and runoff data enabling the impact of individual large rainfall events to be assessed, a critical attribute given the long times required to contain mine tailings, and the probability that one or more very extreme rainfall events will occur over this time frame. Testing of the proposed design parameters for the constructed landform for extreme events has assumed greater importance given the probability of an increase in the frequency of intense rainfall events as a consequence of climate change.

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Progress and results to date

The progress and results of the collaborative research conducted with Professor Coulthard on the proposed Ranger landform were described in the report presented to ARRTC in October 2007 and are in Evans et al (2008). The study found there is a high level of sediment loss and fluctuation of erosion rates in the initial years as the new landform finds equilibrium. This is the phase of catchment conditioning simulated by CAESAR as fine sediment is removed from the catchment, drainage lines are incised, particle size distribution of the surface material is adjusted (self–armouring)and vegetation grows, leaving coarser material in the thalweg[3] of drainage lines.

Simulations, using the Jabiru airport 22-year rainfall record, showed that the Ranger landform catchment used in this study for erosion simulations takes about 5 years to undergo this conditioning. Similar observations of catchment conditioning or surface armouring have been observed in field erosion studies at mine sites and for natural terrains in the ARR (Moliere et al 2002).

Previous studies in the area give a range of denudation rates for waste rock of -2 mm y^{-1} to 7 mm y^{-1} with a median of 0.04 mm y^{-1}. Denudation rates of -1.3 mm y^{-1} to 1.3 mm y^{-1} with a median of 0.02 mm y^{-1} have been measured for natural land surfaces in the region (Erskine & Saynor 2000). In 2007, a >> 100 y return interval rainfall event was recorded in Jabiru. For model simulations where the 'extreme' rainfall year 2006–07 was applied for the first year after rehabilitation, a 9 mm lowering of the land surface was predicted. A lowering of 6 mm was predicted when the 2006–07 rainfall record was applied in year 10 of the 22-year rainfall record simulations. After this initial phase, simulated denudation rates remain at an average of 0.2 mm y^{-1}, within a range of -0.05 mm y^{-1} to 1 mm y^{-1}.

A range of rainfall scenarios over a 1000-year period were simulated for the TCC catchment by Dr Hancock using the Jabiru airport 22-year rainfall record. The other key input parameters used in the simulations included particle size data collected from two sites in the catchment of TCC (QT1 and QT3), and a pit-filled, hydrologically-corrected digital elevation model with a resolution of 10 metres for the TCC catchment. Four different rainfall scenarios were generated, representing:

(a) 22 years of complete rainfall (1972–2006). This data set was termed the 'Standard' rainfall data set for the simulations. This data is typical of rainfall up until the 2006–07 wet season and represents average rainfall conditions for the region.

(b) 22 years of rainfall added end to end to produce a 44 year record with the 2006–07 data added at 44 years to produce a total 45 year synthetic record. This was termed the Enhanced Rainfall 45 year (ER45) data set and represents a return interval of approximately 1:50 years for the 2006–07 season.

(c) The complete 23 year rainfall record including the 2006–07 rainfall data. This data set was termed the Enhanced Rainfall (ER23) data set and represents all the currently available rainfall data. The ER23 data set represents a return interval of approximately 1:20–25 years for the 2006–07 season.

(d) The 22 year rainfall record with the 2006–07 wet season data included at both 11 years and 22 years producing a rainfall record 24 years long. This was termed the ER11 data set and represents a return interval of approximately 1:10 years for the 2006–07 season.

[3] The continuous line connecting the lowest points along a stream bed.

The above four rainfall data sets were added end to end to produce a continuous 1000 year record for input into the CAESAR model.

As observed with the simulations of the Ranger landform, the CAESAR model produces high sediment transport rates in the first 10–20 years as surface roughness in the digital elevation is removed and smoothed as well as the soil particle size distribution is sorted across the catchment according the topography and hydrology. There was no variation in surface condition across the catchment The model was initially run using the standard rainfall data and the particle size distributions from the stwo sites (QT1 & QT3) for 44 years as this allowed 2 cycles of the 'Standard' rainfall data. The resultant digital elevation model and grainsize distribution for the QT1 and QT3 particle size data was then used as the initial input to all simulations.

Overall the QT1 simulations had similar overall sediment output with the QT3 and ER11 rainfall producing the most (Table 1). For both soil data sets total sediment output increased as the inclusion of the 2006–07 rainfall data became more frequent. In general, the simulations using QT3 parameters eroded approximately 1.5 times more material than the QT1 sequence for the same rainfall input. For all simulations there were years when there was no sediment output from the catchment represented by a negative depth of erosion (Table 1). The variability in annual erosion (standard deviation) also increased with the inclusion of the 2006–07 rainfall year sequence.

Table 1 Minimum, maximum and average depth of erosion (metres) within the catchment over 1000 years. Negative values represent deposition.

	standard	QT1 soil		
		ER45	ER23	ER11
minimum	-0.28	-0.30	-0.30	-0.30
maximum	1.65	1.58	1.80	1.79
mean	0.02	0.02	0.02	0.02
SD	0.10	0.10	0.11	0.12
		QT3 soil		
	standard	ER45	ER23	ER11
minimum	-0.31	-0.42	-0.30	-0.30
maximum	1.72	1.73	1.75	1.81
mean	0.03	0.03	0.03	0.04
SD	0.13	0.14	0.14	0.17

For all simulations annual sediment output starts higher and then declines. Examination of annual sediment output for each simulation demonstrates that each has a unique pattern as there is considerable variability in sediment output over the 1000 year modelled period. All simulations have periods of both low (near zero) and high sediment output. In general, lower peaks occurred using the Standard rainfall than those runs that included the 2006–07 rainfall data. Of particular interest are the periods of increased output particularly for the QT3 parameters using the ER11 rainfall at around 400 years.

There was little difference between simulations in terms of erosion and deposition depths (Table 1). All areas of the catchment were subjected to both erosion and deposition (Figure 1).

The major differences between simulations occurred along the drainage lines with increased depth of erosion occurring along the length of the channel as well as extending further up the hillslope. In terms of deposition, the majority occurred at the bottom of hillslope for first order stream catchments. Maximum erosion depth occurred along the main drainage line in the central region of the catchment.

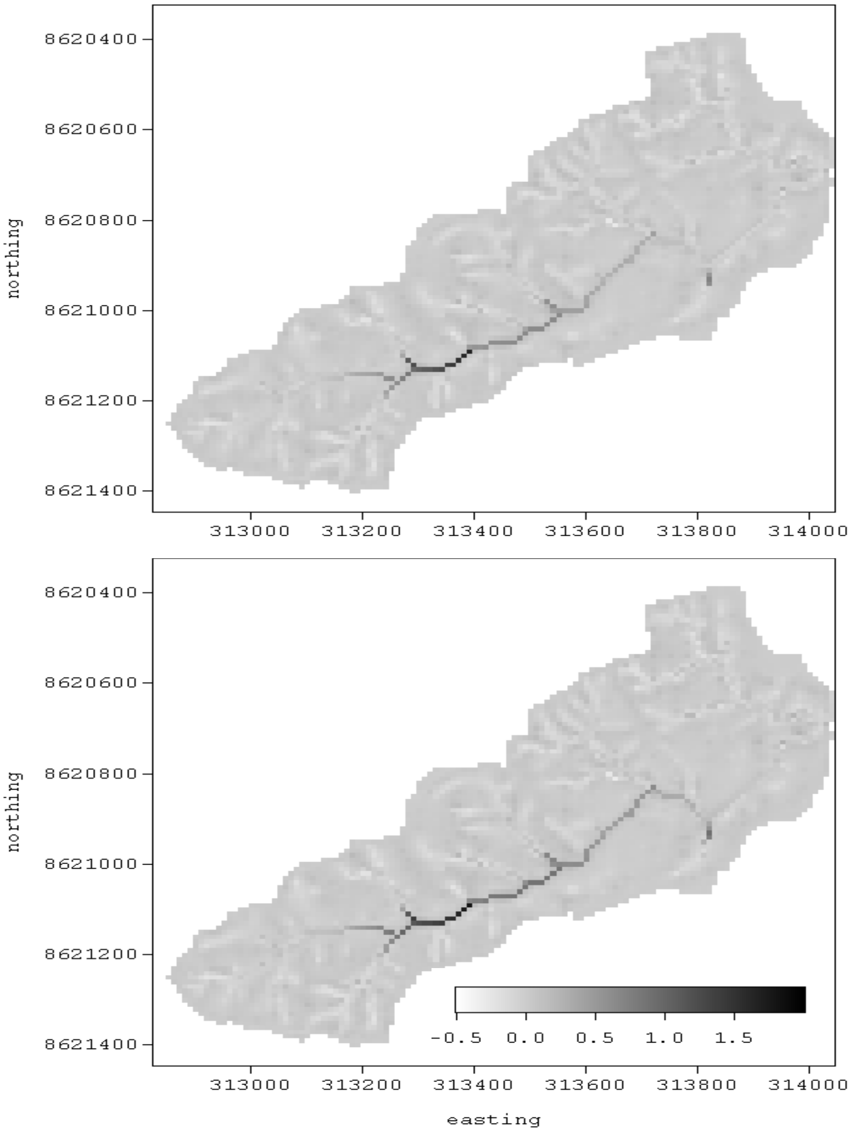

Figure 1 Erosion and deposition patterns for the Tin Camp Creek catchment using enhanced rainfall ER11 (top) and standard rainfall (bottom) and QT1 soil particle size after 1000 years. All dimensions are metres. The erosion key dimensions are metres and negative values represent deposition while positive values equal erosion.

