



Chapter 2
Existing environment and mine
operations

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2 EXISTING ENVIRONMENT AND MINE OPERATIONS

2.1 INTRODUCTION

Ranger mine has been operating for more than 30 years without detriment to the natural and cultural values of the surrounding Kakadu National Park (Kakadu). Although there have been occasional environmental, safety and health incidents at the Ranger mine, the Commonwealth Supervising Scientist, responsible for environmental research and reviews of the environmental performance of uranium mines in the Alligator Rivers Region, continues to report that the surrounding Kakadu environment has remained protected (<http://www.environment.gov.au/ssd/publications/index.html#annual>).

Outcomes of the monitoring and research studies, in terms of impacts on the environment, are evaluated annually by ERA in formal reports submitted to regulators for review and approval (*Wet Season Report, Environment Report, Radiation Protection and Atmospheric Monitoring Program Report*). Separate reports evaluating ERA's performance in environmental management are prepared by regulators and oversight organisations and tabled for discussion at the biannual meetings of the Alligator Rivers Region Advisory Committee. These performance reports are also published on the Supervising Scientist website and in the Annual Report of the Supervising Scientist to the Commonwealth Minister for the Environment.

This chapter provides an overview of the natural and operational environment of the existing Ranger mine. Its purpose is to provide a setting for the Project description outlined in Chapter 3 and draws on the substantial dataset that has been accumulated by ERA and regulators from more than 30 years of environmental, safety and health monitoring and research investigations of the Ranger mine and surrounding region. The chapter is divided into the following sub-sections:

- **Section 2.2** provides background on land tenure, land use, local government, and social setting;
- **Section 2.3** provides information on the economic setting, including the regional economic environment and key industries;
- **Section 2.4** provides a description of the physical environment, which includes climate, geology, topography, land surface/soils, surface water and groundwater characteristics;
- **Section 2.5** provides a description of the bioregions in the vicinity of the Ranger Project Area (RPA), flora and fauna (including biodiversity, introduced and threatened species), and bushfires; and
- **Section 2.6** describes the existing operational environment at Ranger mine, and includes mining and processing, water management, and a brief description of the Ranger 3 Deeps exploration decline.

The geographic (spatial) context of this chapter encompasses (in increasing order) the RPA, the Magela Creek catchment, Kakadu, and the Alligator Rivers Region (**Figure 2-1**). The West Arnhem Region and the Northern Territory (NT) in general are referred in to **Section 2.2** and **Section 2.3** in a social and economic context.

2.2 REGIONAL SETTING

2.2.1 Land Tenure, Land Use and Governance

2.2.1.1 Historical Overview of the Magela Creek Catchment

The Alligator Rivers Region has a long history of human occupation, with archaeological records suggesting sustained human occupation of between 40,000 and 60,000 years (Roberts, *et al.* 1990). From around the 17th century, visits from Macassan fisherman from parts of present-day Indonesia, as well as European navigators and explorers, led to increasing contact between the region's Aboriginal people and other cultures. A more permanent non-indigenous presence was evident from the late -1800s in the form of miners, buffalo hunters, missionaries and settlers (**Appendix 14**).

The Magela Creek catchment within the Alligator Rivers Region (**Figure 2-1**) contains several land use types, including Kakadu National Park, mining leases and native title lands. The catchment is largely within Kakadu, a world heritage listed area and Ramsar site (refer **Section 2.5.3**). The RPA operates in accordance with an authorisation under the Commonwealth *Atomic Energy Act 1953*. Mining lease "MLN1", which is not part of the RPA, is a mineral lease under the NT *Mining Act 1980*.

Historical land use within the region has varied and includes indigenous occupation, followed by exploration and buffalo hunting from the 1880s, the establishment of missions in the Kakadu area in 1900s, pastoral grazing and agriculture from 1906 at Oenpelli, mining exploration from the 1920s, a series of small uranium mining ventures in the 1950s, and tourism from the late 1950s (Levitus 1995). In addition, the Mudginberri Station (north of Jabiru) was used for pastoralism (including an abattoir) in the 1970s and 1980s, and was subject to broad scale clearing and introduced pasture grasses (Bayliss, *et al.* 1997).

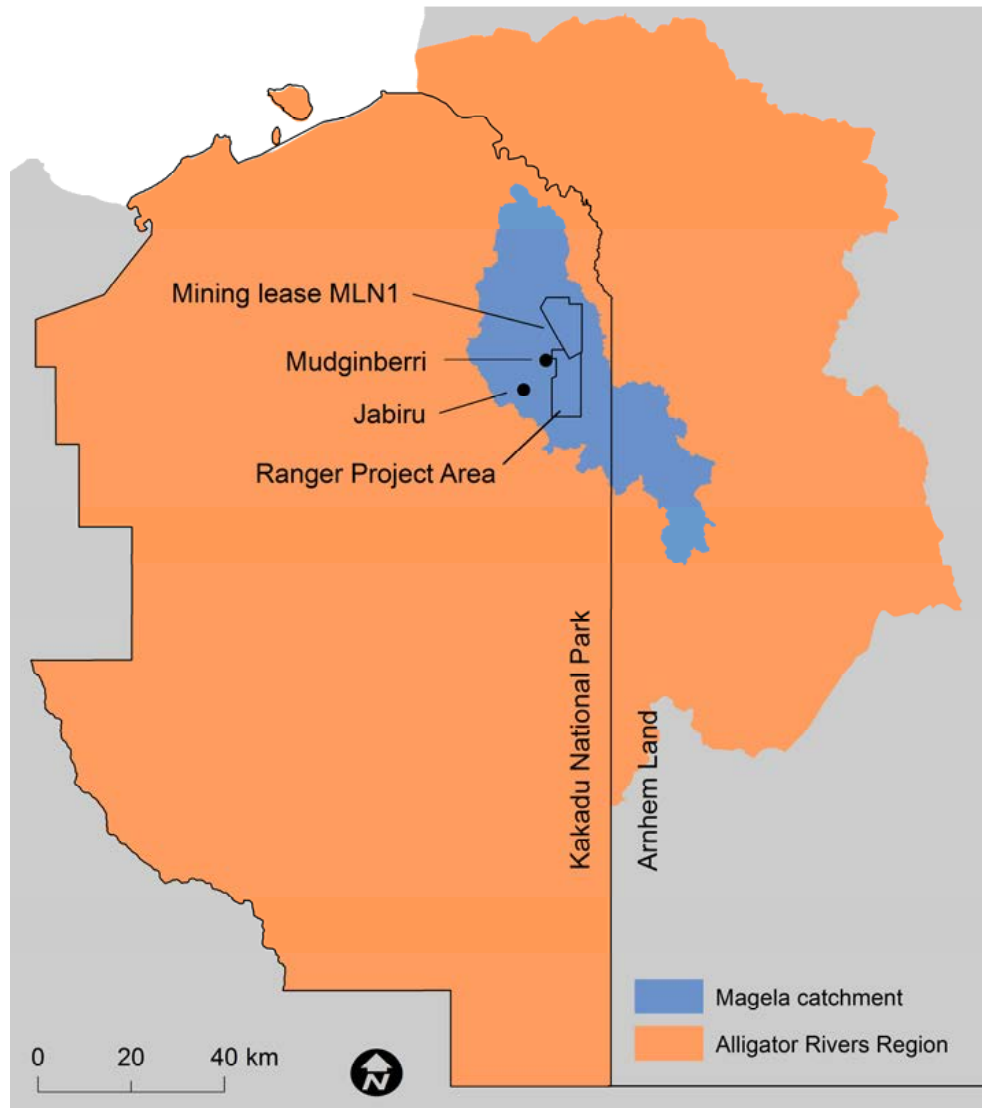


Figure 2-1: Geographic context for the Project

2.2.1.2 Existing Land Tenure

Land tenure in the region, and relevant to the Project, is complex. Land tenure around the RPA is a combination of Aboriginal freehold land and Australian Government freehold land which are managed through a number of leasing, governance and service arrangements. **Figure 2-2** shows land tenure in the area, where land portions relevant to the Project are NT portions 2273, 2376, 1656, 1657, 1662, 1685, and 1686.

Aboriginal freehold title exists across most of the land on the RPA. Aboriginal freehold titles granted under the *Aboriginal Land Rights (Northern Territory) Act 1976* (Commonwealth) are held by the Kakadu Aboriginal Land Trust. NT Portion 2376 is leased back to the Director of National Parks with the lease expiring on 31 December 2077. However, not all of NT Portion 2376 is included in the declaration of Kakadu, as part of it is within the boundaries of the RPA. NT portions 1656, 1657, 1685 and 1686 are within the boundaries of the RPA, and are not included in this declaration or in any lease to the Director of National Parks. The RPA

section of NT portion 1662 is similarly not included in the declaration of Kakadu and is not included in the lease to the Director of National Parks.

The Kakadu Aboriginal Land Trust was handed an Aboriginal freehold title over NT Portion 7127 (currently Portion 2273) under the Commonwealth *Aboriginal Land Rights (Northern Territory) Act 1976* on 16 August 2013. The portion will be allocated once the necessary documentation has been lodged with the Registrar-General.

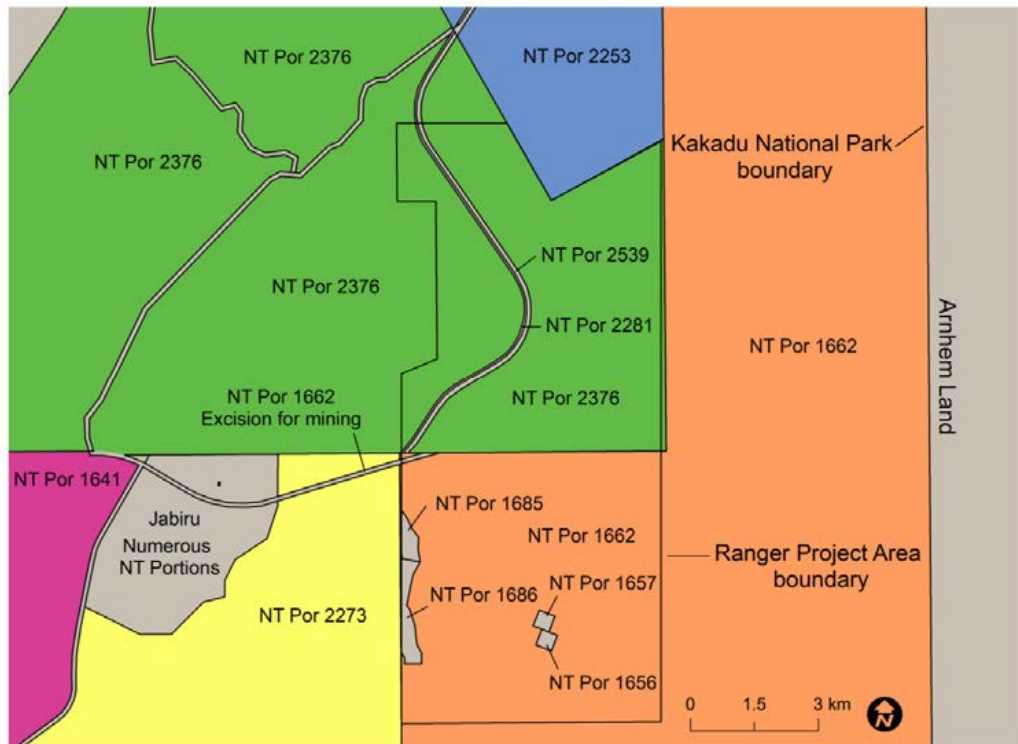


Figure 2-2: Land portions relevant to the Project

2.2.1.3 Governance History

Kakadu was declared under the *National Parks and Wildlife Conservation Act 1975* (Wildlife Conservation Act) in three stages between 1979 and 1991. The *Environment Protection and Biological Diversity Act 1999* (EPBC Act) replaced the Wildlife Conservation Act in 2000 and the declaration of Kakadu continues today under this legislation. Each stage of Kakadu includes Aboriginal land under the *Aboriginal Land Rights (Northern Territory) Act 1976* that is leased to the Director of National Parks, or land that is subject to a claim to traditional ownership under the *Aboriginal Land Rights (Northern Territory) Act 1976*.

The Mirarr are the Traditional Owners of the land encompassing the RPA. There are no strict lines or borders between the Mirarr estate and the estates of neighbouring Aboriginal clans. The Mirarr estate encompasses the RPA, MLN1, Jabiru and parts of Kakadu. The Mirarr exercise their rights as Traditional Owners under two Aboriginal Land Trusts and benefit from fee simple title (a form of freehold ownership legislated by government) to most of the estate. The town of Jabiru and surrounds were excluded from the Kakadu Aboriginal Land Trust as a result of the Fox inquiry (Fox, *et al.* 1977), however a native title claim lodged by the Mirarr is on-going over this land which ERA continues to support.

The Jabiru Town Development Authority was established to govern the town under the NT *Jabiru Town Development Act 1979*, and the land upon which it is situated was leased to the Authority by the Director of National Parks. The town of Jabiru, and the surrounding area, is also governed by the EPBC Act, which treats the Jabiru Town Development Authority as if it were a council and Jabiru as if it were a municipality or a community government area, as defined by the NT *Local Government Act 1978*. The Jabiru Town Development Authority delegates its responsibilities for service provision to the West Arnhem Regional Council and Power and Water Corporation.

2.2.2 Social Setting

The history of Ranger, its establishment and operations has long been a point of national political and societal debate. The complexity of this history has led to conflicting viewpoints on the context and social changes occurring around Ranger operations. While not the only factor, the mine and the establishment of the town of Jabiru has contributed to social change in the Alligator Rivers Regions (**Appendix 14**).

Jabiru was established in 1982. It remains foremost a mining town, but has grown to become a key service centre for the tourist industry and the region. Residential accommodation in Jabiru is almost solely contingent on employment as key employers in the region own all housing infrastructure which is supplied as part of employment contracts. The non-indigenous population of Jabiru is typically employed by ERA (at Ranger mine) or by local services and businesses, Aboriginal organisations, or government departments. The "closed" nature of the town whereby individuals can only become residents of the town via employment has historically been, and remains, a key defining characteristic of the social environment of Jabiru.

A broader description of the social setting of the region where it provides context to existing and potential impacts of the Project across the main social elements is outlined in **Chapter 11**.

2.2.3 Aboriginal Culture and Heritage

The RPA contains several significant Aboriginal sites, including a recorded sacred site, as well as a distribution of archaeological sites and archaeological background scatters. These are described in accordance with guidance provided in the Interim Cultural Heritage Protocol which defines the process for which cultural heritage is to be managed on the RPA as agreed with the Gundjeihmi Aboriginal Corporation (GAC) and the Mirarr. ERA has embedded this protocol into its operational planning through the ERA cultural heritage management system. The protocol and management system comply with the relevant heritage legislation.

2.2.3.1 Sacred and Significant Sites

A sacred site is a site that is sacred to Aboriginal people or is otherwise of significance according to Aboriginal tradition. Archaeological objects are relics of past occupation by Aboriginal or Macassan people, and can include secret and ceremonial objects, log or bark coffins, human remains, portable rock or wood carvings, and engravings or stone tools.

The RPA has one recorded sacred site (Site 5472-15). This site is located approximately 5 km north of the existing mine site and proposed Project, and is listed with the Aboriginal Areas Protection Authority.

A second site of cultural significance (Tree Snake Dreaming) is located immediately north of Pit 3, but is not recorded with the Aboriginal Areas Protection Authority. In 2010, the GAC indicated that they would register this site as a sacred site with the Authority; however, this has not yet occurred. Both sites are surface sites; there are no recorded or registered sub-surface sites of cultural significance on the RPA.

A third site of indigenous cultural heritage significance on the RPA is a cemetery where a small number of local Aboriginal people are buried; this was established prior to mining exploration. This is not a gazetted cemetery and the burials were contemporary for the period rather than being traditional Aboriginal burials.

An external cultural heritage specialist, working on behalf of GAC and with traditional owners, has conducted 31 cultural heritage surveys over the RPA since 2006. These surveys have covered 73% of the RPA (approximately 52 km²) including the Project area. During these surveys, 99 archaeological sites have been identified and recorded along with 69 archaeological background scatters. There are a total of 171 recorded places of indigenous cultural heritage significance on the RPA. There is one site of cultural significance located within the footprint of the Project. This site, R34, is located within a fenced exclusion zone, which protects the site from potential surficial impacts such as clearing. Further information regarding this site and the potential impacts from the Project are discussed in **Chapter 10**.

Kakadu is listed for its cultural and environmental values as a world heritage site. Kakadu was first inscribed on the World Heritage List in 1981 and was subsequently expanded and reinscribed in 1987, and again in 1992. The world heritage criteria current in 1992, and against which Kakadu was most recently inscribed, remain the formal criteria for this property. The World Heritage Convention defines cultural heritage as:

- monuments: architectural works, works of monumental sculpture and painting, elements or structures of an archaeological nature, inscriptions, cave dwellings and combinations of features, which are of outstanding universal value from the point of view of history, art or science;
- groups of buildings: groups of separate or connected buildings which, because of their architecture, their homogeneity or their place in the landscape, are of outstanding universal value from the point of view of history, art or science; and
- sites: works of man or the combined works of nature and man, and areas including archaeological sites which are of outstanding universal value from the historical, aesthetic, ethnological or anthropological point of view.

Cultural values such as language, food and traditional practices form a substantial amount of the living cultural tradition presented to visitors to Kakadu.

A full discussion of Aboriginal and cultural heritage is provided in **Chapter 10**.

2.2.4 Existing Infrastructure and Services

While provision of services and public infrastructure is typically the role of government, the nature of the establishment of Jabiru as a mining town, and its present governance structure, has led to a mix of organisations establishing and maintaining services and infrastructure.

The primary organisations involved in the provision of services and infrastructure in the Alligator Rivers Region today are:

- NT Government: Funds and operates West Arnhem College including Jabiru Area School and Gunbalanya School; funds and operates the Jabiru and Gunbalanya Community Health Centres and maintains major roads in the region and Kakadu (**Appendix 14**);
- West Arnhem Regional Council: Provides core and commercial services such as road works and maintenance within Jabiru and Gunbalanya, waste and water management, sports and recreation, library services, childcare, motor vehicle registry and visitor accommodation (Gunbalanya) (West Arnhem Regional Council 2013);
- ERA: Owns and maintains retail and commercial buildings, and the majority of Jabiru housing accommodation; generates electricity for Jabiru; and manages Jabiru airport;
- GAC: Funds and operates the Djidbidjidbi Residential College; maintains and operates Mudginberri and Whistle Duck outstations and owns residential housing;
- Kakadu West Arnhem Social Trust: Funds Children's Ground (refer Section **11.3.3.1**) and other regional initiatives;
- Wambi Aboriginal Corporation: Maintains infrastructure and roads for outstations within KNP and Manaburduma;¹
- Jabiru Town Development Authority: Holds and administers the lease for Jabiru; and
- Director of National Parks: Maintains Kakadu roads and tracks (DNP 2007).

A full description of existing infrastructure and services ERA contributes to in the region is provided in **Section 11.3.3**.

2.2.5 Transport Network

Interstate deliveries to the Ranger mine originate mainly from South Australia and Queensland, and through the Port of Darwin. Heavy vehicles transporting materials to, or product from, the mine converge on either the Arnhem or Kakadu Highways via the Stuart Highway.² Light vehicles travelling to and from the Ranger mine predominantly utilise the Arnhem Highway. These routes are shown in **Figure 2-3** with around 50% of this route occurring outside of Kakadu National Park.

¹ Except where maintained by Kakadu.

² Vehicle travelling from Darwin also utilise Berrimah Road and Tiger Brennan Drive before converging onto the Stuart Highway.

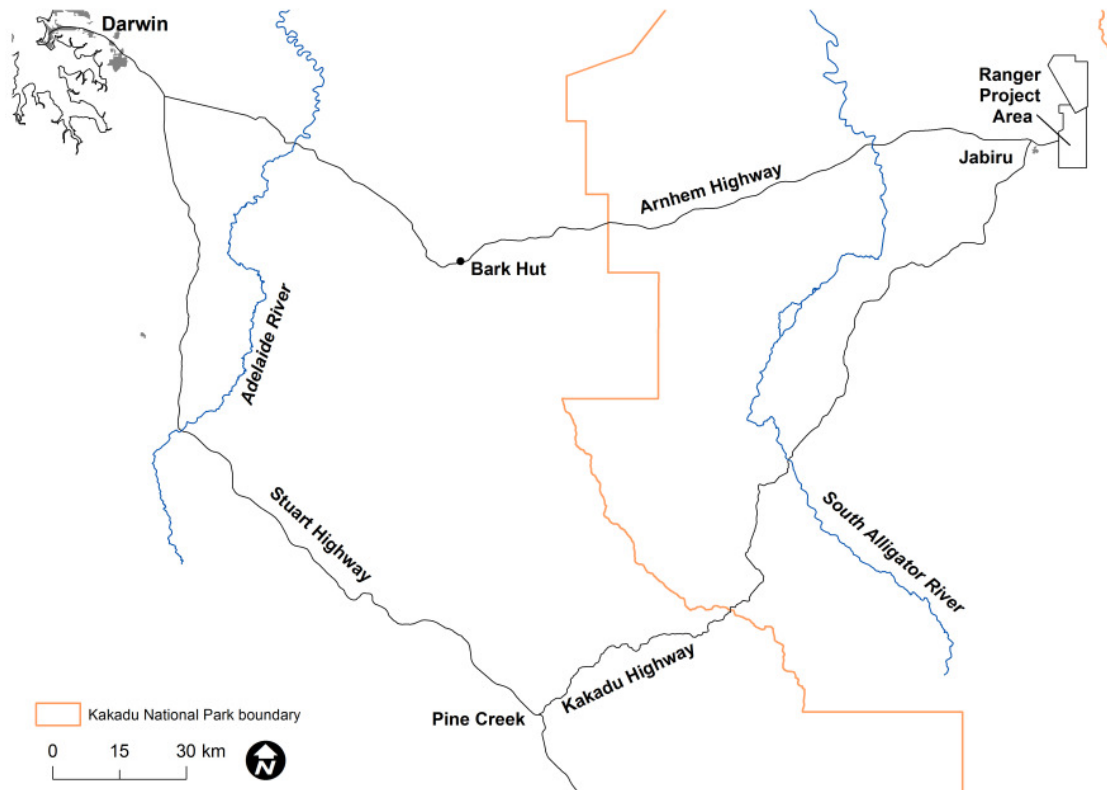


Figure 2-3: Road network servicing the Ranger mine

Berrimah Road

Berrimah Road is a 6.8 km two lane, two way road separated by a painted median connecting the Port Of Darwin with the intersection of Tiger Brennan Drive. The road is sealed and typically does not have shoulders.

Tiger Brennan Drive

Tiger Brennan Drive, between Berrimah Road and the Stuart Highway, is approximately 6.3 km in length. The road predominantly consists of four lanes with two lanes travelling in either direction separated by a vegetated median. The road is sealed and has shoulders on either side.

Stuart Highway

The Stuart Highway (A1) is a national highway connecting Darwin, Katherine, Daly Waters, Tennant Creek, Alice Springs and Port Augusta (the latter being in South Australia). It is classified as an "A" standard road within the road classification hierarchy, thereby theoretically providing a higher standard of driving conditions. It is a sealed, approximately 7 m wide, two-lane carriageway, with one lane in each direction for most of its length. The maximum posted speed limit is 130 km/h. The highway has four lanes (two in each direction) north of the Arnhem Highway. There are typically no shoulders on the side of the road, although some sections have unsealed shoulders.

Arnhem Highway

The Arnhem Highway (A36) is a 220 km rural highway linking Jabiru, within Kakadu, to the Stuart Highway some 35 km south of Darwin. It is also an "A" standard road, and consists of two, 3.5 m wide traffic lanes on a single carriageway, sealed shoulders, signage and line marking that is readily seen in all weather conditions.

