EXECUTIVE SUMMARY

Issued Date: May 2018
Revision #: 0.18.0
IMPORTANT NOTE

This Mine Closure Plan (MCP) has been prepared by Energy Resources of Australia Ltd (ERA) in order to present ERA’s mine rehabilitation strategy for the Ranger mine as at 31 December 2017.

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This MCP represents the status of ERA’s rehabilitation planning for the Ranger mine as at the date above. While all care has been taken to ensure that information contained in this report is true and correct at the time of publication, changes in circumstances following publication may impact the accuracy of its information. This MCP is provided for information purposes only, and is not to be relied on as final or definitive. It will continue to be developed and is subject to change.

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EXECUTIVE SUMMARY

1. OVERVIEW AND ASSUMPTIONS

Chapter 1 presents an introduction and overview of the Ranger mine closure strategy, including the purpose and scope of the mine closure plan (MCP), as well as the assumptions in which the plan is based on.

The Ranger uranium mine is located within the Ranger Project Area (RPA) adjacent to Jabiru, approximately 260 kilometres east of Darwin within the Alligator Rivers Region of the Northern Territory (NT) (Figure 1).

Energy Resources of Australia Ltd (ERA) has owned and operated the Ranger uranium mine since the commencement of operations in 1980. ERA's shares are publicly held and traded on the Australian Securities Exchange, with Rio Tinto, a diversified resources group, currently holding 68.4 per cent of ERA shares. Operations at Ranger are governed by both Commonwealth and Northern Territory legislation and regulations. The key instrument that governs operations at the Ranger mine on a day-to-day basis is the authority (the Ranger Authorisation) issued under the NT Mining Management Act 2001 (Mining Management Act). The main Commonwealth authority, issued under section 41 of the Atomic Energy Act 1958 (Cth) (Atomic Energy Act), provides the key tenure and land access approval required for the operations (the Section 41 Authority). The Ranger Environmental Requirements (ERs) are attached to the Section 41 Authority and set out environmental objectives which establish the principles by which the Ranger operation is to be conducted, closed and rehabilitated and the standards that are to be achieved. The ERs form the basis of closure criteria described in Chapter 6 of the MCP. The Mining Management Act also requires the Ranger Authorisation to incorporate by reference the ERs.

Figure 1: Ranger uranium mine location
Figure 2 represents the parallel NT and Commonwealth legislative approval processes that relate to the mine closure activities at the RPA, and Appendix 1.1 of the MCP provides further details on the legislative framework.
Figure 2: Indicative NT and Commonwealth parallel closure approvals processes
Under the current operational approvals, ERA is permitted to undertake mining and milling activities in the Ranger Project Area (RPA) until 8 January 2021, with final rehabilitation and closure activities to be completed by 8 January 2026. ERA is required to provide a revised MCP, which has been prepared for submission to the Supervising Authority (the NT Department of Primary Industry and Resources (DPIR)) for approval in accordance with the Ranger Authorisation.

ERA has stockpiled reserves at the Ranger uranium mine potentially sufficient to sustain operations until January 2021. For the duration of its mining and process operations, ERA has undertaken rehabilitation activities, with some parts of the disturbed mine footprint well advanced. As an example, Pit 3 has transitioned from an open cut mine to a tailings repository, in accordance with ERA's statutory obligations under the Ranger Authorisation. These work programs have been implemented well in advance of the planned whole-of-site closure.

1.1 Purpose of the MCP

The MCP has been prepared as part of ERA's obligations under the Mining Management Act. The MCP is up to date as of 31 December 2017 and contains the closure strategy for the RPA, which has been developed with reference to Rio Tinto's internal requirements for a closure plan, the Western Australian (WA) Mine Closure Plan Guidelines¹ where appropriate, as well as ERA's vision for closure, which aligns with the goal for final land use specified in clause 2.1 of the ERs:

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

The closure objective is to close and rehabilitate the entire RPA (approximately 950 hectares; ha) to one final landform across the site that will blend with the surrounding landscape.

1.2 Scope

The MCP covers the following areas and assets within the RPA:

- Ranger mine infrastructure, mine pit voids, the exploration decline and all associated utilities within the operational area of the Ranger site.
- Land application areas, wetland filters and other infrastructure associated with the Ranger mine.
- Jabiru Airport and associated infrastructure and utilities (situated in the RPA).

¹ At the request of the Commonwealth Government, and in the absence of Northern Territory closure plan guidelines.
The town of Jabiru and the infrastructure located on the RPA immediately south of the Jabiru Airport, identified as the Jabiru field station currently occupied by the Supervising Scientist Branch are not considered in this MCP.

1.3 Assumptions

Preparation of this MCP is based on the current knowledge of the resource, the prospects of developing other uranium resources in the region and long-range commodity pricing. The MCP has also been reviewed and assessed by the Rio Tinto Technical Evaluation Group to a prefeasibility study (PFS) level and is currently undergoing further review and assessment to feasibility level. This MCP is based on a number of assumptions, including:

- Bulk backfill of Pit 1 with waste rock to produce a final landform over the pit area and commencement of revegetation.
- Ongoing transfer of tailings from the tailings dam to Pit 3 and bulk backfill post consolidation to an above ground land surface with waste rock.
- The current life of mine plan will apply.
- Decommissioning and rehabilitation works will continue from now until 2026.

1.4 Preferred Closure Strategy

The preferred closure strategy involves the backfilling of Pit 1 and Pit 3 following tailings deposition, starting with the most contaminated materials (grade 2 very low grade ore) and residual waste material remaining on the land surface. The final landform will consist of the following key elements:

- All tailings will be transferred to the mined-out pits (e.g. Pit 1 and Pit 3) and subsequently bulk backfilled with mineralised waste rock to produce a surface designed to compensate for consolidation of tailings and to ensure that the landform will remain predominantly water shedding.
- A final landform constructed of waste rock of sufficient thickness to provide an erosion resistant layer and growth medium for plants. This includes the placement of waste rock with the lowest mineralisation (grade 1 waste rock) on the surface, with the highest categories of waste rock placed in the mined out pits.
- A self-sustaining ecosystem of local native plant and animal species consistent with the natural surroundings and capable of being managed under a similar regime to that currently used in Kakadu National Park.
- Temporary passive water and sediment management structures (e.g. sumps and sediment traps), around the perimeter of the landform, designed to manage runoff during the early years of establishment.
1.5 Government Agreement

Separate to this MCP, each year ERA prepares and submits a plan of rehabilitation to the responsible Commonwealth Minister for assessment and approval in accordance with the Ranger Uranium Project Agreement between ERA and the Commonwealth Government (Government Agreement). This plan is submitted for a different purpose, in order to determine the securities amount to be held by the Commonwealth Government, and is prepared separately on a different basis to this MCP.

1.6 Statutory Approvals

The MCP is an overarching document bringing together all aspects of mine closure (excluding closure cost estimates). Final signoff on rehabilitation of the RPA will be provided by the Northern Territory Minister for Primary Industry and Resources and Commonwealth Minister for Resources and Northern Australia acting on advice from the Supervising Scientist.

1.7 Managing for Closure

The existing extensive regulatory framework has been designed to minimise the impacts of uranium mining in the Alligator Rivers Region and the legacy of Ranger mine upon closure. Extensive stakeholder engagement and approvals have also been required for a number of critical issues. Accordingly, the MCP must be viewed as a description of ERA’s current aspirations and plans rather than a complete list of all closure commitments. ERA will continue to manage the rehabilitation and closure process through ongoing communication and consultation with stakeholders and participation in the relevant technical committees.

This MCP represents the outcomes of closure studies to a prefeasibility study level. In the fourth quarter of 2017, ERA also commenced a feasibility study to test the validity of the current closure strategy and increase its knowledge about certain aspects of mine closure that require further work. As at the date of the MCP, the feasibility study is expected to be completed in the third quarter of 2018. The outcomes from the feasibility study will be incorporated into the next iteration of the MCP.

ERA’s accountability for the MCP will include the development, refinement and implementation of ongoing closure strategies through the decommissioning and post decommissioning monitoring periods, in order to achieve the timely approval of relinquishment of the Ranger mine site and RPA.
1.8 Review and Updates

Regular review and updates to the MCP will be undertaken as closure activities progress, to reflect changes that occur. Where a substantial or material change to the closure strategy within the MCP is required, ERA will submit a revision and seek approval from the Supervising Authority.

A draft MCP was submitted to stakeholders during December 2016, in which several aspects of rehabilitation / closure activities were identified for standalone assessment via the Minesite Technical Committee (MTC). These aspects are detailed in Appendix 1.2 of the MCP, and include the specific rehabilitation activity, and the timing and agreed assessment process associated with each. The mine closure plan assessment process is summarised in Table 1.
Table 1: Summary of mine closure plan assessment process

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<th>Expected commencement of works</th>
<th>Initial/Expected submission date</th>
<th>ERA date for required approval</th>
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<td>1 Jan 21</td>
<td>1 Dec 19</td>
<td>1 Jan 21</td>
</tr>
<tr>
<td>Completed works final report</td>
<td>Standalone report</td>
<td></td>
<td>30 Jun 2026</td>
<td></td>
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<tr>
<td>Post 2026 monitoring and management arrangements and access</td>
<td>Regulatory framework</td>
<td>9 Jan 2026</td>
<td></td>
<td>9 Jan 2021</td>
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</tbody>
</table>
2. ENVIRONMENTAL SETTING

Chapter 2 of the MCP provides an overview of the existing environment of the Ranger nearby sensitive receptors and the location of the mine in relation to the local and regional setting. The Chapter provides the backdrop to mine closure and a summary of a 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 operations. For consistency with other regulatory management plans, much of the information provided in Chapter 2 is drawn from ERA's mining management plan, which is subject to annual regulatory approval.

2.1 Physical Setting

2.1.1 Climate

The RPA is located within the Magela catchment (1,600 square kilometres) of the Alligator Rivers Region, within the Northern Territory. This region experiences a hot climate, and is dominated by a distinctly seasonal wet-dry monsoon cycle with large inter-annual and intra-seasonal variability.

The wet season generally occurs from late October to early April, and is dominated by westerly winds, while the dry season generally extends from May to September and is dominated by easterly to south-easterly winds.

Mean maximum temperatures range from 32°C to 38°C, with annual rainfall recorded at 1,563 millimetres (mm). Annual pan evaporation is 2,594 mm, which exceeds rainfall by approximately 1,000 mm.

2.1.2 Physical Environment

2.1.2.1 Topography

The RPA is located within the Koolpinyah Surface plains of the Arnhem Land Plateau, approximately 3.5 kilometres (km) north of Mount Brockman (170 metres (m) above the plain). The plains are characterised by level, rolling or dissected lowlands, contain swamp areas and are generally at a maximum elevation of 45 m above sea level.

Coastal plains extend north of the Koolpinyah Surface along the broader river valleys, and are flat and poorly drained. To the south and east of the RPA, the Arnhem Land Plateau escarpment rises to between 200 m and 300 m above sea level.

2.1.2.2 Geology

Alluvial material has been deposited throughout the region via creek and river flow across the Koolpinyah Surface.

The regional geology consists of the Paleoproterozoic Pine Creek Inlier, which comprises (in order of oldest to most recent) the basement Nanambu Complex (~2,470 mega-annum (Ma)) containing Archaean granitoid gneisses and schists, the Cahill Formation (upper and lower),
and the Kombolgie Sandstone (~1,650 Ma) which forms part of the Katherine River Group of the McArthur Basin.

The RPA is located within the Cahill Formation, which holds areas of significant Uranium mineralisation within the Lower Cahill metasediments (~1,870 Ma) to the east of the Nanambu Complex. Figure 3 presents the stratigraphic sequence at the regional and local mine scale.

![Figure 3: Stratigraphic sequence from regional to mine scale and corresponding geological map of the immediate area of the Ranger orebodies](image)

2.1.2.3 Soils

The type (class) and distribution of soils across the land surfaces of the RPA are influenced by geology, topography and seasonal changes to soil moisture levels. The general soil types present within the RPA include deep siliceous sands, red and yellow earths, duplex soils, alluvial soils and shallow skeletal soils, which can be categorised under the following horizons:

- 'A' horizon (alluvial sands).
- 'B' horizon (bleached zone, and saprolite).
- 'C' horizon (fractured rock).
- 'D' (unfractured rock).

The A and B horizons become saturated during the wet season, however may be entirely dry to the base of the C horizon during the dry season.
The site soils are non-saline and non-sodic and can be gravelly, with clasts of quartz, ferricrete and ferruginous rock. Soil cation exchange capacity is generally moderate to low in the near-surface horizons, which also contain low levels of organic material and nutrients.

2.1.2.4 Geomorphology

The Magela floodplain represents a catchment of 815 square kilometres (km²), and is located 15 km downstream of the RPA. Waters within the floodplain disperse across poorly or undefined channels prior to undergoing discharge into the meandering channel of the East Alligator River, which flows northward along the north-eastern border of the Kakadu National Park and West Arnhem Land.

Soil erosion is highly seasonal and dominated by sheet flow during the wet season. The extent of erosion is dependent on surface rock lag in addition to vegetation cover, as the variability of vegetation cover contributes to the impact of splash erosion.

A radionuclide analysis of sediments accumulated within the Magela floodplain showed the following:

- 90% of sediments transported by Magela Creek were deposited during the first 18 km of the floodplain.
- Sediments sampled after 18 km are sourced from smaller catchments that enter the floodplain at a later stage within the Magela catchment.
- The Magela Creek showed no significant influence on sediment deposition below Jabiluka Billabong over the past 3,000 to 4,000 years.

2.1.2.5 Hydrology

The RPA is located adjacent to Magela Creek and two of its tributaries; Gulungul Creek to the west and Corridor Creek to the south. Figure 4 presents the locations of these creeks.
The regional hydrology is controlled by the wet season monsoon, with flows beginning during mid-December. Flow is reduced to a series of isolated backflow billabongs and swampy depressions during the dry season.
Magela Creek is a seasonally flowing tributary of the East Alligator River. This creek flows through deep, narrow gorges, sand and branching channels with sandy levees (present at the location of the Ranger mine), a series of billabongs and connecting channels at Mudginberri, and a 200 km² floodplain that is seasonally inundated and contains permanent billabongs. The floodplain discharges via a single channel to the East Alligator River, approximately 40 km to the north of the RPA.

Gulungul Creek is approximately 12.5 km in length, with a sub-catchment area of approximately 98.4 km² within the Magela catchment. This creek drains runoff from the catchment to the west and south of the Ranger tailings dam and from relatively undisturbed bushland to the west of Retention Pond 1 (RP1). Corridor Creek drains to the southern side of the Ranger mine operations.

2.1.2.6 Surface Water Chemistry

The chemistry of the water in Magela Creek generally shows a slightly acidic pH (~6.2) and very low electrical conductivity (EC) (~15 to 16 µS/cm, and up to 30 µS/cm during low flow conditions), low turbidity (7 Nephelometric Turbidity Unit; NTU), and low metal concentrations, and is thought to reflect rainfall chemistry more closely than regional groundwater chemistry.

Surface water chemistry for the main channel of Gulungul Creek however suggests impacts from mine-derived solutes that are similar to those observed for Magela Creek.

Further baseline surface water chemistry data is provided in Chapter 2 and Chapter 7 of the MCP.

2.1.2.7 Groundwater

The hydrogeology at the RPA consists of a relatively permeable shallow alluvial aquifer, which overlays a weathered rock layer, followed by a deeper, lower permeability fractured rock aquifer. The weathered rock forms an intermediate layer between the shallow alluvial and deeper fractured rock aquifer, and may also provide a groundwater source due to its connection with the overlying alluvial aquifer. The weathered layer acts as a semi-confining layer which reduces rainfall recharge to the fractured rock, and reduces mixing between the shallow and deep aquifers.

Groundwater flow is generally to the north across the RPA and towards Magela Creek. Groundwater level fluctuations correlate with the wet season – dry season cycle, with the largest response observed within the shallow alluvial aquifer. Groundwater chemistry typically shows relatively low concentrations of total dissolved constituents. Further information on baseline groundwater chemistry is detailed in Chapter 2, and groundwater occurrence and flow, and potential influences on solute transport post closure are provided in Chapter 7.

2 µS/cm: Microsiemens per centimetre
2.2 Social Setting

2.2.1 Land Tenure, Use and Governance

The Magela catchment contains several land use types including the Kakadu National Park (a World Heritage Listed area and Ramsar site) and mining and native title lands (Figure 5). Land tenure around the RPA is a combination of Aboriginal and Commonwealth Government freehold land managed through leasing, governance and service arrangements.

The Mirarr are the traditional owners of the land encompassing the RPA, with the Mirarr estate encompassing the RPA, MLN1, Jabiru and parts of Kakadu, including the wetlands of the Jabiluka billabong country and the sandstone escarpment of Mount Brockman.

Figure 5: Geographic context for closure activities
2.2.2 Aboriginal Culture and Heritage

There is evidence of Aboriginal occupancy of the Kakadu region dating back at least 65,000 years. Cultural heritage surveys over the RPA since 2006 have covered 73 percent (%) of the RPA and recorded 99 archaeological sites and 69 archaeological background scatters. A total of 171 recorded places of indigenous cultural heritage significance exist in the RPA.

2.3 Biological Setting

2.3.1 National Parks and Protected Areas

Most of the RPA is located within the north-east section of the Pine Creek Bioregion (as identified in a national classification of ecosystems) and is surrounded by Kakadu National Park. There are no environments of special significance (including significant breeding sites, seasonal habitats, etc) or listed endangered ecological communities identified on the RPA.

2.3.2 Terrestrial Ecosystems

2.3.2.1 Flora

The main vegetation types present within the RPA comprise woodland and open forest, which are mostly co-dominated by *Eucalyptus miniata* and/or *E. tetrodonta*. An assessment of environmental risk of disturbance to terrestrial flora and fauna species of conservation significance in the RPA has been undertaken by ERA. It simplified the two main vegetation habitats identified; Lowland riparian and rainforest, and woodland. The following four vegetation types are present within the two habitats:

1) Myrtle-pandanus savanna / paperbark forest / coastal deciduous rainforest.
2) Myrtle-pandanus savanna.
3) Open forest.
4) Woodland.

Figure 6 presents a map of the vegetation types within the RPA and surrounding Kakadu.
Over 90 flora species have been recorded across the lowland riparian and woodland areas of the RPA, none of which are classed as threatened or rare species.
Annual weed surveys conducted at the RPA since 2003 have identified approximately 80 weed species. Of these species, gamba grass (*Andropogon gayanus*) is the only weed of national significance that has been recorded in the RPA; however, its occurrence was restricted to isolated plants on roadsides or in the vicinity of the Jabiru Airport, which have subsequently been removed. Thirteen priority weeds have also been identified for the RPA including five species declared under the Northern Territory *Weeds Act 2001*. All priority weeds identified are outlined in Chapter 2.

A weed load assessment undertaken by ELA in 2015 found that the higher weed loads were located in the more highly disturbed areas around the major works areas and in areas where irrigation and slashing are used for site-based water management. The assessment determined that the current system of weed control in response to conditions on site is having a positive impact on the control of the weed load in many weed management areas.

### 2.3.2.2 Fauna

The following NT and/or Commonwealth conservation listed species that have been recorded on the RPA:

- Northern quoll (*Dasyurus hallucatus*).
- Brush-tailed rabbit-rat (*Conilurus penicillatus*).
- Black-footed tree-rat (*Mesembriomys gouldii*).
- Pale field-rat (*Rattus tunneyi*).
- Fawn antechinus (*Antechinus bellus*).
- Northern brown bandicoot (*Isoodon macrourus*).
- Partridge pigeon (*Geophaps smithii smithii*).
- Curlew sandpiper (*Calidris ferruginea*).
- Greater sand plover (*Calidris leschenaultii*).
- Lesser sand plover (*Charadrius mongolus*).
- Merten's water monitor (*Varanus mertensi*).
- Numerous migratory/marine status bird species and one reptile listed under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) (see Chapter 2, Table 2-8).

Recent surveys on the RPA suggest that the northern quoll may be extinct within the RPA. The surveys did identify the presence of the partridge pigeon, fawn antechinus and black-footed tree-rat.

In terms of introduced fauna species, eleven feral fauna species have been recorded within the RPA. Three species (pig, cat and cane toad) are listed under the EPBC Act as key threatening processes to environmental, natural heritage and cultural heritage values.
Details on the fauna and introduced fauna species identified within the RPA are provided in Chapter 2 of the MCP.

2.3.2.3 Aquatic fauna and ecosystems
No listed or endangered macroinvertebrate or fish species, nor any aquatic fauna species considered rare or restricted in distribution, have been recorded in the RPA.

Studies and monitoring undertaken on the aquatic fauna upstream and/or downstream of the Ranger mine indicate no mining related influence or impact has occurred on mussels located within the Mudginberri Billabong. The studies have also identified that there have been no adverse impacts, due to the Ranger mining activities, to macroinvertebrate communities and fish communities within channel and shallow lowland billabongs.

2.3.2.4 Bushfire
Fire within the RPA is managed primarily for asset protection and includes fuel reduction burns, excluding fire from certain areas, and maintaining a network of graded firebreaks. Burns along the RPA boundary are typically coordinated with Parks Australia aerial burns in Kakadu and are designed to minimise the risk of late dry season unmanaged fires travelling into the RPA.

The non-operational area of the RPA north of Magela Creek is burnt by Parks Australia (in cooperation with ERA) as part of annual burning programs. ERA has implemented an annual fire control plan, developed in collaboration with relevant stakeholders.
3. PROJECT OVERVIEW

Chapter 3 of the MCP provides an historical overview of the Ranger ore deposits and mine development. The chapter also includes a description of the current mining operations and major mine infrastructure.