The results demonstrate that there is a unique interaction between both particle size distribution and rainfall. Different particle size distributions produce different sediment transport rates and patterns for the same rainfall. This demonstrates that the relationship between particle size distribution and rainfall is not linear as there appears to be periods where there is enhanced sediment output followed by periods of lower output.

In terms of impact of increased rainfall and storms on sediment output, it is clear that the more frequent returns of the 2006–07 rainfall increases erosion rates. An examination of cumulative sediment output (Figure 2) demonstrates that for both soil data sets erosion follows roughly the same pattern but at approximately 400 years for the QT1 soil and ER23 and ER11 simulations increased erosion while there is a markedly strong increase for the QT3 simulation using ER11 rainfall.

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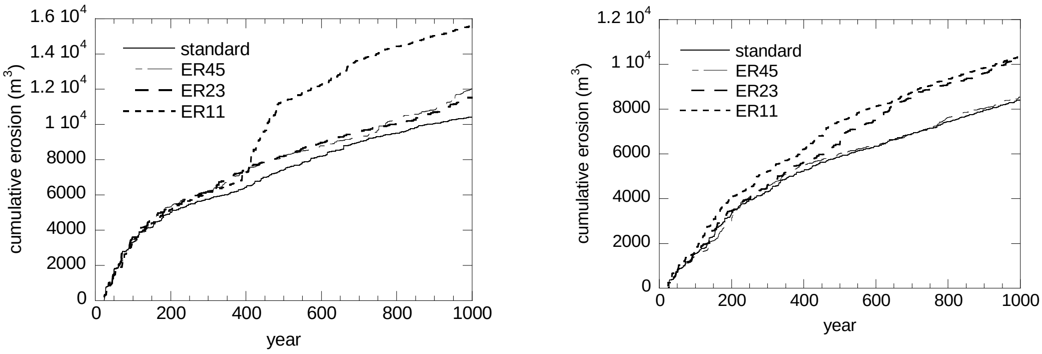

Figure 2 Cumulative erosion for the Tin Camp Creek catchment using the CAESAR erosion model and QT3 (a) and QT1 (b) parameters Standard, ER45, ER23 and ER11 rainfall

Steps for completion

Whilst this work shows great promise to bring new insights into the longevity of mine rehabilitation, there are some steps that need to be taken. These are:

1 Develop model capability to incorporate spatial variability in surface material types and vegetation distribution. Little further simulation work can be done until this step is completed.

2 Test the effects of Digital Elevation Model (DEM) resolution,

3 Test various capping material types such as the laterite mixed proposed for the Ranger vegetation trial plots,

4 Compare long-term erosion rates between CAESAR and Siberia models, and

5 Integrating and evaluating the importance of vegetation on landform stability.

Research programs have been developed co-operatively with both Dr Coulthard and Dr Hancock but competing projects (Ranger landform trial) have taken priority.

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Validation of the SIBERIA model, its erosion parameters and erosion rate predictions

GR Hancock[1], KG Evans & JBC Lowry

Introduction

Erosion models are being used to evaluate the erosional stability of the ERA Ranger mine final landform. The parameter values used in these models are derived through monitoring sheet flow erosion plots under natural rainfall events. There has been some validation against catchment property field data over the long-term using Tin Camp Creek sites which showed that the model could capture catchment form. However there is a need to ensure that the parameter values currently used approximate natural gully development rate.

This is a joint study between Dr Greg Hancock of the University of Newcastle as principle researcher and initiator of the study and ***eriss***. This field study is on an undisturbed site within the Tin Camp Creek catchment in western Arnhem Land near Nabarlek. Soil erosion rates are being measured by the ^{137}Cs method to determine background erosion rates over the last 40–50 years. A network of erosion pins has been installed and annual erosion rates have been and can continue to be measured. Further, an extensive series of gullies exist which are being monitored for their movement on an annual basis which will be compared with gully development predictions of landform evolution models. Soil carbon has also been measured to assess if a relationship exists between soil carbon content and rate of erosion.

Progress and results to date

The study site (Fig 1) is located in the seasonally wet/dry tropical environment of northern Australia, with an annual average rainfall of approximately 1400 mm, mostly falling in the wet season months from October to April. Short, high intensity storms are common, consequently fluvial erosion is the primary erosion process (Saynor et al 2004). The studied undisturbed drainage basin has been unaffected by European agriculture or pastoral activities, but often experiences fire during the dry season.

Caesium-137 and erosion pins

An assessment of slope erosion was carried out using (1) the fallout environmental radioisotope caesium-137 (^{137}Cs) as an indicator of soil erosion status; (2) two numerical models (Siberia and the Revised Universal Soil Loss Equation – RUSLE); and (3) erosion pins.

Two transects (1 and 1a marked on Fig. 2) were sampled for ^{137}Cs in 2002 and 2004, and two models were used to convert ^{137}Cs measurements into soil loss estimates. The theoretical Profile Distribution Model (Walling & He 1999, Walling et al 2002) used to derive net soil loss rates from the ^{137}Cs data gave net soil losses between 50 and 60 t ha^{-1} y^{-1}, while an Australian empirical model (Elliott et al 1990) for uncultivated soils produced estimates between 7 and 8 t ha^{-1} y^{-1}. RUSLE gave estimated soil losses for the two transects of

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approximately 10 t ha^{-1} y^{-1}, while the Siberia model produced values between 0.5 and 2 t ha^{-1} y^{-1} for the transects and values between 4 and 11 t ha^{-1} y^{-1} for the total catchment. Average net soil losses of 14 and 15 t ha^{-1} y^{-1} for the total catchment and slopes, respectively, were measured by erosion pins. These results indicate that Siberia predicts similar erosion rates (same order of magnitude) to those determined by other methods.

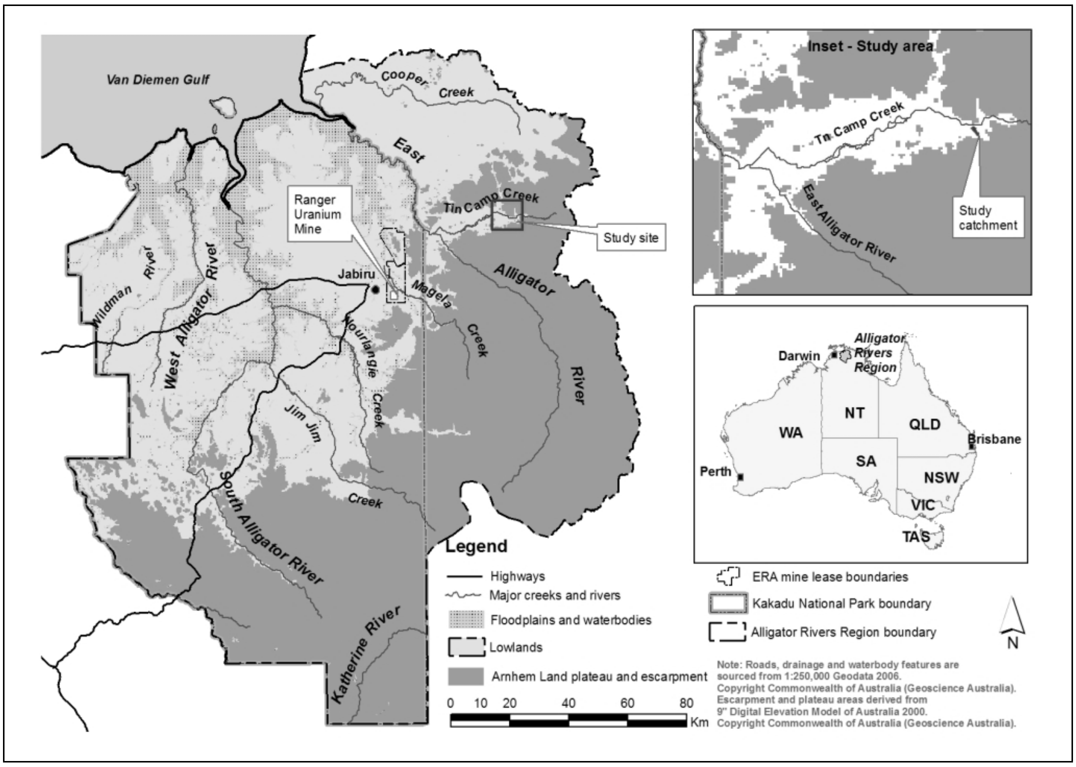

Figure 1 Location of study the Tin Camp Creek (TCC) site and Ranger mine

Excluding the soil loss rate derived from the Profile Distribution Model, the soil losses in the catchment were greater than for other transects in the Northern Territory and similar to rates in the Kimberley region, (measured by the ^{137}Cs Australian empirical model), even though this latter area is affected by pastoral activities. This may be at least partly explained by erosion in Tin Camp Creek catchment during high intensity rainstorms at the commencement of the wet season, especially if the slopes have been affected by fire during the previous dry season (Hancock et al 2008).

Gully mapping

Understanding landscape features such as gullying is an important issue in the long-term dynamics and evolution of both natural, agricultural and rehabilitated (ie post-mining) landscapes. A series of gully heads and other erosion features such as scour holes located in channels have been measured over a five year period (2002–07) in the study catchment (Fig 3). During this period the erosion features were monitored for their headward advance/retreat, enlargement or in-filling. Hillslope erosion was also monitored.

The catchment was subject to a range of rainfall regimes over the 5 years and was burnt on an almost annual basis, so that all grass cover (but not intermediate and overstory species) was removed. Box plot distibutions (Fig 4) of this monitoring show that the erosion features have changed little during this period. The gullies appear to be consistent landscape features that are in equilibrium with conditions during the monitoring period. There was little difference in erosion between years when a fire had occurred and years when there was no fire.