Running generally in an easterly direction from the Stuart Highway junction through to Jabiru, the topography is mostly flat with long straights and broad curves providing line of sight.

A high proportion of traffic is recreational and freight orientated serving a number of tourist attractions and businesses, in addition to the supply needs of both the Jabiru township and the Ranger mine.

Traffic along the Arnhem Highway can be affected by road restrictions and closures during the wet season (November to March) as the road becomes impassable through the low lying flood plains near the Adelaide River, Mary River and South Alligator River. These conditions typically only persist for two weeks each year and ERA traffic is diverted via the Stuart Highway and Kakadu Highway to the Ranger mine when these conditions arise.

Kakadu Highway

The Kakadu Highway (B21) is also designated as a rural highway. Approximately 210 km in length, the highway runs generally in a south westerly direction from the Arnhem Highway at Jabiru to the Stuart Highway at Pine Creek. It is classified as a "B" standard road and hence theoretically provides two, 3.3 m wide traffic lanes, gravel shoulders, signage and line marking to delineate the route.

The topography is similar to that of the Arnhem Highway, but is more undulating and meandering in places. This necessitates reduced speeds, particularly just north of the Mary River road house where there are steep grades and tight curves on approach to the Ikoymarrwa Lookout.

Additional information on the environment in which these routes are found and how they relate to the Project is provided in **Chapter 12**.

2.3 ECONOMIC SETTING

2.3.1 Economic Environment

The Jabiru economy is underpinned by a narrow base, with mining being the town's principal provider of jobs and the main driver of its economic development. While other sectors such as tourism, services and education are significant, they are also highly dependent on economic activity generated by Ranger mine (**Appendix 14**).

Ranger mine is estimated to directly contribute 1.3% of the NT's gross value added (ACIL Tasman 2013). Ranger's contribution alone is equivalent to the direct contribution of a number of industries in the NT including the arts and recreation services industry (1.1%), electricity, gas, water and waste services industry (1.2%) and the information, media and telecommunications industry (1.3%). Mining as an industry contributes approximately 21% of the NT's gross value added making it the largest single industry contribution to the NT

economy. The construction industry is the next largest contributor at approximately 10%. A comparison of all industry contributions to the NT economy is provided in **Table 2-1** and highlights the important role that mining and Ranger mine have in sustaining the NT economy. In total, the three largest contributors to the NT's gross value added are mining, construction and ownership of dwellings.

Table 2-1: Industry contributions to NT gross value added, 2010 – 2011

Type	\$m	Share (%)
Mining	3,400	21.3
Construction	1,670	10.3
Ownership of dwellings	1,570	9.7
Public administration and safety	1,450	8.9
Manufacturing	1,130	7
Health care and social assistance	970	6
Transport, postal and warehousing	700	4.3
Rental, hiring and real estate services	640	4
Education and training	620	3.8
Agriculture, forestry and fishing	590	3.7
Retail trade	580	3.6
Financial and insurance services	560	3.5
Professional, scientific and technical service	500	3.1
Accommodation and food services	340	2.1
Administrative and support services	280	1.7
Other services	280	1.7
Wholesale trade	250	1.5
Information media and telecommunications	220	1.3
Electricity, gas, water and waste services	200	1.2
Arts and recreation services	180	1.1
Total all industries	16,130	100.0

Data source: (ABS 2011a)

According to the Australian Bureau of Statistics census of 2011, the key industries of employment in the region are mining, accommodation and food services, and public administration and safety, respectively (**Table 2-2**):

Table 2-2: Industries of employment for Jabiru and West Arnhem Region

Industry of employment	Jabiru (%)	West Arnhem Region (%)
Mining	36.7	11.9
Accommodation and food services	15.2	8.2
Public administration and safety	6.5	16.8
Education and training	7.5	11.0
Construction	5.8	5.9
Health care and social assistance	4.0	6.6
Combined other	24.3	39.6

Data source: (ABS 2011b)

The majority of Jabiru's population is in the workforce and this is reflected in income statistics for the town. Jabiru stands out when it comes to weekly personal income with a median of \$1,287 for non-indigenous, and \$483 for indigenous, persons (**Table 2-3**). Median weekly income in Jabiru for non-indigenous persons is higher than that for non-indigenous persons in West Arnhem Region (\$1,140) and significantly higher than the equivalent figure for the NT (\$925). It is noted that the median income of indigenous people in Jabiru is considerably greater than the median across the region. The reasons for this are uncertain, but may include receipt of royalties and active employment.

Table 2-3: Indigenous and non-indigenous income comparison

Median total personal income \$/week	Jabiru	West Arnhem Region	Northern Territory
Indigenous persons/households with indigenous persons	\$483	\$270	\$269
Non-indigenous persons/households	\$1,287	\$1,149	\$925

Data source: (ABS 2011c)

A full description of ERA's economic contribution to the local, regional and territory economies is provided in **Section 11.2**.

2.4 PHYSICAL ENVIRONMENT

2.4.1 Climate

The Alligator Rivers Region is dominated by a distinctly seasonal, wet-dry monsoon cycle. The wet season generally extends from late October to early April and experiences predominantly westerly winds, while the dry season is dominated by easterly to south-easterly winds and extends from May to September.

Average annual rainfall is approximately 1,600 mm at Jabiru Airport (1971 – 2013), 1,400 mm at Gunbalanya (Oenpelli) (1910 – 2013), which is located approximately 40 km north east of Ranger mine, and 1,750 mm at Darwin Airport (1941 – 2013) (BOM 2013). More than 90% of annual rainfall falls over 5 months between November and March. The hottest month is October, with a mean maximum temperature of 37.6 °C, and the coolest month is July, with a mean minimum temperature of 18.3 °C (BOM 2013).

Daily evaporation measurements have been made at Jabiru Airport since 1971 using a Class A pan evaporator (Chiew & Wang 1999). The average monthly pan evaporation ranges from 295 mm in October to a low of 160 mm in February. Based on this record, a yearly average pan evaporation of 2,570 mm has been adopted for planning and design at the Ranger mine. Evaporative mine water management systems have been in place since the Ranger mine commenced, maximising evaporation to manage water that is excess to operational requirements. The average rainfall and evaporation values for Jabiru Airport are provided in **Figure 2-4**; annual pan evaporation exceeds rainfall by approximately 1,000 mm.

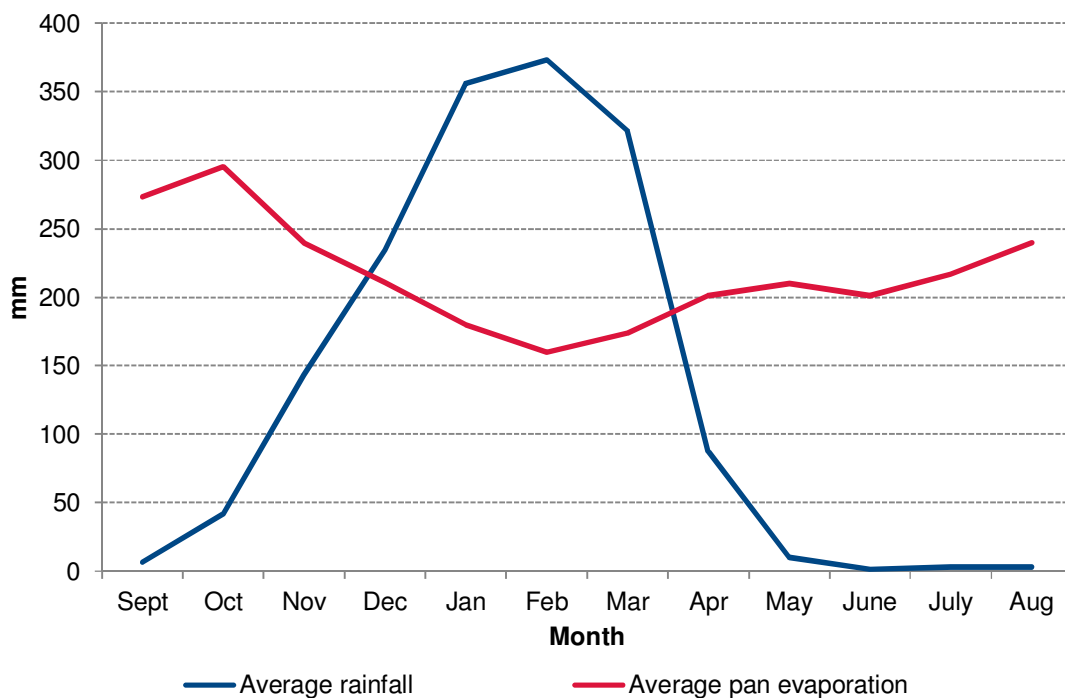


Figure 2-4: Monthly rainfall/ evaporation for Jabiru Airport (1971 – 2013)

2.4.2 Extreme Climate Events

The tropical cyclone season in Northern Australia (including the Gulf of Carpentaria) typically extends over the period of November through to April, averaging around two cyclones a year, with peak activity from December to March (BOM 2009). Increased cyclone activity in the Australian region has been associated with La Niña years, while below normal activity has occurred during El Niño years (Kuleshov & de Hoedt 2003; Plummer, *et al.* 1999). When cyclones and tropical lows are present, the Alligator Rivers Region can experience high winds and rainfall. Cyclone Monica hit the area in April 2006 and the highest April monthly rainfall for 19 years, 305.8 mm, was recorded at Jabiru Airport.

In early 2007, a well-developed tropical low led to an extreme rainfall event that exceeded the historical maximum rainfall recorded for both February and March at Jabiru airport and the Oenpelli³ weather station. Over three days, between 28 February and 2 March, a total of 761 mm was recorded at Jabiru Airport, reaching estimated rainfall intensities of 16 mm/hr. In a special report to ERA, the Bureau of Meteorology stated that this event was "very, very much higher" than 100 year rainfalls (BOM 2007).

2.4.3 Geology

The Alligator Rivers Region (including Kakadu) is located in the eastern section of the major geological structure of the region – the Pine Creek Geosyncline (Press, *et al.* 1995) – which ranges from west of Darwin to east of Gunbulunya (Oenpelli) and south of Pine Creek. The northern part of Kakadu (which includes the RPA) is located on the Cahill Formation (age approximately 2.1 billion years) and is the location of mineralisation of economic significance, in particular uranium (BMT WBM 2010). The Cahill Formation is overlain by younger sandstone of the Kombolgie Formation (age approximately 1,650 million years) that forms part of the Arnhem Land Plateau. Weathering of the Kombolgie Formation in the early to middle Tertiary period (approximately 20 – 30 million years ago) has exposed parts of the Archaean Nanambu Complex (age approximately 2,470 million years). The portion of the Alligator Rivers Region to the west of the Arnhem Escarpment represents the retreating edge of the Kombolgie Formation over the Nanambu Complex surface. Subsequently, many areas have been exposed to elevated levels of uranium and radiation for millions of years. The Ranger mineralisation is hosted by the Cahill Formation, and extends for approximately 14 km, close to the eastern margin of the Nanambu Complex.

2.4.4 Topography

The elevation of the region surrounding the RPA is shown in **Figure 2-5**. The RPA lies on plains approximately 3.5 km north of the Mount Brockman Massif, which is an outlier of the Arnhem Land Plateau and rises over 200 m above the plain. These plains are generally flat and are rarely more than 45 m above sea level. South and east of the RPA, the Arnhem Land Plateau escarpment rises to between 200 m and 300 m above sea level. The Magela floodplain downstream of the RPA is between 2 m and 5 m above sea level (Wasson 1992).

³ Oenpelli weather station represents more than 90 years of high quality rainfall data according to Bureau of Meteorology (website).

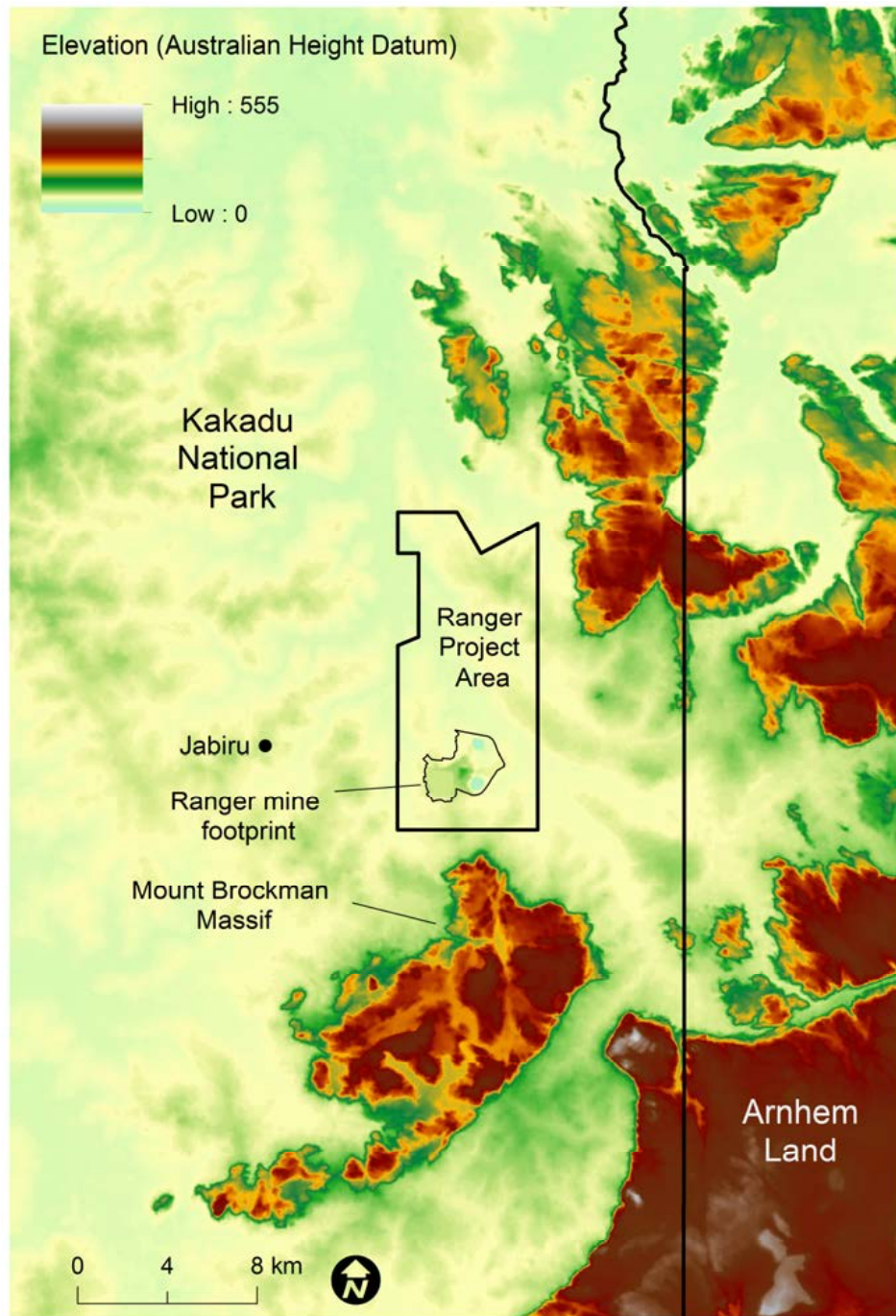


Figure 2-5: Elevation of the region surrounding the RPA and the mine footprint

2.4.5 Geomorphology and Soils

The soils and vegetation of the RPA are influenced to varying degrees by four land surface categories: the Mount Brockman Masiff, Koolpinyah Surface, Alluvial Plains, and Coastal Plains. These four land surfaces are comprised of geomorphological units (**Figure 2-6**) that are described below.

The Mount Brockman Massif, which is a massive quartz sandstone outlier (comprised of the rough rocky hills and dissected plateaux, and flat to gently undulating plains units) is characterised by steep escarpment and skeletal soils. The massif is within the catchments of Magela and Gulungul creeks. Due to its resistance to erosion and low soil moisture retaining capacity, a large volume of localised rainfall is readily accumulated in surface drainage and causes rapid floods in creeks and drainage lines. Water infiltrates joints and fissures and contributes to groundwater recharge and the formation of springs and swamps, some of which last well into the dry part of the year many months after the last rainfall. Much of the Mount Brockman Massif is almost entirely devoid of soil. Soils that occur are mainly skeletal, coarse and sandy in dissected and sloping sections, and can be up to 1.5 m deep in flatter areas.

The Koolpinyah Surface (comprising sandy plains, dissected rolling lowlands, and open flat to gently sloping plains) is characterised by level, rolling or dissected lowlands on the plains on which the RPA is located. The surface consists of deeply weathered bedrock partly overlain by Late Tertiary to Recent sediments derived from the erosion of Cretaceous, Middle Proterozoic and Lower Proterozoic formations. A variety of soils has formed on the Koolpinyah Surface. These are dominated by lateritic red and yellow earths formed by deep and pervasive weathering with similar structure and bearing strengths. They commonly overlie extensive sheets of ferricrete and strongly weathered rock. Differences in soil type can be attributed to the underlying bedrock material.

Alluvial plains have been formed by the flow of numerous rivers across the Koolpinyah Surface. Magela and Gulungul creeks flow in a northerly direction from the Mount Brockman Massif and dissect the RPA. Alluvial materials have been deposited by these creek systems to form the flat Magela floodplains to the northwest. Coarse, sandy Late Tertiary and Quaternary alluvial deposits cover part of the plains within channels of diverted streams and anabranches.

Coastal plains extend north of the Koolpinyah Surface, which are comprised of the seasonally flooded coastal plains and swampy depressions units (includes the Magela floodplain). These plains are flat, poorly drained and penetrate far inland along the broader river valleys. They are composed of old estuarine sediments that have been extensively reworked by river systems to produce complex soil patterns. Generally, these soils are composed of fine materials and are often waterlogged to form clays.

The Magela floodplain is underlain by blue-grey sulfidic clay, which is potential acid sulfate soil material (Willett 2008). This material extends to nearly 40 km from the East Alligator River to just north of Ranger mine on the upper plain (Mudginberri Corridor). Surface expressions of acid sulfate soils can be found in back slopes leading from billabongs and in marginal flood basin areas (Wasson 1992).

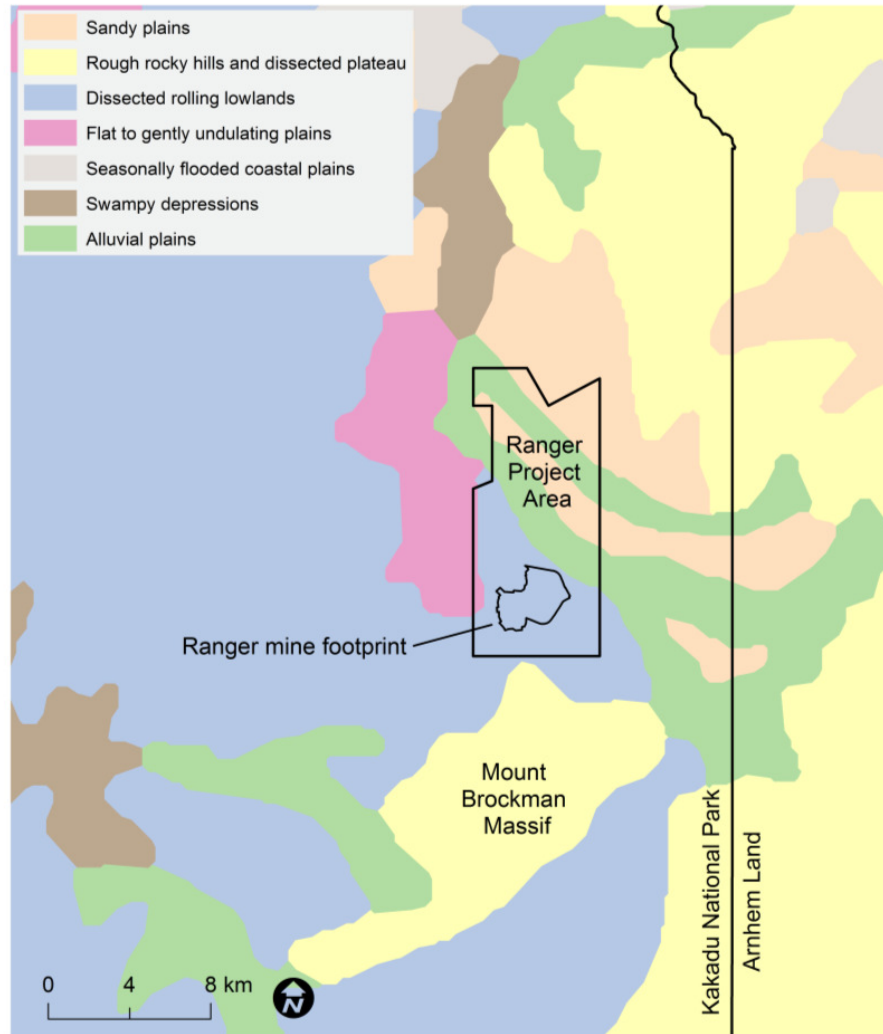


Figure 2-6: Landscape and soil types of the RPA, Ranger mine footprint and surrounds

The type (class) and distribution of soils across the land surfaces of the RPA are influenced by geology, topographic position and seasonal change in the amounts of moisture in the ground (Chartres, *et al.* 1991; Hollingsworth, *et al.* 2005; Story, *et al.* 1969). The strongest influence on soil type is the degree of soil moisture resulting from vertical to lateral water movements in the soil, and the number of wet months each year. Vegetation cover is also an important factor as it influences the amount of soil organic matter, humic acid and physical weathering.

Soil surveys around the Ranger mine, since the mid 1980's, have provided a detailed characterisation of soils across the RPA. The key for classification of soils (**Table 2-4**) was developed by Hollingsworth (1999), based on the studies of White and McLeod (1985). In general:

- upper slopes are underlain by well-drained loamy sand to sandy loam red earths;

- mid slopes are dominated by moderately well drained to imperfectly drained gravelly yellow earths with mottled B horizons, indicating impeded drainage for at least part of the year; and
- lower slopes are underlain by shallow, sandy and gravelly siliceous sand (bleached upper layers) over a ferricrete layer.

The general soil distribution around the Ranger mine is shown in **Figure 2-7**. Land units are defined on the basis of landform, geology, vegetation and soils information. **Table 2-4** contains brief descriptions of the soil characteristics.

Table 2-4: Brief description of characteristics of soils around the Ranger mine (refer **Figure 2-7**)

Map unit (Hollingsworth, 1999)	Map unit description
A0	Organic horizon, sand/loamy surface.
A1	Deep pale brown, yellow and yellowish brown sands, sand/loamy sand surface and generally non-mottled single grained and sandy throughout. Variations include: light yellowish brown and dark brown; and, yellow brown, yellow and faint red brown mottles.
A2	Deep yellowish brown to very pale brown; highly permeable, generally non-coherent sand, bottoming onto ferruginous and quartz gravel and stone. Profiles may vary: depths may extend from 100 cm; in-situ gravels may occur within the lower horizons and the firm clay clod nodules may become hard; 10-15 mm, prominent, red mottles.
B1	Deep brownish yellow to yellowish brown massive gravel free earthy sands with minor mottles common at depth. Profile variations include different degrees of mottles at depth, and on rare occasions overlie a buried zone.
B5	Shallow, gravelly, brown to yellowish brown, massive, earthy sands. Variations may have light brownish yellow and minor light grey horizons at depth, textures may not be heavier than loamy sands.
C1	Moderately deep to deep yellowish brown to light yellowish brown, sandy earths with no gravel present. No profiles bottom onto laterite pavement and gravel pans. Profiles may be deeper, lighter in chroma, and increasing in texture to sandy light clay.
C2	Moderately deep to deep sandy loams over a gravel pan.
C3	Moderately deep to deep, dark yellowish brown to yellowish brown, sandy earths with gravel throughout, bottoming onto ferruginous gravel.
C4	Shallow yellowish brown to brownish yellow sandy earths bottoming onto dense ferruginous gravel and stone. Mottles may occur. Variations include distinct, grey and prominent, red mottles in B-horizon.
C5	Shallow brown to yellowish brown gravelly sandy earths over a ferruginous and quartz gravel pan. Variations include colours to yellowish brown; depth varying to 30 cm; and, gravel contents ranging between 5% and 50% within the profile.
D1	Deep light brownish grey to grey loamy earths, massive.

