

Assessment of the off-site geomorphic impacts of uranium mining on Magela Creek, Northern Territory, Australia

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1 Introduction

Energy Resources of Australia Ranger Mine (ERARM) is located in the 78 km² Ranger Project Area and is surrounded by the World Heritage listed Kakadu National Park (Johnston & Needham 1999) in the seasonally wet tropics of northern Australia (fig 1). Mining and production of uranium concentrate at ERARM have been underway since 1981 (Johnston & Needham 1999). Mining of orebody No 1 was completed in 1994, the smaller orebody No 2 will not be mined, mining of orebody No 3 started in May 1997 (Johnston & Needham 1999) and should be completed by about 2007 (Johnston & Prendergast 1999). Tailings are currently stored in the above grade tailings dam and in the mined-out No 1 pit (Johnston & Needham 1999). At the completion of mining in about 2012, approximately 175 million tonnes of tailings, subeconomic grade ore and waste rock will require containment (East et al 1993, 1994). Artificial engineered landforms covering about 4 km² and up to 17 m above the surrounding area could be constructed (Willgoose & Riley 1993, 1998, East et al 1993, 1994, Riley 1995a, Evans et al 1998). Tailings containment structures, either above or below ground, are required to have an engineered structural life of 1000 years, over which time the tailings should be isolated from the environment (Fox et al 1977, East et al 1993, 1994). The mill tailings may be rehabilitated either in situ as part of the tailings dam (the above-grade option) or buried and capped in the mine pits (the below-grade option). Energy Resources of Australia has decided that all tailings will be returned to pits No 1 and 3 at a level no higher than mean sea level (Johnston & Needham 1999). The Commonwealth Government also approved the Ranger Mill Alternative for the neighbouring Jabiluka ore body in October 1997 subject to a broad range of requirements on environmental protection (Johnston & Prendergast 1999). However following refusal of the traditional land owners to permit the trucking of ore from Jabiluka to ERARM, the Jabiluka Mill Alternative was further developed and approved by the Commonwealth Government in August 1998 subject to a number of environmental requirements (Johnston & Prendergast 1999). Although mining at Jabiluka has been currently suspended, resumption will also generate waste materials.

Pickup et al (1983, 1987) were commissioned by the Supervising Scientist in 1982 to design a program of geomorphic research for the long-term management of uranium mill tailings. They recommended the following series of thirteen investigations to cover:

1. The erodibility of locally available construction materials, their susceptibility to erosion as determined by small plots, the development of an erosion computer model from the plot results, performance testing of the proposed final artificial landforms by both the computer model and field plots, and erodibility assessment of the natural slopes below the artificial landforms (Project R1).

2. The fluvial geomorphology of the Magela Creek system, in particular, the tributaries next to ERARM, the anastomosing sand-bed section upstream of Mudginberri, the Mudginberri Corridor and the lower Magela Plains (Project S1).
3. The potential transport, deposition and storage of mine tailings in the tributaries next to ERARM by developing a new mathematical model based on best current knowledge, local field data and sediment tracing (by studies of escaped mine tailings from the old Northern Hercules Mill at Moline) (Project D1).
4. The patterns of water and sediment movement on lower Magela Creek and its floodplain by remote sensing and dye tracing (Project D2).
5. Accurate estimates of the probability of rare catastrophic floods by slackwater deposits and palaeoflood analysis at the best sites in the Alligator Rivers Region, namely Katherine Gorge, East Alligator Gorge and upper Magela Creek Gorge (Project F1).
6. Detailed sediment budgets, hydrology and sediment sampling of small mine area creeks to determine their potential for containing escaped tailings and to develop a model of tailings dispersion (Project AD1).
7. Detailed assessment of historical channel changes on the four mine site tributaries, and on Magela Creek in the sand zone near the mine site based on all available vertical air photographs since 1950 (Project AD2).
8. The late Quaternary alluvial history of Magela Creek and the mine area tributaries upstream of Mudginberri, the identification of long-term sediment storages and the development and calibration of a mathematical model to simulate future behaviour (Project AD3).
9. The late Quaternary alluvial history of the Magela Creek backwater plain downstream of Mudginberri, the assessment of the impact of sea level changes on the plain, the determination of spatial variation in sedimentation rates, and further development and calibration of the mathematical model associated with Project AD3 (Project AD4).
10. Pollen dispersal on the Magela backwater plain to determine the vegetation communities and sedimentary environments represented by contemporary pollen rain (Project T1).
11. Long-term vegetation and climatic history over at least the last 6–7 ka, and possibly the last 18 ka, to provide analogues of a CO₂-warmed earth and the beginnings of the next glacial maximum (Project F2).
12. Holocene sea level change to determine both the response and rates of aggradation of the Magela backwater plain to sea level change (Project F3).
13. Oxidation and metal kinetics in Magela alluvium assuming a fall in sea level (Project AD6).