3.1 History

Ranger deposits were discovered in October 1969 by a joint venture between Peko-Wallsend Operations Limited (Peko) and Electrolytic Zinc Company of Australasia Ltd (EZ), with feasibility of mining two ore bodies, 'Ranger 1' and 'Ranger 3' being confirmed in 1971. Peko and EZ established Ranger Uranium Mines Pty Ltd, to manage and develop the deposit.

The Commonwealth Government, at the time, had a new policy of public ownership of some energy resources, and in 1975 the Australian Atomic Energy Commission, as agent for the Government, signed the 'Lodge Agreement' which created a public/private partnership for the operation and sale of uranium from Ranger mine. However, in 1981, Government policy had changed and Peko-Wallsend established a new company, Energy Resources of Australia Ltd (ERA), to buy out existing partner (Government) interests.

In August 1977, the Commonwealth Government approved the project under the repealed Commonwealth Environmental Protection (Impact of Proposal) Act 1974.

At the same time, much of the Alligator Rivers Region was declared a National Park and Aboriginal people were given a major role in park management. The Commonwealth Government introduced laws covering the Alligator Rivers Region (Commonwealth Environment Protection (Alligator Rivers Region) Act 1978), this established the following research bodies and committees with the aim of overseeing the environmental regulation of mining in the region:

- Supervising Scientist Branch (SSB).
- Environmental Research Institute of the Supervising Scientist (ERISS).
- Alligator Rivers Region Advisory Committee (ARRAC).
- Alligator Rivers Region Technical Committee (ARRTC).

In 1978, title to the RPA was granted to the Kakadu Aboriginal Land Trust, in accordance with the Commonwealth Aboriginal Land Rights (Northern Territory) Act 1976 and the Commonwealth Government entered an agreement with the Northern Land Council to permit mining to proceed.

The proposed Ranger uranium mine was fully assessed as part of the Ranger Uranium Environmental Inquiry, or Fox Inquiry. The final recommendations provided by the Fox Inquiry specifically relevant to rehabilitation and closure include:
• All required rehabilitative work and all measures required for the continuing protection of the environment be carried out by the operator at its expense. It was recommended that:
  • The operator and its successors be bound by a legally enforceable obligation to carry out necessary work.
  • All obligations be enforceable by appropriate authorities which have the right and duty to enforce them.
  • Performance of these obligations at all times be fully secured.
  • The security be available freely to the appropriate authorities.
• The best practicable technology (developed anywhere, which can be applied to the uranium industry in Australia) to prevent environmental pollution and degradation be adopted from the outset.
• The Ranger project be permitted to commence only if there is a firm, legally binding undertaking by Ranger to place in one or other of the pits the tailings and any stockpiles of low grade ore remaining after milling ceases.
• A co-ordinating committee be established to review and consider any major changes in Ranger’s operating procedures. The Minesite Technical Committee (MTC) was formed as a result.

Mining at Ranger commenced in 1980, with the mining of Ranger 1 orebody (pit 1) completed in 1994, and the Ranger 3 orebody (Pit 3) completed in 2012.

The rehabilitation of Ranger is carried out in accordance with the ERs, which were revised in 1999 and include rehabilitation requirements. The overall objective for rehabilitation and closure is based on the rehabilitation goals outlined in the Ranger Authorisation and the ERs. Final rehabilitation and closure of the Ranger mine and RPA is via the existing statutory review and assessment mechanisms.

Further details on the history of Ranger mine are provided in Section 3.1 of the MCP.

3.2 Overview of Operations

The layout and infrastructure of the Ranger mine are shown in Figure 7 and include:
• Processing area comprising power station (which also provides power to the town of Jabiru), administration and maintenance facilities.
• A tailings dam (also referred to as the ‘tailings storage facility’ or ‘TSF’).
• Two mined out pits – Pit 1 and Pit 3.
• Ore and waste rock stockpiles.
• A number of water retention ponds, water storage structures and constructed wetland filters.
• Water treatment plants.
• Irrigation areas for the disposal of managed release water.
• An access road and service tracks.
• Ranger 3 Deeps exploration decline.
• Jabiru Airport, Jabiru East and associated infrastructure.

Further details on the overview of operations at Ranger mine are provided in Section 3.1.1 of the MCP.
Figure 7: Ranger mine layout and infrastructure
3.2.1 Mining and Processing

Conventional open cut mining of uranium ore was used in Pit 1 and Pit 3. The mined material was categorised by gamma emissions to calculate the uranium grade and determine whether the material should be either stockpiled or immediately processed.

ERA constructed an exploration decline at Ranger mine from near the south-eastern rim of Pit 3. The exploration decline has been completed and extends 2,700 m in length and 450 m below the ground surface. It is currently in care and maintenance.

The processing of stockpiled ore is 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.

Further details on the mining and processing at Ranger mine are provided in Section 3.2.1 and 3.2.2, of the MCP, respectively.

3.2.2 Landform

The final landform discussed throughout the MCP is essentially the area of disturbance defined by the mine footprint. The final landform is located within southern-most section of the RPA (78.6 km²), comprising of approximately 950 ha of intensive revegetation. Both the mine footprint and the RPA are subject to assessment prior to final relinquishment. This section discusses the major infrastructure within the mine footprint where the bulk of the remediation and rehabilitation will occur, including; the Ranger 3 Deeps exploration decline, tailings dam, open pits and stockpiles.

Ranger 3 Deeps exploration decline: ERA constructed an exploration decline at Ranger mine from near the south-eastern rim of Pit 3. The decline extends 2,700 m in length and 450 m below the ground surface. The exploration decline project has been completed and is currently in care and maintenance. There are some infrastructure components that will require decommissioning.

Further details on the Ranger 3 Deeps exploration decline are provided in Section 3.2.3 of the MCP.

Tailings dam: Currently there is an aboveground tailings storage facility. It is designed to contain process water and tailings. The dam embankments have been constructed in seven stages, between 1979 and November 2012 to the current clay core elevation of +60.5 metres Relative Level (mRL). The dam walls run along 4 separate catchment divides.

The construction, operation and closure (and post-closure where applicable) of the Dam is in accordance with Australian National Committee on Large Dams and International Commission of Large Dams (ANCOLD) and Rio Tinto Standard D5: Management of Tailings and Water Facilities. The Dam is monitored and inspected annually by independent engineers.

All tailings within the existing tailings dam will be placed within Pit 3 by 2020. The dam may be used for process water storage post this period, and at relinquishment of tenement forms part of the overall landform design.
Further details on the tailings dam and tailings storage are provided in Section 3.2.4 and 3.4.5, of the MCP, respectively.

Open pits: For closure, Pit 1 and Pit 3 have been approved to be backfilled with tailings and waste rock:

**Pit 1:** Between 1996 and November 2008, ERA deposited approximately 19.9 million cubic metres of tailings, into Pit 1 (+12 mRL), and for the next four years was used as a process water storage facility. ERA undertook works to facilitate the consolidation of tailings to enable bulk backfilling and landform development. ERA received Northern Territory and Commonwealth regulatory approval (via the MTC) for a predicted final average tailings consolidation level in the pit of approximately +7 mRL in March and April 2017, respectively.

**Pit 3:** The initial backfilling of Pit 3 to construct the in-pit drainage and extraction pumping system ceased in 2014, with 33.7 million tonnes of waste rock placed into the pit. Transfer of tailings from the mill, to the pit began in 2015 and will cease when milling stops. Dredging tailings from the storage facility to Pit 3 commenced in 2015 and will cease in 2020. ERA have installed in-pit drainage and extraction pumping systems to enable the removal of water associated with the tailings slurry mixture. There is predicted to be approximately 80 metres of tailings (up to -20 mRL) contained within Pit 3 at the end of the deposition phase. ERA will seek approval for the whole of Pit 3 closure via a standalone application to the MTC, scheduled for submission by 31 March 2019.

Further details on the Pits 1 and 3 are provided in Section 3.2.6 & 3.2.7 of the MCP, respectively.

Stockpiles: There are a number of stockpiles in proximity to the Ranger pits and tailings dam (Figure 8), segregated and categorised based on the grade of mined material (i.e. % of uranium oxide concentrate (U₃O₈)). Grade determinations are made on a truck-by-truck basis using gamma analysis. There are seven grade classes: 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. Grades 3, 2 and 1 material form the majority of the current existing 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.

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3 The most stable form of uranium oxide and the form most commonly found in nature. Uranium oxide concentrate is sometimes loosely called yellowcake. It is khaki in colour and is usually represented by the empirical formula U₃O₈. Uranium is normally sold in this form.
In 2008 an extensive drilling program was implemented to allow a stockpile block model to be built, and tonnages and grades be re-evaluated. From this drilling program 2,944 samples were analysed for sulfur. Of the Grade 1 material that will be used for rehabilitation, the risk of acidic drainage from this material is considered to be very low, with the average and median sulfur content being 0.03% and 0.005%, respectively.

Further details on the stockpiles at Ranger are provided in Section 3.2.7 of the MCP.
3.2.3 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 at the Ranger mine is categorised into five water classes according to its source and composition:

- **Process water** – most impacted water class on site.
- **Pond water** – water quality that requires active management.
- **Release water** – from incident rainfall, quality suitable to leave the site.
- **Potable water** – from two borefields (Brockman Borefield and Magela Borefield). Grey water is treated on site and pumped to leach drains and septic tanks.
- **Treated water** – water that has passed through water treatment plants or brine concentrator.

Each class of water is managed in a specific way, in accordance with Ranger's water management system. The Ranger mine footprint is divided into catchment areas which may comprise of several elements such as retention ponds, sumps, collection basins and groundwater interception ponds. The water management circuit (Figure 9) at Ranger comprises individual water management elements including:

- **Four retention ponds** for dilution and storage of pond and managed release water and sediment control.
- **Three water treatment plants** to treat excess pond water to a level suitable for release to the environment.
- **One operational wetland filter** in Corridor Creek to polish ammonia from treated process water.
- **350 ha of Land Application Areas (LAAs)** where through a network of pipes and sprinkler heads, release-, permeate- and wetland polished water is applied to the LAAs to maximise evapotranspiration.
Figure 9: Ranger mine water circuit
In 2006 a dynamic water and solute balance model was created and implemented using OPSIM. The model considers the characteristics, connectivity and operational rules associated water circuits at Ranger, and the planned changes of those elements through to 2026. The model is routinely tested by annual validation and calibration processes. Model outputs are statistically analysed. Revisions are made to the water model in response to updated operational information or changes in closure plan tactics, and recommendations arising from an annual model validation and calibration process. Typically, median forecasts are used for planning over closure timeframes, with higher confidence forecasts for contingency and capacity planning. Revisions to the model will continue as further detail around closure activities is developed.

Further details on the water management at Ranger are provided in Section 3.2.9 of the MCP.

3.2.4 Jabiru Airport

Jabiru Airport is located within the RPA and caters for light aircraft such as those providing tourist flights, medical services and fly in/fly out services from Darwin. This asset is particularly important for the Jabiru township. No decision has yet been reached regarding its long-term future of the airport.

Further details on Jabiru Airport are provided in Section 3.2.10 of the MCP.
4. FINAL LAND USE AND CLOSURE OBJECTIVES

Chapter 4 of the MCP provides a description of the legal obligations relevant to rehabilitation and closure of Ranger, and description of the agreed post-mining land use and closure objectives.

4.1 Final Land Use

The ERs specify that the RPA needs to be returned to a state in which it could be incorporated in Kakadu National Park (KNP), which is listed under the World Heritage Convention for both cultural and natural values.

A decision on the incorporation of the site to KNP will be made by the relevant authority and may not eventuate until sometime after closure. Therefore, the use of the final landform by local Aboriginal people (on the condition that they are satisfied that the area is safe) is considered to be the most likely final land use. Based on detailed consultation with the traditional owners, the following has been identified as the future land uses: Customary harvesting of bush foods and medicine; recreation; land management activities; and, cultural site visitation and ritual responsibilities.

Recreational use of the rehabilitated site may include: Intergenerational knowledge transfer visits; residential college and school trips; camping trips along Magela Creek; bushwalking trips along traditional walking routes; and, weekend swimming and picnics.

Some Aboriginal people consulted stated that they would like young people to become familiar with certain cultural sites on the RPA post-rehabilitation. This may be facilitated via an organisation (e.g. Gundjeihmi Aboriginal Corporation; GAC) or through private trips.

Other Aboriginal people said they would consider camping at traditional or well-known camping places, including various billabongs along the Magela and associated tributaries. There is a history of long term residence at sites along the Magela (for example 009 camp), where Aboriginal people have spent some years in residence.

Aboriginal people in Jabiru and Kakadu are required to undertake certain rituals associated with the death of a family member and to undertake increase rituals at certain key sites, especially sacred sites which are totemic centres for particular natural species. The sacred sites on the RPA may be locations where such rituals might be carried out in the future as Aboriginal people attempt to reconnect with the rehabilitated land.

In the early days of rehabilitation, it is envisaged that indigenous rangers will make periodic visits to undertake assessment of the cultural criteria associated with closure of the Ranger mine which are detailed in the MCP.

Further details on final land uses are provided in Section 4.1 of the MCP.

4.2 Culturally Important Flora and Fauna

The importance of flora to the Mirarr based on linguistic reference and resource value, across three ecological zones of the RPA (water courses and billabongs, riparian margins and savannah woodland). There are 64 identified culturally important flora species across the three
ecological zones (water courses and billabongs, riparian margins and savanna woodland) on RPA. These have been taken into account in the development of the revegetation species list. Further details on culturally important flora and fauna are provided in Section 4.2 of the MCP.

4.3 Closure Objectives

The closure objectives for the Ranger mine are contained in the ERs which are appended to the s.41 Authority and the Ranger Authorisation. The closure objectives are the statutory requirements for mine closure and form the basis for the closure criteria, as a means of measuring achievement of the closure objectives. The closure objectives are linked to specific aspects of Ranger mine and come under the following six closure themes, which are followed throughout the MCP:

- Landform.
- Radiation.
- Water and sediment.
- Flora and fauna.
- Soil.
- Cultural.

Further details on closure objectives and subsequent cross-referencing to the ERs are provided in Section 4.3 of the MCP.
5. STAKEHOLDER ENGAGEMENT

Chapter 5 of the MCP provides detailed information on ERA’s stakeholder engagement process, and provision of the stakeholder engagement register (Appendix 5.1) for matters relating to rehabilitation and closure.

ERA is, and has always been, committed to stakeholder engagement that is focused on building enduring relationships based on mutual respect, active partnership and long term commitment. ERA's stakeholder engagement strategy incorporates a range of formal and informal processes, which provide information and seek feedback in areas of mutual interest. There are a diverse and complex range of stakeholders with varying levels of interest in and influence, generally comprising external and internal groups:

- Traditional owners and local Aboriginal groups.
- Australian Government.
- Northern Territory and local government.
- Primary regulatory committee
- Regional scientific overview committee.
- Regional overview committee.
- International agencies.
- Others – environmental interest groups.
- Local community.
- Business community, including Rio Tinto, suppliers and shareholders.
- ERA groups, including the ERA Board, Executive Committee, managers, legal team, employees and contractors.

Principles for engagement: Community engagement takes place in accordance with the following guiding principles: Transparent relationships; accessible staff; strategic engagement, and, two-way communication.

With communication in the following formats:

- Quarterly updates on key closure activities.
- Presentations outlining closure strategies, engineering studies, modelling predictions and research and development.
- Participation in the development and progress of scientific studies identified in forums such as ARRTC.
- Site visits to the Ranger mine to inform progress on closure activities and studies.
- Knowledge sharing and peer review of closure strategies, studies, and activities through workshops, conferences and scientific publications.

Since 2001, stakeholder engagement in relation to closure has been a focus. ERA has, and continues to, engage directly with numerous stakeholders on key closure aspects for the Ranger mine, including but not limited to:
• Engineering and design for technical aspects of closure such as water treatment, final landform, tailings transfer and pit backfills.

• The overall planning process, schedule and associated costs.

• Closure criteria, environmental design and closure objectives.

• Legal requirements and obligations associated with the various agreements for Ranger operations and Jabiru.

• Land tenure, governance and post closure land use.

Further details on ERA’s principles for engagement are provided in Section 5.2 of the MCP.

5.1 Socio-Economic Impacts

ERA Ranger operations are currently a significant contributor to the socio-economic matrix of Jabiru, the West Arnhem region and more broadly the Northern Territory. The potential socio-economic impacts of the closure of the Ranger mine have been the subject of significant engagement with key stakeholders and are reasonably well understood. Whilst the current baseline of ERA’s contributions is well understood by the company and its stakeholders, the impacts and management options to transition to a post-mining region have not yet been formalised.

Following the closure feasibility study, ERA will extend the Jabiru social impact assessment (discussed below), to incorporate specific information on the cessation of Ranger operations. The updated study will identify social and economic risks and opportunities associated with closure, and in consultation with stakeholders, identify potential mitigation options. The update will include the outcomes of key decisions on with the future of Jabiru and ERA’s workforce requirements.

Jabiru Transition: A social impact assessment has been completed. The purpose of the study was to assess the impacts associated with ERA’s rehabilitation obligations under the current Jabiru head lease and develop potential mitigation options for the identified impacts. A report completed by Jacobs in May 2017, provided a range of potential social impacts including:

• Displacement of Jabiru residents.

• Impact on employment opportunities and subsequently livelihoods and economy size.

• Loss of Jabiru as a service (health, education, retail) hub for residents in the region.

• Loss of critical infrastructure including electricity and water supply.

• Closure of Jabiru Airport which would impact tourism, regional charters and other users.

The impact assessment report highlighted some potential mitigation measures, including early decision making about Jabiru and closure, and continued engagement to remove uncertainty. More work is required to plan and agree on impact mitigation and transition strategies.
Throughout the next phases of closure, ERA will continue to engage constructively with relevant stakeholders.

Further details on ERA's contribution to addressing socio-economic impacts are provided in Section 5.3 and 5.5 of the MCP.

5.2 Cultural Heritage

The protection of cultural heritage during closure works is of importance to the Mirarr traditional owners and a legislative obligation.

There is a cultural heritage management system in place at Ranger, which will remain in place during closure. It includes a suite of agreements, legislation and company policies and procedures. The management system ensures:

- Compliance with Northern Territory and Commonwealth heritage legislation.
- Cultural heritage incidents are managed in compliance with the ERA Health, Safety and Environment Management System and with the Rio Tinto Communities and Social Performance standard.
- That there is a land disturbance permitting process which ensures compliance with the ERA GAC 2006 Interim Protocol Regarding Cultural Heritage.
- Cultural heritage sites remain protected prior to land disturbance, during the life of the mine, and mine closure.
- That there is site wide awareness of the ERA cultural heritage management system.
- There are cultural heritage operational procedures and work instructions.

Further details on ERA's management of cultural heritage are provided in Section 5.4, of MCP.
6. CLOSURE CRITERIA

*Chapter 6* of the MCP provides detailed information on the ERA’s development of closure criteria across six key themes: landform; radiation; water and sediment; flora and fauna; soils; and, cultural.

The ERs contain a number of primary and secondary objectives for the rehabilitation and closure of Ranger. The overall objective for rehabilitation and closure has been based on the rehabilitation goals outlined in the Ranger Authorisation and the ERs (ERA 2014). Closure criteria, which are also performance criteria, will be used to demonstrate the achievement of the rehabilitation closure objectives and therefore the rehabilitation goals outlined in the ERs. The criteria represent direct measurable and quantifiable values, or tiered assessment processes based on industry best practice frameworks.

To develop closure criteria, the Closure Criteria Working Group (CCWG) was formed with relevant stakeholders and ERA. The process adopted for developing closure criteria is provided in Figure 10. The proposed closure criteria presented in this MCP have been developed from closure studies and reports, including work completed by the CCWG and the closure criteria technical working subgroups, as well as stakeholder feedback to the draft MCP issued in December 2016 (refer Section 6.8 of the MCP).

Closure criteria will continue to undergo review and refinement in collaboration with key stakeholders.
Figure 10: Framework for the closure criteria working group, and subsequent closure criteria development and approvals pathway
To enable measurement and sign off on the required rehabilitation goals identified in the Ranger Authorisation and ERs, these have been used to derive the closure and rehabilitation objectives. The objectives are then used to further articulate rehabilitation "outcomes". There can be one or more rehabilitation "outcomes" for each objective. The "outcome" is then broken down further to enable measurement: a parameter, final criterion and corrective actions are all determined. In some cases, it is necessary to have more than one set of parameters, final criteria and corrective actions for each outcome.

An example of a closure criteria is:

- **Outcome:** Drainage channels are installed and maintained to manage erosion for each catchment and are comparable to landforms in surrounding undisturbed areas.
- **Parameter:** Gully erosion.
- **Final criterion:** Post wet season observations show no unplanned gully erosion has occurred.
- **Corrective Actions:** Earthworks to manage erosion.

Once the RPA has been rehabilitated, there will need to be an ongoing program of monitoring and management in relation to criteria for closure. Key stakeholders are currently working through options to extend ERA’s access to the RPA post 2026, to undertake minor rehabilitation works and ongoing monitoring.

### 6.1 Landform

There are four closure objectives associated with the final landform on the RPA. The closure criteria related to these objectives are presented in detail in Chapter 6, Table 6-1, with a summary of the objectives, outcomes and justifications provided below/overleaf:

**Objective 1 – removal of site infrastructure**

- **Outcome – Supervising authority confirms all plant and infrastructure should be removed from site, unless approved to remain.**

**Objective 2 – final disposal of tailings**

- **Outcome – stakeholders sign off that all tailings have been placed in the mined out pits, Pit 1 and Pit 3.**

**Objective 3 - maintaining the isolation of tailings for 10,000 years**

- **Outcome – the best available modelling (Landform Evolution Model; LEM - determined the best available technology) demonstrates that the tailings will not be exposed for 10,000 years.**

**Objective 4 - relates to the erosion of the landform and has 4 outcomes derived which are:**

- **Outcome 1 - the best available modelling (LEM) demonstrates that the erosion of the final landform (denudation rates) will eventually be comparable to natural landscapes.**
Outcome 2 – drainage channels are designed, installed and maintained to manage erosion for each catchment and are comparable to landforms in surrounding undisturbed areas.