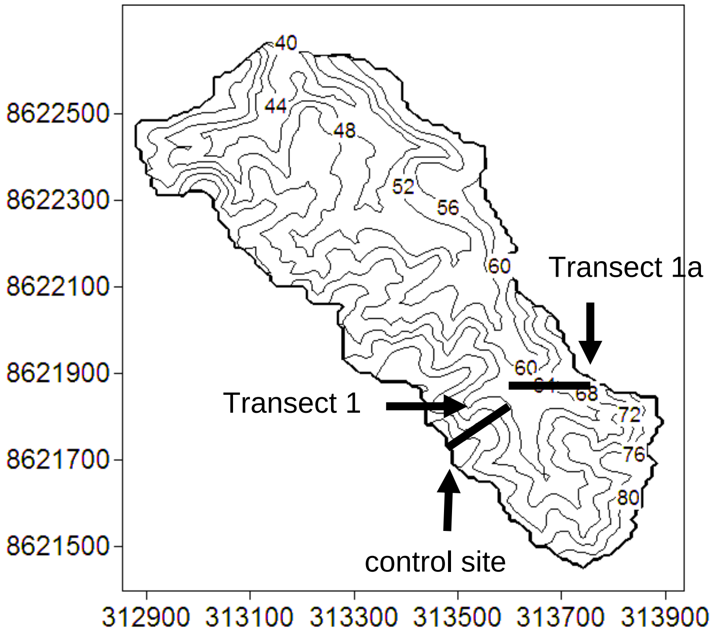

Figure 2 Contour map of the Tin Camp Creek catchment, Northern Territory, Australia**.** Coordinates are UTM WGS84, zone 53 where the x-axis is Eastings and y-axis is Northings.

Depth change of the monitored erosion features appears to be related to hillslope erosion and deposition with strong links found between hillslope and erosion feature aggradation and degradation. There also appears to be a relationship between depth and width of gullies which requires further investigation.

Soil carbon

Soil carbon plays an important role in soil water holding capacity, soil structure and over all soil health. Soil is also a significant store of terrestrial carbon. This part of the study examined soil carbon content at the hillslope and catchment scale in the study area. Results show that soil carbon concentration down hillslope transects is consistent over a number of years and that it is strongly related to hillslope position and topographic factors. These relationships warrant further investigation. An assessment of the relationship between soil carbon and soil erosion using ^{137}Cs and erosion pins suggests that sediment transport and deposition play little role in the distribution of soil carbon. Vegetative biomass appears to be the major contributor to soil carbon concentration with the occurrence of vegetative biomass being strongly controlled by topographic factors.

Steps for completion

The ^{137}Cs work is completed and published (Hancock et al 2008) and the results can be used to further assess how well erosion models simulate natural erosion rates.

Further measurements of erosion pins and gullies will be conducted over the next 1 or 2 years to assess whether there has been a change in erosion rates resulting from Cyclone Monica and/or the extraordinary wet season of 2006–07. The relationships between depth and width of the gullies will also be further investigated.

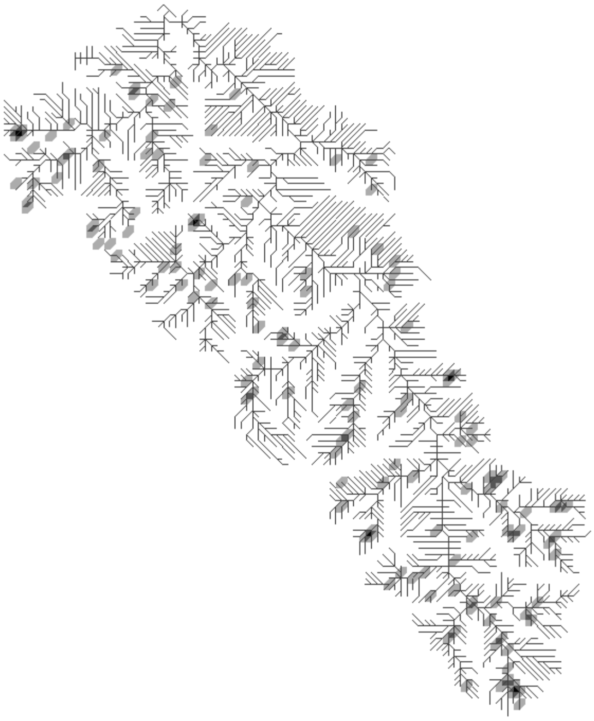

Figure 3 Position of erosion features on the drainage network (represented by grey dots) at Tin Camp Creek. The darker dots indicate two erosion features close to each other.

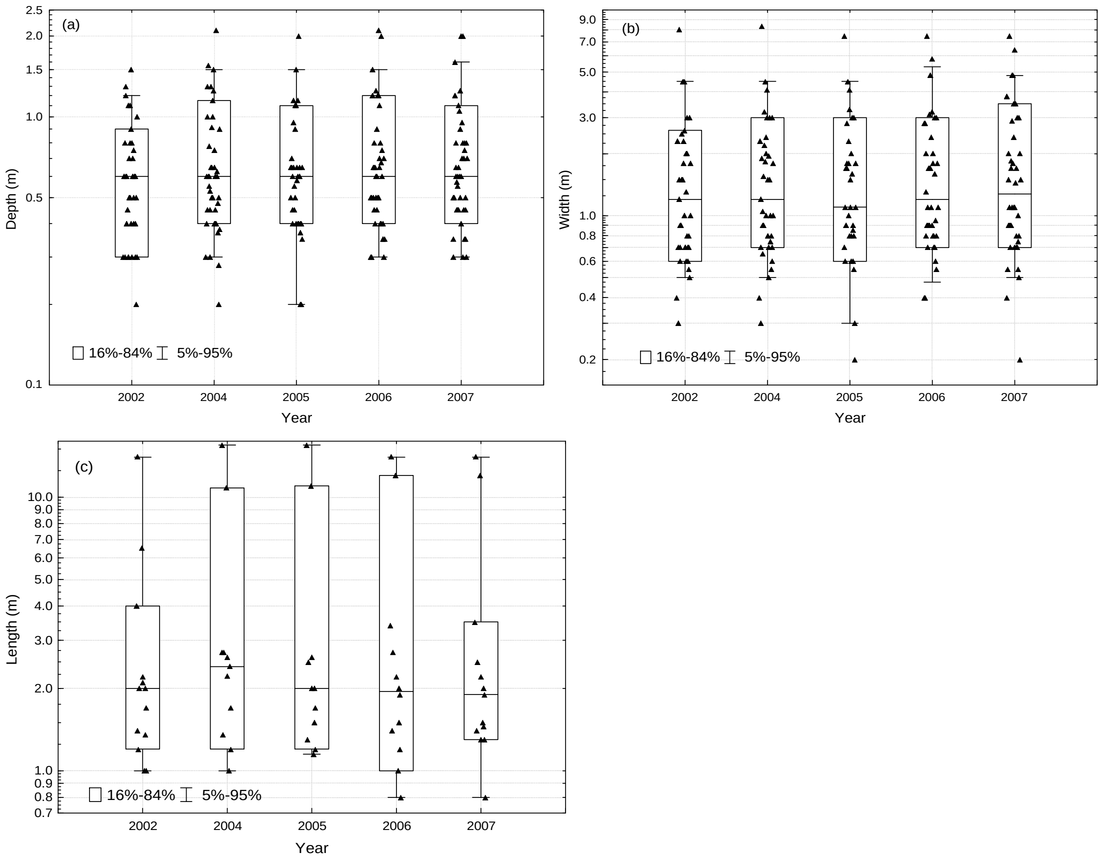

Figure 4 Measured gully features, depth (a), width (b) and length (c). The median line of each data set is shown and the black triangles are the data points.

The soil carbon work is near completion and is being written up for publication. The relationship between hillslope and soil carbon content will be further investigated as part of finalising this study.

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Pre-mining radiological conditions at Ranger mine

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Introduction

The International Commission on Radiation Protection (1991) recommends that the total annual effective radiation dose to a member of the public from practices such as uranium mining should not exceed 1 milli Sievert (mSv). This dose is on top of the natural pre-mining background dose. In a high natural background area such as the area around Ranger mine, determining an additional dose due to mining activities presents a challenge, and pre-mining conditions need to be assessed accurately so that post-mining changes in effective dose rates, especially in the event of deterioration of radiological conditions compared to the pre-mining situation can be quantified. Historical airborne gamma surveys (AGS) coupled with ground truthing surveys, have the potential to provide a powerful tool for an area wide assessment of the pre-mining conditions.

AGS coupled with ground truthing surveys have been used for area wide assessments of current radiological conditions at rehabilitated and historic mine sites (Martin et al 2006, Bollhöfer et al 2008). The aim of this project is to ground truth historical AGS data at an undisturbed radiological anomaly (an analogue of the unmined Ranger 1 and 3 orebodies) in order to extrapolate to pre-mining radiological conditions at Ranger.

An AGS of the Alligator Rivers Region flown in 1976 has been used to identify undeveloped radiologiocally anomalous areas in the vicinity of the Ranger lease as potential candidates for groundtruthing. A comparison of signal intensity with known uranium occurrences in the MODAT database suggests that Anomaly 2 to the south of the Ranger lease may be a suitable analogue site to determine Ranger pre-mining radiological conditions, as it exhibits a strong airborne gamma signal in the 1976 data. Figure 1 shows the pre-mining airborne signal in the Ranger vicinity by extent and intensity (top 70% of values found in Ranger subset) overlaid over the land surface image acquired by the IKONOS satellite in 2001. It also shows a contour map by Eupene et al (1980) which shows the total counts acquired during an airborne survey of Ranger, which is overlaid on the airborne gamma data from 1976.