East (1985, 1986) reviewed this program and proposed a slightly modified list, which included most of the above as well as new projects on the role of termites on soil formation and erosion, as well as on the morphology and sedimentary characteristics of natural hillslopes. At least some progress has been achieved on all of these projects, as shown in table 1. Riley (1995a) consolidated the accumulated results to that time in a discussion of the main issues involved in an assessment of the long-term geomorphic stability of engineered landforms at ERARM.

Alligator Rivers Region

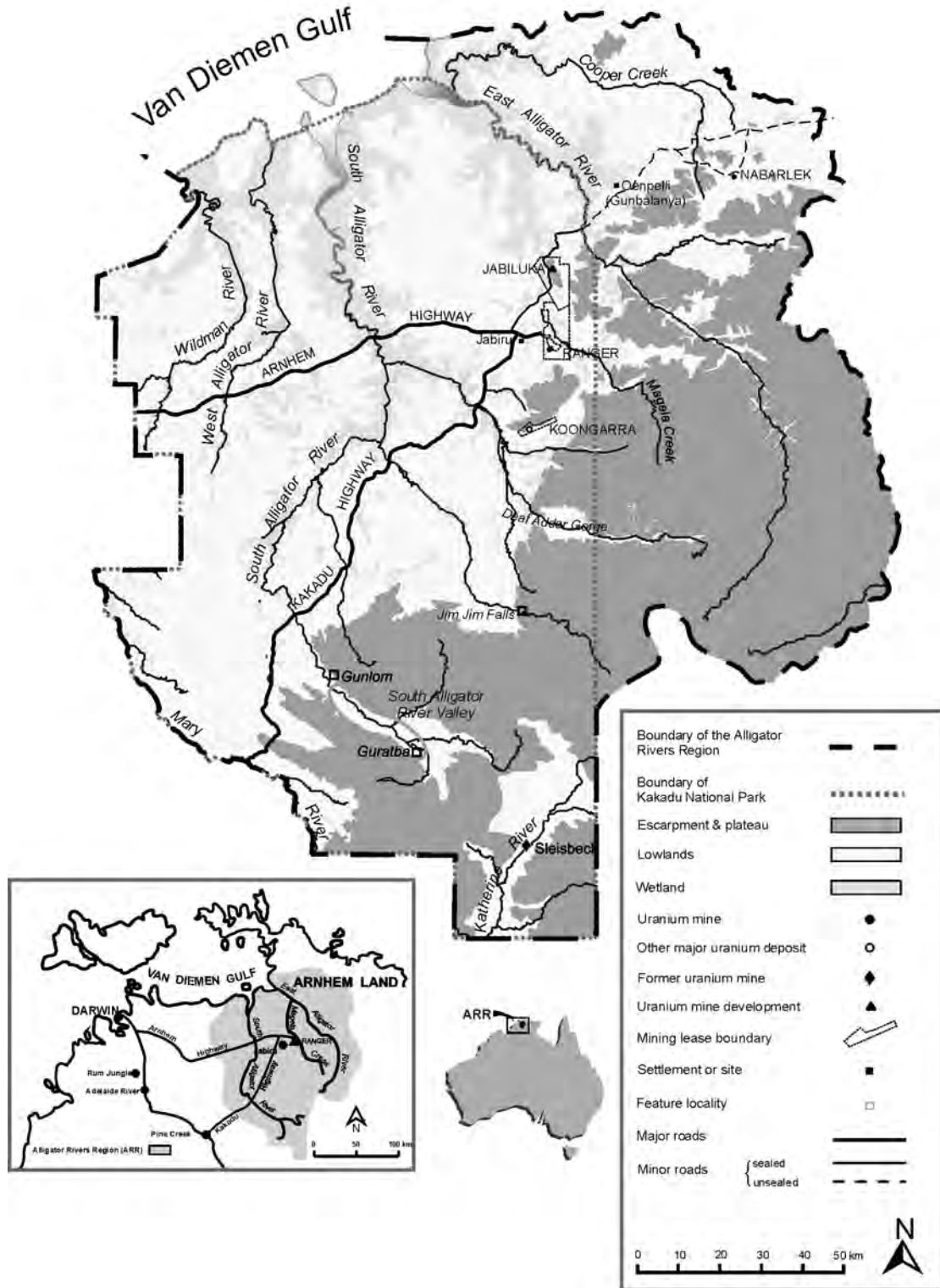


Figure 1 Location of uranium mines and deposits in the Alligator Rivers Region, northern Australia

Table 1 Completed geomorphic research on each project recommended by Pickup et al (1983, 1987)

Project Number	Project Title	Completed Work
R1	Erodibility of materials and alternative designs for ring dyke capping and embankment structures	Duggan (1985, 1988, 1994), East et al (1989a, 1994), Curley (1988), Uren (1990), Willgoose & Riley (1993, 1998), Riley (1992, 1994a, 1995b,d,e), Evans & Loch (1996), Unger et al (1996), Evans (1997), Evans et al (1998, 1999), Saynor & Evans (2000)
S1	Description and mapping of alluvial systems in the Alligator Rivers Region	Nanson et al (1990, 1993), Roberts (1991), Warner & Wasson (1992), East et al (1993)
D1	Potential transport, deposition and storage of tailings in small mine area tributaries	East et al (1988), Duggan (1985, 1988, 1994), Cull et al (1992), Riley & Waggitt (1992), Rippon & Riley (1996)
D2	Patterns of water and sediment movement in lower Magela Creek and its floodplain	Smith et al (1985), Murray et al (1993)
F1	Frequency analysis of floods using slackwater deposits	Baker et al (1985, 1987), Baker & Pickup (1987), Murray et al (1992), Wohl (1988), Wohl et al (1994a)