Map unit (Hollingsworth, 1999)	Map unit description
D2	Deep to moderately deep yellowish brown to pale brown gravel-free loamy earths over a gravel/stone hardpan. Variations include textures to coarse sandy clay at depth; colours from pale brown to grey; and, mottles where sites are ponded.
I6	Deep profiles of grey to brown sands and earthy sands over a generally mottled light grey to pale brown clay and sandy clays.
I8	Profiles are very dark grey to greyish brown loamy earths and sandy earths over a brown to pale brown earthy sand, with mottles common. Considerable variation was found with all soil characteristics.



Figure 2-7: Dominant soil types in areas surrounding the Ranger mine

2.4.6 Surface Water Resources

The Ranger mine is bounded by three ephemeral creek systems: Magela Creek to the north, Gulungul Creek to the west and Corridor Creek to the south. These three creeks form part of the Magela Creek catchment, which covers an area of approximately 1,600 km². **Figure 2-8** shows the location of the RPA within the Magela Creek catchment. Magela Creek is a seasonally flowing tributary of the East Alligator River, with a catchment originating from headwaters on the Arnhem Land plateau. The Creek then flows into lowland woodland and subsequently into a large floodplain. In broad terms, Magela Creek can be divided into the sand tracts (sand bed channels) upstream of Mudginberri Billabong, and the Magela floodplain downstream of Mudginberri (Jansen & Nanson 2004). In more specific terms, Magela Creek comprises four sections:

- Escarpment channels that flow through deep narrow gorges, and which make up around one third of the Magela Creek catchment. These systems are fed by groundwater seeping into the fractured rock of the escarpment and can flow practically all year round. Escarpment rainforest vegetation species (dominated by *Allosyncarpia ternata*) are found in the gullies due to year round water supply.
- Sand bed anabranching channels⁴ with sandy levees. Magela Creek flows through sandy soils that may be more than 5 m deep along the creek channels. This is the section in which the Ranger mine is located.
- A series of billabongs and connecting channels at Mudginberri (termed the Mudginberri Corridor).
- A 200 km² seasonally inundated black-clay floodplain, at 2 to 5 m above sea level, with permanent billabongs, and a single channel that discharges into the East Alligator River approximately 40 km to the north of the RPA and, ultimately, Van Diemen Gulf.

The regional hydrology of the Magela catchment is influenced by the seasonality of the monsoon driven wet season (Wasson 1992). Following the onset of the wet season (usually in November) the sand aquifers in the channels of the Magela Creek middle catchment fill with shallow groundwater and begin flowing as interflow⁵ before surface flow commences. Flow in the creek usually occurs after antecedent rains of 200 – 300 mm in the catchment. There is an exponential decline of flow with time following a flood event, as flow from direct surface runoff ceases (Chapman 1990). Some water remains in groundwater-fed rock pools in the plateau and in swampy depressions and isolated billabongs in the lowlands until the next wet season (Vardavas 1988).

⁴ Alluvial (sandy) water courses comprised of large stable vegetated islands (Jansen & Nanson 2004).

⁵ Rainwater that infiltrates the soil surface and then moves through the upper layers of soil above the water table until it reaches a stream channel or returns to the surface at some point downslope from its point of infiltration

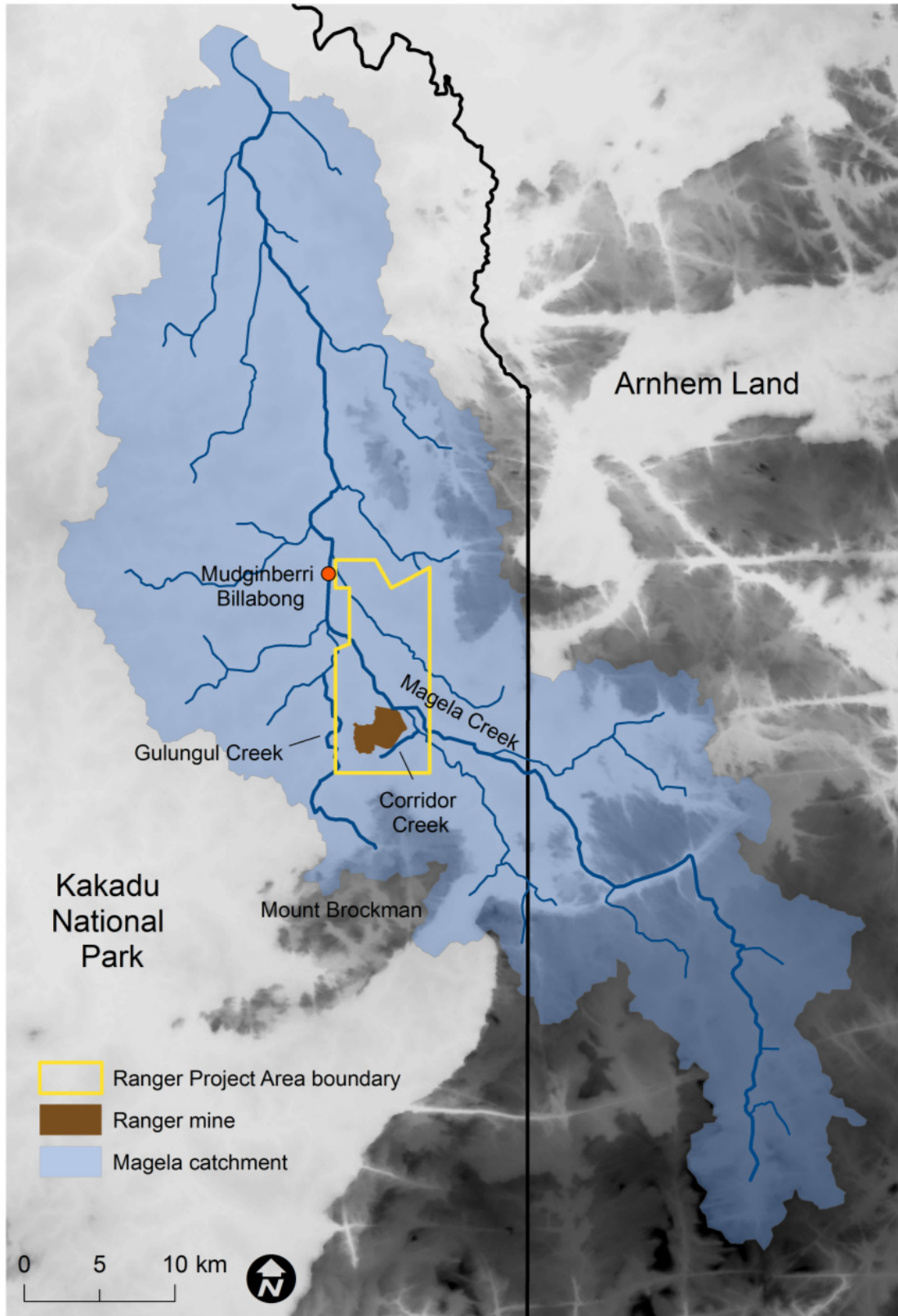


Figure 2-8: Magela catchment

2.4.7 Groundwater

A summary of the current understanding of the groundwater regime of the RPA, which has been characterised by extensive field studies undertaken over the past 30 years, is provided below.

2.4.7.1 Groundwater Occurrence and Units

The tropical, monsoon climate of the NT creates seasonal changes that drive groundwater flow into and out of the Ranger mine area. Put simply, groundwater occurrence and flow through the RPA can be divided into two systems. The shallow groundwater flow system is driven by recharge, evapotranspiration, surface water-groundwater interactions, and topography within the relatively permeable alluvium and weathered rock. The deeper bedrock groundwater flow system is also driven by topography and interaction with the shallow groundwater flow system, but rates of groundwater exchange between the shallow and deep systems are small because the deeper bedrock units have a relatively low permeability. The RPA receives copious amounts of precipitation over several months during the wet season and loses water through evapotranspiration over the dry season. Infiltration of water into the subsurface is limited to the wet season, whereas evapotranspiration removes water from the shallower subsurface throughout the year.

Within the shallower alluvial deposits, groundwater is encountered within the inter-granular pore matrix (referred to as primary porosity), while in the older, deeper fractured rocks groundwater is encountered within the faulted, sheared, cracked and brecciated⁶ rocks (referred to as secondary porosity). In the intermediate layers of weathered bedrock, groundwater can be found within both the primary and secondary porosity.

The alluvial and weathered rock aquifers are more connected to each other than they are to the fractured rock aquifer, as evidenced by similar seasonal variations in groundwater levels and groundwater quality (refer **Appendix 9**). These aquifers have in the past been referred to as the superficial aquifer. Due to the low porosity and significant depth from surface, groundwater within the fractured rock aquifers is weakly connected to near-surface processes, particularly rainfall-recharge. Leaney and Puhlovich (2006) provided evidence that the more permeable shallow aquifers had younger groundwater than the less permeable deeper aquifers, confirming that groundwater in the upper 10 m is modern, with deeper groundwater units containing "old" groundwater unaffected by shallower processes. The recharge rates in the bedrock aquifers corresponded with recharge rates suggested by earlier workers (e.g. Salama, *et al.* 1998). There is thus limited mixing of groundwater between shallow and deep aquifer units.

There has been considerable previous work on hydrogeological conceptual models that INTERA Incorporated has reviewed and further developed into a three-dimensional groundwater flow and water quality transport model (refer **Appendix 9**) The spatial extent or "domain" of this model is indicated in **Figure 2-9** below.

⁶ Brecciated means rock that has been mechanically broken by faulting and shearing, resulting in angular fragments.

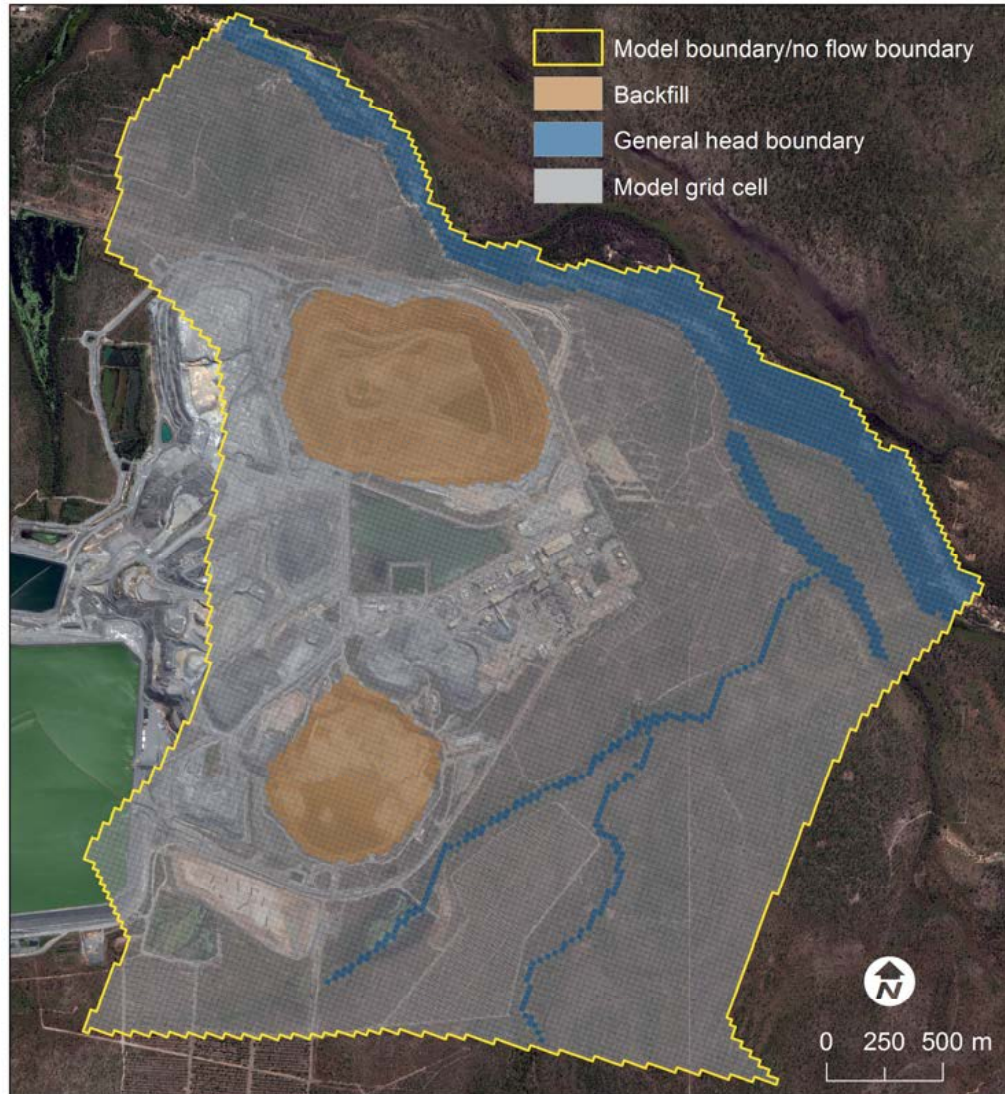


Figure 2-9: Domain for predictive groundwater model⁷

This predictive model of the groundwater compartment that hosts Pit 3 utilises the hydro-lithological units described by previous authors (sediments, weathered rock, un-weathered rock and fault pathways) as well as some new hydro-lithological units to further delineate and differentiate the deeper bedrock geology. This model has been calibrated and is being used to quantitatively predict the amounts, directions and rates of groundwater flow post-closure. These flow paths determine the water quality of the receiving groundwater and surface water environments for constituents of potential concern from the decommissioned Pit 3 (post-closure) and Ranger 3 Deeps to Magela Creek over 10,000 years (as discussed further in **Chapter 13**).

⁷ Modified from INTERA (2014).

2.4.7.2 Groundwater Quality

The groundwater quality characteristics of the RPA have been reported in a number of studies (e.g. Ahmad & Green 1986; Leaney & Puhlovich 2006; Salama & Foley 1997; Weaver, *et al.* 2010). The tropical, monsoon climate of the NT results in deep geological weathering processes, chemically changing various original minerals in the bedrock, such as muscovite, feldspar, biotite, chlorite, quartz and pyrite, which break down to an alteration assemblage containing kaolinite, smectite, goethite, hematite and amorphous silica to which the groundwater chemistry equilibrates. Similar to the surface water bodies on the RPA, the natural background hydrochemistry of the groundwater displays generally "lean" characteristics, typically exhibiting relatively low concentrations of total dissolved constituents. However, because of the slow passage (compared to surface water flow rates) of groundwater through the rocks, the longer contact time does allow a greater degree of mineralisation to occur.

The contemporary knowledge of baseline groundwater quality, after the above noted authors, recognised three aquifer units in the RPA:

- a) alluvial and b) lateritic aquifer;
- weathered bedrock aquifer; and
- fractured bedrock aquifer.

These studies interpreted water quality parameters either using pooled data across the three aquifers (Ahmad & Green 1986), or using data partitioned by aquifer type (Salama & Foley 1997; Weaver, *et al.* 2010). Salama and Foley (1997) described the groundwater chemistry in each aquifer with respect to major ions, pH and electrical conductivity (EC), and recognised the influence of lithology on groundwater chemistry. Weaver, *et al.* (2010) described the background groundwater quality in the vicinity of the tailings dam and considered that groundwater from the weathered bedrock and fractured bedrock aquifers exhibited a specific range of background chemistry (**Table 2-5**).

Table 2-5: Background groundwater in weathered and fractured bedrock aquifers

Element	Background concentration range
Ca	< 5 – 30 mg/L
Mg	5 – 50 mg/L
HCO ₃	50 – 250 mg/L as HCO ₃
Mn	< 5 – 350 µg/L
²²⁶ Ra	≥ 100 mBq/L
U	10 µg/L

Subsequent to these reports, ERA have continued investigating site-wide background hydrochemical conditions for each aquifer, applying US EPA guideline procedures to estimate background concentrations for constituents of potential concern. This has entailed a review of the historical groundwater bore database, and selecting groundwater samples collected between 1980 and 2013 that were considered to be unaffected by mining activity. A total of 135 groundwater monitoring bores on the RPA were reviewed (ERA LIMS database) with respect to concentrations of constituents of potential concern in groundwater. Of the 135 groundwater bores that were reviewed, 44 were considered to be potentially useful for determining groundwater background. The dataset was partitioned with respect to aquifer and rock-type, and screened to ensure that data from the different bores were evenly represented and statistically representative. The review identified that groundwater was heterogeneous within hydrogeological units with respect to constituents of potential concern. Baseline thresholds were developed for the different aquifers and rock-types, and are presented below in **Table 2-6**.

Table 2-6: Threshold concentrations of constituents of concern

Rock type	No of Samples	Aquifer	EC µS/cm	* F_Mn µg/g	* F_U µg/g	Mg mg/L	SO ₄ mg/L
Alluvium/Colluvium	46	1	166	30	0.19	3.7	1.2
Nanambu - Gneiss	132	2	271	132	4.6	25	0.8
Nanambu - Pegmatite	108	2	405	76	7.4	26	1.5
Cahill - Carbonate	12	2	N/A	4	4.6	31	0.6
Cahill - Chlorite	24	2	633	11	14	52	0.94
Nanambu - Gneiss	64	3	411	385	0.86	28	0.4
Nanambu - Pegmatite	12	3	436	274	1.6	5	0.7
Cahill Formation - M_Bt_Gt Schist	24	3	N/A	194	1.81	18	1.34

Reference: (ERA 2013) Report to the Alligator Rivers Region Technical Committee meeting # 31

* Filtered

2.4.7.3 Groundwater Flow Pattern and Behaviour

Groundwater flow patterns and behaviour across the RPA are primarily determined by hydrogeological factors such as water table gradients, lithology, degree of weathering, and most importantly, hydraulic properties (**Appendix 9**; Turner, *et al.* 2014). Hydrolithologic properties that influence groundwater flow include hydraulic conductivity, specific yield, specific storage and porosity (**Appendix 9**).

Groundwater levels are largely controlled by the combination of topography, climate, and surface water stage (**Appendix 9**; Salama & Foley 1997). Notwithstanding some localised perturbations due to the previous but temporary pit excavations and associated retention ponds and waste rock stockpiles, groundwater generally flows northward across the mine site towards Magela Creek, which is the natural landform with the lowest elevation (Salama & Foley 1997; Weaver, *et al.* 2010).

Annual groundwater level behaviour illustrates fluctuations that follow a similar, distinctive wet season – dry season oscillation akin to, but in a more subdued form than, the typical surface water flow hydrograph, typically peaking following wet season recharge and declining during the dry season recession (**Appendix 9**) (**Figure 2-10**). Fluctuations in groundwater levels show very similar patterns in different locations, lithologies, and depths. Along Magela Creek, water exchange between the subsurface and flowing creek depends on groundwater and surface water dynamics (**Appendix 9**). In general, groundwater heads appear to increase several metres during the first one to two months of the wet season and then decrease several metres within the first two to three months of the dry season. This steep rise and fall pattern is observed at bores with shallow, intermediate, and deep screened intervals near both pits (**Appendix 9**). This pattern was observed before, during, and following the 1981 to 2012 mining period for Pits 1 and 3. When surface water flow ceases in Magela Creek and Corridor Creek, subsurface groundwater flow continues through the deeper alluvial sediments of the creek beds throughout the dry season (Ahmad, *et al.* 1982).

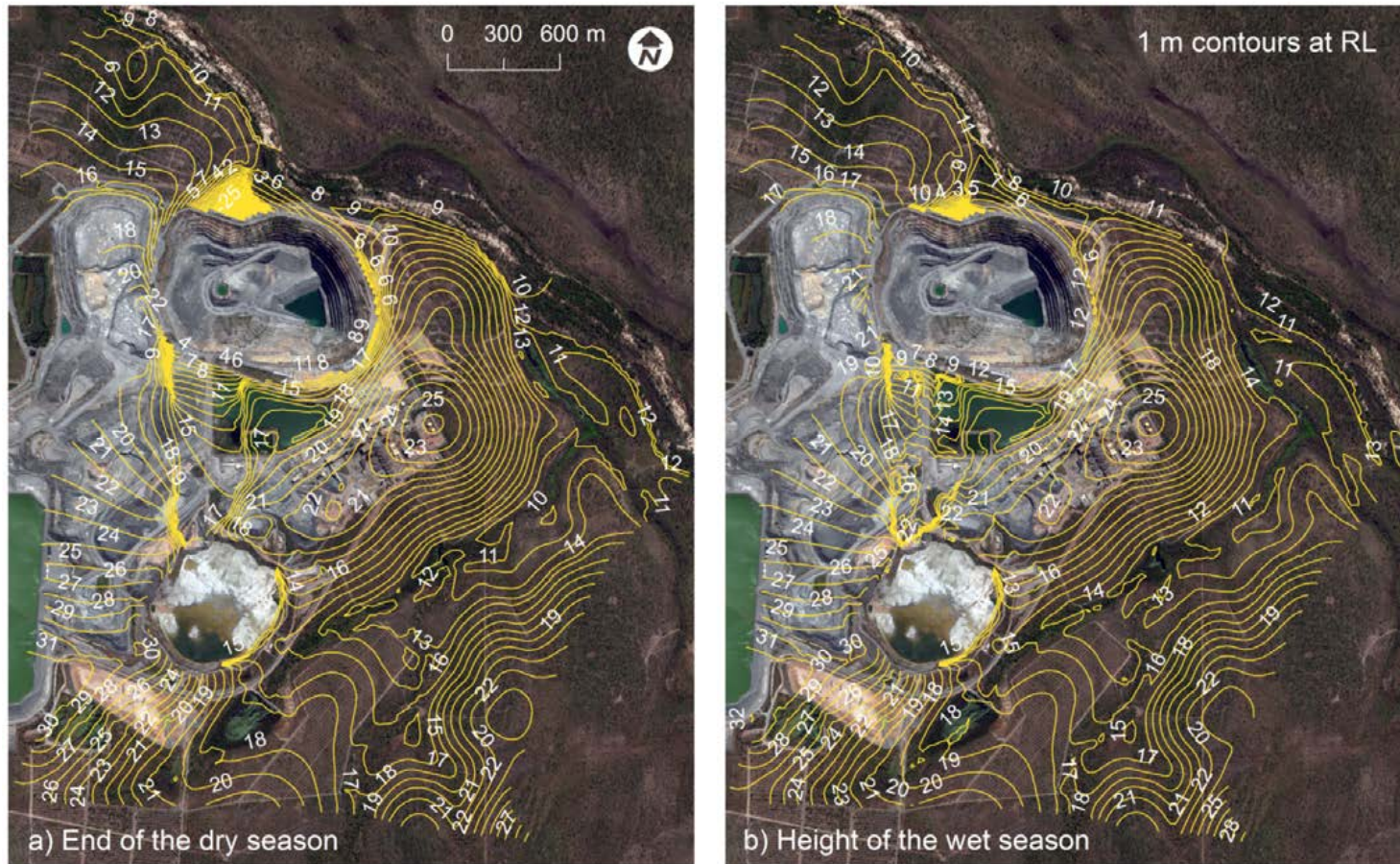


Figure 2-10: Seasonal groundwater head contours⁸

⁸ Modified from INTERA (2014; p. 192)

2.4.8 Radiation

The existing radiation environment within the RPA can be divided into two categories: the pre-mining radiation environment that existed prior to operations at Ranger mine and the current radiation environment that exists prior to the commencement of the Project.

This section describes the radiation environment for both the pre-mining and current operations. An introduction to radiation and information regarding many of the terms used in this section is provided in **Appendix 8**.