Based on the assessment of the historical AGS data it was decided to obtain groundtruthed data in the greater region of Anomaly 2. An extensive fieldwork program to the south of the Ranger lease was commissioned in 2007.

Results and progress to date

The 1976 AGS data were acquired from Rio Tinto by the NT Government, and are available on the public domain (the *Alligator River Geophysical Survey*). Data were re-processed in 2000 by the Northern Territory Geological Survey and then resampled by NTGS at a pixel size of 70 m in 2003.

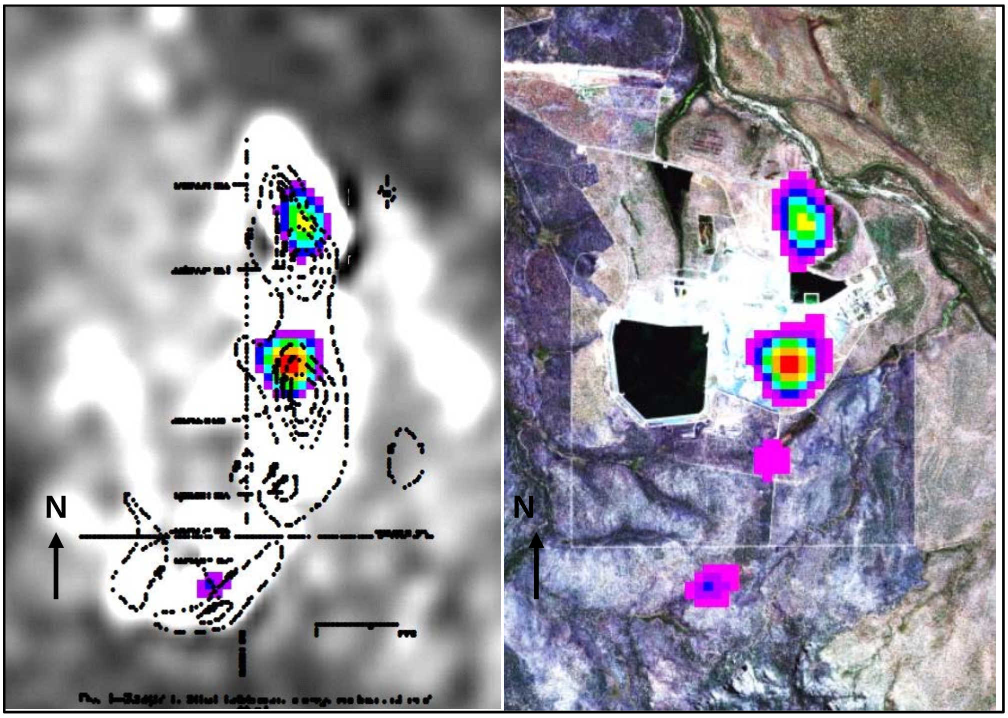

Figure 1 Eupene et al (1980) map of aerial radiometric contours of total count. Overlaid on airborne data (left) and over an IKONOS (2001) optical satellite image (right) with top 70% coloured values.

A radiation survey of the two regions surrounding Anomalies 2A and 2B was conducted in August 2007. It was confirmed that Anomaly 2 actually consists of two anomalies, Anomaly 2A (the southern Anomaly, which has a stronger radiological signal) and Anomaly 2B. Both, dose rate measurements (using environmental dose rate meters) and in situ soil activity concentration measurements (using a portable NaI(Tl) gamma detector) were conducted. The objective of the survey was to:

1 delineate the geographical location of the two Anomalies and compare their actual locations with the locations inferred from the relatively coarse 1976 AGS; and

2 groundtruth four individual 70m x 70m pixels selected from the 1976 AGS date set, spanning a range of 37 to 994 total AGS counts per pixel. Following recent recommendations made in ICRU Report 75 (2006) these measurements on the ground were performed at 40 random locations within each individual pixel.

The location and intensity of the two anomalies were delineated by the 2007 field survey. The survey data showed that there was a spatial offset of approximately 150 m between the 1976 AGS data and the true location of Anomalies 2A and 2B. This was most likely due to the coarse resolution of the 1976 AGS (300 m line spacing) and consequential numerical dispersion of the counts across pixels. Consequently, more fieldwork was required to delineate the true location, extent and intensity of the Anomalies to gain a robust data set, that will allow an extrapolation of the pre-mining AGS data from Anomaly 2 to the now mined Ranger orebodies.

ERA has made available to SSD airborne gamma survey data from an AGS that was flown in 1997. This survey was flown at a higher spatial resolution (200 m line spacing) and was used for refining of further groundtruthing fieldwork in July 2008 to precisely establish the location of Anomaly 2A (southern Anomaly).

Figure 2a shows the ERA data across Anomaly 2A (10% to 100% total count thresholds) and the four areas that were groundtruthed in August 2007. In this figure, a spatial discrepancy can be observed between the true location of the hot spot and the interpolated location from the AGS data . However, this discrepancy is relatively small (compared to that noted for the lower resolution data from 1976) and is not unusual, given the resolution of the AGS that was resampled to 25 m x 25 m.

The rectangle in Figure 2b shows the area across Anomaly 2A which was groundtruthed in July 2008. The purpose of the survey was to determine the area wide dose rate and consequently, recommendations made for the sampling of radionuclides in the environment in ICRU75 (2006) were again followed. Approximately 9.5 hectares were surveyed and measurements were taken randomly along 17 transects, using environmental dose rate meters. A total of 703 measurements were taken in the area.

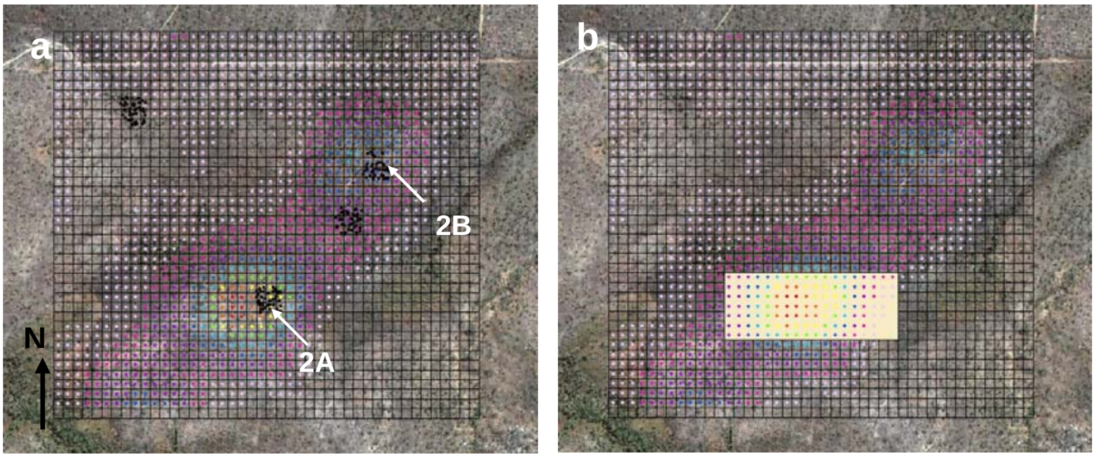

Figure 2 (a) 1997 ERA AGS data, location of the two Anomalies and location of the groundtruthing (black dots) performed in August 2007. The location of the southern hot spot (Anomaly 2A) is ~ 50 m out to the east of the location indicated by the 1997 AGS. There is a similar discrepancy for the northern hotspot (Anomaly 2B). (b) Area surveyed in July 2008. Grid cell size is 25 m x 25 m.

The maximum dose rates measured on ground in July 2008 was 16.3 $\mu Gy \cdot hr^{-1}$, and the minimum was 0.09 $\mu Gy \cdot hr^{-1}$. The area of the hot spot seems to be confined to an area much smaller than indicated by both the 1976 and 1997 AGS data. The field measurements show that the area with dose rates above 10 $\mu Gy \cdot hr^{-1}$ is smaller than ~10 m x 5 m.

Figure 3 shows the results of the on ground dose rate measurements at the area around Anomaly 2A (diamond shaped symbols, data threshold to 5 classes). It also shows the raw line data from the 1997 AGS (total count threshold to 5 classes with red = 10653-17911 and light blue = 559–1774 total counts, respectively), and the interpolated location of the hot spot (red triangles: 25 m pixels of the dose rate 90-100% threshold of the Anomaly 2A region). The five on ground dose rate classes shown are:

0–0.3 $\mu Gy \cdot hr^{-1}$	non-coloured
0.3–0.8 $\mu Gy \cdot hr^{-1}$	green
0.8–2.1 $\mu Gy \cdot hr^{-1}$	yellow
2.1–7.1 $\mu Gy \cdot hr^{-1}$	orange
7.1–16.3 $\mu Gy \cdot hr^{-1}$	red

The red line of the raw AGS data (squares) starts at ~11 000 total counts and increases to around 17 000 total counts around the interpolated 90–100% region (red triangles) of the AGS. The signal then tapers off when approaching the area of the highest readings in the field. This essentially highlights the limits of the relatively coarse line AGS data and the spatial discrepancies that arise from interpolating the raw line data.

It was also found that the dose rate signal on the ground appears to be fanning out to the south due to the movement of surface material through natural erosion processes, which is confirmed by visual inspection. Scrape samples were taken along those erosion lines for further analysis via gamma spectrometry.