Outcome 3 – ensure sediments resulting from erosion of the landform do not cause sand to infill Magela and Gulungul creeks and associated billabongs.

Outcome 4 – suspended sediment loads in Magela and Gulungul Creeks will be approaching background.

Records of tailings placement and infrastructure removal along with the occurrence of inspections throughout the decommissioning phase, will confirm that the objective of removal of site infrastructure have been met.

The length of time required (10,000 years) to contain the tailings is considered to be only measurable through LEM analysis. The modelling predictions should be conservative to give confidence the objective will be achieved, while based on realistic and reasonable worst case scenarios. The constructed landform digital elevation model (DEM) will be re-modelled to confirm initial findings. The criteria will be achieved if the model demonstrates that tailings will not be exposed for at least 10,000 years.

Denudation is considered the most appropriate parameter for comparing erosion characteristics of landform over time. The denudation rate of waste rock landform is unlikely to be similar to natural landforms, in the short term, therefore predicted denudation rates from the LEM are considered appropriate for long-term predictions of denudation rates.

Drainage channels will be important for managing gully erosion on the landform. Drainage channels will be designed and constructed in locations where the LEM has predicted gullying will form. The supervising authority will assess the channel location prior to construction and final contouring. The appropriate design of the landform, erosion mitigations and drainage channels should minimise development of gully erosion. Post wet season inspections will be undertaken to determine the presence or absence of unplanned gully erosion and channels inspected for operating according to design. The method for achievement of the aesthetic of objectives of the landform of the channels blending in, as much as possible, with the surrounding landscape, will require input from traditional owner representative groups.

It is considered more likely that significant levels of erosion will occur in the early stages of the landform design life and it is expected that some maintenance may be required. The need for maintenance should progressively decline as the landform matures and dynamic equilibrium is reached. When drainage channels are considered to have reached functional dynamic equilibrium, this criterion will be achieved.

Event load suspended sediments are considered the most appropriate parameter for site-scale erosion characteristics. Work completed by the SSB in 2012 has demonstrated that turbidity can be used as an indicator for suspended sediment. Event based loads leaving the site will be tracked across a wet season and compared to background (analogue) loads. It is expected that it will take some time for these loads to return to background levels; therefore, achievement of this criterion will be based on the trajectory towards the analogue, which is expected to be between 5 and 10 years.
Details on the process for the development of site specific landform closure criteria are described in Section 6.2.1 of the MCP.

6.2 Radiation

There are two closure objectives relating to radiation with the details on the radiation closure criteria presented in Chapter 6 Table 6-2. A summary of the objectives and outcomes are provided below:

Objective 1 - relates to stable radiological conditions in the impacted mining area that ensures members of the public and traditional owners do not receive a radiation dose that exceeds applicable limits, and that there is minimal restriction of use of the area.

   Outcome 1 – Radiation doses to members of the public are 'as low as reasonably achievable' (ALARA).

   Outcome 2 - Radiation doses to members of the public are below limits

Objective 2 - ensuring that the operations at Ranger do not result in a) a change to biodiversity, or impairment of ecosystem health, outside of the RPA; and b) environmental impacts within the Ranger Project Area which are not ALARA.

   Outcome 1 – to minimise the deleterious radiation effects on terrestrial biota to a level where they would have a negligible impact

   Outcome 2 - to minimise the deleterious radiation effects on aquatic biota to a level where they would have a negligible impact

Radiation doses to members of the public and the surrounding environment have been developed using international guidance from:

- International Commission of Radiological Protection (ICRP).
- International Atomic Energy Agency (IAEA).

The ICRP recommends and ERA has implemented a three-tier approach to radiation protection called the "Fundamental Principles of Radiation Protection":

- **The Principle of Justification**: Any decision that alters the radiation exposure situation should do more good than harm.

- **The Principle of Optimisation of Protection**: the likelihood of incurring exposures, the number of people exposed, and the magnitude of their individual doses should all be kept as low as reasonably achievable, taking into account economic and societal factors (the ALARA principle).

- **The Principle of Application of Dose Limits**: The total dose to any individual from regulated sources in planned exposure situations other than medical exposure of patients should not exceed the appropriate limits recommended by the Commission.
The Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) and National Occupational Health and Safety Commission (NOHSC) have adopted some of these standards and guidelines. These have been subsequently applied to Ranger through the *Code of Practice and Safety Guide on Radiation Protection and Radioactive Waste Management in Mining and Mineral Processing* and other relevant guidelines.

The 2016 IAEA guidance document *Release of Sites from Regulatory Control on Termination of Practice* sets an upper level structure for the development of radiation closure criteria. The release of sites from regulatory control is the final stage in the decommission process and is also the final stage of the practice; therefore, the radiation protection principles of justification, dose limitation and optimisation apply.

The principle of justification is applied at the adoption of the practice of uranium mining as a whole; which includes construction, operation, decommissioning and final close-out of the project. Therefore, it can be assumed that the decommissioning and closure phases of the practice are justified.

The normal dose limitation for the uranium mining practice will apply, which is set out in the 2014 ARPANSA *National Directory for Radiation Protection*. For members of the public this will be 1 milli-Sievert in a year, determined from the sum of effective doses from all possible combinations of exposures.

Based on the limited exposure pathways in the region, a dose constraint of 0.5 milli-Sieverts (500 micro-Sieverts) would be in keeping with the principles for setting dose constraints; however, ERA has elected to keep the recommended 300 micro Sieverts per year default from the IAEA.

ERA has developed, using relevant guidance and standards, a Radiation Management System, which will be applied through the decommissioning phase. Multiple exposure pathways have been considered for the development of the criteria (e.g. dose rates), which are in line with international and national guidelines.

The outcomes that relate to the protection of biota have been derived from the guidance provided by the 2014 ICRP: *Protection of the Environment under Different Exposure Situations*. This document describes the framework for protection of the environment and how it should be applied within the ICRP system of protection.

The ICRP states that the aims in terms of environmental protection are to prevent or reduce the frequency of deleterious radiation effects on biota to a level where they would have a negligible impact on the maintenance of biological diversity; the conservation of species; or the health and status of natural habitats, communities, and ecosystems.

In order to assess if the radiation criteria for radiation effects on biota have been achieved, the framework documented in the 2014 ICRP guidelines or similar international guidance will be used to:

- Determine the radiation dose rate to a reference set of both terrestrial and aquatic biota.
- Compare this to the benchmarks documented as the closure criteria.
If the dose rates are below the benchmark dose rate then it can be concluded that there is an acceptable level of protection to the environment. If dose rates are above the benchmark, a detailed review of the doses to that particular organism will be undertaken along with a review of the actual radiation effects for that organism. An assessment will be made to determine if actual effects will occur and therefore if mitigations are required.

Details on the process for the development of site specific radiation closure criteria are described in Section 6.3.1 of the MCP.

### 6.3 Water and Sediment

The MCP identified three closure objectives relating to water and sediment. The closure criteria are presented in detail in Chapter 6 Table 6-3, with a summary of the objectives and outcomes provided below:

**Objective 1** – relates to chemical pollutants in water, arising or discharged from the RPA, during or following rehabilitation to compromise the primary environmental objectives of protecting the health of Aboriginals and other members of the regional community.

- **Outcome 1** - mine derived analytes will not cause dietary (food and water) resources to exceed limits for human consumption in Magela Creek outside the RPA.
- **Outcome 2** - mine derived hazards will not cause designated recreational water resources to become unsafe for their designated recreational use in Magela Creek outside the RPA and Gulungul Creek secondary contact sites.

**Objective 2**- relates to protection of the Alligator Rivers Region (e.g. aquatic and terrestrial biodiversity, ecosystem health) and protection of the environment from tailings contaminants for 10,000 years.

- **Outcome 1** – ensuring mine derived analytes from on-site surface or ground waters discharged to surface waters off the RPA do not cause detrimental impact to the ecosystem health of the Alligators River Region, and that there will be no detrimental environmental impact off the RPA from tailings contaminants for at least 10,000 years.
- **Outcome 2** - mine sourced solutes do not increase uranium in sediments off the RPA to levels that would be detrimental to ecosystem health of the region.

**Objective 3** – relates to ensuring that the impacts are ALARA on the RPA.

- **Outcome 1** – surface water quality to meet the highest ecosystem protection level and is demonstrated to be ALARA.
- **Outcome 2** - incorporates accumulation of erosion products in Coonjimba and Georgetown Billabong determining it will be ALARA.
ERA have assessed that the impacts off-site as well as on site, and the mitigations in place or possible is part of the process for understanding:

- ALARA.
- BPT (Chapter 8) for considering environmental, technical, social and financial aspects.
- The tiered risk assessment/decision framework under development for considering on and off site potential impacts to environmental values.

ERA are investigate using an assessment process, rather than compliance with a single numeric criterion to determine if closure outcomes in the water and sediment theme (diet and recreation, and ecosystem) are achieved, in line with best practice recommendations to assess environment and health effects or risks.

A framework to assess if the Primary ERs are met, through a risk based tiered approach for drinking water and recreational outcomes, has been developed. For example, Figure 11 depicts the indicative risk based tiered decision tree for drinking water outcomes.
Similar process/decision trees and frameworks have also been developed for recreational water outcomes (Chapter 6, Figure 6-4), and for assessing if there is unacceptable change to the ecosystem in the Alligator Rivers Region, which considers duration, geographic extent of impact and impact recovery has been developed (Chapter 6, Figure 6-5).
The closure criteria assessment approach for water and sediment has been developed using a combination of site specific and national water quality guidelines within a risk-based, tiered assessment process. The tiered assessment process continues to be refined through stakeholder workshops in collaboration with ERA and consultants BMT WBM Pty Ltd. Constituents of potential concern (COPC) present in tailings/process water or waste-rock sources and other key variables have been used in determining the analytes of concern/interest. First tier screening criteria are derived from (i) national drinking water and recreations guidelines values; and (ii) site-specific and ANZECC guidelines values for ecosystem protection.

Details on the process for the development of site specific, risk based, tiered guideline values/screening criteria are described in Section 6.4.2 of the MCP.

6.4 Flora and Fauna

There is one closure objective relating to flora and fauna, the closure criteria are presented in detail in Chapter 6 Table 6-4, with a summary of the objective and outcomes provided below.

Objective - relates to the revegetation of the RPA using local native plant species, obtaining similar abundance and density to those in Kakadu National Park; and to establish an ecosystem, the long-term viability of which would not require a maintenance regime significantly different from that of adjacent areas of the park.

- Outcome 1 - relates to the use of local native plant species.
- Outcome 2 - relates to the species composition and community structure being similar to Kakadu National Park (KNP).
- Outcome 3 - relates to the long-term viability of the ecosystem and the associated maintenance regime.

Derivation of the flora and fauna criteria has been developed with an understanding of both general ecological restoration principles, ecosystem dynamics in northern Australia, and the knowledge gained through 30 years of flora and fauna studies, revegetation trials and research on the RPA and surrounding areas. Studies have been aimed at understanding and achieving the above outcomes.

The closure criteria for flora and fauna were developed through information from reference sites and trials. The topography, hydrology and substrate of the final landform will be different to the pre-mining environment and there is no real analogue in the natural surroundings, which means that a local indigenous ecosystem, more ecologically appropriate to the changed conditions, may be used as a guide for revegetation of the site. Therefore, the reference ecosystem in the case of Ranger mine will be a conceptual model synthesised from numerous reference sites, field indicators, and historical and predictive records.

A revegetation species list was developed in consultation with stakeholders, in particular this was based on:
• Previous analogue vegetation studies in undisturbed areas of the RPA and surrounding areas by ERISS-ERA (125 studied analogue sites, including 10 sites from KNP with land surface similar to Ranger's final landform).

• Recent list of culturally important plant species, identified by the Mirarr traditional owners.

• Learnings from progressive revegetation activities and in particularly the learnings from the trial landform.

• The species list will undergo refinement from a local native seed expert (Kakadu Native Plants Pty Ltd) for assessment of appropriateness based on their local expertise on vegetation, habitats, and seed availability, viability, germination and nursery production rates. A final revegetation species list will be included in the revegetation implementation plan.

The SSB has recommended that the total number of species be assessed over an area of 400 ha. The total number of species that will be planted during Phase 1 of the revegetation program amounts to 49.

The outcome relating to community composition will be defined using the following parameters:

• Species composition and relative abundance.

• Canopy architecture, ground cover index.

• Tree distribution.

The outcome relating to long term viability will be measured using the following 8 parameters:

• Reproduction (flowering and fruiting).

• Recruitment and regeneration.

• Nutrient cycling.

• Fire wind and drought resilience.

• Plant available water.

• Weeds.

• Native fauna.

When assessing rehabilitation performance, some criteria can be considered 'critical', stand-alone criteria necessary to ecosystem establishment (e.g. the use of only local native flora species). However, some criteria such as canopy architecture and ground cover index, are better assessed collectively, or within the context of meeting the overall closure criteria as a whole.

Details on the process for the development of site specific flora and fauna closure criteria are described in Section 6.5.1 of the MCP.
6.5 Soils

There is one closure objective that relates to soils on the RPA. The closure criterion is presented in detail in Chapter 6 Table 6-5, with a summary of the objective and outcome provided below.

The Objective relates to environmental impacts within the RPA being ALARA during and after rehabilitation.

- **Outcome** – contaminated soils on the RPA being remediated to ALARA to protect the environment.

Preliminary site investigations will be completed for all identified contaminated soils that are not already in the process of remediation as part of the larger decommissioning works (i.e. LAAs). Soils found to be above either local background and/or published investigation levels will undergo further detailed investigation, and a remediation plan will be developed, based on ALARA.

6.6 Cultural

There is one closure objective relating to the cultural closure theme at the RPA. The closure criterion is presented in detail in Chapter 6 Table 6-6, with a summary of the objective and outcomes provided below.

Objective – relates to maintaining attributes for which Kakadu National Park is inscribed on the world heritage list, and that the RPA must be rehabilitated to establish an environment similar to the adjacent areas of Kakadu National Park.

- **Outcome 1** – landform design to support cultural land uses.
- **Outcome 2** – traditional owners being satisfied there are no additional water bodies.
- **Outcome 3** – traditional owners being satisfied the riparian zones are in good condition.
- **Outcome 4** – relates to traditional owners being satisfied with the final landform and state of key landmarks.
- **Outcome 5** – traditional owners being satisfied with the water quality and that no silting or sedimentation is occurring.
- **Outcome 6** – traditional owners observing improvement in the progression of revegetation on the landform.
- **Outcome 7** – traditional owners observing improvement in biodiversity on the landform.
In determining the success of the rehabilitation over time, significant emphasis will be placed on ensuring that culturally important flora and fauna are present on the final landform. Of particular importance is social organisation, moieties, and conceptions of landscapes; all of which, if not satisfactorily addressed, will ultimately influence the assessment by Mirarr of the rehabilitation.

The examples of indicators that could be used to reflect traditional owners' attitudes towards the progress of rehabilitation are largely based on visual and aesthetic factors (Table 2). Cultural health indices are based on early consultation work and studies into cultural closure criteria completed by ERA, NLC and GAC, and recent consultation by Dr Murray Garde, linguistic anthropology expert. The indices, have been developed using established models and methodologies used in New Zealand and include a scalar measurement tool developed in a bilingual format that includes information in both Gundjeihmi and English (Table 3).

ERA will continue to work with the GAC and NLC to refine and update cultural closure criteria, for incorporation into the next MCP iteration.

Table 2: Suggested indicators of cultural health of rehabilitated site

<table>
<thead>
<tr>
<th>Landscape surface</th>
<th>Vegetation</th>
<th>Riparian zone</th>
<th>Biodiversity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size of rocks</td>
<td>growth rate</td>
<td>presence or absence of artificial water bodies</td>
<td>natural species numbers and diversity</td>
</tr>
<tr>
<td>Presence / absence of erosion</td>
<td>botanical diversity</td>
<td>visual impressions of water quality, sedimentation, silting of rehabilitated water courses</td>
<td>impressions of hunting potential</td>
</tr>
<tr>
<td>Accessibility</td>
<td>correct species for ecological zone</td>
<td>condition of water course margins, creek banks</td>
<td>impressions of vegetable food availability</td>
</tr>
<tr>
<td>General aesthetic (does it look 'natural')</td>
<td>presence/absence of weeds</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 3: Example of scalar measurement tool for cultural criteria monitoring

<table>
<thead>
<tr>
<th>ga-djalbolkwarreryerre</th>
<th>ga-bolkwarreyiga ga-bolkmakmen gun-yahwurd</th>
<th>kareh ga-bolkmakmen gare lark</th>
<th>ga-bolkmakmen wurd</th>
<th>bon, babolkmakminj wanjh</th>
</tr>
</thead>
<tbody>
<tr>
<td>no improvement yet noticed</td>
<td>some minor improvements</td>
<td>some areas improved, some areas not</td>
<td>noticeable return to healthy state in most areas</td>
<td>satisfactory return to natural state</td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>
Long-term periodic assessment of attitudes and opinions of traditional owners and their kin, in relation to the dynamics of rehabilitation over time, will be undertaken annually. It will determine whether or not the traditional owners feel that rehabilitation in the RPA is progressing towards a desirable trajectory.

Work will continue to ensure the final landform delivers the appropriate cultural outcome, and ensure the right species are planted in the right places. This may be achieved by overlaying the final landform design with the Gundjeihmi system of ecological zones (an-gabo, an-labbarl, etc), and then within each of these zones prescribe the layout/placement of various flora species.

Details on the process for the development of site specific flora and fauna closure criteria are described in Section 6.7.1 of the MCP.

6.7 Status of Closure Criteria

ERA released the draft MCP to stakeholders in late 2016, and received comments on the plan and criteria in mid-2017. Feedback from the Supervising Scientist on the criteria in the 2016 draft MCP was that 53% were agreed to, 43% were partially agreed to and 4% not agreed to.\(^4\) The breakdown of the agreement status by closure theme at the time is shown in Table 4 and Figure 12.

The Supervising Scientist Branch have not commented on cultural criteria, which have been developed in direct consultation with the GAC.

Table 4: Stakeholder acceptance of ERA draft criteria in mid-2017

<table>
<thead>
<tr>
<th>Theme</th>
<th>Number of criteria</th>
<th>Acceptable</th>
<th>Partially acceptable</th>
<th>Not acceptable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Landform</td>
<td>11</td>
<td>6</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>Radiation</td>
<td>4</td>
<td>4</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Water and sediment</td>
<td>5</td>
<td>0</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Flora and fauna</td>
<td>13</td>
<td>3</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>Soil</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>47</strong></td>
<td><strong>25</strong></td>
<td><strong>20</strong></td>
<td><strong>2</strong></td>
</tr>
</tbody>
</table>

\(^4\) These percentages excluded feedback on cultural criteria, which the Supervising Scientist did not comment on.
Updates to the MCP address many aspects of disagreement in each theme. Since the 2016 draft criteria and responses from SSB, both ERA (and consultants) and SSB (and consultants) have completed or progressed several projects to address outstanding issues for closure criteria finalisation and agreement.

ERA is responsible for the development of closure criteria. The Supervising Scientist is developing a series of rehabilitation standards, which although only advisory, will form a key component of the Supervising Scientist's advice on rehabilitation activities at Ranger.

Section 6.8 of the MCP provides details and estimated percentage completion of the various SSB standards under development. This section also provides an overview of the status of work / studies being undertaken across all closure criteria themes to progress agreement and subsequent regulatory approval.
7. SUPPORTING STUDIES

Chapter 7 of the MCP provides detailed information on the ERA’s most relevant supporting studies undertaken over the past 35 years at the Ranger mine, to inform both the development of the overarching closure strategy and design, and closure criteria. The studies presented have been grouped under the following categories; and overview of each category is provided in this section:

- Tailings consolidation.
- Tailings properties.
- Trial landform.
- Environmental protection.
- Landform design and performance.
- Ecosystem establishment.
- Groundwater modelling.
- Surface water modelling.
- Brine management.

7.1 Tailings Consolidation Modelling

ERA commissioned the development of a series of Pit 1 tailings consolidation models since 2003, as part of the Pit 1 closure planning process. The modelling enables prediction of the final tailings elevation within Pit 1 and the forecast volume of process water to be expressed during the consolidation. The Pit 1 model was later adapted for Pit 3 closure.

Numerous tailings characterisation studies and geotechnical investigations were also undertaken to support the conceptualisation of the consolidation models through prediction of the subsurface conditions for the final backfill design. The consolidation modelling program is an extended version of the formulation developed by Somogyi in 1980. The modelling program was presented as a minor thesis, which has been examined by Professor David Williams of the University of Queensland, the model includes:

- A technique to allow for variable basing geometry and/or changing solids deposition rate with time.
- Underdrainage to atmospheric pressure.
- The application of surcharges.

**Method of handling variable basin geometry**

Variable geometry is handled by considering the tailings impoundment as a series of five annular areas, which receive discharge of solid material. The purpose of this technique is to ensure that the model compensates for the greater settlement of solid material that occurs within deeper sections (or “columns”) of the deposit, resulting in a pseudo 3-dimensional consolidation model that is believed to pre-date other such models.
Further details on the variable geometry technique, including comparison of the actual excavated Pit 3 with the modelled pit, and typical density profiles for an earlier Pit 3 consolidation analysis are presented in Section 7.1.1.1 of the MCP.