2.4.8.1 Pre-mining Radiation Environment

Terrestrial

The pre-mining radiological conditions for the Ranger mine have been investigated and reported by the Supervising Scientist (Bollhöfer, *et al.* 2014). The study was based on pre-mining aerial surveys, with extensive ground measurements to provide calibration of the final external gamma radiation dose rates. Ground measurements taken for soil ^{226}Ra concentrations and ^{222}Rn exhalation rates were then correlated to the airborne gamma results to obtain averages for the area. The summary of results from this paper is provided in **Table 2-7**.

Table 2-7: Pre-mining radiological baseline determined by the Supervising Scientist

Location	Gamma dose rate ^{ave} ($\mu\text{Gy/h}$)	^{226}Ra concentration ^{ave} (Bq/kg)	^{222}Rn exhalation ^{ave} (Bq/m ² /s)
Pit 1	0.87 \pm 0.18	1880 \pm 430	2.7 \pm 0.8
Pit 3	0.44 \pm 0.09	880 \pm 200	1.3 \pm 0.4
Djalkmarra land application area	0.20 \pm 0.03	310 \pm 70	0.46 \pm 0.14
Corridor Creek land application area	0.14 \pm 0.02	170 \pm 40	0.25 \pm 0.08
Tailings dam	0.11 \pm 0.01	110 \pm 30	0.16 \pm 0.05
Magela land application area	0.12 \pm 0.01	110 \pm 30	0.17 \pm 0.05
Retention Pond 1 (RP1)	0.11 \pm 0.01	90 \pm 20	0.14 \pm 0.04
RP1 land application area	0.11 \pm 0.01	90 \pm 20	0.13 \pm 0.04
Jabiru East land application area	0.10 \pm 0.01	90 \pm 20	0.13 \pm 0.04
Jabiru	0.11 \pm 0.01	90 \pm 20	0.14 \pm 0.04
Ranger Project Area	0.11 \pm 0.01	110 \pm 20	0.15 \pm 0.05

These results show that the average external gamma dose rate in areas removed from uranium mineralisation ranges between 0.10 and 0.20 $\mu\text{Gy/h}$, with the overall average for the RPA being 0.11 $\mu\text{Gy/h}$. Dose rates above the orebodies were, as expected, much higher, reaching an average of 0.87 $\mu\text{Gy/h}$ above Pit 1.

Similar patterns to the gamma dose rates were observed for both average soil radium concentrations and average radon exhalation, i.e. average ^{226}Ra concentrations over the orebodies (880 – 1800 Bq/kg) were much higher than for the surrounding area (110 Bq/kg), as were the average ^{222}Rn flux densities over the orebodies (1.3 – 2.7 Bq/m²/s) relative to the surrounding area (0.15 Bq/m²/s).

Water

The existing groundwater regime of the RPA has been described previously in this chapter (refer **Section 2.4.7**). Three distinct regional aquifer types were listed: alluvial, weathered and fractured. Recently, ERA conducted a statistical analysis of historic water quality data from 135 bores located within the RPA to determine the site-wide background conditions for each aquifer in each geological unit. The results for uranium and radium baseline groundwater concentrations are presented in **Table 2-8**. Groundwater radionuclide concentrations worldwide range significantly depending upon the amount of uranium mineralisation found in the particular aquifer therefore no specific data has been provided as a comparison. It is expected that these concentrations would be at the higher end of this range, given the amount of naturally occurring uranium in the region.

Table 2-8: Estimated baseline groundwater radionuclide concentrations

Aquifer type	Geological formation with mineralogy	^{238}U (mBq/L)	^{226}Ra (mBq/L)
Alluvial	Nanambu – Gneiss	2.4	12
Weathered	Nanambu - Gneiss	58	72
Weathered	Nanambu - Pegmatite	93	96
Weathered	Cahill - Carbonate	57	–
Weathered	Cahill - Chlorite	175	–
Fractured	Nanambu - Gneiss	11	183
Fractured	Nanambu - Pegmatite	20	–
Fractured	Cahill Formation - Muscovite-biotite-garnet schist	23	108

The radionuclide concentration in Magela Creek, upstream of Ranger mine, is routinely monitored throughout the wet season by both ERA and the SSD and water quality at this location is considered to be unaffected by mining and therefore representative of baseline conditions. The statistical results of Magela Creek upstream monitoring conducted by ERA for the 2010 to 2013 wet seasons are presented in **Table 2-9**. These results compare favourably with the wet season median upstream ^{226}Ra concentration reported by the Supervising Scientist for the period 2001 – 2012 of 1.8 ± 0.9 (Medley & Bollhöfer 2013).

Table 2-9: Magela Creek upstream radionuclide concentrations (2010 – 2014 average)

Magela Creek upstream	²²⁶ Ra (mBq/L)	²³⁸ U (mBq/L)
Average	2.1	0.70
Minimum	1.2	0.16
Maximum	4.0	2.6
Standard deviation	0.9	0.48

2.4.8.2 Current Radiation Environment

The Ranger mine has been operational for over 30 years. During that time there has been extensive monitoring of radiation parameters for exposures to the workforce and nearby members of the public, and to the environment generally. Monitoring is undertaken by ERA, as well as independently by Australian and NT government agencies. The data provided in this section has been summarised from this historical monitoring data and from a targeted radiation environment study conducted as part of the Project.

This new study commenced in 2012 and monitored airborne radon concentrations and external gamma dose rates around proposed Project areas and current occupied areas within the RPA, and in Jabiru. Radionuclide concentrations in dust deposits surrounding the Project area were also monitored. The results of this monitoring are provided in **Table 2-10** and **Table 2-11**, with monitoring locations shown in **Figure 2-11**.

The average radon concentrations measured at all locations fall within the typical worldwide range for radon in outdoor air of 1 to 100 Bq/m³ (UNSCEAR 2000), although areas closer to current operations are, as expected, tending towards the higher end of the range. The concentrations at Jabiru and the Jabiru Airport (in Jabiru East) are consistent with those reported as the baseline (non-mining) component of 23 and 30 Bq/m³, respectively (Martin, *et al.* 2004).

Several of the sites (particularly the Pit 3 viewing platform) are close to operational areas and show elevated dose rates but, in general, results are comparable to the pre-mining dose rates determined by the Supervising Scientist (Bollhöfer, *et al.* 2014), refer **Table 2-7**.

Table 2-10: Current gamma dose rates and radon concentrations surrounding Ranger

Location		Gamma dose rate _{ave} ($\mu\text{Gy/h}$)	²²² Rn concentration _{ave} (Bq/m^3) (Range in brackets)
1	Pit 3 viewing platform	0.31	81 (51 – 126)
2	South of Magela land application area (B)	0.08	69 (45 – 96)
3	Magela Creek north Pit 3	0.15	74 (45 – 144)
4	Magela Creek east Pit 3	0.07	45 (25 – 57)
5	Opposite Ranger car park	0.12	56 (45 – 72)
6	Exploration offices (Jabiru East)	0.11	46 (36 – 61)
7	Jabiru Airport	0.07	37 (25 – 54)
8	Ranger mine village	0.07	48 (26 – 72)
9	Exploration decline offices	0.16	82 (39 – 111)
10	Jabiru water tower	0.06	32 (9 – 57)

Table 2-11: Current radionuclides in dust deposited in the vicinity of Ranger mine

Location ID		Radionuclide deposition rate (Bq/day)		
		²³⁸ U	²³⁰ Th	²²⁶ Ra
1	Pit 3 viewing platform	0.025	0.027	0.104
2	South of Magela land application area (B)	0.009	0.008	0.032
3	Magela Creek north Pit 3	0.009	0.009	0.041
4	Magela Creek east Pit 3	0.006	0.006	0.024
5	Opposite Ranger car park	0.022	0.019	0.087



1	Pit 3 viewing platform	6	Exploration offices (Jabiru East)
2	South of Magela land application area (B)	7	Jabiru airport
3	Magela Creek north Pit 3	8	Ranger mine village
4	Magela Creek east Pit 3	9	Exploration decline offices
5	Opposite Ranger mine car park	10	Jabiru water tower

Figure 2-11: Location of current radiation environment monitoring sites

A large soil sampling survey was conducted in 2010 on the RPA as part of the exploration program. Uranium concentrations were measured in 479 soil samples collected from the top 200 mm of the soil profile. The results for ^{238}U are provided in **Figure 2-12**. The average uranium concentration (^{238}U) was 0.041 ± 0.075 Bq/g;⁹ this is consistent with typical global concentrations, for which the median is approximately 0.035 Bq/g, with a range of 0.016 – 0.11 Bq/g (UNSCEAR 2000).

⁹ The \pm denotes a range, which is established using a statistical calculation of the "standard deviation". The large range simply reflects a broad range of values measured.

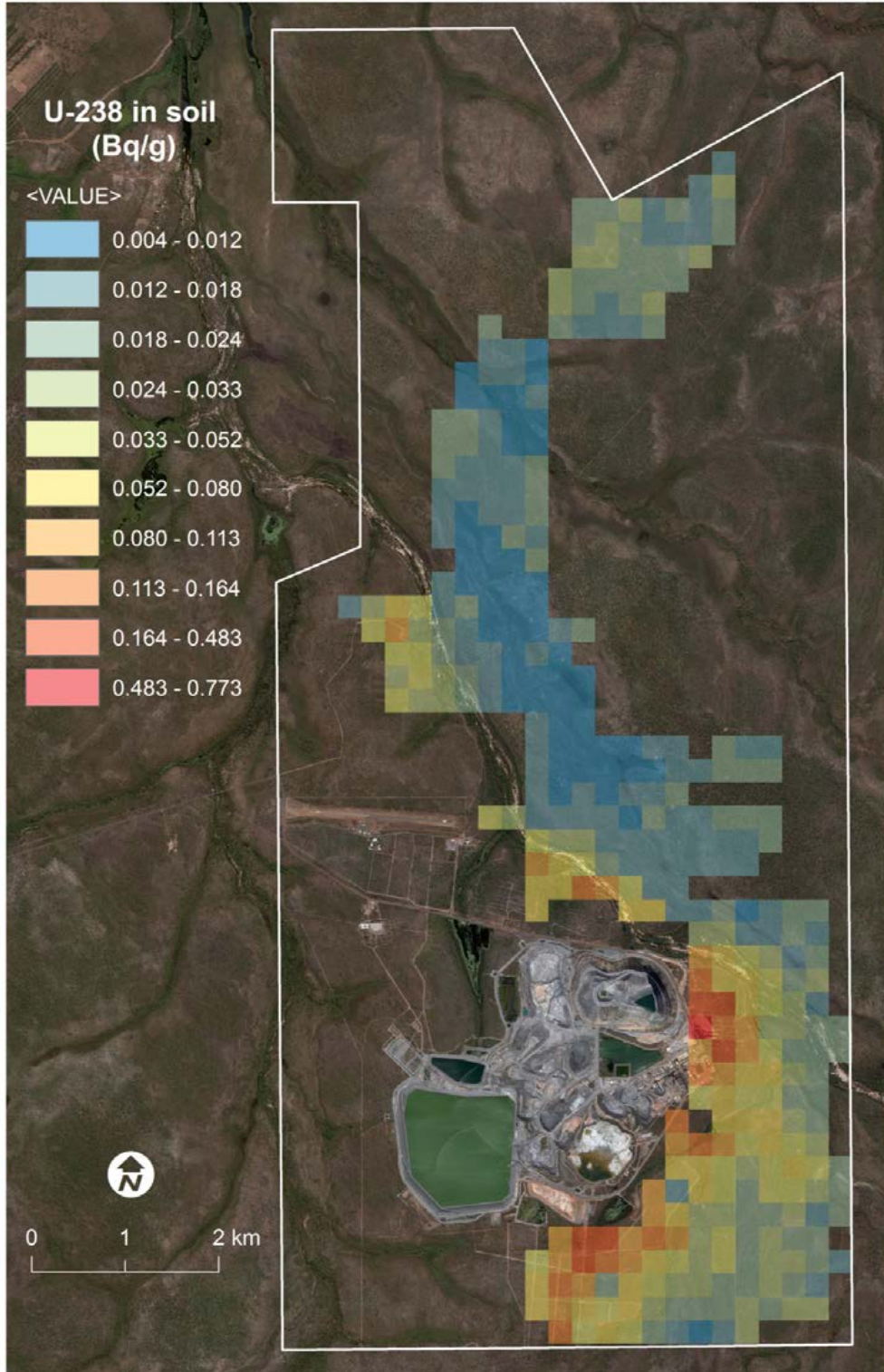


Figure 2-12: Uranium concentrations in surface soils on the RPA

High volume air sampling for long lived alpha radiation in dust and radon decay product monitoring has been conducted at Jabiru water tower and Jabiru Airport (**Figure 2-11**) since 1994, and at the Ranger mine village since 2007. The results of this monitoring are presented in **Figure 2-13** and **Figure 2-14**. Both figures show seasonal variation, with the dry season (June to December) results being higher than those of the wet season. These results include both background and any current mining operations components and overall are low. This has been confirmed by the SSD in their annual reports, where they show similar results from their monitoring for radon decay products and dust in Jabiru every year along with calculated member of the public doses.

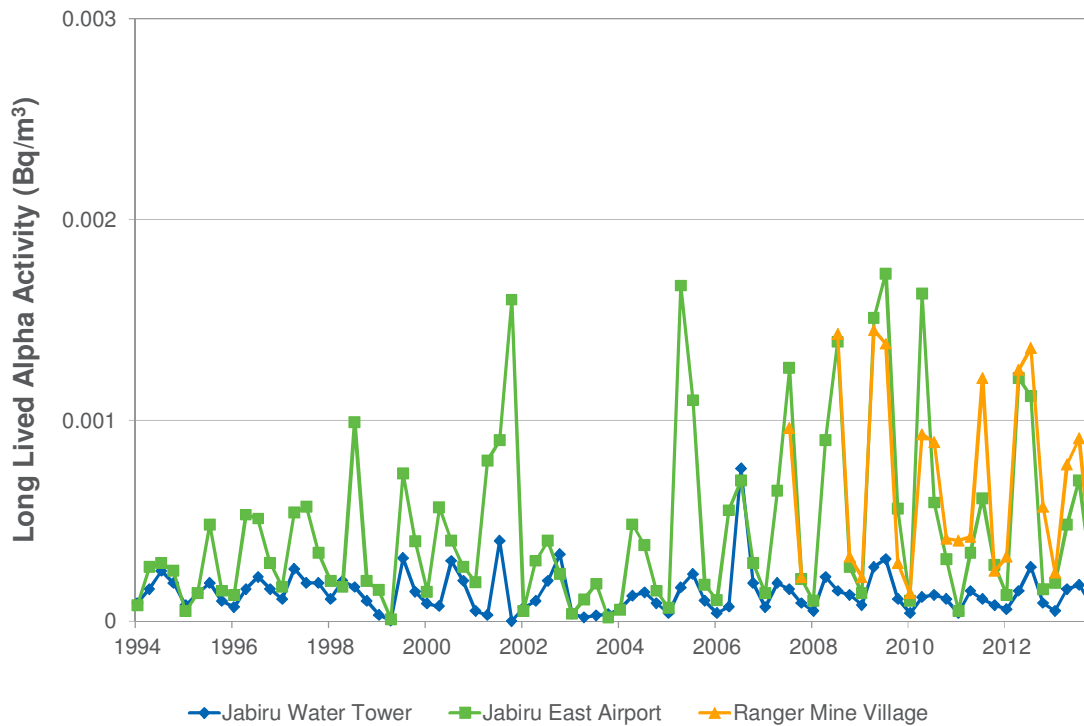


Figure 2-13: Radiation (long lived alpha) in airborne dust concentrations

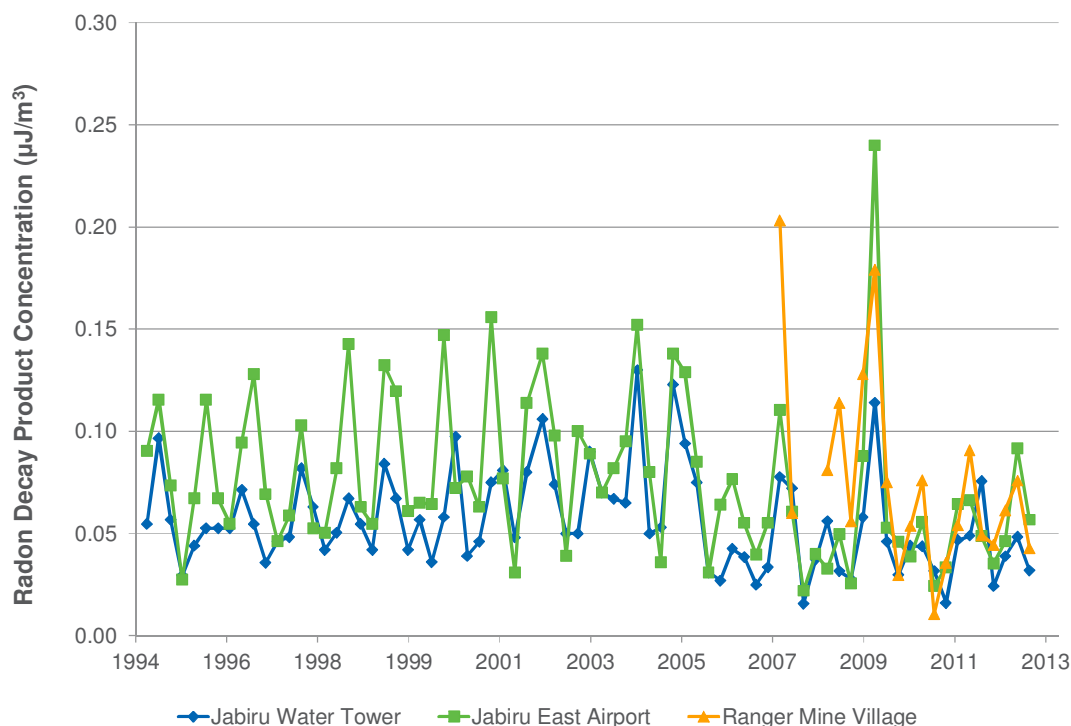


Figure 2-14: Radon decay product concentrations in surrounding areas

Surface water

The radionuclide concentration in Magela Creek, downstream of the Ranger operation, is routinely monitored throughout the wet season as part of the same program that monitors upstream (reported as part of the pre-mining environment). Results for 2010 – 2013 are summarised in **Table 2-12**.

Table 2-12: Magela Creek downstream radionuclide concentrations (2010 – 2013)

Magela Creek upstream	²²⁶ Ra (mBq/L)	²³⁸ U (mBq/L)
Average	2.5	1.9
Minimum	1.1	0.48
Maximum	13	6.1
Standard deviation	2.3	1.6

Overall these results show a slightly higher radium concentration at the downstream site. This is most likely due to current operations but could also be partially attributed to the Magela Creek flowing through an area of naturally elevated radionuclide concentrations. Assessments of risk conducted later in this document have assumed that the increased concentrations are entirely mine sourced as a worst case situation.

Groundwater

Monitoring of uranium in groundwater surrounding the Ranger 3 Deeps mineral resource was conducted during 2013. Results are presented in **Table 2-13** along with radium monitoring results for those bores that form part of the routine Ranger groundwater monitoring program. The locations of these bores are provided in **Figure 2-15** along with details of the aquifer type in which they are screened. The majority of results are below the baseline concentrations estimated by ERA and presented in **Table 2-8**, the exception being bore 23562 that appears to have slightly elevated uranium concentrations; however the baseline data for the alluvial aquifer is from a different formation and this may explain the difference.

Table 2-13: Average uranium and radium concentrations in groundwater surrounding Ranger 3 Deeps

Bore	Aquifer type	²³⁸ U (mBq/L)	²²⁶ Ra (mBq/L)
OB27	Weathered and fractured	1.7	10
83_1deep	Fractured	2.7	5
23562	Alluvial	8.2	–
MC_12DEEP	Weathered	0.19	–
MC27DEEP	Weathered	1.1	–



Figure 2-15: Groundwater monitoring locations in the vicinity of Ranger 3 Deeps

Flora and fauna

Aboriginal people living a traditional lifestyle in Kakadu consume bush foods that contain natural background concentrations of radionuclides. A summary of the available data on the uptake of radionuclides into aquatic and terrestrial foodstuffs was completed by the Environmental Research Institute for the Supervising Scientist (ERISS) and published in their annual research summary (Ryan, *et al.* 2009).

The paper details a model diet for local Aboriginal people, where the information used to derive the model diet was obtained from the following sources:

- A questionnaire developed by ERISS and distributed to local Aboriginal people in 2006.
- Information provided by a local supplier of meats to Aboriginal outstations.
- Data gained from the ERISS Kakadu bush food project over the last 11 years.

The authors collated all available data on radionuclide activity concentrations in bush foods (from natural sources) and used this to determine a baseline radiation dose to Aboriginal people living in the region from ingestion of foodstuffs of 0.84 mSv per year. This radiation dose is irrespective of the mining activity and reflects the natural state for Aboriginal people.

ERISS have included all this data, along with more recently collected information into a database. This database can determine bush food concentration ratios from which the ingestion dose from various parameter inputs and a variety of situations can be calculated (Ryan, *et al.* 2011). The database contains more than 1,500 individual records of radionuclide activity concentrations in various plants, animal tissues and environmental media. All information in the database has associated geospatial information to allow for spatial analysis. ERISS has also developed a bush foods geospatial information system (Walden 2011) called the "bushtucker database". This contains 30 years of data on radionuclide concentrations in traditional bush foods and is available to the public.

A summary of radionuclide concentrations published by ERISS for key flora and fauna of the Alligator Rivers Region is provided in **Table 2-14**.

Table 2-14: Radionuclide concentrations in local bush foods

Bush food	Radionuclide activity concentrations (mBq/g fresh weight) ¹		
	²³⁸ U	²²⁶ Ra	²¹⁰ Pb
Wallaby flesh ²	0.025	1.9	0.7
Magpie goose ³	0.004	0.03	0.05
Mussels ^{1,4}	2.7 – 7.6	450 – 2,500	360 – 800
Turtle flesh ²	0.007	0.16	0.098
Fish ²	0.005 – 0.085	0.22 – 3.5	0.043 – 0.20
File snake ²	0.021	0.031	0.037
Cheeky yams ³	0.06	0.26	0.042
Various fruits ⁵	0.020 - 0.028	0.26 – 71	0.042 – 11
Water lily ²	0.96	5.1	4.3

Notes:

1 – Mussels from Mudginberri Billabong, data provided is dry weight

2 – Source (Ryan, *et al.* 2009)

3 – Source (Martin & Ryan 2004)

4 – Source (Bollhöfer, *et al.* 2011)

5 – Source (Ryan, *et al.* 2005)

2.4.8.3 Comparison to World Environment

The estimated pre-mining radiation environment has been compared with the current radiation environment surrounding the Project and typical world ranges, where available. This information is summarised in **Table 2-15** and shows that the current environment is not significantly different from the pre-mining or baseline conditions, and that radiation levels on the RPA are generally elevated compared to world medians.

Table 2-15: Comparison of pre-mining and current radiation environment to typical world medians

Media and location	Pre-mining environment	Current environment	World median ¹ (ranges in brackets)
Gamma dose rate in general RPA ($\mu\text{Gy/h}$)	0.11 ± 0.01	0.10 ± 0.04	0.057 (0.018 – 0.093)
Gamma dose rate near Pit 3 ($\mu\text{Gy/h}$)	0.44 ± 0.09	0.31 ± 0.14	
²²⁶ Ra in soils of the RPA (Bq/kg)	110 ± 20	–	35 (17 – 60)
²³⁸ U in soils of the RPA (Bq/kg)	–	41 ± 75	35 (16 – 110)
²²⁶ Ra in Magela Creek surface water (mBq/L)	2.1 ± 0.9	2.5 ± 2.3	-
²³⁸ U in Magela Creek surface water (mBq/L)	0.70 ± 0.48	1.9 ± 1.6	-
²²⁶ Ra in groundwater of the RPA (mBq/L)	12 – 108	5 – 10	-
²³⁸ U in groundwater water (mBq/L)	2.4 – 175	0.19 – 8.2	-
Radon in air (RPA) (Bq/m ³)	–	25 – 144	10 (1 – 100)
Radon in air (Jabiru) (Bq/m ³)	23	9 – 57	

1 – source (UNSCEAR 2000)

2.5 BIOLOGICAL ENVIRONMENT SETTING

2.5.1 Bioregions

Bioregions for the Australian continent have been created as part of a national classification of ecosystems, termed the Interim Biogeographic Regionalisation of Australia, to facilitate better planning and implementation of national conservation initiatives in Australia (Thackway & Cresswell 1995). There are currently 89 bioregions and 419 sub-regions in Australia, and each is based on similarities in climate, geology, landform, native vegetation and species information.