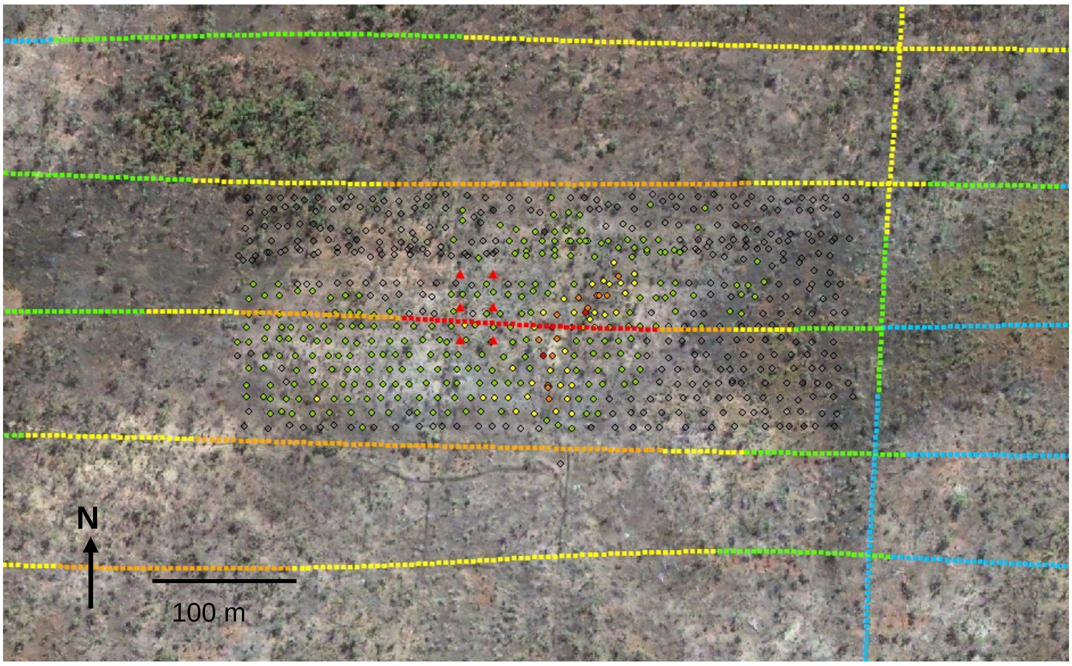

Figure 3 Raw line data for the 1997 AGS, the location of the interpolated hot spot from the AGS data (triangles) and results of the on ground γ dose rate measurements (diamond shapes) performed in July 2008

Steps for completion

Further groundtruthing around the area of Anomaly 2A and Anomaly 2B was performed in July 2008 and September 2008 respectively, and data analysis is underway. It was also realised that futher groundtruthing was required to the southwest of Anomaly 2A and groundtruthing was performed in October 2008. Once data are processed and analysed, an area wide picture of dose rates measured on ground will evolve. As the footprints of the two methods (AGS vs groundtruthing) are very different (Bollhöfer et al 2008), suitable smoothing techniques need to be explored, in order to compare on ground measurements with measurements made from a plane, with a terrain clearing of 50 m for the 1997 and an unknown height for the 1976 data. Modelling the signal measured in the plane using the flight path from the 1976 survey and the dose rates measured on ground, may provide a tool for quality control of the historic AGS data.

Radon exhalation measurements need to be performed at the Anomaly. It is anticipated that a radon exhalation study will be part of the 2009/10 work program.

Summary

Airborne gamma data revealed that Koongarra is not suited as a natural analogue for Ranger pre-mining conditions. Because groundtruthing excercises are costly and need to be carefully planned the most appropriate site needs to be indentified before fieldwork commences. Radiological anomalous areas in the vicinity of the Ranger lease, Anomalies 2A and 2B, may prove valuable analogue sites to determine Ranger pre-mining conditions. Data anlysis of the measurements performed on ground is still underway. Once data analysis is complete, the radiological conditions on ground around Anomalies 2A and 2B will be correlated to the pre-mining airborne signal in an attempt to extrapolate to the area wide radiological conditions at Ranger before mining commenced.

Acknowledgments

The NT Geological Survey, Roger Clifton and Mark Foy are thanked for discussion at an earlier stage of the project, and for data provision for the project. Jared Sellwood, Gary Fox, Robert Thorn and Alan Hughes are thanked for assistance in the field. Thanks in particular to the Mirrar people for allowing access to the sites and thanks to ERA for the provision of 1997 AGS data.

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

A Frostick, A Bollhöfer & D Parry[1]

Introduction

This project aims at developing an innovative, sensitive and cost-effective methodology to assess and monitor impacts of past, present and future uranium mining activities in the wet-dry tropics. Funded through the ARC Linkage Projects scheme, the project is a collaboration with researchers from Charles Darwin University. The objective of the project is to characterise sources and pathways of pollutants in catchments in the Alligator Rivers Region at the decommissioned and rehabilitated Nabarlek minesite, the operating Ranger mine, and at natural analogues in order to develop a joint lead isotope/radionuclide approach for monitoring erosion from a (rehabilitated) uranium minesite to assess post-rehabilitation landform stability.

Due to the source-specific lead isotope signature and the fact that no physical or chemical fractionation of lead isotopes occurs during transport and deposition, stable lead isotopes are ideally suited as a contaminant source tracer. Lead isotopic fingerprinting relies on the fact that three of the four stable lead isotopes, lead-204, lead-206, lead-207 and lead-208, are produced by the decay of uranium-238 ($^{238}U \rightarrow {}^{206}Pb$, $t_{1/2} = 4.5 \cdot 10^9$ yrs), uranium-235 ($^{235}U \rightarrow {}^{207}Pb$, $t_{1/2} = 0.7 \cdot 10^9$ yrs) and thorium-232 ($^{232}Th \rightarrow {}^{208}Pb$, $t_{1/2} = 14 \cdot 10^9$ yrs), respectively, whereas ^{204}Pb is of primordial origin only.

In uranium and thorium rich minerals radiogenic lead is continuously produced over time. For example, monazites with high Th/U exhibit $^{208}Pb/^{207}Pb$ and $^{206}Pb/^{207}Pb$ ratios much higher than the present day average crustal (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) for example measured $^{206}Pb/^{207}Pb$ ratios in particulates from uranium tailings at Ranger as high as 9.69, whereas $^{208}Pb/^{207}Pb$ are as low as 0.0494, in agreement with results from a study of airborne dispersion of Ranger mine origin dust (Bollhöfer et al 2006).

Coupled with the measurement of radionuclide and trace metal concentrations, this technique enables identification and quantification of the deposition pathways of solids (Frostick et al 2008b, Munksgaard et al 2003). Past and present erosion, and subsequent deposition of contaminants can be identified and quantified.

Results

Nabarlek

Results of the study around the Nabarlek mine lease have been summarised and have been published in Frostick et al (2008b).

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Ranger and analogue

Sample collection in 2007/08 has concentrated on the Ranger lease area and the Magela catchment, the Nourlangie Creek billabongs, and the Ranger Anomaly 2 outside of the mineral lease area. The location of samples that were taken around the Ranger and Koongarra mineral leases are shown in Figures 1 and 2, respectively. Results and data interpretation from inductively coupled plasma mass spectrometry and gamma spectrometry analyses of these samples are due in late 2008.