**Underdrainage**

Underdrainage is represented within the model by allowing for seepage forces and negative excess pore pressure. Further details on this concept, including the various pore pressures applied for an under-drained deposit are presented in Section 7.1.1.2 and Appendix 7.2 of the MCP, respectively.

**Outputs**

The model outputs include the following:

- Density, permeability, void ratio and effective stress profiles for each "column" at user defined times.
- Cumulative consolidation flows to the surface and base of each "column".

**Validation**

The model and under-drain case has undergone validation against a number of published scenarios published in the 1990s and a large-scale investigation published in 1986. The validation process showed excellent agreement between the Ranger model and the published studies.

Validation was also undertaken against a number of real-life applications, including, for example: Golden Cross Gold Mine; New Zealand and Century Zinc Mine; Queensland, the Granites Gold Mine, Northern Territory; and a coal mine in the Hunter Valley.

Further details on the model validation undertaken is provided in Section 7.1.1.4 of the MCP.

**Pit 1 Tailings consolidation**

Tailings consolidation modelling has been undertaken for Pit 1 since 2003. The most recent tailings consolidation model in 2012, estimated an average final tailings level within Pit 1 at 7 mRL, with 0.5 mRL in the centre of the pit, and 12 mRL towards the outer edges. The validation studies indicated that the majority of process water (greater than 99%) will be removed via the decant structures by January 2026, assuming that bulk backfill activities commence during August 2016. Bulk backfill activities did not commence until May 2017; however, the conceptual modelling does not suggest significant impacts to the tailings consolidation or flow of process water over time as a result of the delay.

Figure 13 and Figure 14 present the predicted final tailings level across Pit 1 from the conceptual models, and the predicted flow of process water during consolidation respectively.

Validation and update of the tailings consolidation models was undertaken through installation of settling monitoring plates and upstands across Pit 1, which were raised to align with the initial bulk fill layers, and provide confirmation of the consolidation rate as well as estimates of the volume of expressed process water over time.
Further detail on the Pit 1 tailings consolidation is provided in Section 7.1.2 of the MCP.

Figure 13: Predicted final tailings level (metres) across Pit 1
**Pit 3 tailings consolidation**

A number of field and laboratory studies have been conducted to confirm the Pit 3 tailings geotechnical properties and provide updated parameters for the in-pit tailings consolidation modelling.

Testing indicated that the geotechnical properties of the tailings have, and will continue to, vary with time. To account for this and provide a sensitivity analysis, three sets of consolidation parameters were considered in the modelling:

- A conservative (i.e. relatively slow consolidation) model.
- Best estimate model.
- Non-conservative (i.e. relatively fast consolidation) model.

Consolidation modelling was carried out for all three parameters and results demonstrated that consolidation could be achieved by 2026 for all cases. Wick drains are required to promote consolidation, and a rock drainage layer will be installed on top of the tailings as an interception layer to enable extraction of water expressed up through the tailings material.

The consolidation model was updated to reflect the "as constructed" situation in early 2016. Results indicate that the majority of parameters are essentially the same. With the use of wick drains (at a higher density for Pit 3), both achieve effective consolidation by December 2026.
Figure 15 presents the conceptual model at the end of consolidation. However recently obtained data has indicated that a greater density of wick drains across Pit 3 is required to ensure a similar level of consolidation reported in 2014.

Details on the outcomes of the tailings consolidation studies are described in Section 7.1.3 of the MCP.

Figure 15: Indicative conceptual cross-section of Pit 3 at the end of consolidation, as at 2014 (source: INTERA)

7.2 Tailings Properties

Tailings transfer from the tailings dam to Pit 3 began in 2015, and is supported by a number of studies undertaken in order to validate the expected tailing volumes and also to provide key information to feed into the overall dredge program. Studies included: tailings dam geophysics (bathymetric) survey; tailings dam magnetometer survey; tailings dam characterisation and cone penetration test program.

The studies provided information on the segregation and characterisation of tailings within the tailings dam, validated the expected tailings volumes, and informed the current dredge program.

Details on the tailings volume and transfer studies are described in Section 7.2 of the MCP.
7.3 Trial Landform

The design of the final landform comprises a number of physical and biophysical features, including but not limited to: its waste rock construction, erosion, bedload, stability, water management, radiological aspects, revegetation and ecosystem development.

A trial landform was constructed within 8 ha of the north-western corner of the tailings dam, to trial various aspects of the landform design and inform modification of the digital terrain model (described in Section 7.5) and the closure criteria expectations. The trial landform also provides the opportunity to apply adaptive management during ecosystem establishment.

The trial stands 4 to 7 metres above the original ground surface and was constructed using 800,000 tonnes of primary and weathered waste rock. The design incorporated treatments to allow testing of the performance of different types of substrates:

- Waste rock only, and blended waste rock with fine grained material.
- Different depths of mixed materials over the waste rock only layer.
- Different planting methods.
- Different irrigation regimes.

The landform design incorporates runoff and catchment management features, and monitoring systems to provide water quality data to inform decision-making on future water management strategies.

Annual monitoring has been undertaken since construction to monitor the success of the landform in establishing a functioning terrestrial ecosystem. This included a Landscape Function Analysis to measure stability, infiltration and nutrient cycling, as well as assess the ability of the trial landform ecosystem to act as a biophysical system.

Section 7.3 of the MCP presents further details on the constructed landform design.

7.3.1 Runoff, Soil Erosion and Solute Loss

Four erosion plots were constructed within the trail landform, and were located to represent two types of potential final cover layers and planting methods. Raised borders surrounding the plots were installed to isolate the plots from runoff. Figure 16 shows the location and layout of the plots within the trial landform.

Monitoring of stage height, suspended sediment concentration, electrical conductivity and discharge from the plots has been undertaken, as well as water sampling. Monitoring results including generation and transport of solutes, hydrology and bedload yields have been reported regularly.

Section 7.3.2 of the MCP provides further details on the erosion plot studies.
Monitoring of runoff at the trial landform suggests an exponential relationship exists between event rainfall and event runoff over the full range of rainfall data; however, this has not been statistically confirmed. The studies also suggest that event rainfall greater than 30 mm generally generates proportionally greater runoff due to the complete infill of the surface storage, which allows runoff from the whole plot surface.

Runoff and erosion rates have been measured at the trial landform and used to assess the long-term geomorphic stability. The measured export rates from the trial landform have been compared to the modelled rates from the landform evolution model to provide a stability estimate that can be applied to the final landform. Measurements show an exponential decrease in mean annual bedload yield over time, since construction of the trial landform.

Further details on the erosion studies and results including bedload yields are outlined in Section 7.3.2.2 of the MCP.

Numerous studies characterise the Ranger waste rock as potentially generating materials such as soluble manganese, magnesium, sulfate, uranium, calcium, aluminium, iron and potassium. Solute generation has been shown to decrease over time as the source of the solutes decline and stabilise, however “first flush” after the dry season will always show elevated concentrations.
Laboratory analysis of water samples collected from the trial landform has allowed estimation of the total dissolved solid load for Plot 1, as well as annual and seasonal trends for dissolved and trace metals, and major ion concentrations for runoff from the trial landform plots. Concentrations of sulfate, calcium, sodium, potassium, barium and uranium were higher in trial landform runoff than in upstream control sites on Gulungul and Magela creeks.

Section 7.3.2.3 of the MCP presents further details on the studies and their findings.

7.3.2 Radon Exhalation

Long term changes in radon exhalation, soil activity concentration and terrestrial gamma dose rate were measured across the trial landform area, taking into account rainfall, cover type, weathering, erosion and compaction effects, and developing vegetation. The study showed average soil radioactivity differed for the two different surface treatments compared to waste rock only, with a seasonal difference in average radon flux densities.

Section 7.3.3 of the MCP presents further details on the radon exhalation studies over the landform area.

7.3.3 Revegetation Trials

Revegetation of the trial landform was undertaken during March 2009, in all areas except for a 40 – 50 m strip along the northern edge and outside of the irrigated zone. Bi-annual monitoring of the revegetation has been conducted since then and reports consistent results that also support the findings from previous revegetation studies. Importantly, the monitoring shows tubestock survival rates are higher than for direct seeding.

In 2014, the self-recruiting rate in the tubestock areas of waste rock section was 20 times higher than in the laterite mix section, and high ground vegetation cover (albeit most of weeds) contributed to the higher landscape function analysis indices of the laterite mix area.

The findings have caused a shift in the focus of the revegetation monitoring on the trial landform, from comparing plant survival rates over alternative substrates and planting methods, to monitoring the growth and performance of individual plants.

Section 7.3.4 of the MCP presents further details on the revegetation trials conducted on the trial landform.

7.3.4 Plant Available Water Studies

A plant available water study was conducted on the trial landform to identify whether the trial landform waste rock tubestock section is able to store an adequate water supply to support a sustainable woodland that is similar to the woodland of the Georgetown analogue area. The study utilised various methods to estimate the different soil water balance components within the trial landform. Based on soil physics, the results confirmed that a 4 m thick waste rock cover provides enough water to support a savanna woodland. This was tested considering rainfall distribution, by comparing the plant available water within the 4 m waste rock layer with the actual water use of a eucalypt woodland within the Georgetown analogue area. Assessment of annual dry season plant available water was also undertaken between 2010
and 2016, to identify whether the plant available water held by the landform during the dry season was adequate to support a mature, sustainable tropical woodland.

It is important to note that the waste rock cover on the current landform over the two pits will be thicker than 7 m. Although the thickness of the waste rock cover varies over other sectors of the final landform based on the natural ground surface, this variation shall not pose a constraint on plant available water.

Further details on each study and the findings are described in 7.3.5 of the MCP.

7.4 Environmental Protection

7.4.1 Baseline Terrestrial Radiation

To determine the achievement of criteria for both human health and environmental protection, the pre-mining radiation baseline is required. All assessments against radiation criteria will be made based on the above-background mine-sourced radiation dose.

A study on pre-mining radiological conditions has been undertaken for the Ranger mine, and is based on pre-mining aerial surveys, with extensive ground measurements to provide calibration of the final external gamma radiation dose rates. This data was correlated to the airborne gamma data collected for the site. Average gamma dose rates showed higher concentrations in areas above the orebodies compared to surrounding areas, as could be expected. A similar pattern was observed for the average soil radium concentrations and average radon exhalation.

A summary of the gamma dose rate data and discussion of the results is provided in Section 7.4.1.1 of the MCP.

7.4.2 Baseline Water Radiation

ERA undertook statistical analysis of historical water quality data collected from 135 bores, installed within either the alluvial, weathered and fractured rock aquifers throughout the RPA. The analysis was undertaken to identify the site-wide baseline conditions for each aquifer within each geological unit.

In terms of surface water within the RPA, monitoring of radionuclide concentrations within Magela Creek is also routinely undertaken during each wet season. The water quality at this location shows no impacts due to mining, and is, therefore, considered representative of baseline water quality conditions.

Section 7.4.1.2 of the MCP presents a summary of the baseline groundwater and surface water radionuclide data collected.

7.4.3 Bushfood Radiation Baseline

Radiation work undertaken for the site (including monitoring) focusses on radiation exposure to people living a traditional lifestyle within the area, and downstream of the RPA, as well as plants and animals within these areas.
ERISS 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 milli-Sieverts per year.

Available data on radionuclide activity concentrations in bush foods has been collated within a database, and used to identify a baseline radiation dose to Aboriginal people living within the region, irrespective of the mining activity (reflects the natural state for Aboriginal people living in Kakadu National Park).

The database contains over 1,500 records from various plants, animal tissues and environmental media, and can be used to calculate the ingestion dose for each food item according to a range of parameter inputs and situations.

Section 7.4.1.3 of the MCP provides further information on the database and a summary of published radionuclide concentrations for flora and fauna within the region.

7.4.4 Contamination Investigations

A contaminated site register and chemicals register has been developed for the whole site by ERA, that contains identified potential contaminants, locations at which contamination could occur, and environmental and human health risk assessments. Additional targeted assessments have been undertaken at pre-2011 contaminated areas to identify and define the extent of groundwater contamination.

Furthermore, ERA have assessed the risk of acid sulfate soil generation at Coonjimba Billabong (discussed later in this section).

As part of the feasibility study ERA plans to undertake a contaminated sites assessment, which will inform the development of any remediation plans, if required, and update the contaminated site register. A component of this work will be the development of a site-specific ecological investigation level for uranium to allow the assessment to be completed.

Details on all contaminated sites assessments are discussed in Section 7.4.2 of the MCP, with references to individual studies also listed. Incorporation of these data into the conceptual site modelling of contamination sources is discussed in Section 7.7 of the MCP.

7.4.4.1 Contamination Investigations in LAAs

Numerous studies have been undertaken to identify the storage and transport of contaminants (ions, metals and radionuclides) within the LAAs, both during the operational phase of the mine as well as post-closure, when the public are able to access the RPA. Extensive field investigations have been carried out across the LAAs (Figure 17) between 2008 and 2011 to characterise the following: radiological and heavy metal conditions at the site; enable development a radiation dose model as a basis for rehabilitation strategies; assess the vegetation status; and develop a rehabilitation strategy for the LAAs.

Details and outcomes of the field investigations undertaken are summarised in Section 7.4.2.1 of the MCP.
Figure 17: Extent of radiation field investigations in LAAs 2008 – 2011
7.4.4.2 Radiation Contamination in LAAs

In 2007/08 a collaborative project was started by ERA involving Dr Riaz Akber (SafeRadiation) and ERISS, to assess the radiological status of the land application areas, develop a dose model and propose rehabilitation strategies for the LAAs.

From these studies, an estimate of the amount of radionuclides applied through land irrigation of the various LAAs and the results were then used to determine the external gamma radiation dose rates in the LAAs. Averaged over the entire 338 ha of LAAs at Ranger, the additional external gamma dose rate due to land application is 0.03 micro-Sieverts per hour.

It was found that the contribution of land application areas to the terrestrial diet for adult radiation dose is only 2.5 micro-Sieverts per year.

Section 7.4.2.1 of the MCP presents further details on the studies and the effective dose rate estimates obtained.

7.4.4.3 Effective Dose Estimate

The radiation contamination studies outlined in Section 7.4.2.1 provided the information and data used to calculate the total radiation dose associated with various exposure pathways.

The dose was calculated for an adult, 10 year old (juvenile) and 1 year old (infant), according to radioactivity of different radioisotopes applied to the land until 2008, and modified radioactivity 100 years and 1000 years in the future. The results indicate that remediation for radiological contamination will not be required.

However, additional soil sampling has recently been completed in the land application areas to supplement these findings. The outcomes of this additional work will be reported in the next iteration of the MCP.

Section 7.4.2.2 of the MCP presents further details on the studies and the effective dose rate estimates obtained.

7.4.4.4 Generation of Acid Sulfate Soils in Billabongs

The presence (and extent) of acid sulfate soils within the black soil of Coonjimba Billabong has been confirmed through studies undertaken at this site during 2009. The Coonjimba Billabong is a landscape sump which collects water and solutes from the surrounding catchment. The studies indicate that these soils are formed via recharge from surface water, due to a sulfur concentration gradient extending from the surface to the base of the soil profile, and barriers to vertical water/ solute movement within the profile. Furthermore, annual wetting and drying of areas of the billabong enables oxidation (and generation of acid) during the dry season, and re-mineralisation of the acid during the wet season when the billabong becomes inundated with water. As a result, acid sulphate soils should not be disturbed as the low landscape profile provides natural containment when the billabong evaporates during the dry season, acidic water from the Coonjimba Billabong cannot flow to Magela Creek due to disconnection between both water sources during the dry season, and due to this, there is low environmental risk to the billabong ecosystem or to downstream water quality and ecosystems.
Section 7.4.2.3 of the MCP provides further information on the potential acid sulfate soils occurring within these areas.

7.4.5 Baseline Water and Sediment Studies

Extensive studies and monitoring on the water and sediments within the RPA has been undertaken to characterise baseline (pre-mining) conditions at the site and surrounding water bodies. Establishment of a baseline dataset allows early detection of potential impacts that are related to mining activities.

Section 7.7 of the MCP provides information on the groundwater studies and monitoring undertaken for the site, including the baseline water quality data collected.

Due the connectivity of content, the following section amalgamates the surface water, groundwater and sediment baseline data and information collected within the RPA and surrounding area, which has been described throughout Section 7.4.3.1 of the MCP.

Surface water quality monitoring has been ongoing at Ranger and in the surrounding environment for several decades providing a significant volume of reference data for surface water quality within the creeks and billabongs. Studies have collected baseline water quality data to describe background conditions in billabongs and creeks within the Magela catchment.

Baseline data has been collected from existing, available historical studies and data, as well as monitoring and sampling conducted prior to commencement of mining activities at the Ranger mine. Derived baseline water quality data for Magela Creek against which change in water quality could be determined, based on:

- Ranger water quality data base.
- Northern Territory DPIR check monitoring water quality database.
- Northern Territory Water Resources Division (WRD).

The majority of the surface water baseline samples were collected at site GS8210067, located upstream of the Ranger mine. The DPIR data are independent of the Ranger mine, and the WRD data collected from the downstream site GS009 prior to the 1976 – 77 wet season comprises pre-mining data.

The surface water quality baseline data, including discussion of the data, can be referred to in Section 7.4.3.1 (specifically Table 7-13) of the MCP.

Groundwater baseline data has been collected from 135 bores across the RPA, which are installed within the three distinct regional aquifer/aquitard types: alluvial, weathered and fractured rock aquifer. (See Chapter 7, Figures 7-28 – 7-30 for a location of the corresponding groundwater bores.) A statistical analysis of the water quality data has been undertaken by ERA to identify the site-wide background conditions for each aquifer and geological unit.

Threshold concentrations have been identified for the following five groundwater COPC, and discussed at ARRTC in 2012. Table 7-14 of MCP Section 7.4.3.1 presents the threshold concentration associated with each COPC listed: Electrical conductivity (EC; µS/cm); manganese (Mn); uranium (U); magnesium (Mg); sulfate (SO₄); and, radium-226 (²²⁶Ra).
The baseline water quality data reported to ARRTC included discussion on the geochemical behaviour of uranium and manganese in groundwater, the reactions of uranium and manganese with the fracture minerals that line aquifer wall-rocks and modelling work completed to support the knowledge base of background concentrations of COPC at Ranger.

Figure 18 presents the sample locations and the major element groundwater chemistry for the bores sampled across the RPA. Below describes the key for the figure:

- Mg, calcium (Ca) and bicarbonate (HCO₃) water type: Shown as yellow markers and associated with the Lower Cahill Carbonates; the Weathered Lower Mine Sequence; and, the Fractured Lower Mine Sequence.
- Sodium (Na), chlorine (Cl) and potassium (K) water type: Shown as blue markers and associated with the alluvium (weathered hanging wall sequence, and the weathered Nanambu Complex).

The results are consistent with previous reviews which indicate the two above groundwater matrices within the RPA, as well as a third general type from a non-specific hydro-lithology that overlaps the major element chemistry of the two other groundwater types.
Figure 18: Sample location map and multivariate statistics showing the Na, Cl, K groundwater type (blue squares), Mg, Ca, HCO₃ groundwater type (yellow triangles) and the general groundwater type (orange circles). The eight colour-groups list the hydrolithic units in which groundwater are screened.
Further details on the groundwater baseline for the RPA is provided in Section 7.4.3.1 of the MCP.

Sediment quality has been studied at a number of wetlands (both natural and constructed) within the RPA, including routine annual sediment monitoring conducted by ERA between 1982 and 2001. A review of all sediment data was undertaken during 2013, which recommended resumption of the sediment monitoring program to provide a pre-closure baseline assessment for sediments both inside and outside of the RPA.

Uranium was identified as the primary constituent of concern based on the available data (1982 to 2013). This data showed a consistent trend in uranium concentration at the following billabongs relevant to the RPA (in order of highest concentration to lowest): Georgetown Billabong; Coonjimba (approximately equal to Georgetown Billabong); Gulungul Billabong; and, Mudginberri.

Following this study, sediment data collected between 2002 and 2006 was reviewed, to identify the ecological risk associated with sediments at the onsite water bodies. The results showed the following trend in ecological risk (highest to lowest): RP1 wetland filter; Corridor Creek wetland filter; RP1; Georgetown Billabong; Coonjimba Billabong (approximately equal to Georgetown Billabong).

The Supervising Scientist has also conducted a sediment sampling and analysis program during 2007, 2011 and 2013, at billabongs within the Alligator Rivers Region. The data obtained shows a clear distinction between the water bodies within the RPA, and non-impacted offsite water bodies (outside the RPA).

A comprehensive sediment study reported in 2015, provided sediment core data in addition to surface sediment data. The study included metal concentration data and lead (Pb) isotope ratios, $^{206}\text{Pb}/^{207}\text{Pb}$ and $^{208}\text{Pb}/^{207}\text{Pb}$. The study demonstrated that measurement of lead isotope ratios in the sediments is a powerful tool to determine whether erosion products from uranium rich sources are being transported downstream, albeit at relatively low concentrations.

Further information on the sediment quality baseline and the studies undertaken is provided in Section 7.4.3.1 of the MCP.

7.4.5.1 Aquatic Fauna Baseline

Aquatic community studies have been conducted by the Supervising Scientist at a number of potentially impacted and control sites within several catchments of the Alligator Rivers Region. ERA commissioned an aquatic fauna survey during 2010 to assess the condition of the aquatic ecology of the creek and billabong systems, with the aim for this data to form the benchmark for future monitoring in the event that the heap leach facility is implemented. The data was collected from several of the RPA 'control sites', hence was able to be included within the baseline dataset.