A small (0.3 km²) section in the northeast of the RPA is contained within the Arnhem Plateau Bioregion. Most of the RPA (99%) is located in the northeast section of the 28,520 km² Pine Creek Bioregion (**Figure 2-16**). The features of the Pine Creek Bioregion are summarised from Environment Australia (2008):

- a landscape broadly consisting of hilly to rugged ridges with undulating plains;
- vegetation communities that include eucalypt woodlands, with patches of monsoon forests;
- major land uses that include conservation, pastoralism, intensive rural freehold blocks, horticulture, mining, and indigenous freehold; and
- major population centres at Batchelor, Adelaide River, Pine Creek and Jabiru.

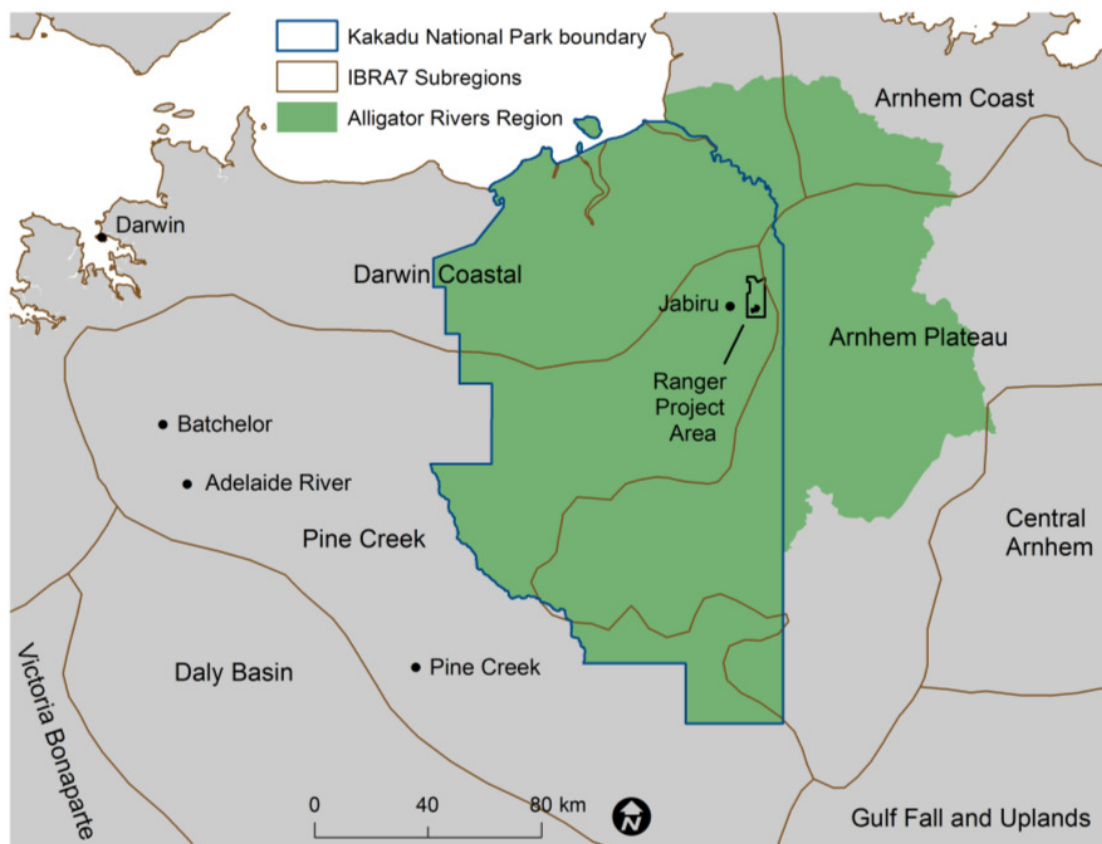


Figure 2-16: Bioregions in the vicinity of Kakadu, the Alligator Rivers Region, and the RPA

2.5.2 National Parks and Protected Areas

The Project is located on the RPA which is surrounded by, or within 150 km of national parks or protected areas (**Figure 2-17**). These include:

- Kakadu National Park, which surrounds the RPA. Kakadu is located within the Alligator Rivers Region of the NT and covers an area of approximately 19,800 km². Kakadu is a Commonwealth National Park jointly managed by Traditional Owners and Parks Australia through the Kakadu National Park board of management. The board is

represented by scientists and Traditional Owners, of which the latter form a majority. The park is world heritage listed for its outstanding natural and cultural values. The wetlands are listed as Wetlands of International Importance under the Ramsar convention, meeting all nine selection criteria, and support approximately three million waterbirds as well as large populations of many other vertebrate and invertebrate species (BMT WBM 2010).

- Wardekker Indigenous Protected Area, which covers an area of 13,950 km², and includes a large proportion of the Arnhem Land Plateau – which is noted for its ecologically sensitive sandstone heathland communities (Environment Australia 2009). The area is managed by the Wardekker land management agency.
- The Mary River National Park, which lies approximately 115 km west of the RPA and consists of 14 separate (discontiguous) land parcels. The park is managed by the Parks and Wildlife Service of the NT, and a draft joint management plan with traditional Aboriginal owners is in progress. The park contains cultural heritage sites (indigenous and non-indigenous) and extensive wetlands, and has recreational value (e.g., fishing).
- Nitmiluk (Katherine Gorge) National Park, which is approximately 123 km south of the RPA. The park is owned by the Jawoyn Aboriginal people, and jointly managed with the Parks and Wildlife Service of the NT. The park is characterised by the presence of dissected sandstone formations with gorges and sites of cultural significance.

Given the significant distances and small localised nature of the Project it is highly unlikely that there would be any influence or potential for environmental impact to the Wardekker, Mary River or Nitmiluk parks. Subsequent discussion therefore focusses on the adjacent and downstream Kakadu and the biological setting of the RPA.

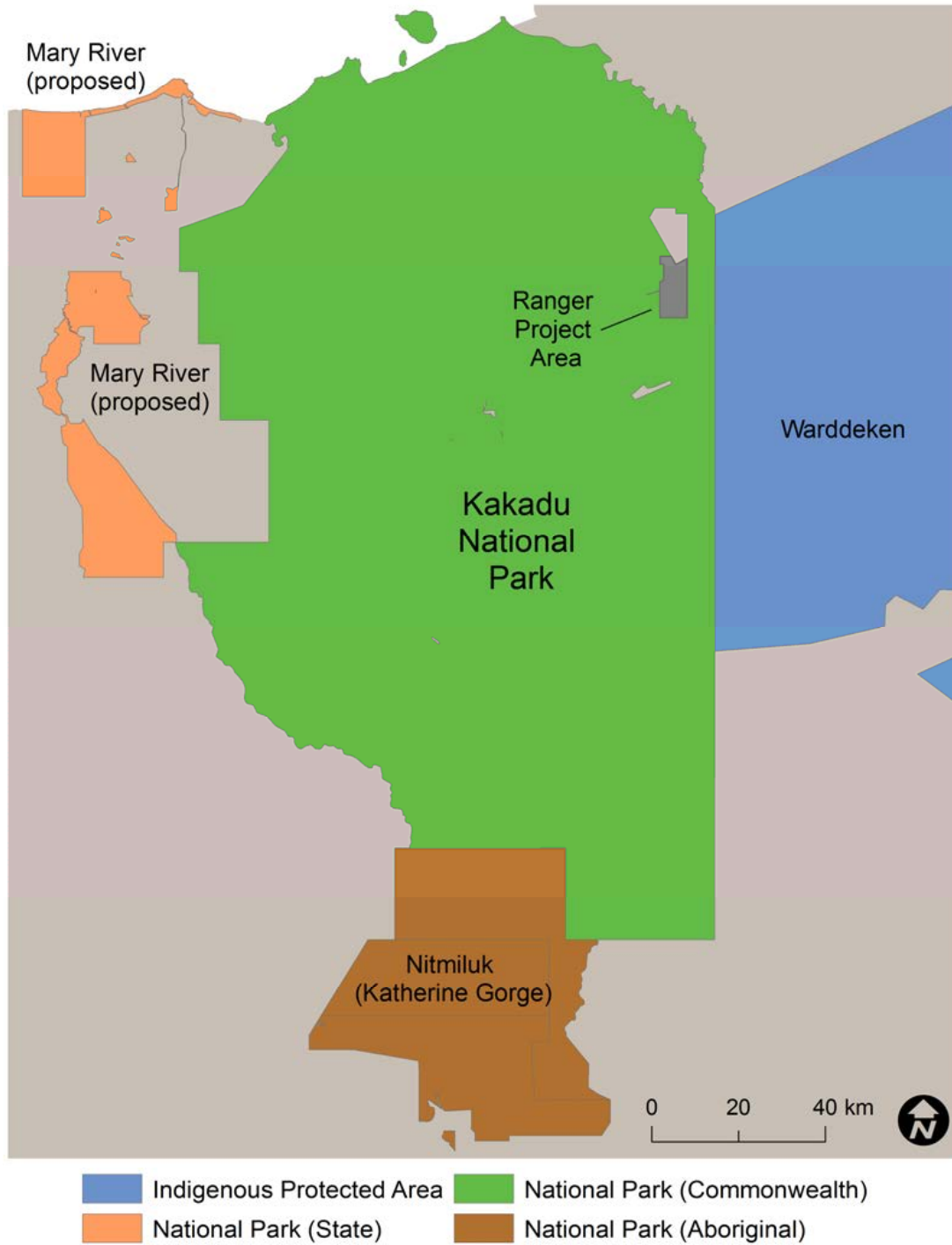


Figure 2-17: Location of protected areas in the vicinity of the RPA

2.5.3 Ecologically Sensitive Habitats

The entire Kakadu is listed as a single wetland site under the Ramsar Convention (The Convention on Wetlands of International Importance), which includes 6,830 km² of wetlands. The Ramsar convention prescribes the listing of wetland areas of international importance due to their ecological and hydrological features (BMT WBM 2010). The wetlands of Kakadu are also part of an East Asian-Australasian Flyway that was established to protect areas used by migratory shorebirds. Kakadu contains 39 migratory bird species that are listed under the Bonn Convention, 52 bird species listed under the China-Australia Migratory Bird Agreement, and 49 bird species listed under the Japan-Australia Migratory Bird Agreement (DNP 2007).

One ecological community that occurs in the Alligator Rivers Region is listed as endangered under the EPBC Act: the Arnhem Plateau Sandstone Shrubland Complex. The Complex is located approximately 1.5 km from the eastern boundary of the RPA, and approximately 4 km from the location of proposed infrastructure for the Project. This ecological community was listed as endangered because it is threatened by inappropriate fire regimes and invasion by weeds and feral animals (Department of the Environment 2014b).

There are no sensitive environments (e.g. significant breeding sites, seasonal habitats or wetlands areas) of special significance (including Ramsar sites) within the RPA or the footprint of Ranger mine. The RPA is surrounded by (but separate from) the Ramsar wetlands of Kakadu.

2.5.4 Terrestrial Habitats

A number of terrestrial flora and terrestrial vertebrate fauna surveys and monitoring programs have been undertaken on the RPA (**Figure 2-18**). The focus of many of these surveys has been on monitoring, such as the impact of dry season irrigation on vegetation in the land application areas over time (e.g. Addison & Gardener 2005), or assessing environmental impacts through a whole ecosystem approach to monitoring that examined biota in a number of billabongs on the RPA over time (Corbett, *et al.* 2004). Other surveys have focussed on pre-impact baseline information in areas that have been cleared of vegetation for mine infrastructure. The most recent survey on the RPA was conducted in September 2013 and is described in **Chapter 9** and **Appendix 12**.

2.5.4.1 Vegetation Communities

Although there is a 1:1,000,000 scale map of vegetation communities for the NT (Wilson, *et al.* 1990), the vegetation habitat map (scale 1:250,000) for Kakadu is at a larger scale and includes the RPA (Schodde, *et al.* 1987). The latter has therefore been used as a key source document for this section. Vegetation communities have also been mapped in greater detail on the RPA (refer **Appendix 12**).

The map describes 19 habitat (vegetation) types in Kakadu, of which four occur in the RPA. The habitat types are based on their relevance to vertebrate fauna habitat. A summary of the habitat types on the RPA and surrounding Kakadu, as classified by Schodde *et al.* (1987), can be found in **Figure 2-19** and **Table 2-16**.

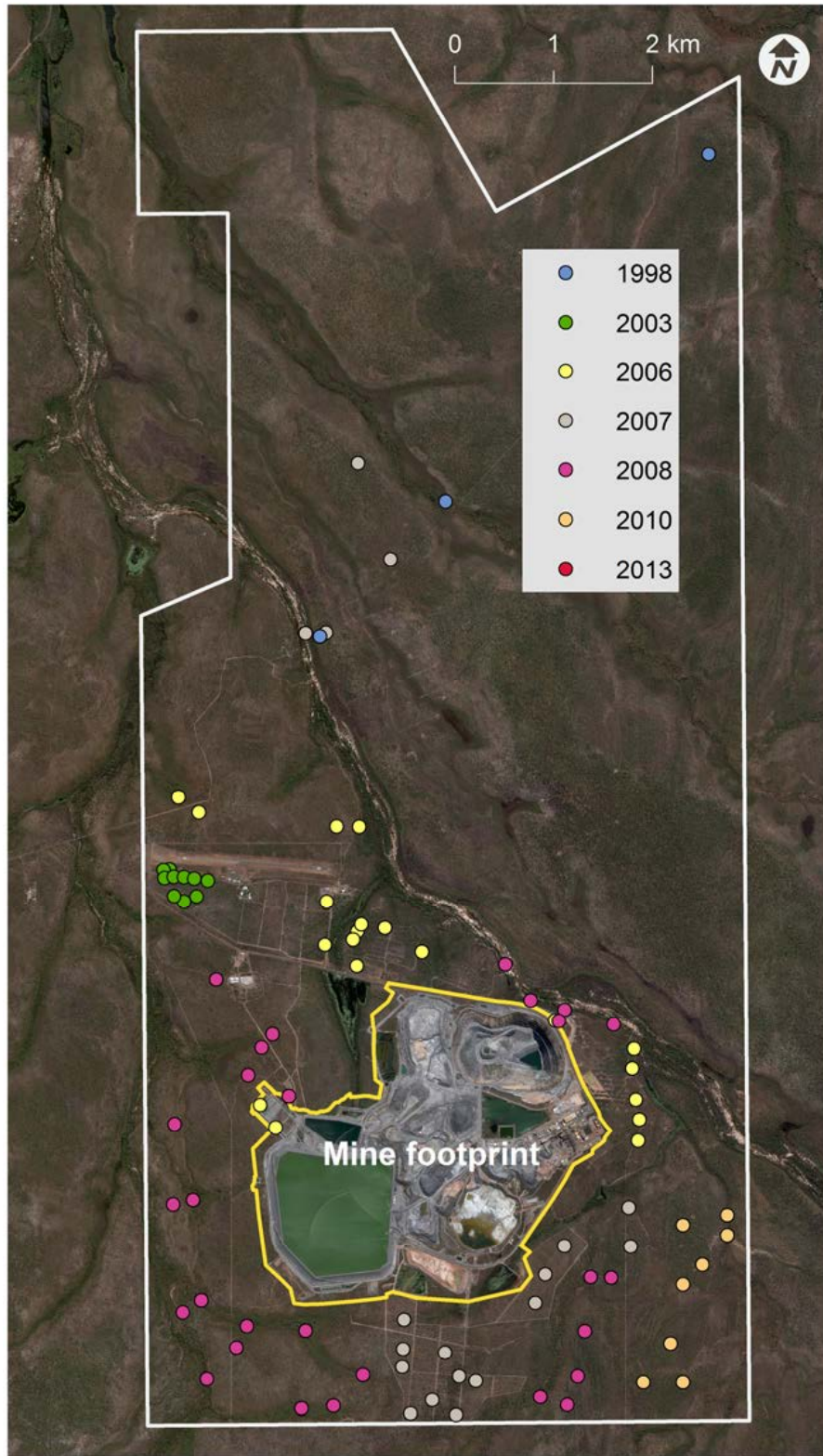


Figure 2-18: Flora and fauna survey locations within the RPA

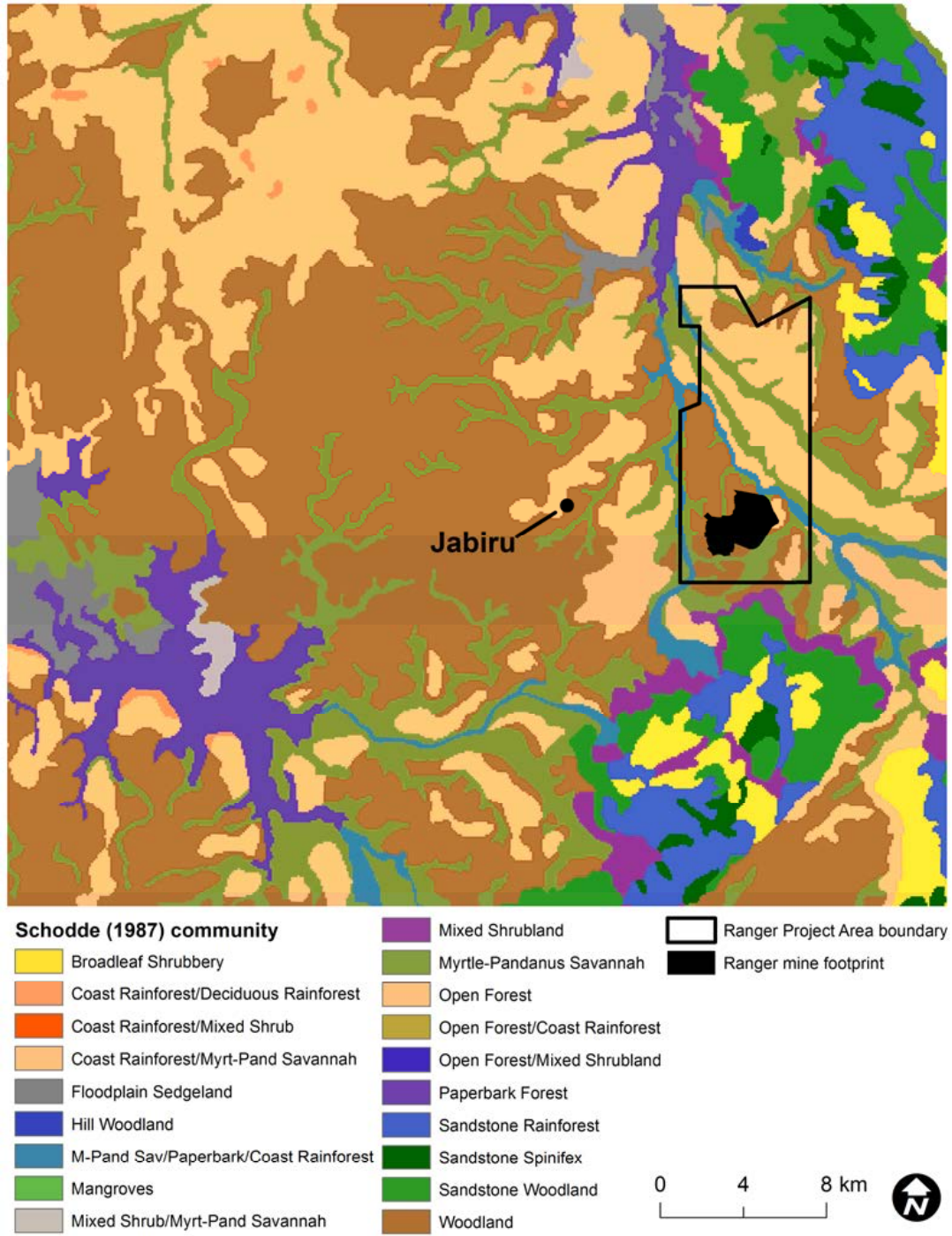


Figure 2-19: Vegetation of the RPA and surrounding Kakadu (Schodde, *et al.* 1987)

Table 2-16: Summary description of vegetation types present on the RPA (based on Schodde, *et al.* 1987)

Habitat	Summary description
1	<p>Myrtle-Pandanus Savanna/Paperbark Forest/Coastal Deciduous Rainforest</p> <p>Paperbark forests line freshwater creek systems and the edges of billabongs and are dominated by <i>Melaleuca</i> spp. Canopy can be 15 to 20 m in height and can vary greatly from open to almost closed. The shrub layer varies from sparse to dense and comprises <i>Acacia</i> spp., <i>Ficus</i> spp. on marginal areas and the ubiquitous freshwater mangrove <i>Barringtonia acutangula</i>. <i>Pandanus aquaticus</i> and <i>B. acutangula</i> line streams and channels. In zones edging woodland (which is often the case on the RPA), the trees are wider spaced and often form an ecotone with myrtle-pandanus savanna. In this ecotone area other eucalypts, bloodwoods and other savanna trees co-dominate with the paperbarks. Coastal deciduous rainforest habitat is not present on the RPA according to the description of Schodde <i>et al.</i> (1987); therefore a summary description will not be given.</p>
2	<p>Myrtle-Pandanus Savanna</p> <p>Consists of grassland with small open pockets of woodland, mixed shrubland and rainforest trees, interspersed with strips of pandanus (<i>Pandanus spiralis</i>) along the edges of floodplains and with paperbarks <i>Melaleuca</i> spp., along creeks and streams. Tall trees from such as <i>Corymbia</i> spp. and <i>Eucalyptus</i> spp. are sparingly present. A very patchy shrub layer of <i>Melaleuca viridiflora</i>, <i>M. nervosa</i> and <i>P. spiralis</i> occur. Common grasses include annuals from genera such as <i>Digitaria</i>, <i>Ectrosia</i>, <i>Panicum</i>, <i>Schizachyrium</i> and <i>Sorghum</i> and perennials grasses including those from genera such as <i>Eriachne</i> and <i>Themeda</i>. Sedges (Cyperaceae) are also a common component of the ground cover.</p>
3	<p>Open Forest</p> <p>Tall (12 to 20 m) open forest dominated by <i>Eucalyptus miniata</i> and <i>E. tetradonta</i> and there are other species of eucalypts present in the canopy. The only frequent non eucalypt that occurs in the canopy is Ironwood <i>Erythrophleum chlorostacys</i>. The shrub layer consists of <i>Acacia</i> spp., <i>Calytrix exstipulata</i>, <i>Croton arnhemicus</i>, <i>Gardenia</i> sp., <i>Livistona humilis</i>, <i>Petalostigma quadriloculare</i>, <i>Planchonia careya</i>, <i>Terminalia</i> spp. and <i>Xanthostemon paradoxus</i>. Ground cover is usually sparse, inconspicuous, and comprises mostly annual grasses of <i>Sorghum</i> spp. and other herbaceous plants are present.</p>
4	<p>Woodland</p> <p>This habitat typically lacks a distinct canopy and is more stunted (usually less than 12 m) than open forest, being dominated by bloodwoods (<i>Corymbia</i> spp.), but also contains eucalypts such as <i>E. miniata</i>, <i>E. tetradonta</i> and <i>E. tectifera</i>. However it is quite variable in structure and can be tall on slopes to the point where it grades into open forest. The shrub layer is the same as in open forest but much sparser. The palm, <i>L. humilis</i> is common and pockets of <i>P. spiralis</i> may also be present. The ground cover is much denser than in open forest, containing mainly annual grasses, e.g., <i>Sorghum</i> spp. In stunted woodlands perennial grasses <i>Heteropogon triticeus</i> and <i>Sehima</i> sp. dominate.</p>

The habitat types from Schodde *et al.* (1987) represent a mixture of similar habitats and include small, mappable components of various habitats. Habitat type 1 is a combination of three habitats (Myrtle-Pandanus Savanna, Paperbark Forest and Coastal Deciduous Rainforest, refer **Figure 2-19**), but primarily represents habitats along Magela Creek and Gulungul Creek on the RPA. The vegetation is linear, following the edges of the creek channels, but often grades quickly into woodland. Coastal Deciduous Rainforest habitat has never been recorded on the RPA during previous surveys, although it is present elsewhere in Kakadu.