AD1	Sediment budget of small mine area creeks	Duggan (1985, 1988, 1994), Cull et al (1992)
AD2	Medium term system behaviour	Nanson et al (1990, 1993), Roberts (1991)
AD3	Evolution of Magela Creek channels, floodplains and mine area tributaries upstream of Mudginberri	Nanson et al (1990, 1993), Roberts (1991), East et al (1993)
AD4	Evolution of Magela Creek backwater plain downstream of Mudginberri	East et al (1989b), Clark et al (1992a,b), East et al (1992)
T1	Pollen dispersal on the Magela backwater plain	Clark & Guppy (1988), Clark et al (1992a)
F2	Long term vegetation and climatic history	Clark & Guppy (1988), Clark et al (1992b)
F3	Holocene sea level change	Woodroffe et al (1986, 1987, 1989), Clark et al (1992b)
AD6	Oxidation and metal kinetics in Magela alluvium	East et al (1992), Willett (1992)

Extensive research has been conducted on the hydrology, erosional processes and landform evolution of the ERARM waste rock dumps over the last 15 years (for examples, see Willgoose & Riley 1993, 1998, East et al 1994, Riley 1994a, 1995a,b, Evans & Loch 1996, Unger et al 1996, Evans 1997, Evans et al 1998, 1999, Saynor & Evans 2000). The results of this work are being used to assess the adequacy of proposed structures and rehabilitated landforms in relation to their stability. SIBERIA, a landform evolution model, has been used for this purpose (Willgoose & Riley 1993, 1994, 1998, Unger et al 1996, Evans 1997, Evans et al 1998). The design selected should, among other things, minimise both short- and long-term, off-site impacts. Assessment of off-site impacts requires detailed information on exported solute and particulate loads as well as on the fate of this material once it leaves the mine site (Riley & Waggitt 1992). Previous work has been completed on these topics and needs to be reviewed to establish whether it is adequate for off-site impact assessment. The purpose of this report is threefold:

1. To collate and review all of the existing data relevant to the discharge of solutes and particulate material from the rehabilitated mine site and from nearby tributaries of Magela Creek;
2. To determine the fate of particulates in the off-site system; and
3. To collate and review all of the existing material relevant to an understanding of the long-term behaviour of Magela Creek and its tributaries.

A brief introduction to the regional geomorphology of the Alligator Rivers Region is presented first to provide a spatial framework for the following work. The dynamics of soil and solute losses from the waste rock dump on ERARM and other disturbed areas as well as from undisturbed areas in the Alligator Rivers Region are then discussed before reviewing the particulate and solute yields reported for the same area. Then the likely fate of particulates discharged from the mine site is assessed from the published work and the need for additional work on the magnitude and frequency of extreme flood events and their impact on the landscape, is outlined. The long-term behaviour of Magela Creek and its tributaries is presented next before drawing the main conclusions and recommendations from the above review.

2 Regional geomorphology

Jennings and Mabbutt (1986) mapped two geomorphic regions in the Alligator Rivers Region, which they called the Bonaparte-Diemen Lowlands and the West Arnhem Plateau. The former are dissected lateritic lowlands also containing alluvial, estuarine and coastal plains whereas the latter is a dissected sandstone plateau. These formally defined regions are too broad for present purposes and so they are further subdivided below. The geomorphology of the Alligator Rivers Region has been outlined by Williams (1969a, 1991), Galloway (1976), Russell-Smith et al (1995) and East (1996), among others. They have described the main landforms relevant to this report as the Arnhem Land plateau, the Arnhem escarpment, the Koolpinyah erosion surface, the alluvial plains and the deltaic estuarine floodplains. The first two are part of the West Arnhem Plateau whereas the last three are part of the Bonaparte-Diemen Lowlands. Each of the above landforms is briefly described below.

The Arnhem Land plateau is an exhumed, essentially bedrock, tabular upland (fig 2), which constitutes the upper catchment of most major rivers. It is formed predominantly of resistant, horizontally-bedded, vertically jointed, quartz sandstone of the Middle Proterozoic Kombolgie Formation and produces low sediment yields of predominantly sandy material (Roberts 1991). A deeply incised, trellised drainage pattern has developed along the closely spaced joints and faults. Williams (1991) emphasised that the sandstones have long operated as a very effective caprock, protecting the underlying rocks from erosion. Outliers of sandstone form isolated massifs, such as Mt Brockman and Nourlangie Rock, at varying distances from the main plateau.

The Arnhem escarpment is the most striking scenic feature of Kakadu National Park and marks the edge of the plateau (fig 3). It varies from about 30 to 330 m high and exhibits a range of different forms depending on the underlying geologic structure (Galloway 1976). Quartz sandstone of the Kombolgie Formation outcrops in the scarp, which retreats episodically by collapses of large sandstone blocks, followed by centuries of near stability. Galloway (1976) speculated that the rate of scarp retreat may be of the order of 1 m/1000 years but Roberts (1991) calculated rates of only 0.02–0.2 m/1000 years. Rivers leaving the plateau either flow over the scarp as spectacular waterfalls (fig 4) or dissect the scarp by relatively long, narrow, deep bedrock gorges that follow joints and faults (fig 5). Near the escarpment, Roberts (1991) found that sand fans began to accumulate at 230–220 and 120–100 ka, which coincide with the start of the penultimate and last interglacials, respectively. Roberts et al (1990) reported the then oldest dates of human occupation in Australia (50–60 ka) based on thermoluminescence dating of these sandy footslope deposits, which contained Aboriginal artifacts.