The study reports results and analyses on water quality, zooplankton, aquatic macroinvertebrate and fish collected from creeks and billabongs within the region.

Further information on the studies undertaken is provided in Section 7.4.3.1 of the MCP.
7.4.5.2 Surface Water and Sediment Monitoring

ERA conducts statutory and operational water quality monitoring as required by the Ranger Authorisation. The surface water and sediment monitoring programs are annually reported in the Ranger Water Management Plan.

In addition to ERA’s monitoring programs, the Supervising Scientist also undertakes an independent surface water quality monitoring program at Magela and Gulungul creeks, and other reference water bodies within the region (discussed below). Both organisations have undertaken operational monitoring, consisting of weekly grab samples, event based sampling and real-time continuous data upstream and downstream of the site, and for ERA’s monitoring program, mid-stream along the creek lines. Data is also collected by ERA via telemetered sites along Magela and Gulungul creeks.

Water quality data from the statutory monitoring sites is also reported to the MTC each week during the wet season, and results are assessed against the relevant water quality criteria for both creeks. At the end of the wet season, a detailed interpretation of all monitoring data and investigative studies is provided to MTC.

Figure 19 presents the locations of the operational and statutory surface water monitoring sites in relation to the Ranger mine.
Figure 19: Location of RPA statutory (yellow) and operational surface water monitoring sites
Details of these studies are provided in Section 7.4.3.2, with the baseline data collected from the monitoring programs described in Section 7.4.3.1 of the MCP, respectively.

As previously noted, the Supervising Scientist undertakes independent surface water quality and biological monitoring programs at various water bodies within the region. These programs have been developed over 30 years and are leading practice.

The surface water quality program monitors chemical, physical and biological measurements, with a key component being continuous monitoring of pH, EC, turbidity and stream flow within Magela Creek and upstream and downstream of the mine site (Figure 19).

The biological monitoring programs use two approaches (early detection and assessment of overall ecosystem responses) to assess toxicity impacts from the Ranger mine operations on downstream aquatic systems. The early detection technique involves assessment of the freshwater snail (*Amerianna cumingi*) response (in-situ) to Magela Creek water, due to the high sensitivity of this species towards uranium and magnesium within the environment.

The ecosystem-level responses are assessed using benthic macro-invertebrate and fish community data from Magela and Gulungul Creek sites, which is compared to historical data and data from control sites (i.e. data from sites that show no impacts due to mining).

The Supervising Scientist combines various aspects from each monitoring program to provide an integrated monitoring program with multiple lines of evidence. These studies show that during the operational phase, the mine derived COPC have not adversely affected the abundance or diversity and quality of aquatic organisms located downstream of the Ranger mine.

Section 7.4.3.2 of the MCP presents further details on these studies undertaken by the Supervising Scientist, including website links to sources of information on each monitoring program.

ERA engaged consultants BMT WBM to assess the changes in water quality chemistry using data collected by ERA at various test sites, in comparison to data from control sites at Magela Creek and Gulungul Creek. This information forms a pre-closure baseline for off-site control, and on-site exposed or contaminated sites. The studies indicate a long-term change in water chemistry at most of the test sites (i.e. increasing dominance of magnesium), particularly in Gulungul Creek directly adjacent to mine discharges, and also at billabongs.

Further details on the water quality studies undertaken and the identified changes are provided in Section 7.4.3.2 of the MCP.

In addition to the above, studies have been undertaken on the solute loads from the Ranger mine, within various waterbodies within the RPA and surrounding area (i.e. at upstream and downstream sites). Estimated downstream (MG009) loads of magnesium and sulfate are two and three times higher, respectively, than the estimated loads at the upstream site (MCUS). The results suggest no adverse impacts from mining, which demonstrates the capacity of the Gulungul and Magela Creeks to assimilate magnesium loads of this magnitude.

Section 7.4.3.2 of the MCP provides details on the studies undertaken, as well as the resulting magnesium and sulfate loads identified within Magela Creek.
Constituents of potential concern

Previous studies for the Ranger mine and RPA have identified COPC in the ore and milling processes and waste rock, and their presence and/or risk to receiving waters. The following COPC have been identified for assessment:

- COPC from waste rock: total mono-nitrogen oxides (NOx); total suspended solids (TSS); turbidity; magnesium; calcium; sulfate; manganese; and, uranium.

- COPC from tailings / process water: Ammoniacal nitrogen (NH₃-N); phosphorus (Total P / PO₄-P); copper; lead; cadmium; iron; zinc; chromium; vanadium; and, potentially nickel.

The studies indicated that the COPC generated from the tailings / process water pose a negligible risk compared to contributions from waste rock and natural sources, and hence, do not require formal closure criteria (Figure 20). Monitoring and management should instead focus on the COPC from the waste rock.

![Figure 20: Relative contribution of COPC from waste rock, tailings and the natural environment (source: INTERA)](image)

Other COPC that are considered to be low risk but require established closure criteria include:

- Ammoniacal nitrogen (NH₃-N): no risk expected however this COPC contains a site-specific guideline.

- Metals that may originate from the ore / mill, including:
  - Copper, cadmium, lead and uranium enriched greater than 10 times background concentration.
- Manganese and vanadium as process additives.
- Nickel and chromium from stainless steel used in the mill and iron from the mill grinder.
- Zinc and cadmium from galvanised roofing.

Groundwater modelling shows that contaminants from the tailings/process water source peaks at approximately 12 years for Pit 1 tailings flux and 10,000 years for the combined Pit 1 and Pit 3 tailings. Predicted loads of tailings sourced COPC entering Magela and/or Corridor Creek are compared with the ANZECC/ARMCANZ guidelines and NT detection levels and are significantly lower than guidelines or below detection limits.

Section 7.4.3.3 of the MCP presents details on the studies undertaken, the COPC concentrations measured at Magela Creek and Gulungul Creek and a discussion of the study findings.

**Water quality risk to wildlife drinking water**

No Australian water guidelines are currently available for toxicity to vertebrate fauna, hence various international guidelines are used for waterbodies at and surrounding the Ranger mine, where applicable. These include:

- Short term maximum drinking water guidelines for wildlife for nitrate, nitrite, copper and lead published by the British Columbian Ministry of Environment.
- United States guidance values for chemical and radiation toxicity, however only the uranium guideline is applicable for the RPA.

A review of pond water quality during mine operations showed seepage and runoff from waste rock within the trial landform reports concentrations significantly lower than the available guideline values. The study indicates a low risk to wildlife from drinking water on the landform site, and that closure criteria is not necessary for wildlife drinking water on the rehabilitated areas.

Section 7.4.3.3 of the MCP provides further details on the studies undertaken and the COPC data analysed.

**Derivation of site specific guideline values**

Site specific water quality guideline values have been developed by the Supervising Scientist for magnesium, electrical conductivity (EC), uranium, manganese and ammonia based on the toxicity to local species within Magela Creek. The guidelines are presented in Section 7.4.3.4 of the MCP, and the derivation of these were based on the ANZECC & ARMCANZ (2000) recommended methods, which are considered to provide the most comprehensive guidance and are a leading practice approach.

The guideline values have also been supplemented with international guideline values for manganese and ammonia. Site specific guidelines have also been defined for turbidity and uranium levels within sediments.
Information from additional studies (planned or underway) to address identified key knowledge needs (e.g. toxicity of mixtures; site specific eutrophication assessments, acid sulfate soil potential and effects) may result in changes to guidelines. Such updates and changes will be captured in future iterations of the MCP.

Section 7.4.3.4 of the MCP presents the studies from which the guideline values were developed.

*Fate of chemicals in the Magela Creek system*

A number of early studies in the 1980s have been undertaken that provide information to support assessment of the fate of chemical species associated with sediment deposition or attenuation processes in creek beds, billabongs and on the floodplain. Other works describe the uptake of metals, and radionuclides from water to sediment and water/sediment to biota in the artificial and natural waterbodies on and surrounding the Ranger mine site.

The surface water model will be used to update predictions of concentrations of COPC in waters on and off the RPA, which can be compared directly against criteria for water. For sediment quality criteria and other assessments (e.g. diet) an understanding of the transport and fate of the COPC is required.

Concentration factors for uptake of metals and radionuclides between water, sediment, soils and biota have also been established within an ERISS database, and can be used to estimate uptake of predicted COPC into sediments and biota. This, in turn, can be used to assess the potential environmental and human health impacts and whether the environmental objectives and closure outcomes are achieved.

Section 7.4.3.5 of the MCP lists the studies undertaken and the details associated with each, Section 7.8 discusses the surface water model.

*Prediction of existing groundwater contamination*

Studies into the existing groundwater contamination on site have been undertaken by Environmental Resources Management (ERM) and Golder Associates in conjunction with ERA. A characterisation of groundwater contamination was undertaken, along with identification of potential sources and transport mechanisms in areas where contamination occurs. Monitoring programs were also developed to further understand and manage contaminated groundwater.

ERM recently developed of a conceptual hydrological model for the Corridor Creek LAA and Gulungul Creek upper tributary area based on the source-pathway-receptor framework.

Further details on the studies described above are provided in Section 7.4.3.6 of the MCP.
7.4.6 Flora and Fauna Baseline Monitoring

Numerous baseline monitoring studies and other flora and fauna studies have been undertaken for the RPA, to address the following potential key closure issues and risks:

1) Revegetation with local native plants.
2) Establishment of terrestrial and aquatic ecosystems.
3) Propagation of weeds.
4) Impacts from fire.
5) Impacts from feral animals.

The establishment of habitats on the final landform is predominantly dependent on the success and final composition of the revegetation. These habitats will support fauna assemblages that are similar to the KNP, including culturally important fauna species. Trends in the composition and abundance of fauna are identified through annual monitoring of the final landform and analogue sites. A number of studies have been completed on the ecological communities of the RPA, which have been used to develop aspects of the proposed flora and fauna closure strategy.

A summary of the studies undertaken is presented in Section 7.4.4 of the MCP, and includes studies which have been undertaken for purposes not specifically related to mine closure.

7.5 Landform Design and Performance

A number of landform studies have been undertaken to address key closure issues and risks, including removal of all site infrastructure and backfilling of pits, containment of tailings, and erosion of the final landform. These studies, including those completed by both ERA and the Supervising Scientist, on the trial landform have informed the overall design and predicted performance of the current final landform design.

The final landform, which is the whole RPA area, aims to simulate the hill slope and environmental processes that determine the sustainability and diversity of ecosystems in analogous undisturbed environments. The land use values ascribed to the mine area by the traditional owners are also being considered in the design.

The design of the final landform has been determined from a digital terrain model of natural analogue areas. Each version of the landform has been subjected to landform evolution modelling by the Supervising Scientist to assess the performance of the landform over 10,000 years.

The final landform design originally described in the 2005-06 Closure Model, which was issued to stakeholders, continues to be revised to ensure that it takes into consideration changing stockpile material grades, volumes and locations. The current digital terrain model is Version 5, which incorporates learnings from previous landforms and erosion modelling, as well as work undertaken on the development of the design criteria.
The shape of the current final landform has been designed based on the requirement that the landform must maintain pre-mining drainage and catchment areas, as well as prevent undue degradation due to potential changes in rainfall patterns associated with climate change.

The ERISS group applied a modified version of the CAESAR-Lisflood landform evaluation model to assess the geomorphic stability of the final Ranger landform over time frames ranging from decades to millennia. The model is conservative in nature, having only minimal vegetation on the surface for the entire 10,000 year period, and excludes any orthodox storm water and erosion control structures.

The model predicts denudation rates decreasing over time, with rates approaching background for the region, and an exponential decline in erosion /gully formation, but also potential for the formation of 9 metre gullies that are close to buried tailings (Figure 21 and Figure 22). As described, the landform design is an iterative process. Design of drainage channels and other erosion mitigations is ongoing to minimise the potential impact on landform stability and revegetation success.

Figure 21: Corridor Creek catchment – extent of erosion/deposition zones after simulated period of 10,000 years (source: SSB)
There are limitations of the modelling work which are currently being addressed by the Supervising Scientist Branch to ensure model outputs are both plausible and scientifically defensible. These are:

- Development of a stochastic synthetic rainfall dataset which will enable a range or probability of likely outcomes to be provided;
- Enhancing the effect of vegetation community growth on landscape evolution within the landform model.
- Consideration of the role of fire.
- Integration of a dynamic vegetation model linking soil moisture to biomass growth.
- Implementation of an effective weathering function into the model to reflect the natural rate of both physical and chemical weathering.
The SSB have advised that landform erosion modelling results are indicative only, as such this information has only been used to guide the development of the final landform. The results of the simulations to date provide a guide for future enhancements.

Section 7.5 of the MCP presents the studies undertaken and the relevant details.

7.5.1 Final Landform Material Properties

The final landform will contain all material with the potential to cause impacts at the base of the mined pits. Extensive solute modelling studies have been undertaken for this design, and storage in this area is not considered to cause significant negative impacts to the natural downstream environment. Waste rock will be used to backfill the pits and remaining landform area, with low uranium waste overburden rock used as the capping material.

Various studies, have been undertaken by ERA and others (e.g. 1985 – 2002) to assess particle size distribution and soil formation, as well as the rapid weathering and physical degradation associated with the chemistry and mineralogy of the waste rock landform. It was found that the exposed waste rock weathers rapidly to form rudimentary soil materials and that a stony amour developed within five years. These mechanisms assist in reducing infiltration rates.

These studies and their findings are described in Section 7.5.1 of the MCP.

7.5.2 Landform Flood Study

The current concept design for erosion and sediment discharge control at the final landform has been developed based on a flood study undertaken during 2017. A watershed bounded network model, rainfall runoff model was prepared for the proposed final landform terrain (Figure 23). The model covers the final landform area and nearby downstream areas. Design flows have been prepared for a range of Annual Exceedance Probability (AEPs) from the one every year (1EY) event to the probably maximum flood. Two design scenarios were used for this study:

- Establishment / short term conditions scenario, which represents the stage where the soil is becoming consolidated and vegetation cover is being established.
- Long term conditions scenario, where vegetation cover has become similar to the analogue site, and significantly contributes to the erosion resistance of the site.

The scenarios are relatively simple and ignores factors such as the effect of seasonality, fires, etc; however, it is considered they provide a reasonable basis for the development of conceptual drainage and sediment control systems for the final landform.

A conceptual system for erosion and sediment control with four key components was developed, as follows:

- **Component 1 – Surface Treatment:** Measures on the hillslopes to reduce erosion and sediment discharge.
• **Component 2 – Drainage Channel Treatment:** Measures along the more defined drainage lines to reduce erosion and sediment discharge.

• **Component 3 – Edge Sediment Basins:** The design of sediment basins around the edge of the final landform to capture sediment discharging from the landform.

• **Component 4 – Second Layer Sediment Basins:** Where the terrain permits, a second sediment basin has been positioned further downstream from the final landform, providing a second layer of protection to limit sediment discharge from the site.

Figure 23: Watershed bounded network model sub-catchments (source: Water Solutions)
Section 7.5.2 of the MCP presents details on the study and the design flow rates for each scenario. The conceptual design that has been developed based on this study is discussed in detail in Chapter 10 of the MCP.

7.6 Ecosystem Establishment

7.6.1 Revegetation Trials

Numerous revegetation studies have been undertaken by CSIRO, ERISS and ERA both historically (during the 1980s and 1990s prior to construction of the trial landform) and more recently (year 2000 onwards). The historical studies are listed in Table 7-26 of Section 7.6.1, and comprise investigations related to the final landform morphology, revegetation and ecosystem establishment. These studies, in conjunction with vegetation monitoring data collected from the trial landform and analogue sites, provide support and confidence in the proposed revegetation strategy for closure of the RPA, in providing a self-sustaining, long-term ecosystem.

The revegetation program relied on planting three-month-old seedlings of native woodland species that are endemic to the surrounding woodland environments; however, a successful trial was also carried out, which used direct seeding to establish more than 2,000 plants per hectare of freshly tilled waste rock at two sites. Aside from the revegetation programs, a rehabilitation program was also implemented between 1998 and 1999, which included remediation of erosion on roads and tracks, the removal of redundant access tracks and rehabilitation of former low grade ore stockpiles (approximately 9.8 ha).

The 'recent' studies conducted at the RPA provide information regarding local seed provenance, flora species composition and community structure, and vegetative features in constructed waterbodies. These studies are summarised in the sections below.

7.6.2 Seed Provenance

Revegetation of the RPA using local native plant species is specified under clause 2.2(a) of the ERs. As such, a 30 km seed collection zone was adopted by ERA in 1994, to enable collection of local seeds for revegetation of the trial landform. Since then, it has been identified that this zone may not provide adequate seed at closure, as some plant species within this area are naturally low or erratic seed producers, and bushfires can wipe out harvests and delay flowering and seed production.

Studies were undertaken by ERA from 2011 to 2013 to potentially extend the 30 km seed collection zone. These studies included assessment of environmental factors, gene flow and species traits known to influence genetic variation in plants, as well as identification of zones containing plant genetic variation. The resulting zones match the eco-geography of the Ranger mine area, hence maintain 'home site' advantage of local plants.

The Atlas of Living Australia environmental modelling tool was used to predict a zone showing a similar environment to the RPA, and was named the Ranger 'environmental provenance zone'. The model used environmental layers relevant to plant species distribution in the Top End (mean annual evaporation, annual evaporation, mean annual temperature, annual
drainage and topographic wetness index) to estimate the zone area. Investigations into revegetation species distribution indicates that each is well represented within the conservative provenance zone (Figure 24).

Figure 24: Proposed conservative provenance zone (bordered by the red line) and the GAC approved provenance zone within KNP (bordered by the blue line)

Seed collection within the proposed conservative provenance zone should be well adapted to the current conditions of the RPA, as well as provide sufficient genetic diversity to reduce inbreeding, promote the plants' adaptive potential and increase the resilience of the revegetation areas against moderate changes in climate. The scope of changes in climate and the associated risks for revegetation should be assessed in the future.

The outcomes of the study were submitted to the ARRTC and the GAC Board, and approval was granted for ERA to collect seeds only from within KNP, in areas where edaphic conditions are closer to the future conditions at Ranger under global climate change scenarios.

Further details on the seed provenance studies undertaken at the RPA are provided in Section 7.6.2 of the MCP.

7.6.3 Flora Species Composition and Community Structure

A number of studies on plant species composition and relative abundance has been completed by ERA and ERISS within the RPA and surrounding analogue sites, and has informed
development of a revegetation species list for the trial landform during 2007. In 2014 this list was provided to GAC for consultation. Furthermore, the Mirarr have also developed a list of culturally important flora within the region. The criteria for this includes (but is not limited to) whether the plant is used as a cultural resource (i.e. food, medicinal, aesthetic, material culture and/or ritual purpose), provides faunal linkages and promotes biodiversity.

A consensus on the Ranger revegetation tree and shrub species list was reached during March 2016 by the flora and fauna closure criteria technical working group. The species list is provided in MCP Table 7-27 of Section 7.6.3, and will be planted in the following two main planting phases:

- **Phase 1**: 48 ‘framework’ species, that aim to dominate and help re-establish the natural mechanisms of the savanna woodland regeneration, and accelerate biodiversity recovery.

- **Phase 2**: 22 ‘niche’ plant species, that are either less likely to occur in abundance in a savanna woodland, occur only within riparian margins, billabongs or watercourses, or that are known to naturally recruit. These will eventually be revegetated once suitable habitats are developed.

The Mirarr acknowledge that it may not be possible to propagate and establish all species, as planting of the phase 2 species may be more site-specific, dependent on habitat type or subject to other environmental restrictions. However, it is intended that the majority of species identified by the Mirarr will be planted where practicable, to address cultural and aesthetic values. This list will be used for revegetation, and also as a basis for assessing whether revegetation is similar to the natural surroundings.

Details on the flora studies undertaken can be referred to in Section 7.6.3 of the MCP.

### 7.6.3.1 Flora and Fauna Monitoring Sites

As part of the flora studies undertaken at the RPA, Eco Logical Australia (ELA) was engaged during 2016 to develop and implement a long-term flora and fauna monitoring program. The program was developed to document the condition and seasonal variation at a total of 17 sites, including reference sites in adjacent areas of Kakadu National Park and relatively undisturbed areas within the RPA. Two surveys were undertaken, during the late wet season (April) and early wet season (October). Fauna surveys were carried out at 4 of 17 sites. Figure 25 presents the monitoring locations.

The program aimed to provide a comparative dataset in which to measure future rehabilitation success. Bi-annual monitoring of the sites will continue to be undertaken to establish baseline data of the long-term dynamics, seasonal fluctuations and responses to natural disturbances (i.e. fire or cyclones).
Figure 25: Survey sites (courtesy of Eco Logical Australia)
7.6.4 Emergent Vegetative Features in Constructed Waterbodies

Two wetland filters exist within the RPA; these are the Corridor Creek wetland filter (currently in operation) and the RP1 wetland filter (not operational at present). The dominant vegetative species within the RP1 wetland filter has been characterised. A description of previous studies on species present inside and outside of the RPA, the historical distribution and abundance of the species in the wetland filters, propagation methods, and their tolerances to environmental factors such as water quality and hydrological regimes was also included.

Four reports were prepared between July 2013 and November 2014 to document the emergent vegetative features in the two artificially constructed waterbodies and water management sumps within the RPA. During this time, acidic conditions were observed within the Corridor Creek and RP1 wetland filters; however, recruitment of new plants and viability has shown no affects due to these conditions.

The reports provide evidence towards the natural colonisation and successful establishment of aquatic vegetation habitats within the constructed waterbodies of the RPA, as well as an understanding of environmental conditions required to support these habitats.

Section 7.6.4 of the MCP presents further information on the aquatic vegetation studies undertaken at the constructed waterbodies.