A tool has been developed by ERA to assess the environmental risk of disturbance (e.g. clearing for exploration or construction) to terrestrial flora and fauna species of conservation significance on the RPA (Brady, *et al.* 2007). As part of this work, the vegetation habitat map of Schodde *et al.* (1987) was simplified and broadened into two habitats (**Figure 2-20**).

- Lowland riparian and rainforest, which represents denser vegetation of the lowlands, typically associated with streams, creeks and billabongs. This habitat is equivalent to habitat type 1 (as described in **Table 2-16**). The area of this habitat within the RPA represents 1.1% of the equivalent habitat found in Kakadu (**Table 2-17**); and
- Woodland, which includes all vegetation growing in lowland areas dominated by trees (except for lowland riparian and rainforest). This habitat is equivalent to habitat types 2, 3 and 4 (as described in **Table 2-16**). According to the Brady, *et al.* (2007) classification system, most vegetation within the RPA (94%) is woodland, which represents 2.4% of the equivalent habitat in Kakadu (**Table 2-17**).

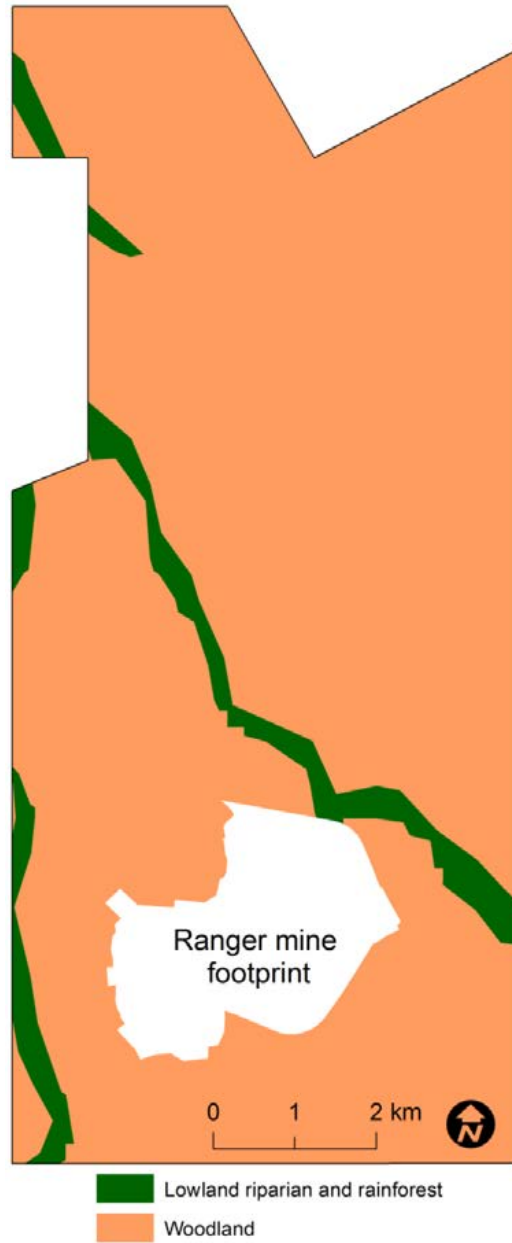


Figure 2-20: Vegetation habitat map of the RPA (based on Brady, *et al.* 2007)

Table 2-17: Area and proportion of vegetation communities on the RPA and Kakadu

Community (Schodde et al. 1987)	RPA (ha)	RPA (%)	Kakadu (ha)	Kakadu (%)	RPA community as a percentage of equivalent habitat in Kakadu (by area)
Myrtle Pandanus Savanna/Paperbark/ Coastal Rainforest	434	6	39,487	4	1.1
Myrtle Pandanus Savanna	1,863	26	170,802	16	1.1
Open forest	3,018	42	336,269	32	0.9
Woodland	1,870	26	508,000	48	0.4

2.5.4.2 Flora Species

Native

Approximately 1,600 terrestrial and aquatic flora species have been recorded in Kakadu, including about 17 species considered rare or threatened (DNP 2007). In particular, the flora of the sandstone escarpment region is diverse, with many species endemic to the region, such as the rainforest species *Allosyncarpia ternata* (Press, et al. 1995).

There has been a substantial survey and monitoring effort of the terrestrial flora across the RPA over the past 10 – 15 years. No species of conservation significance listed under the *Territory Parks and Wildlife Conservation Act 2000* (Territory Parks and Wildlife Conservation Act) and/or the EPBC Act has been recorded during those surveys. In a recent survey (2013) of lowland riparian and woodland areas of the RPA, over 90 flora species were recorded (**Appendix 12**). These species are also common in surrounding Kakadu and did not include any threatened or rare species.

Introduced

Kakadu has approximately 120 species of plants that are considered invasive. This figure represents approximately 8% of the number of plant species in the Kakadu. There are four weeds of national significance in Kakadu: mimosa (*Mimosa pigra*), salvinia (*Salvinia molesta*), olive hymenachne (*Hymenachne amplexicaulis*) and gamba grass (*Andropogon gayanus*). Other species of concern in Kakadu are para grass (*Urochloa mutica*) and mission grass (*Cenchrus pedicellatum*).

The RPA has been annually surveyed for weeds by ERA since 2003, and approximately 80 species have been recorded. Gamba grass is the only weed of national significance that has been recorded on the RPA; however, it has been restricted to isolated plants on roadsides, which were subsequently removed. **Table 2-18** lists the five weed species in the RPA that are declared under the NT *Weeds Act 2001*. These species are all declared as Class B (growth and spread to be controlled).

Table 2-18: List of weed species in the RPA declared under the NT *Weeds Act 2001*

Common name	Species	Class
Hyptis	<i>Hyptis suaveolens</i>	B
Mission Grass	<i>Pennisetum polystachion</i>	B
Spinyhead Sida	<i>Senna obtusifolia</i>	B
Flannel Weed	<i>Sida acuta</i>	B
Grader Grass	<i>Sida cordifolia</i>	B

Conservation Significant Species

No terrestrial or aquatic vegetation communities or flora species of NT/national conservation significance have been recorded on the RPA.

2.5.4.3 Fauna Species

Native

Kakadu contains over one third of Australia's bird species (271), one quarter of Australia's land mammals (77), 132 reptile species, 27 frog species, and over 246 fish species recorded in tidal and freshwater areas (DNP 2007).

Since the 1990s, a significant decline has been recorded in the abundance of 10 species of small mammals in the park, including the Territory Parks and Wildlife Conservation Act listed fawn antechinus (*Antechinus bellus*) and pale fieldrat (*Rattus tunneyi*), and the EPBC Act listed northern quoll (*Dasyurus hallucatus*), northern brown bandicoot (*Isoodon macrourus*), and common brushtail possum (*Trichosurus vulpecula*) (Woinarski, *et al.* 2010). The decline has been attributed to a high fire frequency, feral cats, and cane toads (Woinarski, *et al.* 2010).

Introduced

A list of feral fauna species in Kakadu is shown in **Table 2-19** and includes nine mammal, six insect, one amphibian, and two reptile species. These fauna species adversely impact on biodiversity and ecosystem stability by damaging or transforming habitats, killing or out-competing native species and spreading disease (Bradshaw 2008). Three vertebrate species (the pig, cat and cane toad) are listed under the EPBC Act as key threatening processes to environmental, natural heritage and cultural heritage values. The remaining vertebrate species (dog, Asian water buffalo,¹⁰ cattle, horse, donkey, mouse, rat, flower-pot snake and house gecko) are listed as feral animals, as defined under the Territory Parks and Wildlife Conservation Act.

¹⁰ The water buffalo has been present over a long period and despite its designation as a feral animal, it is now of cultural significance to the local indigenous population who consider it a food source.

The cane toad (*Rhinella marina*) was first reported in Kakadu in 2001, and is now widely distributed. The species has impacted on biodiversity and fauna abundance due to the toxicity of the adults and tadpoles to predators, and by outcompeting native predator species from its diet of invertebrate and vertebrate species. In particular, there has been a notable decline in the northern quoll (*Dasyurus hallucatus*) and monitor lizards such as the northern sand monitor (*Varanus panoptes*), with this decline being directly attributed to the cane toad (Winderlich 2010).

Table 2-19: List of feral fauna species in Kakadu National Park

Type	Common name	Scientific name
Mammal	Pig	<i>Sus scrofa</i>
Mammal	Dog	<i>Canis lupus familiaris</i>
Mammal	Water buffalo	<i>Bubalis taurus</i>
Mammal	Cattle	<i>Bos taurus</i>
Mammal	Cat	<i>Felis catus</i>
Mammal	Donkey	<i>Equus asinus</i>
Mammal	Horse	<i>Equus caballus</i>
Mammal	Black rat	<i>Rattus rattus</i>
Mammal	House mouse	<i>Mus domesticus</i>
Insect	Ginger ant	<i>Solenopsis geminate</i>
Insect	Pharaoh's ant	<i>Monomorium pharaonis</i>
Insect	Singapore ant	<i>Monomorium destructor</i>
Insect	Ghost ant	<i>Tapinoma melanocephalum</i>
Insect	Big-headed ant	<i>Pheidole megacephala</i>
Insect	European honey bee	<i>Apis mellifera</i>
Amphibian	Cane toad	<i>Rhinella marina</i>
Reptile	Flower-pot snake	<i>Ramphotyphlops braminus</i>
Reptile	House gecko	<i>Hemidactylus frenatus</i>

Conservation Significant Species

Eight fauna species of conservation significance have been recorded in the RPA during previous surveys (**Figure 2-21**). A description of all the EPBC Act listed species and potential threats is provided in **Chapter 14** and **Appendix 12**.

The northern quoll (listed as endangered under the EPBC Act and critically endangered under the Territory Parks and Wildlife Conservation Act) has been recorded in and around the RPA (**Figure 2-21**) during three separate surveys (Corbett 1999; 2000; Corbett, *et al.* 2004). This species once occurred commonly in rocky escarpment and eucalypt woodlands across the Top End of the NT (Department of the Environment 2014a), but has undergone widespread and dramatic decline as a result of the arrival of the introduced cane toad (*Rhinella marinus*) that has spread across the top end (Firth, *et al.* 2010; Rankmore, *et al.* 2008). Several comprehensive surveys have been undertaken in the RPA since the arrival of the cane toad but no northern quolls were recorded, suggesting that the local population has been severely impacted or made locally extinct. The cane toad has been recorded on the RPA during several surveys and is regarded as abundant, particularly in and around annual or permanent water bodies.

The partridge pigeon, listed as vulnerable under both the EPBC and Territory Parks and Wildlife Conservation Act has been recorded on the RPA in eucalypt woodland many times during systematic surveys (**Figure 2-21**) and during ERA bird watch events. The partridge pigeon occurs in lowland eucalypt woodland and open forest of the northern Australia savanna (Fraser, *et al.* 2003). The species is known to move up to two kilometres to drink and has a home range of eight hectares on average (Fraser, *et al.* 2003). The partridge pigeon has declined noticeably in some regions of northern Australia, possibly due to feral predators, changed fire regimes, grazing and exotic grasses (Woinarski, *et al.* 2007). The partridge pigeon is still abundant throughout areas of Kakadu (Watson & Woinarski 2004), Litchfield National Park, the Tiwi Islands (Woinarski, *et al.* 2003) and the RPA (Firth 2008a; b; 2010; Smith 2009).

The fawn antechinus, recently listed as endangered under the Territory Parks and Wildlife Conservation Act, has been recorded in several previous surveys within the RPA (Brady, *et al.* 2006; Firth 2008a; b; 2010) and was trapped at one site and photographed at two sites during a 2013 survey (refer **Chapter 9**). The species is restricted to savanna woodland and tall open forest in the Top End of the NT. The preferred habit of the species is tree hollows and fallen logs, and infrequently burnt areas are more suitable.

Seven bird species listed under the various migratory agreements¹¹ and as migratory under the EPBC Act have been recorded on the RPA: cattle egret (*Ardea ibis*), common sandpiper (*Actitis hypoleucos*), grey plover (*Pluvialis squatarola*), marsh sandpiper, little greenshank (*Tringa stagnatilis*), rainbow bee-eater (*Merops ornatus*), whimbrel (*Numenius phaeopus*), and the white-bellied sea eagle (*Haliaeetus leucagaster*). These species are seasonally widespread and common throughout Kakadu (and much of continental Australia where suitable habitat is available) as a consequence of the extensive wetlands that occur in the Park (DNP 2007).

¹¹ China Australia Migratory Bird Agreement, Japan Australia Migratory Bird Agreement, Republic of Korea-Australia Migratory Bird Agreement.

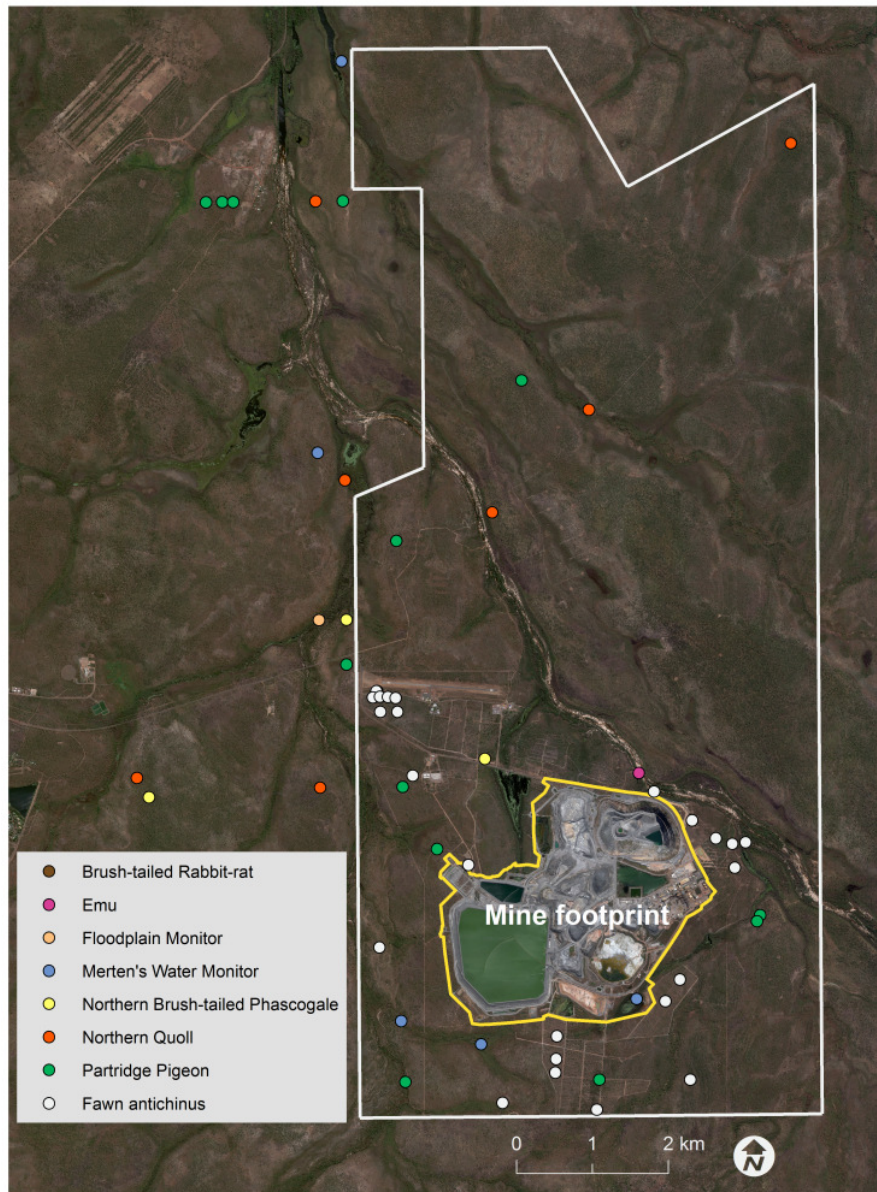


Figure 2-21: Listed fauna species of conservation significance recorded in the RPA and surrounds

2.5.5 Aquatic Fauna and Habitats

Surveys of the aquatic habitats of the RPA and surrounds have been conducted over more than 40 years, including the initial assessments conducted for the Fox Report¹² in the 1970s (Fox, *et al.* 1977). More recent surveys that have assessed the billabongs and associated riparian zones within the RPA and surrounds are detailed below.

Aquatic vegetation, aquatic micro-crustaceans, aquatic macroinvertebrates, fish, frogs, aquatic and riparian reptiles, riparian birds, water birds, native riparian terrestrial mammals, and microbats were sampled over two periods – 1994/1995 (Corbett 1996) and 2000/2001

¹² The Fox Report was the result of an enquiry by the Commonwealth government into the feasibility of uranium mining in the Alligator Rivers Region.

(Corbett, *et al.* 2004) – in three billabongs on the RPA (Georgetown, Coonjimba and Djalkmarra¹³) and two reference billabongs (Sandy and Buba) (**Figure 2-22**). The aim of these surveys was to obtain a comparative data set to assess whether or not operational activities at Ranger mine had impacted biota in billabongs on, and immediately next to, the mine. Corbett, *et al.* (2004) concluded that, for most biota, there were relative differences between billabongs within and between surveys. However, there were no statistically significant differences in the number of functional groups,¹⁴ species richness¹⁵ or relative abundance¹⁶ between Ranger and reference billabongs and between the two sampling periods for most biota.

A comprehensive aquatic survey was undertaken in the 2009 wet season of creeks and billabongs within a 30 km radius of Ranger mine (**Figure 2-22**), which included sites both outside and within the possible influence of mining operations (WRM 2010). No listed or endangered macroinvertebrate or fish species were recorded, and there were no species considered rare or restricted in distribution.

SSD has been monitoring aquatic fauna downstream of the Ranger mine to assess the 'health' of aquatic communities, and potential impacts from mining for at least 30 years. Data have been collected on a range of water quality, and habitat variables have routinely been collected in conjunction with the aquatic fauna sampling.

Uranium and radon bioaccumulation data were obtained (intermittently) from freshwater mussels (*Velesuino angasi*) and forktail catfish (*Arius leptaspis*) in Mudginberri Billabong from 1980 to 2000. From 2000 to 2008, data on mussels and catfish were obtained annually from this billabong and a reference site in Kakadu (Sandy Billabong). Since 2009, a bulk mussel sample has been taken from Mudginberri Billabong at the end of each dry season. The results show a consistent low level of uranium in mussels from Mudginberri Billabong from 2000 to 2011, which indicated an absence of any mining related influence (Bollhöfer, *et al.* 2013). The bioaccumulation studies have found radionuclide and metal uptake to be largely related to natural features of the catchment (e.g. geology, natural sediment concentrations).

Macroinvertebrate communities have been sampled from different sites within the Magela Creek catchment at the end of the wet season, each year from 1988 to 2012. Upstream and downstream sites at two exposed (potentially impacted) streams (Gulungul and Magela Creeks) and two control sites (Burdulba and Nourlangie Creeks) were sampled. A dissimilarity index was used to measure the extent to which macroinvertebrate communities at the two sites differ. The evidence supports a conclusion that changes to water quality downstream of Ranger mine as a consequence of mining during the period 1994 to 2012 have not adversely affected macroinvertebrate communities (Humphrey, *et al.* 2013).

Fish abundance was monitored in channel and shallow lowland billabongs on the RPA and in Kakadu. For the channel billabongs, Mudginberri Billabong was compared to two control billabongs from independent catchments (Nourlangie Creek and Wirnmuyurr Creek); for the

¹³ Djalkmarra Billabong was excised by Pit 3 in the late 1990s.

¹⁴ Sets of species which require similar space and resources.

¹⁵ The number of species recorded in an ecological community, landscape or region.

¹⁶ How common or rare a species is relative to other species in a given location or community.

shallow lowland billabongs, three exposed billabongs (Georgetown, Coonjimba, and Gulungul) were compared to three control billabongs (Sandy, Buba, and Wirmuyurr). Based on this monitoring it was concluded that changes to water quality downstream of Ranger mine as a consequence of mining during period of 1994 to 2012 had not adversely affected fish communities in both types of billabongs (Buckle & Humphrey 2013).

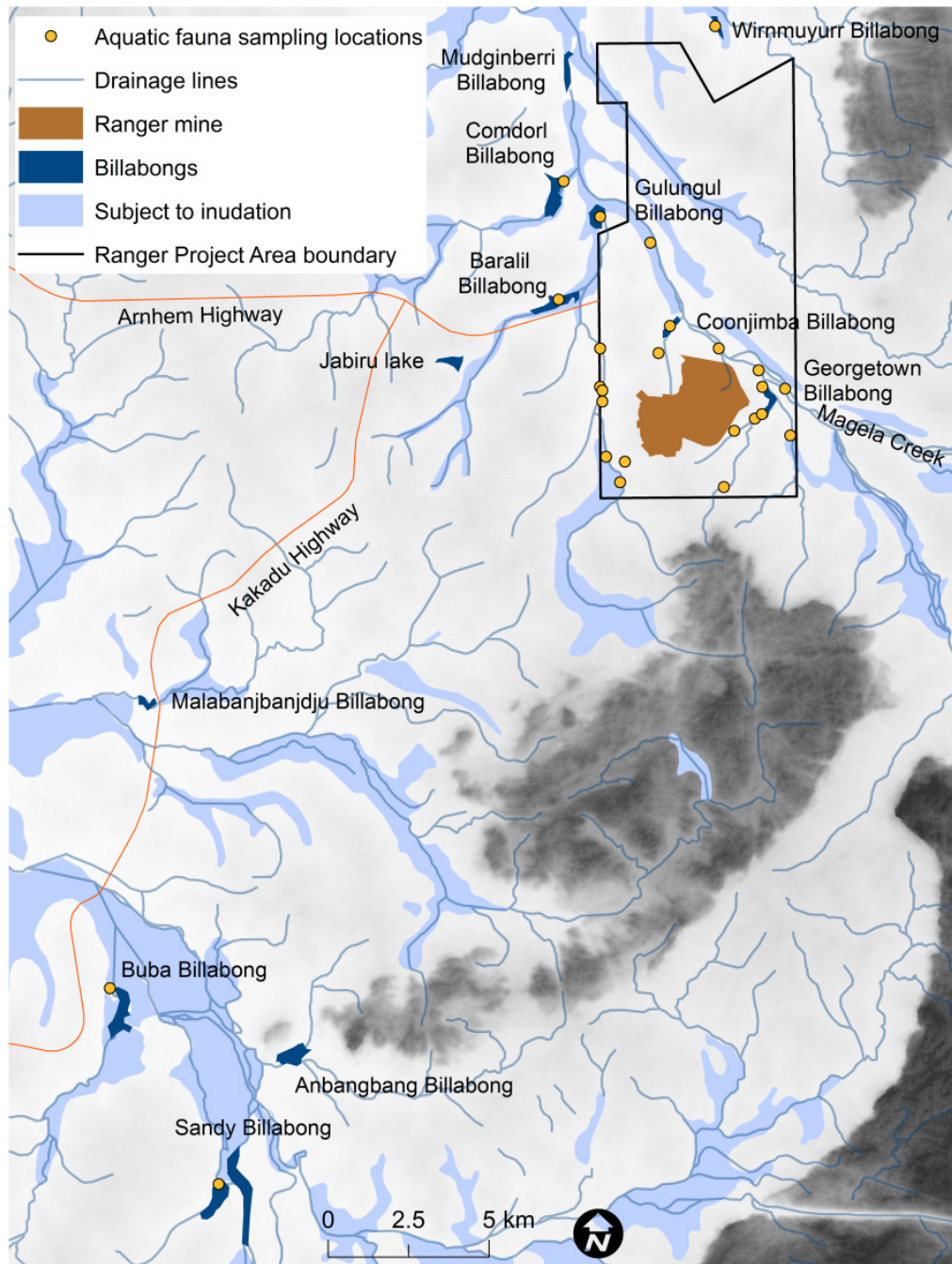


Figure 2-22: Billabong survey locations on the RPA and surrounding Kakadu

2.5.6 Bushfires

The RPA is surrounded by the eucalypt savanna dominated landscape of Kakadu. High annual wet season rainfall promotes extensive vegetation growth, particularly from annual grasses dominated by sorghum (*Sorghum intrans*). The subsequent curing of the vegetation during the long dry season (May to September) results in a highly flammable landscape, where fire is an annual event (Russell-Smith, *et al.* 2003) and a major force in shaping and altering the natural landscape (Edwards, *et al.* 2003). Fire weather becomes especially severe in September to November due to a combination of low humidity, average maximum temperatures above 35°C, and low soil moisture (Gill, *et al.* 1996). Changes to fire management practices in Kakadu since the late 1980s have resulted in a higher frequency of early dry season fires and a reduction in late dry season fires (Russell-Smith, *et al.* 1997). The management approach in Kakadu has been to copy the indigenous burning regime by using helicopter incendiary burning combined with on-ground burning (Edwards, *et al.* 2003). **Figure 2-23** shows the frequency of a) late dry season and b) combined (early and late dry season) fires from 2000 to 2013 (NAFI 2014). During this period, approximately 55% of Kakadu was burnt each year.