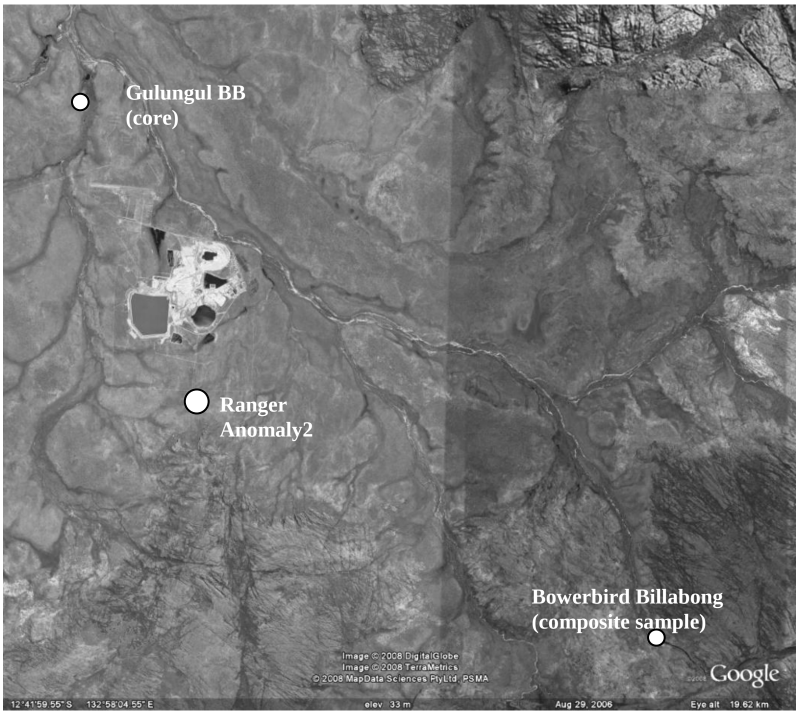

Figure 1 Location of the 2007/08 sampling sites around Ranger Mineral Lease

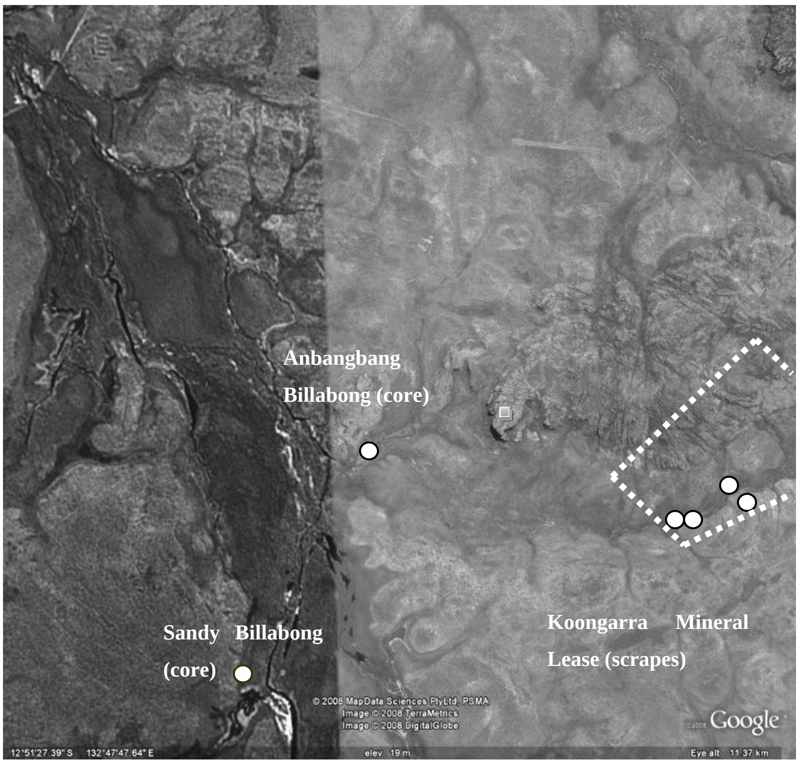

Figure 2 Location of the 2007/08 sampling sites around Koongarra Mineral Lease

In 2006–07 three sediment cores were taken in Georgetown Billabong by EWLS and were kindly supplied to ***eriss*** for analysis of radionuclides and stable lead isotopes. Results from the inlet and outlet cores are shown in Figure 3. The results from the inlet show a random pattern of lead isotope ratios measured with depth, indicative of a high degree of mixing that may have occurred during sample collection and/or through bioturbation in these sediments. However, lead isotope ratios in sediments from the outlet display a marked stratification with uraniferous sediments influencing the lead isotope ratios at less than 20 cm depth.

Highest radiogenic ^{206}Pb/^{207}Pb isotope ratios of ~1.90 were measured in the top 10 cm of the core. Assuming two component mixing of highly radiogenic erosion products from Ranger mine with a ^{206}Pb/^{207}Pb isotope ratio of 9.69, with sediments exhibiting a background ratio of ~1.51, allows to calculate a ~5 % contribution of radiogenic, mine origin lead in the top 10 cm of the outlet core.

Key trace metal and radionuclide activity concentrations in these cores will also be assessed when results of ICPMS analyses are available later in 2008. The core from the mid-section of Georgetown Billabong has also been analysed and data analysis is underway.

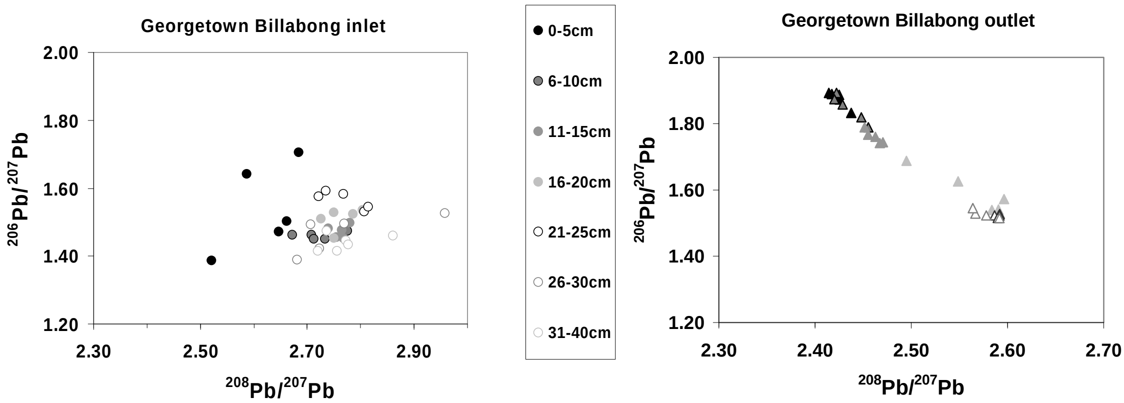

Figure 3 Lead isotope ratios measured in sediment cores from Georgetown Billabong at the inlet (left) and outlet (right)

Scrape samples were collected in 2006 on and in the vicinity of the Ranger lease. Locations are given in Frostick et al (2008a) and shown in Figure 4.

Figure 5 summarises the stable lead isotope results measured in these scrape samples and from some sediment cores from the Gulungul catchment. It can be seen that samples from the Gulungul catchment taken close to the tailings dam southern road culvert (TDSRC in Figures 4 and 5) exhibit more radiogenic lead isotope ratios indicating a contribution of uraniferous material to the total sediment composition. Lead isotope ratios are most radiogenic in the black soils downstream of the southern tailings dam wall (TDSRC Flow 1 and 2). It has previously been shown that the black soils in the Gulungul catchment attenuate high concentrations of uranium and trace metals (Mellor, 2006). In contrast, surface scrapes from Jabiluka Billabong on the Magela Creek floodplain downstream of the Ranger mine exhibit common lead isotope ratios and no siginificant contribution of radiogenic lead. More samples from the Magela catchment are currently being analysed and a full interpretation and discussion of the data is expected late in 2008.

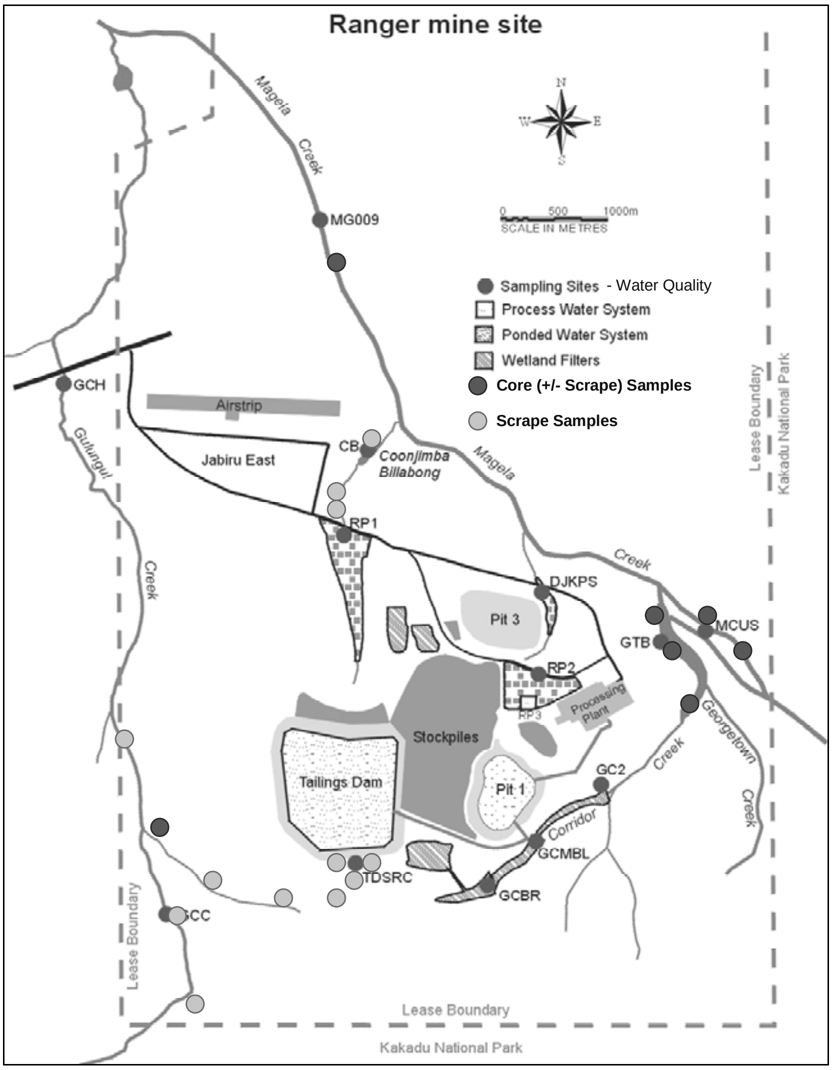

Figure 4 Location of the 2006 sampling sites around Ranger uranium mine

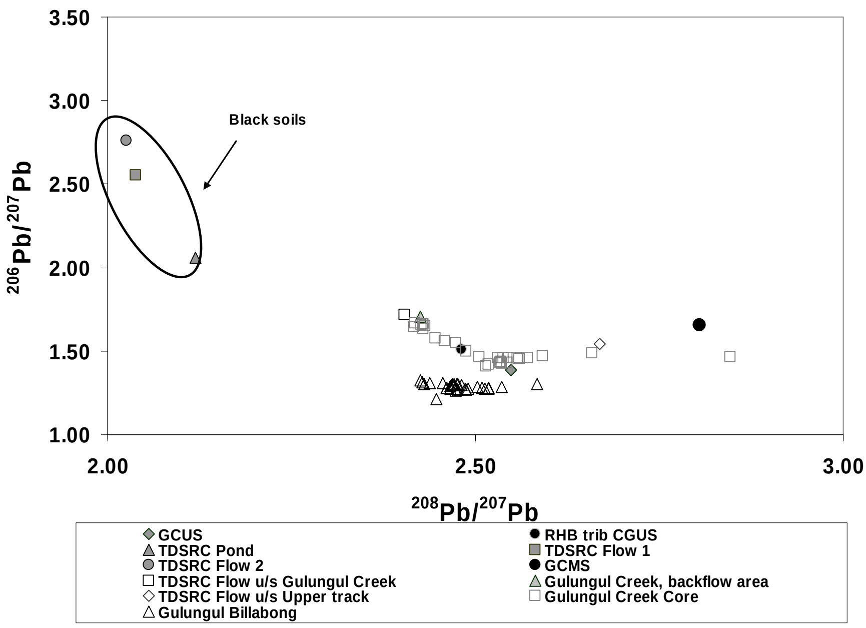

Figure 5 Stable lead isotope ratios measured in surface scrapes from the Ranger lease and sediment cores from the Gulungul catchment

Steps for completion

It was envisaged that the Koongarra Mineral Lease and the Nourlangie Creek catchment could be used as a natural undisturbed radiogenic analogue for this study. However, due to current access restrictions onto the Koongarra lease area , only 4 scrape samples were able to be collected from within the mineral lease. An additional/alternative analogue site was therefore required. Samples have been taken from the vicinity of the Ranger Anomaly 2 and are currently being analysed. Further samples from drainage channels around the Anomaly have been collected during the late dry season in 2008.