7.7 Groundwater Modelling

7.7.1 Ranger Conceptual Model

A conceptual model is a depiction or distillation of an often-complex real-world system developed to answer a specific set of questions. A conceptual model has been developed for the RPA in 2016 by INTERA that focuses on groundwater and surface water flow and transport of COPC at the mine site and surrounding area. ERA has commissioned INTERA to complete further hydrogeological studies that will be included in subsequent updates of this closure plan. The scope of this work includes an update to the Ranger calibration and groundwater flow models to incorporate improved data coverage and knowledge since the model was constructed. Section 7.7.1 of the MCP provides an illustration (Figure 7-47) of the various models that will be developed and used to demonstrate the transport and fate of contaminants within the context of the whole of site conceptual model. The figure also shows the links between the whole of site conceptual model and the various numerical models developed to date, for example:

- Whole of site conceptual model.
- Groundwater and tailings consolidation models.
- Surface water model.
- Integration with future studies: Food and diet, recreation, radiation, eutrophication, acid sulfate soils, closure criteria assessment framework, and cumulative surface water risk assessment.
The Ranger whole of site conceptual model describes the elements of Ranger’s hydrogeologic and surface water environment that are important to understanding groundwater and surface water flow and solute migration. It provides a scientific framework based on the available evidence by which ERA can assess and implement decommissioning and closure activities consistent with regulatory environmental controls and rehabilitation requirements.

The conceptual model was developed using existing information, data and studies, and provides a scientific framework in which to assess and implement decommissioning and closure activities, consistent with regulatory environmental controls and rehabilitation requirements.

The Ranger conceptual model was created following best practices for development of conceptual models, including those found in the Australian groundwater modelling guidelines.

The important elements of the conceptual model are classified into:

- **Features**: (key physical characteristics including topography, hydrogeology, vegetative cover and pit backfill design).
- **Events**: (timing of changes to the RPA).
- **Processes**: (driving forces of groundwater, surface water and solute movement within the RPA).

The model also comprises multiple interrelated conceptual models at the following three spatial scales (Figure 26), which are described in Sections 7.7.1.4 to 7.7.1.5 of the MCP, respectively:

1. **Regional** (Section 7.7.1.4): The domain for the regional-scale conceptual model for the Ranger mine encompasses 434 km² of the Magela Creek watershed surrounding the mine site. Rainfall, evapotranspiration and surface water flow contributions to the water balance are far larger than the groundwater flows. Rainfall and surface water flow contribute more than 99% of total annual inflow, whereas surface water flow and evapotranspiration contribute more than 99% of total annual outflow;

2. **Site-wide** (Section 7.7.1.5): Within the regional-scale model is the 83 km² of the domain for the site wide-scale conceptual model that encompasses the entire Ranger mine and about 14 kilometers of Magela Creek. This conceptual model includes descriptions of the mining operations, water production and management activities, and decommissioning activities and detailed descriptions of the physical setting. Important findings include
   
   a. Rainfall and surface water flows provide the largest inflows of water into the site-wide domain, whereas evapotranspiration and surface water flows are the largest outflows for water exiting the site-wide domain.
   
   b. Seasonal surface water flow in Magela Creek is the largest of all the creeks in the site-wide domain.
   
   c. Magela Creek floods multiple times in most wet seasons and can add large amounts of water to surrounding soils and alluvium.
d. Electrical conductivity (EC) and COPC concentrations were higher at monitoring stations located downstream of Ranger mine; however, these concentrations are typically lower than the accepted site trigger levels.

e. The hydrogeological framework throughout the site comprises the shallow alluvium, followed by the weathered and unweathered Nanambu Complex, Cahill Formation and Nourlangie Formation rocks, and mine wastes.

f. The alluvium is likely to contain the most permeable aquifer materials, but is limited in areal extent. Due to the low-permeability Ranger Fault, the deep lower mine sequence and upper mine sequence rocks generally supply a low rate of water to the Brockman Borefield; however, the rocks immediately within, and surrounding, the Deeps Faults are more permeable than most Cahill Formation rocks and can produce higher flow rates within these areas.

g. Recharge is estimated at 5 – 10% of annual rainfall.

h. Likely recharge areas include the higher elevation areas within the site-wide domain. Groundwater discharge is to surface water via creek banks and bed sediments. Water outflow by evapotranspiration also occurs within the site.

i. Groundwater hydraulic head is topographically driven, and water level trends are related to seasonal rainfall.

j. Groundwater flow rate is low due to the low-permeability hydrogeologic units, Ranger Fault and compartmentalised aquifers within the region.

k. The site water balance indicates water contributions from rainfall, evapotranspiration and surface water flow far outweighs groundwater contribution. Mine activities contribute approximately 0.9% and 0.4% to total annual inflow and outflow respectively, however this will cease at mine closure.

3. Individual areas of concern containing COPC sources (Section 7.7.1.6 to 7.7.1.14), hence COPC related processes. These areas include Pit 1, Pit 3, tailings dam, processing plant, LAAs, Ranger 3 Deeps exploration decline and ventilation shaft, and landform waste rock.
Figure 26: Ranger conceptual model spatial scales (source: INTERA)
Conceptual models for the areas of interest/concern examined the operational and decommissioning period and post-closure periods. Conservative and reactive COPC were evaluated for each of the different conceptual models, and include:

- Magnesium (potential toxicity to Magela Creek biota).
- Uranium.
- Manganese.
- Radium-226.
- Total ammonia as nitrogen.
- Nitrate as nitrogen.
- Total phosphorus.
- Polonium.

The findings of the modelling indicate only the tailings dam, processing plant area and LAAs released COPC into groundwater, surface water, soil or a combination of areas within the RPA during the mining operational and decommissioning period.

Further details on the setup and findings of the models at each spatial scale, and the evaluations of solute egress during the post-closure period for each area of interest / concern are provided in the sections referred to above.

### 7.7.2 Pit 3 Conceptual Model

Post-closure, COPC in the Pit 3 waste rock backfill, tailings and brine is likely to migrate towards Magela Creek.

Numerical modelling was undertaken for Pit 3 to estimate post-closure magnesium loads from this location. The model was run with the following scenarios at Pit 3:

1. Low permeability caps over the tailing and shallow waste rock.
2. The inclusion of a low permeability cap over the tailings and shallow waste rock.

The first scenario (no cap) predicted magnesium loads would be approximately 3% and 0.05% of the historical upstream of Ranger mine annual average magnesium load in Magela Creek, for the tailings and waste rock respectively (i.e. negligible).

The second scenario, including a low-permeability cap, results were compared to the first scenario, no cap, modelling results. A negligible reduction in magnesium load was observed (4,000 kilograms per year (kg/year) to 1,600 kg/year), in relation to the historic, upstream of the Ranger mine, average loading upstream (135,000 kg/year) and from the waste rock of the final landform (137,000 kg/year) (Figure 27).

Further details on the numerical modelling studies undertaken, and tables of the estimated magnesium loads is presented in Section 7.7.1.7 of the MCP.
7.7.3 Pit 1 Conceptual Model

A similar numerical modelling study was undertaken for Pit 1, to estimate post-closure magnesium loads. The magnesium loads were identified as approximately 2% and 4% of the historical annual average magnesium load in Magela Creek, upstream of Ranger mine, for the Pit 1 tailings and pit tailings flux respectively (i.e. negligible).

Further details on the Pit 1 numerical modelling, including the resulting magnesium loads is presented in Table 7-30 of Section 7.7.1.8 of the MCP.

7.7.4 Tailings Dam Conceptual Model

The post-closure groundwater impacts estimated from the tailings dam are expected to be less than observed during the operational phase. This is due to removal of the tailings material, including the majority of the COPC source mass (tailings and process water), which reduces the hydraulic gradient driving groundwater flow within the tailings dam area.

Section 7.7.1.9 of the MCP presents further information on the tailings dam conceptual model, including the cross-sections of the tailings dam illustrating the predicted downgradient flow, which the conceptualisation is based on.
7.7.5 Processing Plant Area Conceptual Model

The sources of COPC within the process plant area as well as aerial sources associated with dust and dispersion from operational activities have been identified (Table 7-33 of Section 7.7.10) and are considered in the conceptual model.

Previous studies conducted between 2006 and 2009 identify COPC within the groundwater at the processing plant (Figure 28). However, no impacts were observed in bores located nearby and down-gradient from the processing plant, hence migration of COPC within the groundwater from the processing plant is understood to be very slow. The majority of COPC sources will be removed once processing is completed, hence the processing plant is not expected to be continued source of COPC for groundwater post-closure.

Based on the distance from the processing plant area and the associated affected groundwater to Corridor Creek and Georgetown Billabong, potentially contaminated runoff and/or groundwater discharge from the processing plant area are not expected to be a concern for surface water post-closure.

Further information on the processing plant conceptual model is provided in Section 7.7.1.10 of the MCP.

Figure 28: Groundwater flow pathways from the processing plant area towards Pit 1, Pit 3, Georgetown Billabong and Corridor Creek tributary (source: INTERA)
7.7.6 LAA Conceptual Model

The conceptual model considers the following five land application areas (LAAs) across the RPA:

- Magela LAA (MLAA) and MLAA extension.
- Djalkmarra LAA (east) and the Djalkmarra LAA extension (west).
- RP1 LAA and the RP1 LAA extension.
- Jabiru East LAA
- Corridor Creek LAA.

COPC such as uranium and radium-226 are retained within the shallow soil (refer to Section 7.4.2); however, any future transport into surface water by erosion and runoff would be diluted to very low levels. Irrigation with the dilute water produced by treatment plants and natural recharge has been flushing out the COPC and will continue to do so prior to closure. The groundwater chemistry measured at all LAAs is also expected to show little to no impacts by closure.

The remediation of contaminated sites, including the LAAs, will be assessed and managed according to the closure criteria described in Chapter 6.

Section 7.7.1.11 of the MCP presents further details on the conceptualisation for the site LAAs, including the measured COPC concentrations in groundwater sampled in the vicinity of the LAAs.

7.7.7 Ranger 3 Deeps Conceptual Model

The Ranger 3 Deeps decline and ventilation shaft will be backfilled with cemented aggregate fill and waste rock, which are potential COPC sources. Numerical modelling was undertaken to estimate COPC migration from the proposed Ranger 3 Deeps mine\textsuperscript{5} at closure, and identified the following:

- Solute loading to Magela Creek will be negligible.
- Groundwater level within the deeper groundwater system is expected to recover to pre-excavation conditions at post-closure.
- Depressurisation caused by excavation and dewatering of the exploration decline and shaft is not expected to cause long-term impacts.

Section 7.7.1.12 of the MCP provides further detail on the Ranger 3 Deeps mine conceptual model.

\textsuperscript{5} in June 2015, ERA’s board made the decision that the project should not proceed to final feasibility study in the current operating environment. The Ranger 3 Deeps decline and associated infrastructure remains on care and maintenance.
7.7.8 Landform Waste Rock Conceptual Model

Landform waste rock will leach COPC, and migrate to Coonjimba, Gulungul and Magela Creeks, and the Corridor Creek tributary by runoff and groundwater discharge. The estimated magnesium loading within runoff is very small compared to concentrations observed within groundwater discharge.

Section 7.7.1.13 of the MCP provides further details on the conceptualisation, and the estimated magnesium loadings from runoff and groundwater discharge from the landform waste rock, including that within the footprint of Pit 1 and Pit 3.

7.7.9 Pit 1 Solute Egress Modelling Conclusions

A solute egress model was developed for Pit 1 by INTERA to estimate the potential mass loading of contaminants of potential concern (COPC) from the Pit 1 waste rock, tailings, and pit tailings flux to Corridor Creek, for a period of 10,000 years after closure. The solute transport model is based on earlier models by the CSIRO and the previous set of conservative conceptual and numerical modelling tools that were designed to evaluate closure of Pit 3. The model shows COPC generated from weathering of waste rock placed in the shells of Pit 1, and over the landscape before solutes egress with groundwater into the receiving environment.

The solute egress model predictions indicate no detrimental impact to the surrounding environment over 10,000 years due to the tailings and brine storage within Pit 1, as required under the Ranger Authorisation.

Detail on the conclusions obtained from the solute egress modelling are provided in Section 7.7.2 of the MCP.

7.7.10 Pit 3 Solute Transport Modelling

A conceptual model of groundwater–surface water interaction based on the key driving forces, processes, and hydrogeologic features was developed to serve as a defensible foundation for the numerical models.

A numerical solute transport model was developed by INTERA to quantify the potential impact of solutes leaching from different backfill scenarios at Pit 3 closure, to Magela Creek, for a period of 10,000 years after closure. The solute transport model models COPC that are generated from weathering of the waste rock placed internally and externally of Pit 3, before solutes egress with groundwater into the receiving environment.

Both conceptual and numerical models were developed to assess the ability of the proposed Pit 3 backfill options to meet the ERs outlined in the Ranger Authorisation.

An assessment of the potential effects of the predicted solute loading to Magela Creek from tailings and brine placement in Pit 3 was undertaken in 2014, using the results of the INTERA modelling and surface water modelling.

The solute egress model and impact assessment confirms no detrimental impact to the surrounding environment over 10,000 years due to the waste rock, tailings and brine storage.
within Pit 3, as required under the Ranger Authorisation. Details on the conclusions obtained from the solute egress modelling are discussed in Section 7.2.3 of the MCP.

7.7.10.1 Study Objectives

The Pit 1 and Pit 3 modelling studies described in the above sections were applied to closure scenarios both with and without mitigation measures. Mitigation measures incorporated into the modelling were a low permeability cap at the top of the shallow waste rock backfill, low permeability cap over the tailings, and a cut off wall between Pit 3 and Magela Creek. While the low permeability cap was initially identified as the preferred mitigation option, the modelling identified that mitigation through the use of low-permeability caps was preferred over the cut-off wall. However, when reviewing the effectiveness of these caps in reducing solute loads to Magela Creek in the context of the overall site, the modelling predicts they have only a marginal impact on loads. The conceptual model indicates the use of low-permeability caps will not be required (refer to Section 7.7 of the MCP).

7.7.10.2 System Conceptualisation

The hydrogeological and geochemical conceptual models incorporate new data and information acquired from field investigations at the Ranger mine, and form the basis of the modelling studies undertaken for Pit 1 and Pit 3. Chemical analysis data from samples collected from the Ranger waste rock stockpiles was used to estimate upper bounds on source concentrations, with the assumption that conditions in the waste rock stockpiles are geochemically analogous to conditions that will exist in waste rock backfill within Pit 1 and 3.

7.7.10.3 Model Development and Approach

A three-dimensional groundwater flow and solute transport model was developed for Pit 1 and Pit 3, based on the hydrogeological conceptual model and groundwater level data from 2005 and 2006. The model is based on a conservative modelling approach, and satisfies the 10,000-year prediction requirements of the regulators.

The model has been calibrated using 73 calibration targets and final calibration yielded good residual statistics.

Mine closure is expected to increase recharge (and groundwater level) to areas located up gradient of the pits. This may cause exfiltration of groundwater at the ground surface due to the lower permeability of the shallow aquifer sediments compared to the waste rock backfill, and/or increase evapotranspiration in down-gradient areas (i.e. between Magela Creek and Pit 3). The modelling approach uses drain and evapotranspiration boundary condition cells to remove and track water and solutes that may otherwise become numerically trapped during the simulations. The solute mass removed through the evapotranspiration boundary condition is assumed to directly reach Magela Creek, and so is added to the solute mass delivered to the creek by the direct transport pathway of groundwater baseflow.

7.7.10.4 Reactive Transport Modelling

The reactive transport modelling undertaken for Pit 3 suggested that attenuation of uranium and manganese transport is effective over a duration of less than 100 years within the Magela
sands, and less than 7,500 years within the weathered rock. No attenuation was observed for radium-226 within the Magela sands or weathered rock aquifers.

Solute loadings were conservatively estimated for a range of COPC from the Pit 3 waste rock, tailings and brine sources to Magela Creek, with the study indicating that solute loadings to the creek from Pit 3 brine's reactive solutes are negligible, and that solute loading is independent of recharge rate. Therefore, the installation of a low-permeability cap on the shallow waste rock in Pit 3, for the purpose of reducing recharge, will have little impact on reducing loading to groundwater from the pit. The modelling supports the view that low permeability capping of the Pit 3 shallow waste rock is not required.

Section 7.2.4.4 of the MCP provides further details on the reactive transport modelling, including modelled COPC and concentrations.

7.7.10.5 Secondary uranium and magnesium minerals associated with the waste rock landform

In 2016 ERA investigated a Ranger stockpile to identify secondary minerals formed after prolonged burial and exposure to weathering. ERA collected weathered rocks and exfiltrated groundwater from recently exposed faces of a stockpile, to analyse for secondary minerals (weathered rock samples), and test the groundwater for elements that are associated with these minerals. It is considered that the variably water-saturated groundwater environment of the stockpile represents the future weathering environment of the upper waste rock zone of the final landform, but not the permanently groundwater-saturated lower waste rock zone that will occur in the shells of Pit 3 and Pit 1. This permanently saturated zone should support sulfate reducing bacteria, which is known to facilitate the mineralisation of magnesite.

The study was undertaken to validate the solute transport modelling by comparing the laboratory analyses to the secondary minerals identified by the modelling as being generated by weathering.

The laboratory results confirmed several of the main secondary minerals identified from the solute transport modelling, as well as identifying some additional secondary minerals. ERA is currently reviewing the geochemical source term with respect to predicting the seepage of contaminants from the waste rock final landform and buried tailings. The investigation confirmed that the solute transport model is conservative for uranium (as discussed in Section 7.2.4.3 of the MCP).

Section 7.2.4.5 of the MCP presents further details associated with the study.

7.7.11 Peer Review

A peer review of INTERA’s solute egress modelling, including sections on the calibration of the numerical flow model have been undertaken over the past two years by Dr Leslie Smith, Professor at the University of British Colombia, Canada (Smith, 2015, 2016). Dr Smith specialises in the peer review of project work at mine sites and hazardous waste management facilities, contaminant plume migration and modelling, seepage analysis at dam sites, fluid flow and solute transport in fractured rock, peer review and performance assessment of low and high-level nuclear waste disposal programs, analysis and modelling of groundwater systems,
well field developments, dewatering systems, and review of work plants on site characterisation.

The peer review concluded that the hydrogeologic models developed were considered to be well-suited for their intended purpose.

In addition to the peer review by Dr Smith, calibration of the 3D groundwater flow model and solute transport modelling from the Pit 3 backfill have been independently (peer) reviewed by Juliette Woods (Principal Groundwater Modeller at South Australia Department of Environment, Water and Natural Resources).

Details on the outcomes of the peer review are described in Section 7.7.4 of the MCP.

7.8 Surface Water Modelling

A surface water model was developed during 2013 to estimate concentrations of COPC downstream of the Magela Creek and Gulungul Creek confluence after mine closure. The modelling results were used to identify whether the concentrations exceed the proposed criteria (99% species protection or field ecotoxicology tests).

7.8.1 Method

The surface water model was developed through an update of the original model to the current landform design (V5) and the current RPA conceptual model (described in Section 7.7). Groundwater seepage from surface waste rock, and Pit 1 and Pit 3 tailings were identified from the RPA conceptual model as post-closure influences, and were also entered into the surface water model. The annual loads and concentration of COPC associated with groundwater seepage were converted to a suitable input format for the surface water model, and the model was run with these inputs under the rainfall, evaporation and river flow conditions observed in Magela Creek between 1/1/2000 and 31/12/2015. COPC reporting below the confluence of Magela Creek and Gulungul Creek (downstream of the drainages from the final landform) were described for the peak and long-term solute egress scenarios.

Figure 29 shows the location of the represented reach that was modelled (downstream of Gulungul Creek), and Figure 30 shows the node locations within the model in which the mine-related contributions were added for the simulation.
Figure 29: Represented reach downstream of Gulungul Creek (orange arrow)

Figure 30: Drainage conduits and nodes (yellow lines with blue nodes), contoured topography at 2 metres and 5 metres intervals. (The waste rock boundary area is colour coded with respect to sub-catchment area and waste rock thickness.)
7.8.2 Model Results

The modelling results indicate that streamflow within Magela Creek will dilute the post-closure inputs of COPC to below background concentrations downstream of the Gulungul Creek confluence (i.e. the post-closure landform does not pose a risk to the downstream environment).

ERA are in the process of updating the surface water model, and the updated information will be provided in the next iteration of the MCP.

ERA have also commissioned a repeat of the surface water modelling using an independently developed surface water model, with the aim to provide predictions of dissolved and suspended sediment within, and outside of, the RPA. Stakeholders have been involved in developing the scope for this study. The data from this modelling study will:

- Inform the risk assessment process to identify whether water quality closure criteria will be met.
- Identify the need for additional studies.
- Inform development of ALARA assessment criteria for surface water COPC within the RPA.

Section 7.8.3 presents further details on the modelled findings, and a discussion of the results in Section 7.8.4.

7.9 Brine Management

Process water currently undergoes treatment at the brine concentrator. The treatment produces clean water for discharge to available wetland filters and a concentrated brine solution which requires long term disposal. During the Integrated Tailings Water and Closure Pre-feasibility Study (ITWC PFS), it was identified the best practicable technology for long term brine management is injection into the Pit 3 underfill.

A number of studies were completed to determine the suitability of the waste rock underfill to store brines, with no impact to the environment for over 10,000 years, these included:

- Solute egress modelling of brine, refer Section 7.7.3 of the MCP.
- Available void volume for brine storage versus maximum brine volume production.
- Waste rock compression and permeability testing.

A summary of the second two studies is provided in the following section.