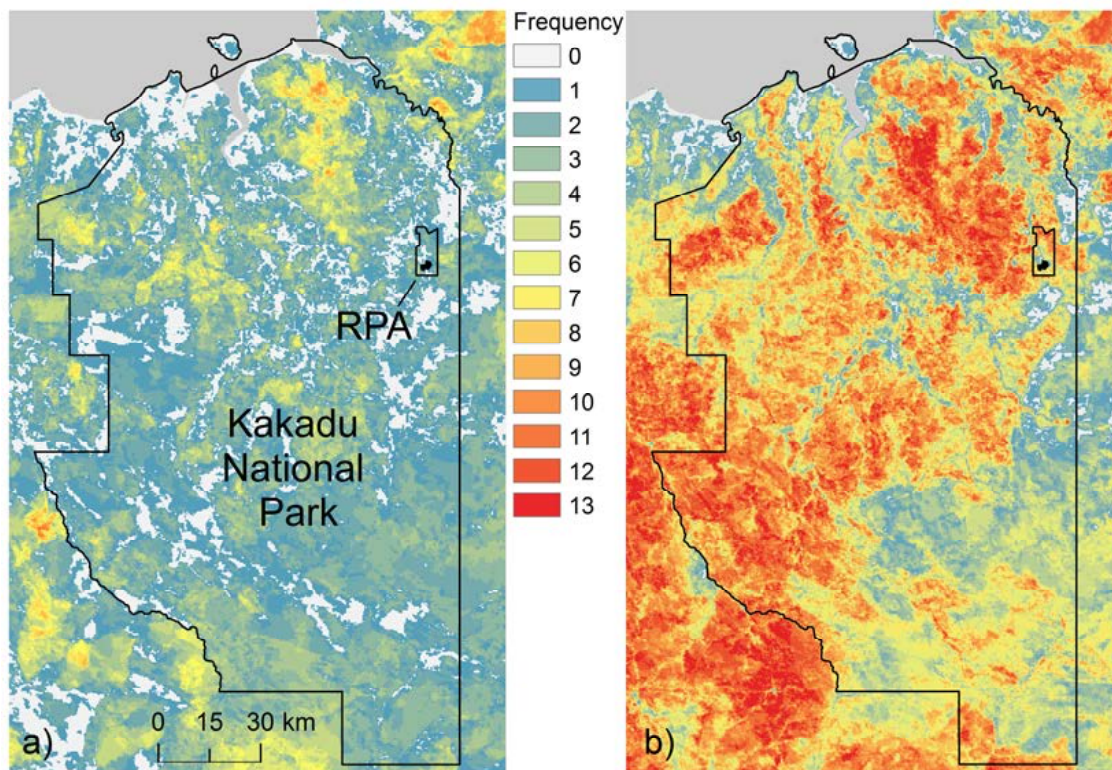


Figure 2-23: Fire frequency in Kakadu and the RPA over a 13 year period

Despite the adoption of early dry season burning by management agencies, total fire frequency (which includes both early and late dry season fires) has been shown to have a deleterious impact on the environment (Andersen, *et al.* 2005). A higher early dry season fire frequency increases grass fuel levels, which in turn encourages higher intensity fires. Such a fire regime may have a similar negative impact on flora and fauna as infrequent late dry season fires (Bowman, *et al.* 2004). The decline of small mammals in Kakadu has been partly attributed to a high fire frequency (Woinarski, *et al.* 2010), and frequent fire has

adversely affected sensitive flora species in sandstone escarpment habitats (Russell-Smith, *et al.* 1998). Further to this, a high fire frequency has been shown to have a propensity for producing a grass-fire cycle (D'Antonio & Vitousek 1992) where trees and shrubs are replaced by annual grasses. The presence of grassy weeds such as mission grass (*Pennisetum polystachion*) and gamba grass (*Adropogen gayanus*) can exacerbate the effects of a grass fire cycle (Rossiter, *et al.* 2003).

Fire within the RPA is managed by ERA and is guided by five year and one year fire management plans. The role of a five year fire management plan is to provide the context and direction for the long-term management of fire by ERA. In support of the five year plan, a one year fire management plan is developed each year following an annual review of the previous year's fire management. A one year plan contains specific actions to be undertaken in that year by ERA personnel to meet the targets of the five year fire management plan.

Asset protection on the RPA is the primary management use of fire by ERA. This is implemented through fuel reduction burns, excluding fire from certain areas, and maintaining a network of graded fire breaks. Fuel reduction burns are conducted each year to reduce the likelihood of unplanned fire damaging or destroying assets. The burns are usually undertaken in the early dry season (late April – June), when the resulting fires are characterised as being cool, which produce smaller burnt areas (patchy) and remove fuel without damaging the over- or under-story vegetation. A particular focus is along the boundaries of the RPA, where burns are typically coordinated with Parks Australia aerial burns in neighbouring Kakadu. These burns are designed to minimise the risk of late dry season unmanaged fires from travelling into the RPA. The non-operational area of the RPA north of Magela Creek is burnt by Parks Australia (in co-operation with ERA) as part of their annual burning program.

2.6 EXISTING RANGER MINE SETTING

2.6.1 Overview

Conventional open cut mining of uranium ore ceased in November 2012. Stockpiled ore continues to be processed through Ranger's processing plant where uranium is leached from the ore using sulfuric acid. The uranium is then purified, concentrated, precipitated, calcined (dried), placed into drums and exported. Components of the mining and processing operations are shown in **Figure 2-24** and include:

- mill area comprising power station (which also provides power to the township of Jabiru), processing plant, administration and maintenance facilities;
- a tailings dam;¹⁷
- two mined out pits – Pit 1 and Pit 3;
- ore and waste rock stockpiles;
- a number of retention ponds and a constructed wetland filter;
- water treatment plants;

¹⁷ The tailings dam is often referred to as the "tailings storage facility" or TSF.

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- irrigation areas, for the disposal of managed release water;
- access road and service tracks; and
- Jabiru Airport and associated infrastructure (refer **Section 2.2.4**).

These components are described in detail below.



- | | | | | |
|-------------------------------|--|---|--|-----------------------------------|
| 1 Car Park | 19 Demineralisation Plant | 37 Radiometric Sorting | 55 Retention Point 1 Land Application Area | 73 Borrow Pit |
| 2 Security | 20 Power Station | 38 Primary Crushing | 56 Retention Pond 1 | 74 Pond |
| 3 Bulk Fuel | 21 Plant Services | 39 Pond Water | 57 Retention Pond 1Wetland Filter | 75 Exploration decline vent shaft |
| 4 Shellsol | 22 Grinding | 40 Mine Wash Down | 58 Retention Point 1 Land Application Area Extension | |
| 5 Simon Carves Yard | 23 Leaching & Clarification | 41 Retention Pond 2 | 59 Accommodation Camp | |
| 6 Water Management Yard | 24 Tailings Neutralisation & Process Water Head Tank | 42 Retention Pond 3 | 60 Workshop (Gagadju) | |
| 7 Ammonia Handling | 25 Corridor Road | 43 Mines Office | 61 Jabiru East Land Application Area | |
| 8 Emergency Dump Tank | 26 Water Treatment Plant 1 | 44 Orica Explosive Storage | 62 Office of the Supervising Scientist | |
| 9 Calciner & Product Packing | 27 Neutralisation | 45 Trial Evaporation Channels | 63 Telstra | |
| 10 Solvent Extraction | 28 Acid Leach | 46 Pit 1 | 64 Airport | |
| 11 Sand Filters | 29 Laterite Treatment Plant | 47 Georgetown Creek Mine Bore 'L' | 65 Exploration Storage Yard | |
| 12 Administration | 30 Coarse Ore Stockpile | 48 Corridor Creek Land Application Area | 66 Jabiru East Potable Water Supply | |
| 13 Product Warehouse | 31 Fine Crushing | 49 Retention Pond 5 | 67 Exploration Core Yard | |
| 14 Engineering & Supply | 32 Secondary Crushing | 50 Corridor Creek Wetland Filter | 68 Djalkmarra Land Application Area | |
| 15 Ranger 3 Deeps portal | 33 Acid Plant (Decommissioned) | 51 Tailings Dam | 69 Djalkmarra Land Application Area Extension | |
| 16 Decline Laydown Area | 34 Acid Storage | 52 Retention Pond 6 | 70 Pit 3 | |
| 17 Exploration Decline Office | 35 Brine Concentrator | 53 Trial Landform | 71 Levee | |
| 18 Sub Station | 36 Water Treatment Plant 2 | 54 Magazine | 72 Magela Land Application Area | |

Figure 2-24: Ranger mine layout and infrastructure

2.6.2 Mining and Processing

Mining at Ranger involved a conventional open cut process which begins with drilling and blasting. Pit 1 was mined out in 1994 and has been used for tailings storage since 1996. Mining in Pit 3 ceased on 28 November 2012 and the pit is currently being prepared for the transfer of tailings from the tailings dam. Pit 3 is scheduled to receive tailings direct from the plant from 2015.

Material that was extracted during mining of Pit 3 was transported by truck and passed beneath a discriminator which measured the gamma emissions of each load. Mined material was categorised by the discriminator for either stockpiling or immediate processing according to the grades shown in **Table 2-20**. Stockpiled material from Pit 3 will continue to be processed until January 2021.

Table 2-20: Indicative ore grades and material type

Grade	Grade range (% uranium oxide)	Material type
1	0.00 – 0.02	Un-mineralised rock
2	0.02 – 0.08	low grade ore
3	0.08 – 0.12	low grade ore
4	0.12 – 0.20	ore
5	0.20 – 0.35	ore
6	0.35 – 0.50	ore
7	> 0.50	ore

Grades 3 to 7 are classified as ore grade material. Grade 2 ore material has traditionally been considered sub-economic – ultimately to be returned as backfill to the mined out pits and subsequently covered by Grade 1 un-mineralised rock to generate a final landform.

2.6.2.1 Processing

Figure 2-25 is a schematic of the Ranger mine processing plant. The major processing stages are described below:

1. Uranium ore is crushed to a size finer than 19 mm in a three stage crushing and screening circuit. The fine ore is then mixed with water and ground to a size finer than 0.22 mm in a grinding circuit that includes one rod and two ball mills.
2. The ore slurry is thickened before being pumped to leaching vessels where, over a period of 24 hours, more than 90% of the uranium in the ore is dissolved using sulfuric acid and pyruosite (an oxidant).
3. The uranium in solution is then separated from the depleted ore in a seven stage washing circuit in a process known as counter current decantation. After separation, the acidity of the depleted ore (tailings) is partially neutralised with lime before being pumped to the tailings storage facility, while the uranium solution is passed through a

- clarifier and set of sand filters. The filtering removes any fine solid particles before the uranium solution enters the solvent extraction circuit.
4. At this stage, the uranium solution is carrying many other dissolved elements in addition to uranium. The solvent extraction process uses a chemical reagent (an amine) carried in special grade kerosene to purify and concentrate the uranium solution. Ammonia is also used in this process. The resulting pure but weak uranium solution is then pumped to precipitation tanks.
 5. A uranium compound (ammonium diuranate) is precipitated from the clean uranium solution with the further addition of ammonia. The substance is bright yellow and commonly referred to as 'yellowcake'.
 6. In the final stage of the process, the yellowcake is heated to 800 °C in an oil-fired, multi-hearth calciner. The calcination process produces the final product – uranium oxide, which is a dark green powder. The product is packed into 200 L steel drums. These are sealed and transported by road, using an accredited transport company, to a secure holding facility in Darwin. The containers are generally transported by rail to Adelaide, and then exported by ship; however, they have also been exported from the Port of Darwin in the past.

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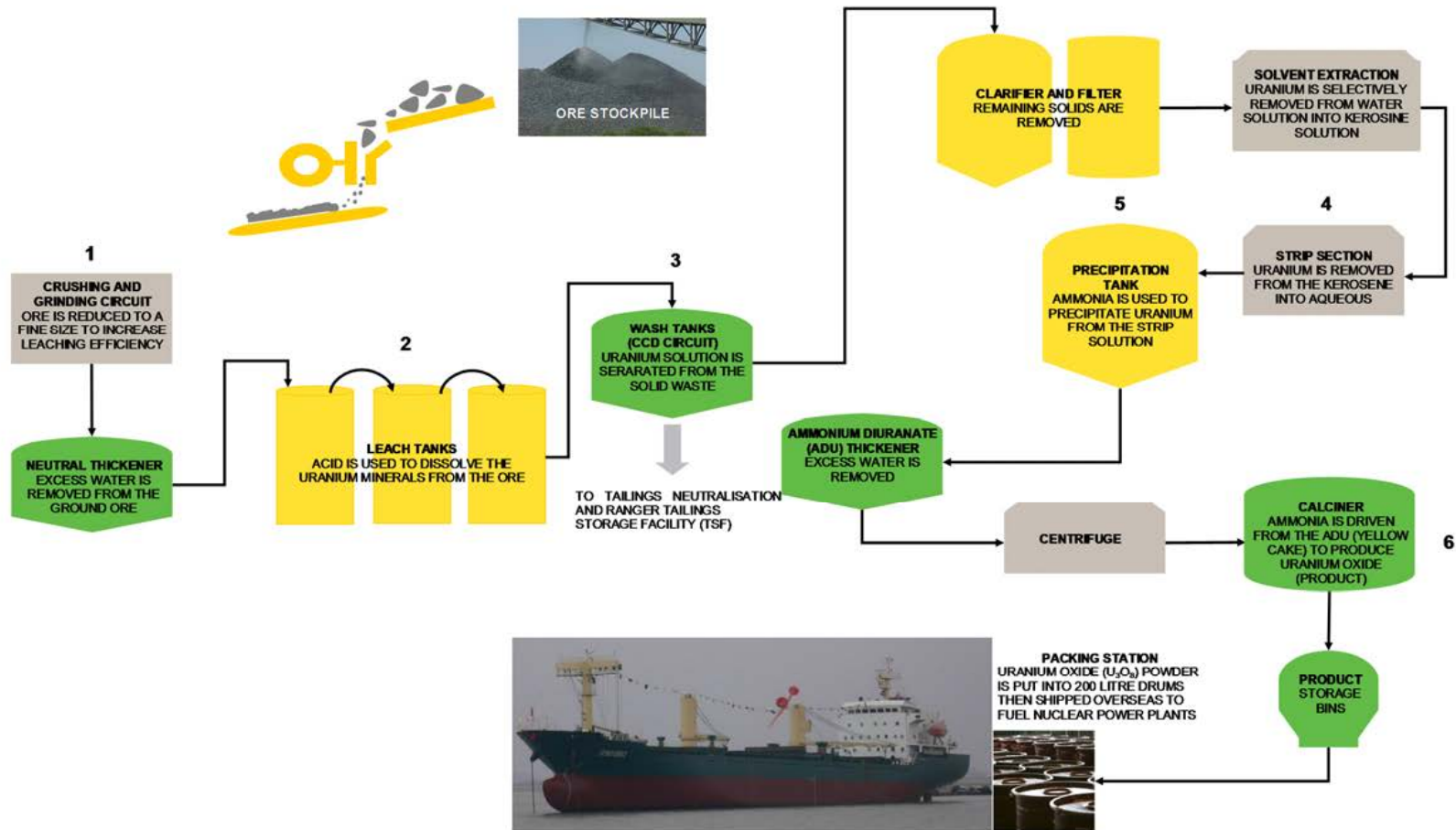


Figure 2-25: Uranium extraction process

2.6.2.2 Tailings Storage

The tailings dam and Pit 1 have been approved for the storage of tailings and process water in accordance with relevant ministerial conditions. Tailings are deposited to achieve the maximum practicable density and both sub-aqueous (below surface) and sub-aerial (in air) deposition methods have been used in the past.

Pit 1

Approximately 19.8 Mt of ore was mined from Pit 1 between May 1980 and December 1994. Once the pit was mined out, tailings deposition into the pit commenced in 1996, to an average height of relative level (RL) +12 m, until deposition ceased in November 2008. Pit 1 then functioned as a process water storage facility until 2012. Between May and October of 2012, 7,700 prefabricated vertical drains (wicks) were installed within the upper 40 m of the Pit 1 tailings mass. Their purpose was to affect release of entrained tailings water, thus promoting the development of a trafficable surface upon which to commence backfill operations. Subject to approval (via the MTC approval process), the backfill of Pit 1 with non-mineralised waste rock will start in 2015 to allow transition from a process water catchment to a pond water catchment. Backfilling is anticipated to be completed in 2017 with rehabilitation and revegetation ongoing until 2020, and rehabilitation monitoring from 2015 to 2025.

Tailings dam

The tailings dam is an above ground facility designed to store neutralised mill tailings and process water. The free process water inventory held in the dam is progressively reduced through passive evaporation. The dam has a dyke (turkey nest) structure with walls constructed using appropriate soil and rock materials. The eastern, southern and western walls of the tailings dam run along ridges approximating catchment divides which separate Coonjimba Creek from adjacent surface water catchments, including Gulungul Creek to the west and the Djalkmarra and Georgetown catchments to the east. The tailings dam embankments have been constructed in seven stages between 1979 and November 2012 to the current clay core elevation of RL+60.5 m.

Performance of the tailings dam is monitored and inspected annually by independent engineers in accordance with the Ranger Authorisation (**Appendix 1**) and is operated within the requirements of the Australian National Committee on Large Dams and International Commission of Large Dams guidelines for tailings dam design and operation (ANCOLD 1999). The monitoring data and the outcomes of the engineering inspections are reported to the regulators to confirm that the structure continues to perform according to its design and operational criteria.

Pit 3

As outlined previously, open cut mining in Pit 3 commenced in July 1997 and ceased in November 2012. During that period, approximately 94 Mt of ore was mined from the pit. Subject to final regulatory approval (via the MTC approval process), deposition of tailings from the milling of ore stockpiles into Pit 3 will commence in 2015 and will cease January 2021 when processing also stops. Following a period of consolidation in 2023 – 2024, the tailings in the pit will be covered by rock backfill.

2.6.3 Stockpiles

A number of stockpiles comprising ore grade material and waste are situated in the vicinity of the Ranger pits and the tailings dam. Approximately 21 Mt of ore will be processed from stockpiles, while about 127 Mt of waste exists within the stockpiles, which will be used for backfilling and shaping of the final landform for closure. The location of stockpiles is shown in **Figure 2-26** with the mine plan stockpile designation. Grades 3, 2 and 1 material form the majority of the current existing long term stockpiles. Lateritic or heavily weathered ore types have historically been placed in the long term stockpiles.

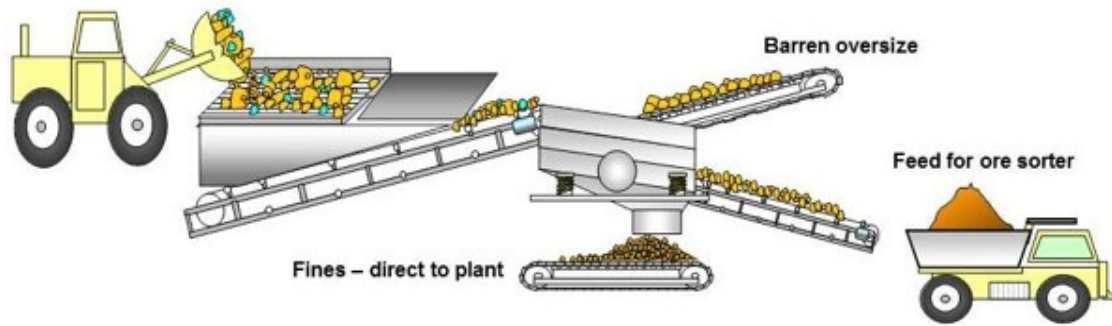
The run-of-mine (ROM) stockpile containing ore for processing is located to the east of Pit 1 and next to the primary crushing facilities.



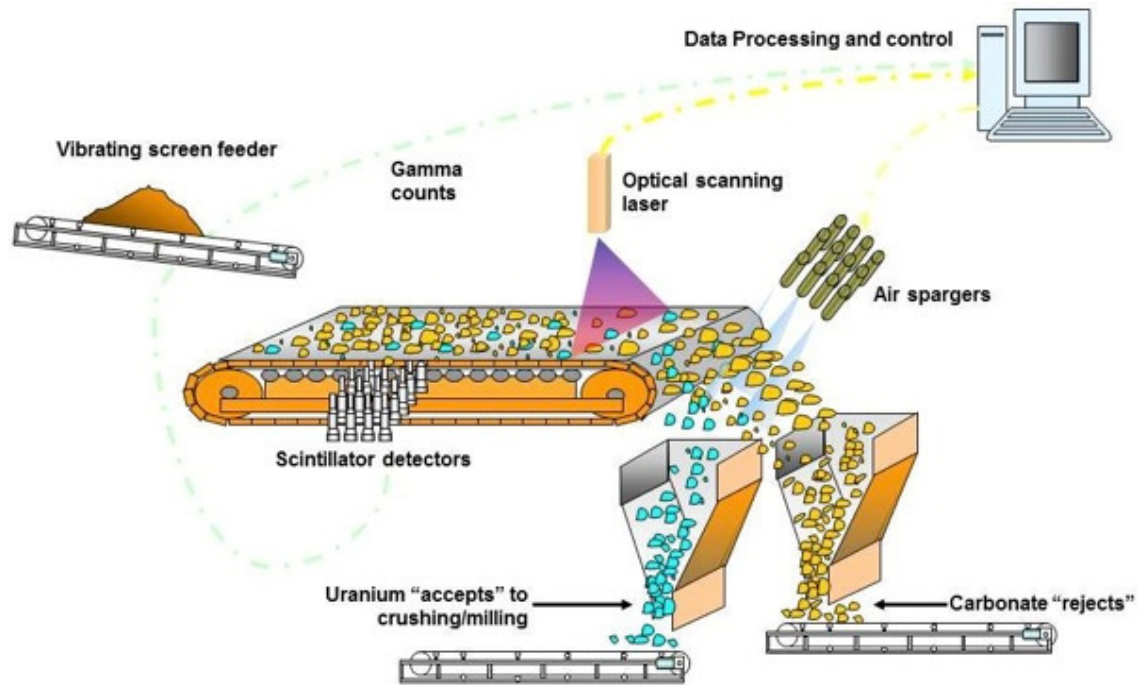
Figure 2-26: Ranger stockpile locations

2.6.4 Ore Sorting Plant

Beneficiation of low grade ores, containing high concentrations of carbonate minerals, can be achieved by passage through the existing mobile screen plant (**Figure 2-27a**) and ore sorter (**Figure 2-27b**). The ore sorter upgrades the ore grade by separating mineralised fragments from un-mineralised fragments using an array of radiometric or optical detectors and air jets. Lower grade ore is therefore converted to a higher grade stream and waste stream thus increasing the quantity of ore grade material that can then be fed to the processing plant.



a) Existing mobile screen plant



b) Ore sorting plant

Figure 2-27: Schematic of existing ore sorter

2.6.5 Water Management

Water management is the most significant environmental and operational aspect of the Ranger mine, and is an integral part of ERA's health, safety and environment management system. It encompasses all aspects of water capture, storage, supply, distribution, use, and disposal. Water is managed according to the Ranger water management plan which describes the method used to control water on site. The plan, which fulfils the requirements of the Ranger Authorisation and is approved annually by regulators, outlines the approach ERA takes to:

- protect both the wider environment and Magela Creek from the impacts of mining and processing operations;
- meet all current statutory requirements;

- manage water inventories and discharge mechanisms based on water quality according to a whole of mine approach rather the source of the water; and
- strategically manage process and pond water inventories in accordance with the current closure model.