Acknowledgments

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

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Radon exhalation from a rehabilitated landform

A Bollhöfer, P Lu[1], R Akber[2] & B Ryan

Introduction

Radon (^{222}Rn) exhalation depends on the soil (or rock) radium content, soil porosity and moisture, and vegetation cover and hence the measured radon exhalation flux density can vary greatly over short distances. For the rehabilitated landform, radon exhalation will also depend on the depth of the layer containing uranium rich material, and the characteristics of the capping material. A project conducted in 2002–05 measured radon exhalation in the vicinity of and on the operational Ranger mine site, and identified key controlling factors. Annual and diurnal variations of radon exhalation were described in this study. The outcomes have been published and factors determined, which allow prediction of radon flux densities from the soil radium content of various geomorphological units (Lawrence et al 2009). This work is important as knowledge of the source term of radon exhalation from the ground and the factors controlling its variation are needed in order to tie in results of regional radon and radon progeny measurements with predictions of radon dispersion models.

Temporal and geographical variations of radon exhalation have also been observed at the rehabilitated Nabarlek mine (Bollhöfer et al 2005). Radon flux densities reported immediately after the rehabilitation work at Nabarlek were on average 4–5 times higher (Kvasnicka 1996) than the results from the study 10 years after rehabilitation. While the use of different methodologies may have contributed to these differences in measured exhalation rates, it is possible that time-dependent landscape processes might also be responsible. In particular, it has been suggested that the porosity of the soil might have decreased over the years due to gradual weathering, infilling of voids by fines and compaction of the material, hence reducing the overall radon flux.

Specific soil closure criteria for the rehabilitation of Ranger Uranium mine need to incorporate radiological aspects to ensure that exposure of the public to radiation after rehabilitation of the mine is as low as reasonable achievable. As the inhalation of radon is likely to be a main contributor to radiological dose, radon exhalation and its temporal variability need to be estimated for the rehabilitated landform. Radon exhalation may change during the geomorphic evolution of the landform and as vegetation develops through time. The proposed trial landform will provide a unique opportunity to determine factors controlling the evolution of radon exhalation, over a period of many years. Radon exhalation for various cover thicknesses and vegetation types, taking into account weathering, erosion and compaction effects, and the effect of developing vegetation on the landform, will be determined. The project will enable ***eriss*** and ERA to predict a long-term radon exhalation flux from the rehabilitated landform and contribute to the development of radiological closure criteria and effective design of the landform.

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[2] SafeRadiation Pty Ltd, Brisbane, Qld, Australia

Methods

Conventional charcoal canisters have been used to determine the radon exhalation of the natural soil profile underlying the planned trial landform, before the landform is constructed. The charcoal cups were deployed in the 2008 dry season and exposed for three days. The charcoal canisters used were a standard brass cylindrical design with an internal diameter of 0.070 m, depth 0.058 m and wall thickness 0.004 m.

If the 'open face' of a brass charcoal canister is sealed against a surface, then all the radon emanating from the surface will diffuse into the canister and adsorb to the charcoal. With this configuration radon flux densities can be calculated assuming that the radon exhalation rate from the ground is constant over the exposure period. The existing data for natural land surfaces indicate that diurnal variations in ^{222}Rn exhalation rates in the Alligator Rivers Region are small, probably less than 20% of the mean exhalation rate (Todd et al 1998, Martin et al 2002), and consequently an assumption of a constant radon flux density is reasonable.

Progress to date

Radon (^{222}Rn) can diffuse from depths of several meters with lower layers making a decreasing contribution. The diffusion of ^{222}Rn can generally be described by Fick's law and ^{222}Rn diffusion length for dry soils has been reported to be in the 1–2 m range (van der Graaf et al 1992) and 2–5 m for sandy type materials (Holdsworth & Akber 2004). However, Lawrence (2004) determined that diffusion lengths of ^{222}Rn in stockpile structures differed substantially from normal ground and may be much larger, in the order of tens of metres. Consequently, as ^{222}Rn may reach the top surface from the base of the land form structure it was deemed necessary to conduct a survey of the substrate, before the landform is constructed. In addition, these data will contribute to the acquisition of baseline data for radon exhalation on the Ranger lease area. Figure 1 shows the location of the radon exhalation survey and the individual sampling sites.

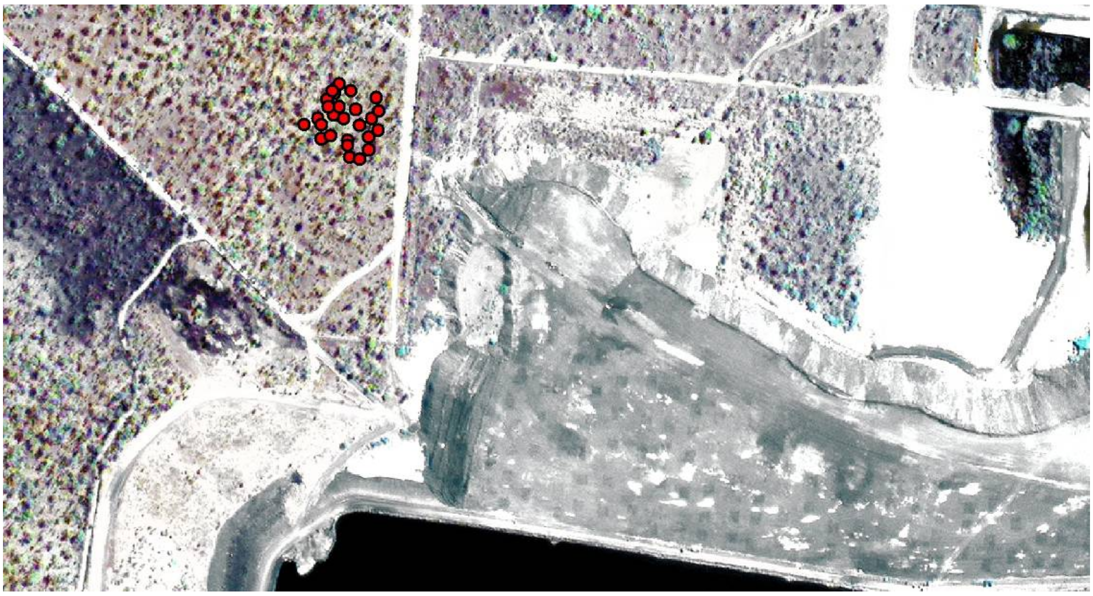

Figure 1 Location of the radon exhalation survey and individual charcoal cup locations. The north western corner of the tailings dam can be seen at the bottom of the picture.

Results of the study on radon flux densities from the substrate are shown in Figure 2. A goodness of fit test shows that the distribution is better described by a log-normal rather than a normal distribution. which is typical for radon exhalation measurements reported elsewhere (Lawrence et al 2009, Bollhöfer et al 2005). Ott (1990) states that a concentration undergoing a series of independent random dilutions in the environment tends to be log-normally distributed and this theory is especially appropriate for representing inert substances and gases released at high concentrations, such as soil radon, into carrier media, undergoing physical movement and agitation before they are measured (Ott 1995).

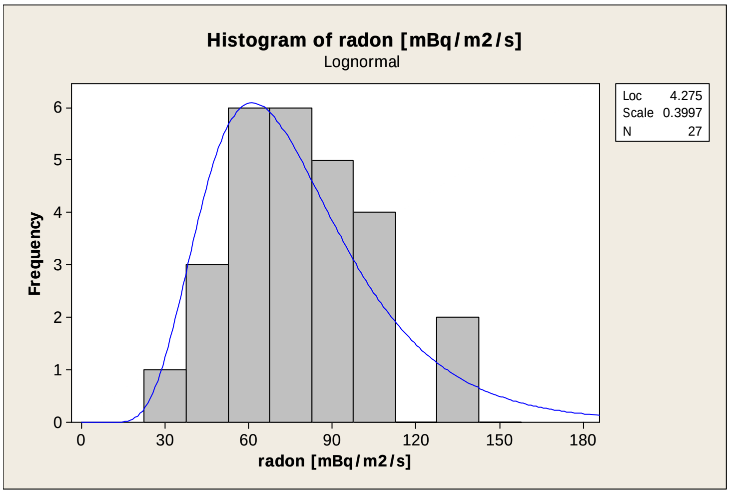

Figure 2 Histogram of radon flux densities measured on top of the substrate of the planned trial landform, dry season 2008

Radon flux densities range from 24 to 144 $mBq\cdot m^{-2}\cdot s^{-1}$ and the geometric mean and median amounts to 73 $mBq\cdot m^{-2}\cdot s^{-1}$. This is similar to late dry season environmental radon flux densities previously determined at Jabiru East of 64 $mBq\cdot m^{-2}\cdot s^{-1}$ (Lawrence et al 2009) and the average for the region of 64±25 $mBq\cdot m^{-2}\cdot s^{-1}$ (Todd et al 1998).