7.9.1 Pit 3 Underfill Tests

To determine the dry density, at various stresses, and final void volumes/ storage capacity of the Pit 3 underfill rock, compression, permeability and brine reactivity testing was undertaken on four representative samples of underfill material from Pit 3. The test results were then used
to estimate the Pit 3 underfill storage capacity. Assumptions used in the calculation are conservative, and detailed in Section 7.9.1 of the MCP.

The results of the testing and subsequent calculation show the following:

- Underfill reacts with hot, concentrated brine, with minimal weight loss occurring. Reactivity is unlikely to significantly affect the hydraulic conductivity or voidage.
- The sample 2 material (laterite with schist muscovite) showed higher compressibility, hence a lower void ratio and higher dry density. This material is not recommended for use within the Pit 3 underfill.
- Permeability decreases significantly with increasing dry density (reduced void ratio).
- Storage capacity (conservative) estimates suggest that the underfill contains sufficient capacity to store the volume of brine produced by the brine concentrator.
  - Pit 3 underfill is suitable for storage of between 2,885 megalitres (ML) and 3,043 ML of brine concentrator brine. Note: this is dependent on the amount of weathered material present within the underfill.

Section 7.9.1 of the MCP provides further details on the studies undertaken during the Pit 3 underfill testing and the findings of each.

### 7.10 Future Studies

The following studies will be undertaken in future for the RPA, and are detailed in Section 7.10 of the MCP:

- Radiation dose assessment: To confirm that radiation dose criteria will be met post-mine closure, for potential exposure to the public and aquatic biota.
- Nutrient cycling in revegetated waste rock landform: To assess whether in situ litter decomposition and associated nutrient cycling are functioning to replenish macronutrients for plant growth.
- Conceptual site modelling: Updates to the current surface and groundwater solute transport modelling. Other study components include downhole geophysics investigations of historical bores; an investigation into the use of electromagnetics to establish baseline geophysics conditions; and cone penetration test sampling of the Pit 3 tailings.
- Soil assessment: ERA will be undertaking a series of soil assessments as part of the feasibility study, for uranium and other identified COPC.
- Surface water modelling: Construction of a hydrodynamic model to simulate the behaviour of the catchments hosting the RPA and resulting concentrations of COPC both on and downstream of the RPA in the post closure phase. The model is based on the current closure strategy and will identify any mitigation required.
- Surface water pathway risk assessments: A collaborative project with the Supervising Scientist Branch and CSIRO to conduct a cumulative risk assessment for the surface
water pathway. This project will assist in prioritising the existing ARRTC Key Knowledge Needs and provide input into BPT and ALARA assessments for the RPA.

- Phase 3 closure criteria and detrimental impact framework development: ERA and consultants BMT WBM will continue to work with stakeholders to develop the framework for interpreting proposed magnesium criteria in the context of potential detrimental impact to recognised environmental values of the waters on and off the RPA.
8. BEST PRACTICABLE TECHNOLOGY (BPT)

Chapter 8 describes the process and identification of the best practicable technology (BPT) for the Ranger mine rehabilitation and closure. It includes details on the preliminary BPT assessments undertaken during the Ranger 2011-12 Interim Tailings, Water and Closure prefeasibility study (ITWC PFS) and the 2016 review of tailings treatments.

8.1 Overview

The definition of BPT in the ERs effectively establishes a framework to assess currently available technology. The intent behind BPT is to ensure that choices between different operational and closure designs/mitigation methods made at any point during the mine life, utilise technology that ranks highest when assessed against the factors below;

- World's best practice.
- Cost-effectiveness.
- Proven effectiveness.
- Age of equipment.
- Social factors.
- Is consistent with the Primary Environmental Objectives.

The BPT also removes the necessity for the ERs specifying particular technologies which may become obsolete.

ERA have revised and expanded the original BPT matrix published by the Supervising Scientist in 2000. The revised BPT matrix enables technical staff in assess individual components of a project, as well as assess the overall BPT for the final closure proposal. There are currently 25 criteria used in the matrix, which can be categorised under the following headings:

- Traditional owner culture and heritage.
- Protection of people and the environment (operational phase).
- Fit for purpose.
- Operational adequacy.
- Rehabilitation and closure.
- Constructability.

The revised matrix was used for the ITWC PFS and the 2016 tailings assessment to rank alternative technologies for closure. Like risk assessments, BPTs undergo review from time-to-time to ensure options remain fit for purpose. Future BPT assessments will also be completed for the rehabilitation/closure activities identified for standalone assessment via the MTC (Appendix 1.2 of the MCP).
The BPT assessment ranks, weights and scores technology options. The final BPT score for each technology option was calculated using the rank of the option against the each of the criteria. The BPT score essentially summarises performance of the option against current international performance standards.

8.2 ITWC PFS Technical Options Assessment

The ITWC PFS program was commissioned to evaluate the technology for reclamation, treatment and transfer of tailings from the tailings dam to the mined-out Pit 3, and salt management technology to ensure physical containment of brine for 10,000 years. The assessment was split into two; PFS1 (tailings and brine management) and PFS2 (closure strategy options and closure plan development) and BPT workshops were conducted.

8.2.1 PFS 1 - Tailings Reclamation, Transfer, Treatment and Deposition (Pit 3)

Three categories were considered for reclamation of tailings from the tailings dam; excavation, hydraulic mining and dredging. Hydraulic mining and dredging emerged from the workshop with approximately equal BPT assessment ratings. An additional assessment of the advantages and disadvantages of each technology was undertaken, with dredging emerging the preferred option.

Filtration and cementation were considered as possible treatment methodologies to assist with consolidation of the tailings, and to reduce the risk of dispersion of solutes, respectively. Through the BPT it was noted that filtration is retained for the whole-of-project but was expensive with limited advantages and cementation required further trials and high capital costs, and was therefore discounted.

Options assessed for deposition of tailings into Pit 3 considered either subaerial or subaqueous techniques for thickened tailings and dry-stacking or co-disposal with waste rock for filtered tailings. Subaqueous deposition was preferred principally because it was rated more highly under the operability and operating costs criteria. Subsequent to this initial BPT workshop, consolidation modelling demonstrated that subaerial deposition would provide an advantage over subaqueous deposition. Both options had been determined as BPT, and therefore the method was changed.

8.2.2 PFS 1 - Salt Treatment and Disposal

A total of seven options for the disposal of saline water was assessed through the BPT process. They were categorised under the following headings:

- Brine injection.
- Crystallisation.
- Thermal distillation.

The overall outcome was that brine injection to the underfill without rock screening was the highest ranked in the BPT assessment. The only uncertainty remaining for the preferred option related to the potential for reactivity between the brine and the waste rock of the underfill and
possible limitation on the volume available for the storage of brine. Further assessment prior to a final decision on the salt management option to be implemented. For this reason, crystallisation was taken forward into the overall strategy assessment pending further test work to confirm on the brine injection option.

8.2.3 PFS 1 - Final Landform Construction, Revegetation and Ecosystem Reconstruction

The landform reconstruction and revegetation program has gone through significant options analysis and refinement over several years and there are no longer major competing alternatives for their implementation. Instead of ranking options, each of the current plans for landform construction, revegetation and ecosystem reconstruction were reviewed against each criterion to identify possible options for improvement and to record any uncertainties.

8.3 PFS 2 – Closure Strategy and Plan

At the completion of PFS 1, there were a number of core technical options for tailings and salt management. The combinations of feasible options are outlined below:

- Dredged tailings which are thickened and pumped to Pit 3 combined with injection of brine into the constructed base of Pit 3 (underfill).
- Dredged tailings which are thickened, then filtered, and pumped to Pit 3 combined with injection of brine into the constructed base of Pit 3 (underfill).
- Dredged tailings which are thickened and pumped to Pit 3 combined with crystallization of brine to be placed within Pit 3.
- Dredged tailings which are thickened, then filtered, and pumped to Pit 3 combined with crystallization of brine to be placed within Pit 3.

These options were then combined with two possible processing cessation dates (2016 & 2020). This provides a total of eight possible closure strategies (1B, 1C, 2B, 2C, 3B, 3C, 4B, 4C). The BPT assessment was divided into 2 stages.

The key options that were eliminated in the stage 1 assessment were tailings filtration and brine crystallisation; results of the stage 1 assessment are shown in Figure 31.
Stage 2 BPT workshops were limited to 1B and 1C, however, extended water treatment cases (5B and 5C) were considered as well. This was to allow for the scenario where process water volumes exceeded the brine concentrator treatment capacity; allowing for longer term treatment of process water. The highest BPT score was for Strategy 1B Brine injection, thickened tailings, milling until 2020, however the results were marginal.

8.4 2016 Supplementary BPT Assessment

A review of the ITWC BPT assessment was conducted in August 2016; this determined that with the exception of tailings treatment, all technical options selected as BPT remained valid. The initial PFS 1 BPT assessment for tailings treatment considered thickening as the base case option to reduce consolidation times in Pit 3. Subsequent to this decision of thickened tailings, consolidation values in Pit 1 indicated thickening may not be necessary. A supplementary workshop was undertaken considering unthickened tailings deposition with additional treatment methods including:

- Unthickened tailings (A2).
- Unthickened with prefabricated vertical drains (wicks) (A3).
- Unthickened tailings with extended water treatment (A4).
- Unthickened tailings, with inline agglomeration and wicks (A5).
- Unthickened tailings with neutralisation and wicks (A6).

Tailings treatments brought forward from the previous ITWC BPT assessments include:
• Thickened tailings (A1).
• Thickened and filtered tailings (A7).
• Thickened, filtered and cemented tailings (A8).

These options were assessed using the BPT process with the same assessment criteria as used in the ITWC PFS (Table 5). Of the eight options assessed, three options were considered viable (A1, A3 and A5). However, the two highest scoring options were:

• Unthickened with prefabricated vertical drains (wicks) (A3).
• Thickened tailings (A1).

There was no material difference in the assessment scores for the thickened (A1) and unthickened with wicks (A3) options. However, based on the performance of the Pit 1 backfill strategy and tailings consolidation being achieved via this method, and the results of subsequent consolidation modelling, A3 was identified as the preferred option.

Table 5: Supplementary tailings treatment assessment

<table>
<thead>
<tr>
<th>Strategy</th>
<th>Technology</th>
<th>Showstopper</th>
<th>Overall rank</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Hard</td>
<td>Soft</td>
</tr>
<tr>
<td>A1</td>
<td>Thickened tailings (ITWC base case)</td>
<td>32.6</td>
<td></td>
</tr>
<tr>
<td>A2</td>
<td>Unthickened tailings</td>
<td>✓</td>
<td>-100</td>
</tr>
<tr>
<td>A3</td>
<td>Unthickened tailings, with prefabricated vertical drains (wicks)</td>
<td>41.3</td>
<td></td>
</tr>
<tr>
<td>A4</td>
<td>Unthickened tailings, with extended water treatment</td>
<td>✓</td>
<td>-6.5</td>
</tr>
<tr>
<td>A5</td>
<td>Unthickened tailings, with inline agglomeration and wicks</td>
<td>✓</td>
<td>10.9</td>
</tr>
<tr>
<td>A6</td>
<td>Unthickened tailings with neutralisation and wicks</td>
<td>✓</td>
<td>17.5</td>
</tr>
<tr>
<td>A7</td>
<td>Thickened and filtered tailings (ITWC assessed)</td>
<td>✓</td>
<td>13.0</td>
</tr>
<tr>
<td>A8</td>
<td>Thickened, filtered and cemented tailings (ITWC assessed)</td>
<td>✓</td>
<td>6.8</td>
</tr>
</tbody>
</table>
9. RISK ASSESSMENT AND MANAGEMENT

Chapter 9 provides a description of ERA's overarching risk assessment framework. The chapter discusses the outcomes of the closure risk assessments that have been undertaken in recent years, including the integration of sources, stressors, pathways and endpoints identified in the ARRTC ecological risk assessment.

9.1 Risk Assessment Framework

ERA's overarching approach to potential health, safety and environmental risks is embedded in its Hazard Identification and Risk Management Standard, which has been certified to meet the requirements of the standard AS/NZ ISO14001:2004 and AS4801. The framework consistent with the intent of the following Australian standards, and corporate management standards and practices:

- AS/NZS ISO 14001 Environmental management systems.
- AS4801 Occupational health and safety management systems.
- Rio Tinto Risk policy and standard.
- Rio Tinto HSEQ management system - Element 3 hazard identification and risk assessment.
- Rio Tinto HSE performance standards.
- ERA Ranger Environmental Requirements, which require risk controls to safeguard:
  - The protection of attributes for which the Kakadu National Park was inscribed on the World Heritage list.
  - Protection of ecosystem health of wetlands listed under Ramsar Convention on Wetlands.
  - Protection of health of the members of the regional community.
  - Maintenance of the nature and biological diversity of aquatic and terrestrial ecosystems of the Alligator Rivers Region, including ecological processes.

The hazard identification and risk management framework is presented in Figure 32. Importantly, risk assessments undertaken by ERA are for setting priorities and management strategies, not for calculating the risk exposure.

A closure specific risk assessment was undertaken by ERA in 2016, which incorporated all other risk assessments undertaken over the life of Ranger. In addition to incorporating previous risk assessment outcomes, the best practicable technology preferred options were taken forward in the closure risk assessment. The ERA risk assessment methodology includes representation from relevant stakeholders, and ecological, social, engineering and radiation specialists, and leading government science bodies.
Prior to commencing the closure risk assessment, reviews of the previous risk assessments were undertaken, these included:

- Pit 1 Interim Tailings, Water and Closure Prefeasibility (ITWC PFS) risk register, 2008.
- ITWC PFS risk register, 2011.
- PFS tailings and brine management closure risk register, 2013.
- Ranger Pit 1 closure risk environmental register, 2016.

Consideration has also been given to the sources, stressors, pathways and endpoints described in the Alligator Rivers Region Technical Committee (ARRTC) ecological risk assessment, which was a collaborative project between Supervising Scientist, ERA and key stakeholders. Where practicable, parameters from the ecological risk assessment have been incorporated into the closure risk assessment.

Outcomes from the closure risk assessment will continue to be reviewed and additional risks identified at workshops will be considered in future iterations of the Ranger MCP.

9.2 Closure Risk Assessment

The purpose of the closure risk analysis was to identify and evaluate the consequences and significance of the threats on the surrounding environment associated with the closure of the Ranger mine, ensuring that the ERs and objectives are met in the short, medium and long-term.
The closure risk assessment considers three defined phases, with each phase having its individual risks identified. The three phases are:

- **Decommissioning** – scheduled to end in 2020, but likely to continue to 2026.
- **Stabilisation and monitoring** – post decommission, where the site is developing into a viable ecosystem and trending towards the achievement of the closure criteria.
- **Post closure** – after the closure criteria have been achieved and a close-out certificate has been issued. This period continues indefinitely from the time of issue of the close-out certificate. The site will have been returned to the traditional owners.

Socio-economic impacts, Jabiru field station and Jabiru Township were excluded from the closure risk assessment and will be addressed in separate bodies of work.

### 9.3 Risk Identification and Analysis

The closure risk assessment was and will be conducted by teams with relevant qualifications and experience relating to the activity of concern and area of risk.

The aim of risk identification is to generate a comprehensive list of credible risks over the life of the project, based on the previous operational, current and planned closure activities.

The hazards were analysed to identify any significant risk to human health, safety, or the natural environment with all current and proposed mitigation measures in place.

Risk is defined in terms of consequence and likelihood of the adverse impact occurring. Both hazards and risks are elements or actions giving rise to a condition that may cause harm, whereas potential impacts (consequences) are the effect or result triggered by the risk being realised.

The likelihood and severity of consequences were defined for each environmental aspect and factor (receptor) relevant to the closure of Ranger.

The risk assessment process also qualitatively assesses "control effectiveness", which enables ERA to make informed decisions regarding the need for additional risk management. Ranking is based on the expert opinion of the risk assessment team and the risk assessment process defined in the MCP.

Potential credible risks were identified by considering the activities and phases associated with the closure of the Ranger mine. For each risk (threat), one or more possible causes (triggers/indicators) was identified and together these were used to define the potential impacts (consequences) of each risk scenario.

Each risk scenario is given an identification number, defined in terms of likelihood and consequence, and ranked according to the closure risk assessment matrix. The highest ranked potential impacts (Class III and Class IV) were identified for consideration of additional risk reduction treatments, with lower ranked potential impacts subject to operational controls and continued improvement. Some additional risks were identified as Class I and II risks.
It is worth noting, that existing controls are considered when determining the risk ranking, therefore according to ISO 31000, it is the residual, rather than inherent risk that has been ranked.

To focus the risk assessment process and ensure that it is conducted to sufficient levels of detail, a breakdown structure was developed from previously identified key areas of risk. The developed structure is summarised in Table 6.

Table 6: Risk breakdown structure

<table>
<thead>
<tr>
<th>Category (risk code)</th>
<th>Sub-category</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aquatic ecosystem (TA)</td>
<td>Onsite water bodies (TA1)</td>
</tr>
<tr>
<td></td>
<td>Offsite water bodies (TA2)</td>
</tr>
<tr>
<td></td>
<td>Onsite water and waste management (TA3)</td>
</tr>
<tr>
<td>Terrestrial ecosystem (TB)</td>
<td>Landform (TB1)</td>
</tr>
<tr>
<td></td>
<td>Revegetation (TB2)</td>
</tr>
<tr>
<td></td>
<td>Fauna (TB3)</td>
</tr>
<tr>
<td></td>
<td>Weeds (TB4)</td>
</tr>
<tr>
<td></td>
<td>Fire (TB5)</td>
</tr>
<tr>
<td>People (TC)</td>
<td>Radiation (TC1)</td>
</tr>
<tr>
<td></td>
<td>Diet (TC2)</td>
</tr>
<tr>
<td></td>
<td>Cultural heritage (TC3)</td>
</tr>
<tr>
<td></td>
<td>Stakeholder and legal expectations (includes agreements, commitments, etc) (TC4)</td>
</tr>
<tr>
<td></td>
<td>Community (includes workforce) (TC5)</td>
</tr>
</tbody>
</table>

NB: Categories and most sub-categories align with the themes of the ecological risk assessment
9.4 Risk Assessment Results

Forty-five (45) risks were identified over the three phases of closure, with 23 of these risk identified as Class III and would require active management. Figure 33 depicts the breakdown of the risk rankings into the 3 main categories and Figure 34 identifies the control effectiveness ranking by sub-category.

![Figure 33: Distribution of risks across category](image)

![Figure 34: Control effectiveness by category](image)
There were no Class IV (critical risks) identified.

Of the 23 risks classified as Class III (high) none were identified for sub-categories diet, fire or fauna.

9.5 Class III Risks by Sub-Category

9.5.1 RPA Waterbodies (TA1)

Only one Class III risk was identified (TA1-02) which relates to high erosion from the final landform potentially causing waterbodies (e.g. Georgetown Billabong and/or Coonjimba Billabong) to infill, or for increased sedimentation in creek beds to occur, smothering aquatic biota.

The Supervising Scientist Branch has modelled the geomorphic stability of the Djalkmarra, Corridor, Gulungul and Coonjimba Creek catchments for a period of 10,000 years using the LEM. The model is conservative in nature, having only minimal vegetation on the surface for the entire 10,000-year period and excludes any planned, orthodox storm water and erosion control structures to reduce bedload yields.

It is expected that early bedload yield activity from the trial landform influenced by time since construction, rather than rainfall intensity, will exceed natural yields, but over time and with continued stabilisation of the landform, bedload are predicted to be comparable to natural yields.

The final landform will be constructed and revegetated to control erosion. The landform will incorporate several engineered mitigations/controls, such as:

- Design, implementation and management of orthodox storm water and erosion control structures on the final landform to reduce bedload yield – (e.g. sumps installed as silt and contaminant traps as passive water management techniques for the initial settling of the landform); the use of existing retention ponds, such as RP1 post closure.
- Implementation of an active water management strategy and inventory control during the decommissioning and stabilisation phases of closure, based on similar practices currently implemented at Ranger.
- Iterative landform design informed by the landform evolution modelling predictions; this includes locating and sizing of proposed stormwater and erosion control structures.

9.5.2 Offsite Water Bodies (TA2)

Two Class III risks were identified (TA2-02 & 03) for this sub-category:

TA2-02: relates to the potential for poor quality water from Pit 3 tailings, brines and waste rock backfill entering offsite water bodies (e.g. Magela Creek, Mudginberri, Ramsar wetlands, etc), via groundwater and/or surface water pathways.

TA2-03: relates to the potential for poor quality water from cumulative sources (e.g. the final landform, legacy sites, pits etc), to enter offsite water bodies via groundwater and/or surface...
water pathways. The risks associated with Pit 1, as an isolated source, were ranked Class II but it is one of the sources included in the "cumulative source".

The tailings and overlying waste, and expressed process water (or pit-tailings flux; PTF) have been identified within the Pit 1 source as potentially emitting COPC to Corridor Creek. In addition to Pit 1, waste rock from the landform has also been identified as a major source of COPC. Magnesium is the main COPC present within each source.

A large body of work has been undertaken to help define the risks of the Pit 1 and waste rock landform COPC sources, and includes the development of a conceptual site model, which considers the interactions between all potential sources and surface water and groundwater interactions. The conceptual model estimates peak annual magnesium from all waste rock and in-pit tailings, brine and PTF to be under 150,000 kg per year, compared to annual average loading from operations (180,000 kg/year) and natural loads (135,000 kg/year). The main source of magnesium loading is from the waste rock cover, with tailings and brine representing much smaller sources.

A number of other COPC relevant to waste rock, and tailings/process water were identified and have been assessed accordingly for closure. Detailed information on the studies (including the predicted loads and concentrations, and assessment against the available guidelines) are provided in Chapter 7 of the MCP. The studies show loads of metals and nutrients from the combined Pit 1 and Pit 3 waste rock and tailings sources present a low risk following closure.