To meet the objectives of the water management system, ERA employs various tools including a release plan calculator, operational water balance model (known as OPSIM), routine monitoring, and historic meteorological records. These tools allow ERA to plan, manage, validate and continuously improve water management.

2.6.5.1 Water Classes

There are four classes of water at Ranger mine that are managed according to their quality (**Table 2-21**): pond water, process water, potable water, and managed release water. Waste water is a class that is managed at Ranger mine, but not according to quality. The water management catchments for the pond, process, and managed release classes are shown in **Figure 2-28**. All five water classes are described in the following sub-sections.

Table 2-21: Indicative quality of water classes in terms of chemical composition

Parameters	Pond water	Process water	Potable water	Managed release water
pH	7.8	3.9	7.8	7.3
EC (µS/cm)	1,200	25,600	370	210
Aluminium (mg/L)	0.82	460	0.006	0.09
Calcium (mg/L)	27	530	28	3
Magnesium (mg/L)	180	5,970	41	26
Manganese (mg/L)	0.33	2,200		0.012
Uranium (mg/L)	5.2	27	0.01	0.0097
Ammonium (mg/L)	0.09	890		< 0.01
Sulfate (mg/L)	720	34,000	1.3	96
Ra (mBq/L)	5,400	24,000		77



Figure 2-28: Water class catchments at Ranger mine

Pond water

The pond water inventory is derived from rainfall that falls on the active mine site catchments, thereby generating water of a quality that requires management. Pond water typically includes:

- seepage and surface water runoff from the mineralised rock stockpiles;
- seepage from the low-grade rock stockpiles;
- runoff and water that infiltrates the southern, north western and western tailings dam embankment wall;
- seepage into the Ranger 3 Deeps exploration decline; and
- runoff and discharges from the processing areas not directed to the process water circuit.

The main areas used for storing pond water include retention pond 2 (RP2), retention pond 3 (RP3), and historically Pit 3.

Excess pond water collected during the wet season is managed through:

- passive evaporation from water bodies; and
- treatment by one of three existing water treatment plants.

Treated water is water that has passed through one of the three water treatment plants or through the brine concentrator (see below). Treated water can be divided into the following categories:

- water treatment plant permeates: water that has been treated to remove a significant amount of the dissolved solids to allow it to be considered release water;
- water treatment plant brines: water that contains the remaining dissolved solids removed from the pond water, and is typically discharged to the tailings dam;
- brine concentrator distillate: purified water that is produced by the brine concentrator;
- brine concentrator brine: residue water which is currently transferred to the tailings dam after the distillate has been extracted;
- partially treated water: treated water that has been combined with pond water to achieve improved water quality through dilution; and
- polished waters that are passed through the Corridor Creek Wetland Filter (CCWLF).

The treated water from the water treatment plants is released via managed release sites during the wet season. In the dry season, pond water permeates are used to irrigate the land application areas (see description below). Reject brines from the water treatment process are added to the process water inventory.

Throughout the year, pond water is used as a supply for mine operations, including dust suppression, vehicle washing, power station cooling, and makeup water for the processing plant.

Process water

The process water inventory is derived from waters that have passed through the uranium extraction circuit. Process water inventory is also increased by rainfall on the designated process water catchments, including the tailings dam. Process water is characterised by a relatively high dissolved salt load that identifies it as the most impacted water class on site. Most of the water used in the process plant is sourced from the process water circuit to maximise recycle opportunities and to avoid adding to the process water inventory by using pond water. Currently, the process water inventory is controlled by minimising input and maximising evaporation. Process water that is treated by the brine concentrator is released as distillate to the downstream environment.

Potable water

Potable water is used for drinking and ablution purposes (e.g. safety showers) and parts of the plant where high quality water is required. Potable water at Ranger mine and Jabiru East is monitored monthly in accordance with the requirements of the Ranger Authorisation and continues to meet the health guidelines for physical and chemical characteristics as defined by the Australian Drinking Water Guidelines (NHMRC & NRMCC 2011). Both chemical and microbiological quality is monitored by regular sampling. Continuous measurements of electro-conductivity (EC) and pH in the distribution system are made to ensure that any deviations from baseline quality are detected immediately.

The potable water supplies for Ranger mine and surrounding areas are extracted from two borefields (**Figure 2-29**). Brockman borefield provides water for use at the Ranger mine and the Magela borefield provides water for Jabiru East.

The Brockman borefield comprises four production bores drilled between 1982 and 1984, as well as other bores drilled during exploration and evaluation or used for monitoring. The annual extraction volume for the period October 2012 to September 2013 was approximately 182 ML (which is equivalent to 498 kL/d). An assessment of the sustainable production yield for the Brockman borefield was undertaken in late 2009 and determined that a sustainable production yield is around 600–800 kL/d ($7 - 9 \text{ Ls}^{-1}$), although production rates as high as 900 kL/d could be sustainable in periods of consistent above average rainfall (Golder Associates 2010).

The Magela borefield comprises two production bores that were first established in the early 1980s as a potable water supply for the original township of Jabiru East. The borefield was decommissioned when the Jabiru East community was relocated to Jabiru, but was recommissioned in 2004 to supply the airport and the Office of the Supervising Scientist field station following an incident at Ranger mine where potable water was contaminated. The annual extraction volume for the period October 2012 to September 2013 is approximately 79 ML (or 216 kL/d). Further discussion on groundwater quality is provided in **Section 2.4.7.2**.



Figure 2-29: Location of Brockman and Magela borefields on the RPA

Managed release water

Managed release waters are derived from rainfall that falls on selected catchments within the mine footprint. The water does not come into contact with mineralised rock or tailings.

Release water streams include ponds (e.g. RP1), drains, access road culverts, pump stations, and release points. The quality of these waters is such that they do not require treatment (inclusion into the pond water or process water inventory) but are shed and leave the site as stormwater runoff. These waters are closely monitored as an integral part of statutory and operational management to ensure that water quality objectives are met in Magela Creek.

The locations of the release water streams are shown in **Figure 2-30**.

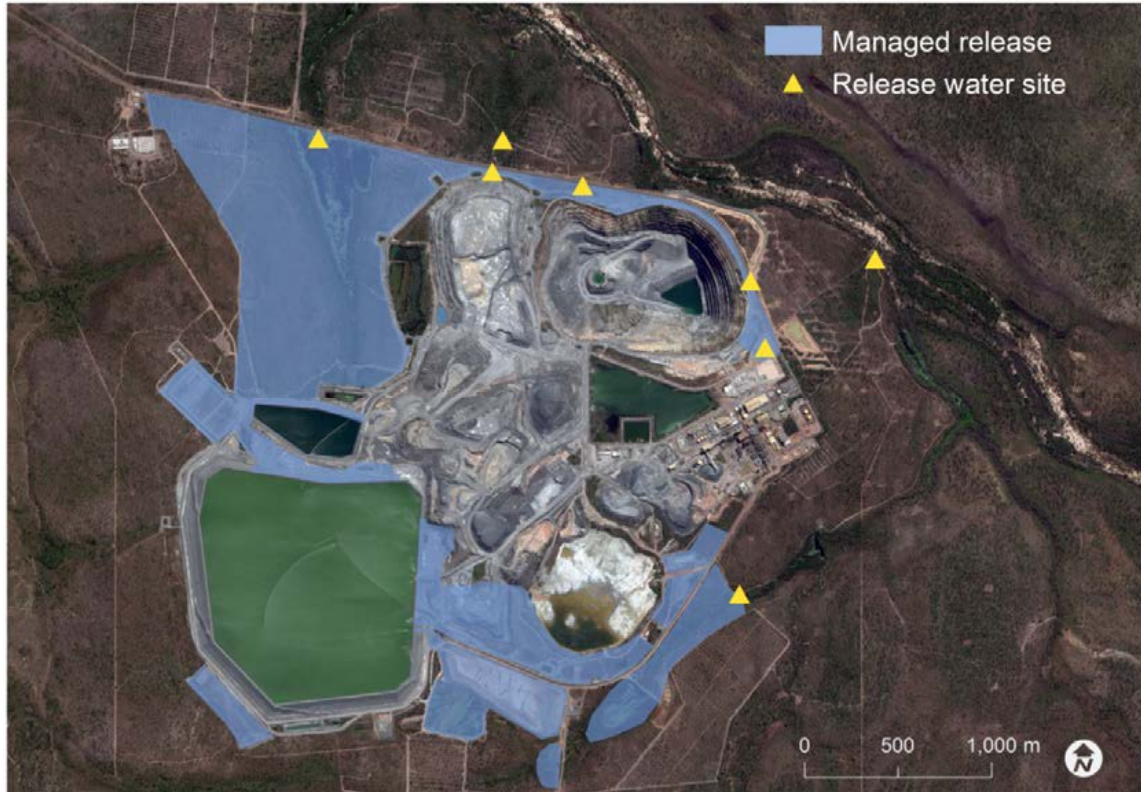


Figure 2-30: Release water sites on the RPA with managed released water catchment

Waste water

Grey waste water (e.g. from showers and toilets) at Ranger mine is treated on site. The water is pumped into septic tanks and then to leach drains.

2.6.5.2 Water Management Practice

The Ranger mine footprint is divided into catchment areas (**Figure 2-31**). These areas generate surface run-off and/or seepage as a result of incident rainfall. Each catchment may comprise of several elements such as retention ponds, sumps, collection basins and groundwater interception ponds. Detailed delineation of catchments is used in the operational aspects of the mine.

The water circuit for Ranger mine, including the five water classes, the different treatments and water management features are shown in **Figure 2-32**. A description of the individual water management elements are provided below. Further detail on the features shown in **Figure 2-32** and pertaining to process water and tailings storage is provided in **Section 2.6.6.2**.

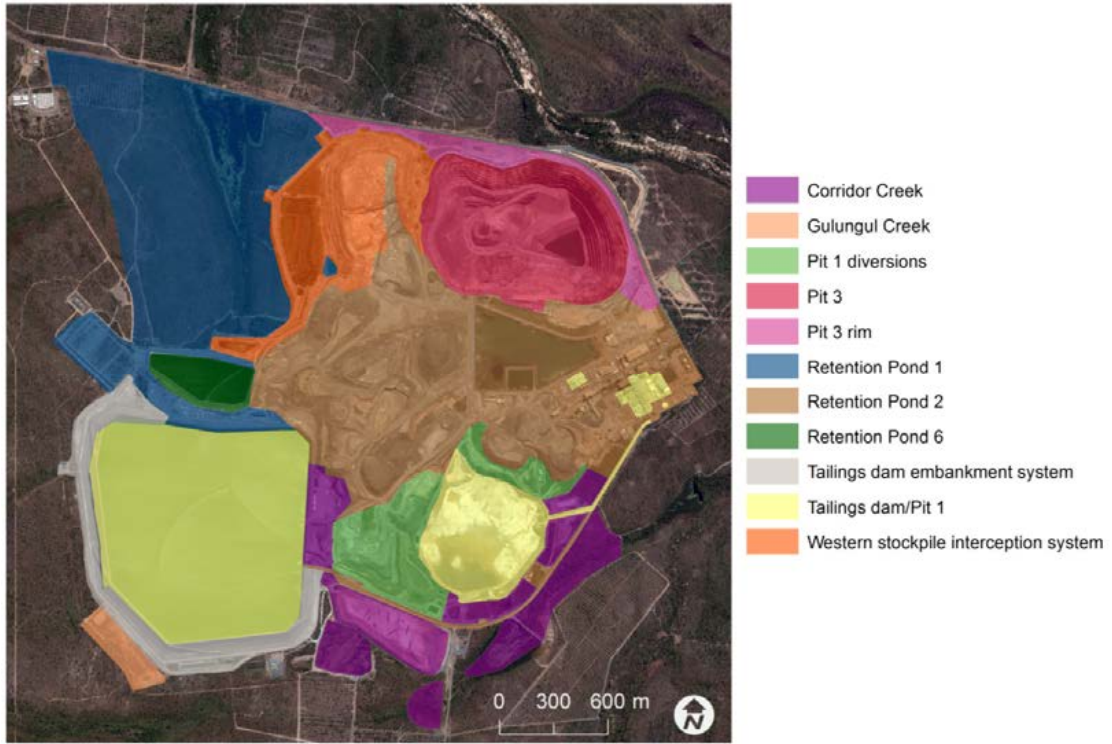


Figure 2-31: General arrangement of surface water catchments area Ranger mine

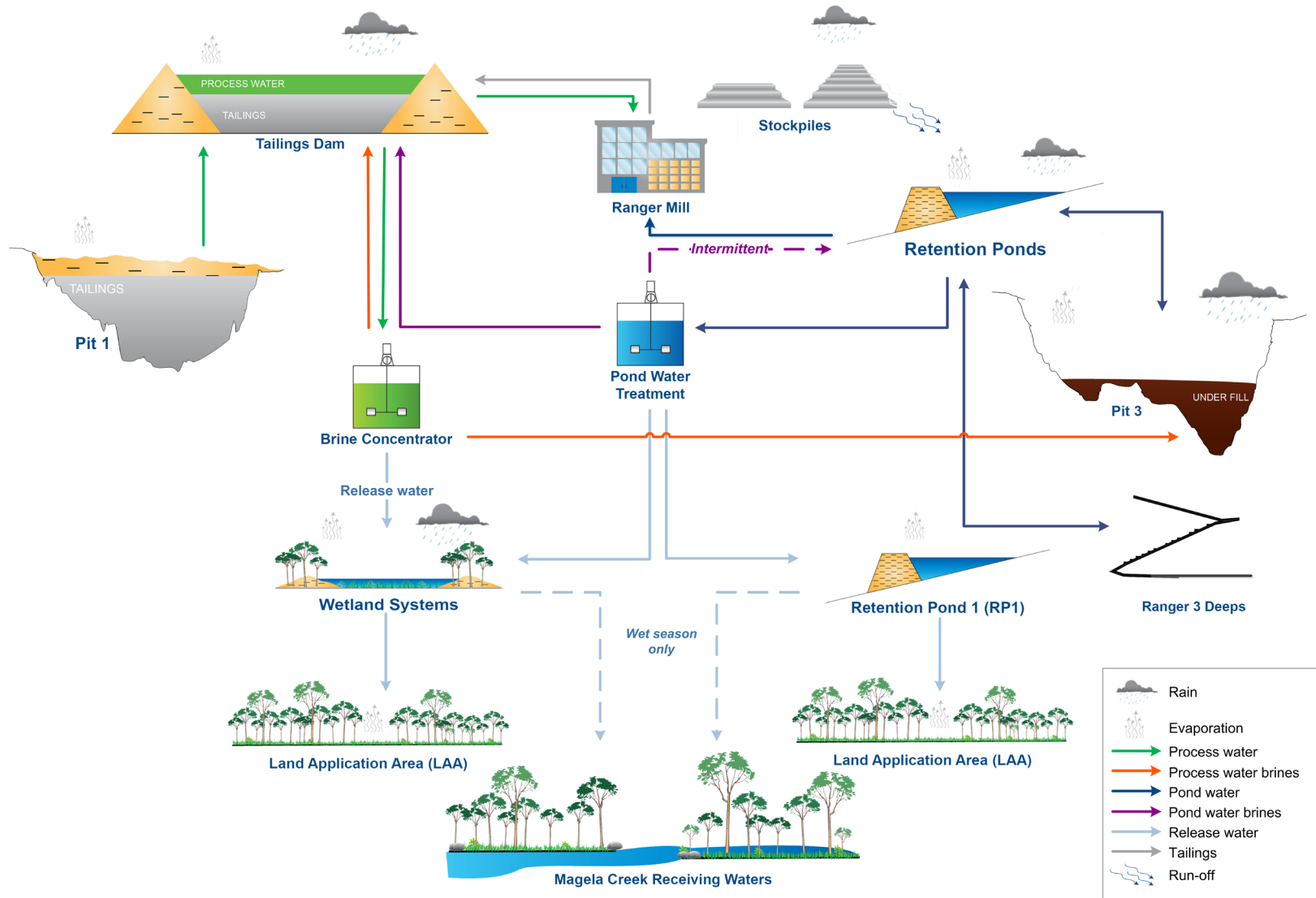


Figure 2-32: Ranger mine water circuit

Retention ponds

Four retention ponds are used at Ranger to provide sediment control, and dilution and storage of pond and managed release waters:

- RP1 comprises an earthen embankment which dams Coonjimba Creek to form an impoundment, providing approximately 390 ML storage under normal conditions (**Figure 2-33**). The pond is used for managing release water, and provides sediment control and dilution prior to water being released into the environment across a control weir and spillway.
- RP2 comprises an earthen wall impoundment in the former Djalkmarra Creek catchment (now subsumed by Pit 3) providing about 1150 ML of storage. The pond is equipped with a system that allows transfers to Pit 3 during the wet season and removal from Pit 3 to RP2 during dry months for treatment and disposal. RP2 is the primary distribution point to all pond water disposal facilities and contains seepage water and runoff from mineralised stockpile.¹⁸
- RP3 is an earthen impoundment within RP2, providing about 61 ML of storage for acidic pond water sourced from the decommissioned sulfur stockpile and acid plant. RP3 water is used in processing, diverted to Pit 1 or blended with RP2 water for treatment.
- RP6 is a turkey-nested, double-lined pond that was commissioned in December 2012. It receives water from RP2 transfers and from rainfall, and has a maximum water storage capacity of approximately 976 ML.



Figure 2-33: RP1 with stockpiles in the background

¹⁸ Modification to the arrangements for Pit 3 will be made, once tailings transfer to Pit 3 commences in 2015 (subject to final regulatory approval via the MTC process).

Water treatment plants

Ranger mine operates three water treatment plants used to treat excess pond water inventory to a level that is suitable for release. All water treatment plants are currently configured to treat only pond water using pre-filtration followed by reverse osmosis. The process results in four distinct streams that may be directed to specific destinations:

- permeate: suitable for release via RP1 in the wet season, or irrigation through land application areas during the dry season;
- backwash from pre-filtration: pond water with additional suspended solids (predominantly algal particles), which can be returned to RP2 or the process water inventory;
- chemical clean water: contains chemicals that must be discharged to the process water inventory; and
- brine: generated by the reverse osmosis process with relatively high total dissolved solids and is typically discharged to the tailings dam.

Wetland filter

Ranger currently operates one wetland filter – the Corridor Creek wetland filter. This wetland filter is a combination of natural and constructed wetlands (or cells) with a surface of approximately 71 ha and a total water volume (at full capacity) of approximately 38 ML. Since the end of the 2011 dry season, the Corridor Creek wetland filter has not been used to polish¹⁹ untreated pond water, and has received only treated pond water and release quality water.

Land applications areas

The land application areas (LAAs) have been used at Ranger mine since 1985 and have a total area of approximately 350 ha. ERA defines land application as the process by which water (release water, permeate, wetland polished water) is applied to the LAAs through a network of distribution pipes and sprinkler heads, thereby maximising evapotranspiration loss while minimising surface pooling and seepage, and preventing surface runoff during operations.

LAAs in operation at Ranger mine are shown in **Figure 2-34**. Note, that the Magela LAA was decommissioned in 2007.

¹⁹ Polishing refers to the treatment of water of various qualities by a combination of biogeochemical treatment processes prior to release.



Figure 2-34: Location of LAAs

Brine concentrator

The brine concentrator was commissioned in September 2013 and produces clean distilled water (distillate) by using thermal energy to evaporate water that is sourced from the process water inventory (**Figure 2-35**). The expected distillate production capacity of the brine concentrator is 1.83 GL per annum. Distillate from the brine concentrator is discharged through the Corridor Creek wetland filter prior to release to Magela Creek, with brine currently transferred direct to the tailings dam. The release of distillate has been subject to approval in accordance with the NT Mining Management Act, which resulted in an amended Ranger Authorisation.



Figure 2-35: Brine concentrator

2.6.6 Water Balance Model

Since 2006, ERA has planned its medium and long-term water management at Ranger mine through the OPSIM water balance model. The model utilises daily rainfall data from Jabiru Airport and incorporates detailed information relating to factors such as mine schedule, processing plant operation, site catchments, water storages, water movements, and groundwater inputs. Model outputs include variables such as spillway flows and water inventories. The model allows for assessment of the risks associated with different water management strategies in response to a range of rainfall and operational conditions.

The OPSIM model is routinely evaluated against actual site data for the previous wet and dry seasons, and refined as necessary. ERA conducts an annual review and revalidation workshop to assess changes to water management in the dynamic mine setting and to ensure that the water balance model continues to be the best possible tool for water management.

2.6.7 Ranger 3 Deeps Exploration Decline

ERA is constructing an exploration decline at Ranger mine from near the south eastern rim of Pit 3 (**Figure 2-36**). This has enabled an underground exploration and infill drilling program to increase orebody knowledge, and provide geological, geotechnical and radiological data and direct information on hydrogeological conditions, particularly potential water inflows to underground workings.

The exploration project is ongoing at the time of preparation of the Draft EIS and is being conducted in phases eventually extending to approximately 3 km in length and 350 to 400 m below surface. The decline development has progressed above and parallel to the target mineralised zone.

The decline will subsequently provide access to the mineral resource should the Ranger 3 Deeps underground mine proceed.



Figure 2-36: Spatial extent of the exploration decline

2.6.7.1 Existing Infrastructure

The exploration decline project consists of the following infrastructure components:

- a box-cut and a covered portal;
- development of 3 km of decline (at 1:6 grade);
- drilling of the mineralised zone to provide core for detailed geological, geotechnical, hydrogeological and mineralogical analyses;
- Ancillary works including construction of:
 - a site office, crib room and muster area which is located near the entry point of the portal;
 - an ablution block including showers which is located near the entry point of the portal;
 - roadways;
 - a refuelling bay where the vehicle fleet for the Ranger 3 Deeps exploration project refuel;
 - water and communication services;
 - warehouse and lay down area for underground consumables;
 - additional storage capacity at the existing surface explosives magazine; and
 - a ventilation shaft.

The underground mine will utilise this existing mining infrastructure (e.g. decline, vent shaft), and where practicable the ancillary infrastructure and services, in some cases with modifications and extension.

2.6.7.2 Water Management

Water management for the Ranger 3 Deeps exploration decline has been addressed in an exploration decline water management plan which describes how potential human health or environmental impacts associated with surface water or groundwater are being managed. The plan was subject to approval by regulators, is valid for the life of the Ranger 3 Deeps exploration program; reviews and amendments are undertaken annually, or when conditions change, or in response to incidents or investigations.

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