Radon flux densities and soil activity concentrations will also be measured immediately after 20 cm of the top soil at the planned trial plot has been stripped, and before the landform is constructed. This will provide information on the contribution to the radon flux densities from the top 20 cm of the soil and also on radon flux densities from the subsoil profile. In addition, the collection of samples of waste rock and laterite that will be used for construction will provide a relationship between radon flux densities and soil activity concentrations for the different construction layers in the landform.

Future work

Once the landform is constructed, radon exhalation measurements will be performed every four months to determine annual variability in radon flux densities. The measurements will be conducted on the three different capping treatment areas on the trial landform, to determine whether there is a difference in radon exhalation depending on cover thickness, vegetation cover and developing vegetation on the landform. The project will continue for several years to determine the influence of weathering, erosion and compaction effects, on radon flux densities from the rehabilitated landform.

Acknowledgments

Graeme Passmore and Chloe Bradley from EWLS are greatfully acknowledged for supporting the project in the field.

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Erosion studies of the Ranger revegetation trial plot area

MJ Saynor, KG Evans & P Lu[1]

Introduction

The start of the project, scheduled for the 2007–08 work period was postponed and rescheduled to start in the 2008–09 work period.

The trial landform area is located immediately adjacent to the northwest corner of the Ranger tailings dam and will represent an extension of the topography extending out from the wall in a northwest direction (see cleared footprint in Figure 1). The constructed trial landform will cover an area of 8 hectares (400 m x 200 m).

Figure 1 Trial landform prior under construction adjacent to the northwest wall of the tailings dam (20-Oct-08)

The total area will be divided into three 2.7 ha sub-plots with different growth medium treatments; and separated by drainage lines:

1 30% lateritic material mixed with waste rock to a depth of 2 m (planted with tube stock in one half and by direct seeding in the other);

2 30% lateritic material mixed with waste rock to a depth of 5 m (planted with tube stock in one half and by direct seeding in the other); and

3 Waste rock material, divided down the middle of the plot length wise, planted one side with tube stock and by direct seeding on the other.

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Erosion plot requirements on demonstration plots at Ranger

Considering the 2.7 ha size of each treatments, it is proposed to construct four erosion plots with dimensions of 30 m x 30 m (900 m^2) on each of the treatment areas as shown in Figure 2. That is, one on each of the lateritic mix sites with different vegetation treatments and two on the wasterock material (different vegetation trials). It was decided that two plots on the laterite treatment (one on each vegetation type) would be appropriate as it is unlikely that there would be much difference between erosion on the 2 m wasterock/laterite mix and the 5 m wasterock/laterite mix. ***eriss*** has previously worked with plots of 20 m x 30 m (600 m^2) at several locations on the Ranger wasterock dump area (Evans & Riley 1993, Saynor et al 1995, Evans et al 1998, Saynor & Evans 2001).

The small sub-plots within the 2.7 ha areas are appropriate for detailed erosion studies which include topographic survey, water and suspended sediment discharge measurement and bedload measurement. Small plots have been used in previous studies in the ARR to obtain data to derive erosion model input parameter values and in numerous studies worldwide with peer acceptance. It should also be noted that a plot size of 900 m^2 is compatible with the resolution provided by landsat imagery and is similar to plot sizes used in the cyclone Monica tree fall study (Staben & Evans 2008).

Surface runoff from the plots will be measured with a flume, located at the plot outlet. The removal of the water from the plot surface down over the batters and into Retention Pond One (RP1) needs to be properly engineered/constructed so that erosion of the batter slopes is not an issue with respect to the integrity of the trial and the structure. There will also need to be some form of structure to reduce the impact of suspended sediment and perhaps bedload (sedimentation basin) into RP1 and further downstream into Magela Creek.

Erosion plot location on demonstration landform

It is proposed that the erosion plots be located along one side of the larger treatment areas near the up-slope end with the flumes off to the side and at the down-slope end of the erosion plot (Figure 2). To reduce the risk of pooling in the erosion plots and also the larger areas, the ripping *must* be level along the contour. It is likely. that water will pool in all rip lines as the surface will have a very low longitudinal slope.

Plot construction

To isolate the 30 m x 30 m erosion plots from runoff from the rest of the demonstration surface area, borders will be constructed around the plot boundary using 150 mm wide damp course and mortar. Concrete is then laid along the outer edge of the damp course covering the 40 mm long leg and the nails.

Half-section 250 mm diameter PVC stormwater pipes (Figure 3) will be placed at the down slope ends of the plots to catch runoff and channel it through rectangular broad-crested (RBC) flumes (Bos et al 1984, Clemens et al 2001) where discharge will be measured. A reservoir will be constructed at the end of the plots to trap bedload sediment in the runoff. A RBC flume with a trapezoidal broad-crested control section will be placed at the downstream end of the reservoir and equipped with a level sensor mounted in a stilling well to measure discharge (Figure 4).

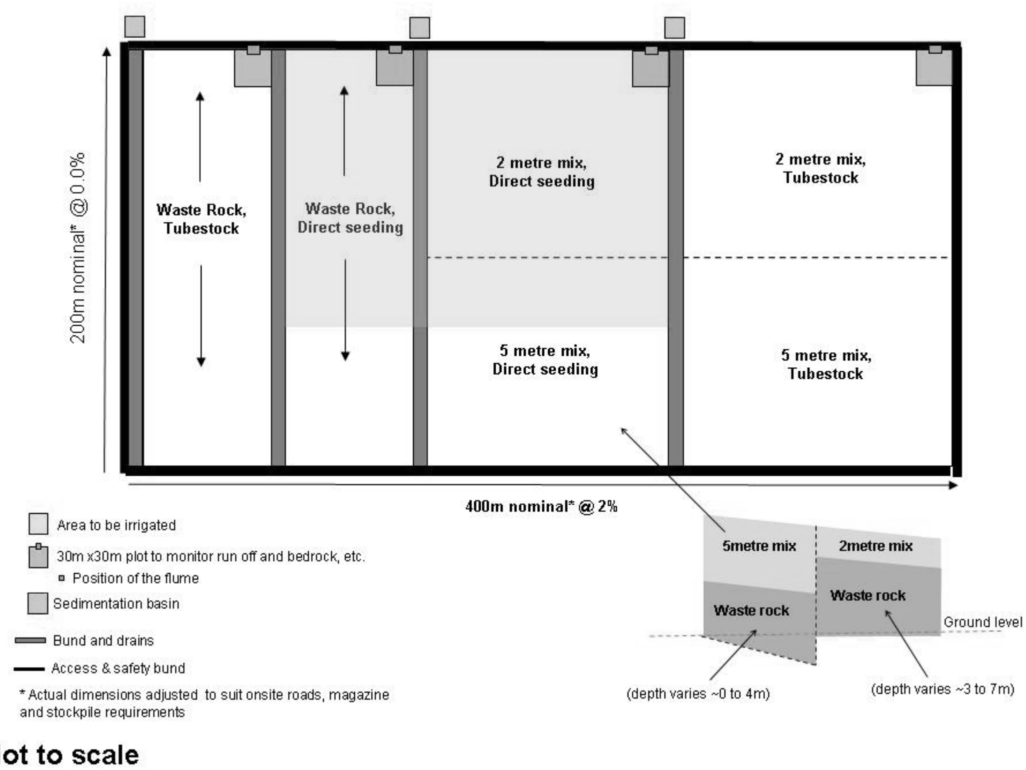

Figure 2 Layout of the plots on the demonstration landform. Note that the flumes will be at the bottom end of the plots and not in the middle as is shown (source: EWL Sciences 2008).

Figure 3 Damp course surrounding a previous erosion plot at Ranger. Note the large boulders present.

Erosion pins will be installed on a 10 m grid spacing across the entire landform surface. All pins will be measured on installation but in subsequent years only those areas with visible erosion or deposition will be measured and an assumption will be made that the surface of other areas has remained constant. The ground surface of these plots including the erosion pin locations will be surveyed immediately following installation to provide the reference land surface.

Flume size

RBC flumes with a 150 mm throat/restriction were used for earlier erosion trials on the wasterock dumps at Ranger. Overtopping did occur on one occasion and therefore it is recommended, based on peak discharge estimates, that RBC flumes with either a 200 mm or 250 mm throat/restriction are used for the trial landform.

Figure 4 RBC flume on an earlier erosion plot at Ranger. In the plots on the demonstration land form the flume will be located at the left end of the plot near the edge of the landform.

Instrumentation

The erosion plots will be constructed as soon as practicable after the demonstration trial landform has been built and prepared. The flumes will be installed at the outlet of the plots and instrumented with the following equipment and sensors: pressure transducer, shaft encoder, turbidity probe, data logger, automatic water sampler, conductivity probe. A raingauge will be installed near the flume to record the rainfall at each of the plots. The data will be accessed automatically by telemetry, downloaded once a day and then stored in the hydrological database Hystra. Decisions on how often the plots will be visited to clear bedload and collect water samples will be made after the plots are in place and there has been an opportunity to observe bedload erosion rates and discharge relative to rainfall event size.

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