Surface water COPC concentrations were also estimated as part of the assessment. Surface water modelling was undertaken to estimate peak and long-term loads and concentrations of COPC. The model predictions indicate that magnesium, manganese, uranium and total ammonium nitrogen (TAN) concentrations reporting below the confluence of Magela Creek and Gulungul Creek were below the current site specific guideline values for protection of 99% of species.

Based on a comparison of load limits and guideline values to the predicted loads, downstream solute concentrations, and the magnesium calcium ratios, the major cumulative sources in the post closure final landform do not pose a risk to the downstream environment.

Natural controls that reduce the concentrations further than predicted include natural attenuation of reactive COPC in groundwater and surface water. Existing active operational water management controls will also remain in place during decommissioning.

Future controls include the design and construction of passive sediment and water management structures as required, across the whole of site post closure landform to manage solutes from waste rock sources. The existing and future controls provide a high level of confidence in the control effectiveness (C1) of the risk.
9.5.3 Onsite Water and Waste Management (TA3)

Four Class III risks were identified for this sub-category (TA3-01, TA3-02, TA3-04 and TA3-05).

**TA3-01**: relates to the risk of uncontrolled release of contaminated material (e.g. process liquor or slurry) into the onsite environment during the transfer of tailings to Pit 3 and has previously been identified as a risk in ERA’s process safety management framework. As such, this risk has undergone an extensive bow-tie analysis to identify critical risk controls to gain a better understanding of the extent and quality of barriers and mitigation measures that exist for its management. It is a risk that is only relevant to current closure activities.

**TA03-02**: relates to the uncontrolled release of process water from the tailings dam, and is only relevant during a two-year time frame (2022-2024) during decommissioning activities. There may be no requirement to store process water in the tailings dam in the long term, this is yet to be determined.

Several controls are proposed to manage this risk, including:

- Active management of the sequencing of process water treatment and tailings transfer to minimise storage volumes.
- Engineering assessment of suitability of the tailings dam for process water storage
- Tailings dam operations manual.
- Compliance with Rio Tinto D5 standard.
- Hydrogeological assessment of potential for seepage and implementation of mitigations if required.

Preliminary hydrogeological modelling and assessment, focussing on the adequacy of the tailings dam to store process water, has been completed. As a process water storage facility, the average seepage rate over the 5-year period is estimated to be 28 cubic metres per day. Should the tailings dam be used to store process water, it is likely that further studies will be required.

**TA3-04**: relates to the potential migration of hydrocarbons into the groundwater from buried Blackjack (gear oil). Radiation concerns limit options for off-site disposal, and used oil needs to be disposed of in line with Rio Tinto and ERA policies and standards, and the Ranger Environmental Requirements prescribed by the s.41. Three options were evaluated:

- High temperature incineration.
- Burial within Pit 3 tailings.
- Separation of light hydrocarbons, to be recycled as a fuel additive, with solids being disposed of in Pit 3 tailings.

Currently option 1 is preferred as it is a low risk proven technology which has been used in the past at Ranger. If constructed, the incinerator would continue to operate until six months after milling ceases at Ranger.
The level of options assessment that has occurred provides a high level of confidence of the control effectiveness proposed to manage this risk.

**TA3-05**: relates to the seepage of impacted groundwater from the tailings dam plumes and the potential transport of elevated concentrations of COPC to surface water. The location and pathways for the transport of elevated concentrations of COPC from the tailings dam plumes have been the subject of numerous studies; the outcomes of which inform the Ranger conceptual site model, discussed in Chapter 7.

Key decommissioning activities and events that will lead to a reduction in the localised hydraulic heads and migration of COPC from the tailings dam to down-gradient creeks and tributaries have been identified.

However, uncertainty still exists with regard to solute concentrations and transport from the tailings dam, therefore additional groundwater studies are proposed to gain a better understanding of the system.

### 9.5.4 Landform (TB1)

Four Class III risks were identified for this sub-category (TB1-02, TB4-03, TB1-04, TB1-06).

- **TB1-02**: relates to erosion and gully formation across the landform exposing tailings in Pit 1. The LEM undertaken on the conceptual landform predicts that two large gullies will form over the southern parts of Pit 1. A comparison of the tailings surface RL and predicted depth of the gullies was undertaken and the results indicate that there will be a 5 m cover of waste rock in place over lying the tailings. Therefore, tailings will not be exposed over a 10,000-year time frame. Notwithstanding this, ERA will make minor adjustments to the final constructed landform, with the aim that any drainage channels or significant gully formation will occur outside the shell of the pit.

- **TB4-03**: relates to the risk of consolidation being significantly greater than predicted in Pit 3, with the potential consequences of delay in the success of the revegetation and/or a delay in the completion of process water treatment by 2026. Numerous controls are in place to manage this risk, including placement of wick drains and underdrainage. A substantial proportion of the consolidation will occur during the decommissioning phase, when the landform is actively managed and there is a high confidence level in control effectiveness.

- **TB1-04**: relates to the risk of consolidation being significantly greater than predicted in Pit 1. The majority of the consolidation in Pit 1 will occur during current operations, with opportunities to correct and/or rectify any settlement issues during and immediately after the bulk backfill, scheduled to commenced in quarter 4 2016.

- **TB1-06**: related to excessive erosion impacts landform stability and revegetation success. The final landform has been designed with moderate slopes, negating the risk to landform stability from mass failure. See risk TB1-02, discussed above regarding the outputs from the LEM undertaken by the Supervising Scientist. Proposed controls to minimise erosion and landform stability risks include (but not limited to):
• Surface treatments – ripping, concave slopes and using available woody debris and rock.
• Drainage channel treatment.
• Edge sediment basins & second layer sediment basins.
• Construction of access tracks.
• Revegetation strategy tailored to landform elements.

9.5.5 Revegetation (TB2)

Three Class III risks were identified for this sub-category (TB2-04, TB2-05, TB2-06)

TB2-04: relates to the risk of low plant propagation in the nursery, which has the potential to impact on ERA’s ability to achieve the required time frames for rehabilitation. Kakadu Native Plants Pty Ltd, a locally owned and run indigenous supplier, provide seedlings for much of the revegetation projects. This supplier has extensive expert propagation and plant knowledge; however, propagation success can be affected by a number of variables, which are outside the control of the supplier, including but not limited to: lack of viable seed, technical issues such as disease or equipment failure, fire and/or fauna (birds, possums) destroying potential seed sources, high fire frequency limiting access during seed collection, etc. Existing mitigating controls are:

• Expert knowledge of supplier.
• Supplier prequalification process.
• Multiple plant nurseries to deliver plant volumes in later years. Ongoing collection of seed and appropriate storage.
• ERA establishes a new nursery in 2017-18.

Based on the level of existing propagation expertise and supply history to date and other mitigation measures, this risk has a control effectiveness ranking of mostly effective/adequate design (C2).

TB2-05: relates to low plant survival rate during establishment and vegetation decline at mature stage.

ERA has undertaken extensive revegetation studies to inform the proposed revegetation strategy and to support long term plant survival. The aim in all these trials has been to establish species that occur locally in eucalypt dominated woodland communities, results indicate that:

• Waste rock (mine soils) can sustain the growth of local native tree species, at least until the age of 17 years old, the age of the oldest trial data.
• Planting nursery-grown tubestock results in a more reliable and rapid establishment than direct seeding.
• initial irrigation has enhanced plant establishment and permits year-round planting.
Existing and proposed controls include:

- Irrigation during plant establishment.
- Adjustment to planting strategies based on performance.
- Infill planting during stabilisation phase.
- Weed control and fire exclusion for 5-7 years.
- Revegetation plan informed by trials.
- Landform store-and-release waste rock cover is thicker than 7 m over the rock base.
- Initial fertilisation and inoculation of tubestock.
- Plant species selection will consider topography and predicted edaphic conditions.
- Surface pitting resulting from a mechanical cultivator.
- Natural weathering of waste rock.
- Partial, selective contour ripping
- Modelling predicts that waste rock cover of 4 – 7 m thick, will provide sufficient plant available water for a mature eucalypt woodland.
- Subsurface compaction layers to enhance water holding capacity.

There remains several outstanding aspects of the landform's store-and-release cover design and revegetation strategy that are currently being reviewed, including assessment of infiltration rates as a function of the landform slope and surface preparation; and the assessment of the effects of ripping/spot cultivation on water storage, erosion rates, nutrient recycling, etc. The ongoing work to address these aspects of the revegetation strategy is reflected in the control effectiveness ranking of C3.

**TB2-06:** relates to the inability to plant-out the landform within the timeframe, which could result in ERA not meeting its compliance obligations and loss of community trust. There are many existing and proposed controls which include:

- Implementation of the revegetation strategy informed by trial landform studies and other onsite revegetation trials.
- Expert propagation knowledge and implementation provided by existing contractor.
- Supply of contractor prequalification process in place.
- Implementation of closure schedule to meet the timeframe.
- Supporting the development of GAC’s ranger program to assist with the revegetation activities.
9.5.6 Weeds (TB4)

Two Class III risks were identified for this sub-category (TB4-01, TB4-02).

**TB4-01**: relates to exposed land surface, which in turn leads to increased weed recruitment. During decommissioning and stabilisation phases there will be ongoing weed management, which is likely to lead to reduced potential for weed recruitment on the landform.

**TB4-02**: this risk relates to weeds from RPA impact on KNP weed diversity and density. Weed management within KNP is mainly focussed on weed species that impact upon wetlands. During decommissioning a key concern would be the introduction of gamba grass on the RPA, which is already present in KNP mainly along roadsides, but under control by Parks. ERA is currently demonstrating success in managing mission grass. Once the Gamba Grass is detected the ERA weed management team manages the weeds, removing it from the area. Existing and proposed controls are listed below:

- Spraying of the final landform surface prior to planting.
- Ongoing weed management.
- Ongoing liaison with KNP regarding fire, weed and feral animal management strategies.
- Material selection for surface cover - e.g. limited laterite at the surface and use of weeds-free material.
- Weed and seed inspections during decommissioning and stabilisation.
- Implementation of post decommissioning access tracks for ongoing weed and fire management.
- Maintaining a weed free buffer zone around the rehabilitated site.

9.5.7 Radiation (TC1)

One Class III risk was identified for this sub-category.

**TC1-01**: relates to the risk of radiation doses from the final landform not meeting as low as reasonably achievable (ALARA) during the stabilisation and post closure phases. The pathways for exposure of members of the public to radiation from the rehabilitated landform are shown in Figure 35.
A large body of work has been done to understand the radiological risks associated with the ore and the waste rock, and throughout operations material has been segregated according to grade.

The final average uranium content across the landform is expected to be less than 80 parts per million uranium or 1 Becquerel per gram, which is lower than the level for exemption published in the ARPANSA 2014 National Directory for Radiation Protection. Based on these assumptions, the radiation doses to the public are optimised to ALARA.

The existing and proposed controls identified during the risk assessment to mitigate this risk include:

- Material movement planning and stockpile resource model.
- Dust control during decommissioning.
- Final landform thickness reduces the likelihood of exposing tailings and radon emanation from tailings.
- Potentially applying access restrictions to particular areas of the RPA post closure to keep doses below dose constraint.
- Implementation of the engineering dose constraint of 300 micro Sieverts per year across the landform.
• Storm water and erosion control, design and management structures.
• Iterative landform design informed by LEM.
• Trial landform studies has informed the landform design and LEM.
• Active water management strategy and inventory control.

The level of control effectiveness ranking of high (C1) reflects ERA's long term experience with managing radiation and exposures on site.

9.5.8 Cultural Heritage (TC3)

Two Class III risks were identified for this sub-category (TC3-01, TC3-02).

**TC3-01** relates to the potential for damage to cultural heritage sites or sacred sites.

**TC3-02** relates to the potential for surface water runoff and groundwater transport from the landform with the potential to affect a sacred site.

The risk of damage occurring to a cultural heritage site on the RPA carries a high compliance consequence but low likelihood, compared to the risk of damage to a sacred site via surface water runoff and groundwater transport which carries a high community trust and cultural heritage consequence but low likelihood.

ERA has a comprehensive cultural heritage management system that protects the cultural heritage values within the RPA, and it conforms to ERA GAC Interim Cultural Heritage Protocol (2006), relevant Northern Territory and Commonwealth heritage legislation and Rio Tinto cultural heritage management standards. In addition to administrative controls, there are two key heritage protection mechanisms within the management system:

• Standard operating procedures, which provide work instructions and detail a procedure and process with specific accountabilities.

• Physical controls including, but not limited to:
  • Cultural heritage surveys prior to land disturbance.
  • Boundary of archaeological sites marked with red star pickets.
  • Boundary of significant sites enclosed with permanent steel posts and rail fence.
  • All cultural sites marked with cultural heritage signage.
  • Bunds or other environmental protection near sites.
  • Cultural site vibration monitoring.
  • Periodic audits of all cultural sites by an external cultural heritage specialist and Mirarr.
The cultural heritage management system is subject to Rio Tinto business conformance audits, risk reviews, ERA site managed assessments and ongoing improvements. Elements may vary due to changes in the working environment of ERA operations, changes to Northern Territory or Commonwealth heritage legislation, or cultural criteria as requested by traditional owners.

9.5.9 Stakeholder and Legal Expectations (TC4)

Three Class III risks were identified for this sub-category (TC4-01, TC4-02, TC4-03).

TC4-01 relates to the potential for the rehabilitated site failing to meet stakeholder and/or community expectations.

This risk has a high community trust consequence, low likelihood and will be managed predominantly through ERA's existing stakeholder engagement protocols.

The existing and proposed controls, identified during the risk assessment, to mitigate this risk include:

- Early engagement with stakeholders to understand their needs and the ability to meet these needs.
- Application of BPT process.
- Completion of management of change processes for all significant changes.
- Engagement via communication fora (e.g. ARRTC, ARRAC, MTC, stakeholder workshops, etc).
- Complex information presented in various forms.
- External commitments register.
- GAC board endorsement of cultural criteria and overall closure strategy.
- Socio-economic impact assessment.
- GIS study undertaken to model the potential view lines, which has been approved by stakeholders.

TC4-02 relates to mine closure impacting the economic sustainability of the region.

The Jabiru economy is underpinned by a narrow commercial 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 the Ranger mine. ERA engaged consultants to undertake a socio-economic impact assessment, which concluded in May 2017, aimed at assessing the impacts associated with ERA's rehabilitation obligations under the current Jabiru head lease that potentially extend to the removal of town assets and rehabilitation of the land, and develop potential mitigation options for the identified impacts (refer Chapter 5).
TC4-03 relates to the potential for delays to rehabilitation and/or closure activities extending beyond 2026.

This risk has a high compliance consequence, low likelihood, and ERA is committed to apply all necessary resources to achieve closure by the statutory date. ERA will commit to ensuring compliance with Commonwealth environmental requirements and closure criteria as required under the Ranger authorisation.

9.5.10 Community (TC5)

One Class III risk was identified, TC5-01, which relates to the potential introduction of new health and safety risks to the Ranger closure workforce.

ERA maintains a Health, Safety and Environment management system, which aligns with the standards to which they are certified (ISO 14001:2004 Environmental management systems and AS 4801:2001 Occupational health and safety management systems).

This risk will be managed via the continued application of the Rio Tinto and ERA Safety Management Systems, including specific hazard and operability studies (HAZOP) and risk analysis of new activities.
10. IMPLEMENTATION

Chapter 10 of the MCP presents the closure implementation strategies and key closure activities for the Ranger mine, in addition to a description of the closure work programs for each key closure activity.

The closure activities to be undertaken at Ranger mine consist of the following:

- Pit 1 tailings impoundment and backfill.
- Water treatment.
- Pit 3 tailings and brine impoundment and backfill.
- Tailings dam deconstruction.
- Contaminated sites remediation.
- Processing plant and other infrastructure deconstruction.
- Final landform contouring and revegetation.

The proposed closure strategy for the Ranger mine has been developed based on a review of the closure options, with the preferred option selected through a BPT assessment (outlined in Chapter 8 of the MCP). The closure strategy will continue to be reviewed and updated as works are completed or revised, to ensure feasibility and a best practice approach to all closure activities.

Table 7 provides an overview of the closure activities and schedule. A current schedule of all closure tasks has been developed and is presented in Table 10-1 of the MCP and is supported by schematics (Figures 10-1 to 10-15). The schedule is indicative, and subject to ongoing revision to reflect the status of closure activities. A schedule for activities that will be occurring in the next 2 years is provided in Appendix 10.1 of the MCP.

Table 7: Overview of closure activities and schedule

<table>
<thead>
<tr>
<th>Aspect / activity</th>
<th>Status</th>
<th>Timeline</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pit 1 closure</td>
<td>Ongoing</td>
<td></td>
</tr>
<tr>
<td>Pit 3 closure</td>
<td>Ongoing</td>
<td></td>
</tr>
<tr>
<td>Tailings management</td>
<td>Ongoing</td>
<td></td>
</tr>
<tr>
<td>Brine management</td>
<td>Ongoing</td>
<td></td>
</tr>
<tr>
<td>Contaminated sites management</td>
<td>Scheduled</td>
<td></td>
</tr>
<tr>
<td>Processing plant closure</td>
<td>Scheduled</td>
<td></td>
</tr>
<tr>
<td>Water storage</td>
<td>Scheduled</td>
<td></td>
</tr>
</tbody>
</table>
10.1 Pit 1 Closure

The following presents a summary of the pit closure activities that have been carried out by ERA at Pit 1 to date:

- August 1996: ERA commenced deposition of tailings material within the mined-out Pit 1.
- August 2005: Received regulatory approval to increase the tailings deposition level within the pit to an interim level of 12 mRL.
- December 2008: Deposition reached approximately 18.9 million cubic metres (25.6 million tonnes) of tailings material since commencing deposition within the pit during 1996.
- 2012: Installation of pre-fabricated vertical drains (or wicks) to promote consolidation of tailings material and to dewater the tailings:
  - Following installation of the vertical drains, the pit was dewatered to promote consolidation in preparation for construction of a pre-load layer across the pit. Activities associated with the pre-load layer were undertaken until January 2016.
- May 2017: Bulk backfill of Pit 1 commenced, which aims to move 13 million tonnes of rock into Pit 1 by January 2020:
  - The bulk backfill activities will promote further tailings consolidation and expression of process water for treatment, remove Pit 1 from the process water catchment area and facilitate the development of the final landform over the pit enabling vegetation.

Further detail on the backfill and remediation activities that have been undertaken at Pit 1 since 1995 are provided in Section 10.1 of the MCP, as well as the current progress towards the Pit 1 closure milestones (Table 10-2 of Section 10.1).

10.1.1 Pit 1 Closure Objectives and Risks

Section 10.1.1 of the MCP presents the objectives and/or outcomes for each closure criteria theme identified in Chapter 6, relevant to Pit 1 closure. They incorporate technical requirements, human health and ecosystem health, and cultural land use requirements (traditional owners). The section also identifies environmental risks associated with closure,
including the existing and proposed controls for all risks discussed in Chapter 9 of the MCP, with a summary provided below.

The risks identified for closure of Pit 1 are related to the aquatic ecosystem (TA); terrestrial ecosystem (TB) and people (TC) drawn from the risk breakdown structure in Chapter 9:

Aquatic ecosystem risks:

- **TA1-01**: Water quality in billabongs and creeks on the RPA is not ALARA (Class II; moderate).
- **TA2-01**: Water quality from Pit 1 entering offsite water bodies (Class II; moderate).

Terrestrial ecosystem risks:

- **TB1-02**: Erosion and gully formation across landform surface exposes contained tailings in Pit 1 (Class III; high).
- **TB1-04**: Consolidation settlement is significantly greater than predicted in Pit 1 (Class III; high).

People risks:

- **TC1-01**: Radiation doses from the final landform are not ALARA (Class III; high).
- **TC1-02**: Radiation levels from final landform exceed annual dose limits (Class II; moderate).
- **TC2-01**: Elevated contaminant levels within bush tucker.
- **TC2-02**: Levels of contamination in offsite drinking water exceed health guidelines.

Various studies have been completed to assess these risks and develop mitigation strategies where required. Further information on these and the relevant chapters of the MCP that outline the studies completed is provided in Section 10.1.1.

10.1.2 Pit 1 Backfill and Closure Design

The Pit 1 closure strategy has been designed to meet the closure objectives and mitigate the identified environmental risks described above. The mitigation measures that will be implemented to manage the estimated environmental impacts will continue to be reviewed and refined for the final design and include all engineered controls. The key elements of the closure design can be summarised under the following:

- Inclusion of decant structures into Pit 1 to facilitate removal of pit tailings flux during tailings consolidation.
- Placement of mineralised material (low 2s) below the water table to prevent or minimise pyrite oxidation and the associated increased rate of magnesium leaching from the waste rock. Waste rock will be placed in 3 metre lifts to the final landform surface following completion of the low 2s material placement.
The bulk backfill design for Pit 1 provides the controls / mitigation measures developed to address the risk TB1-04 discussed in Section 10.1.1 of the MCP. The pre-load (or initial capping of Pit 1) was undertaken in three stages from 2013 to 2016, and included the placement of geotextile, careful placement of waste rock and, later, a thin layer of laterite. During this time, 28 settlement standpipes were also installed to monitor settlement and validate the tailings consolidation model.

The design of the revegetation layer is yet to be finalised and is subject to additional approvals. This application is currently scheduled to be submitted in May 2018, pending completion of all relevant studies. Revegetation of Pit 1 is expected to commence in 2020, initially on the perimeter of the landform, once backfilling is complete.

Section 10.1.2 of the MCP provides further information on the backfill, closure design and revegetation as well as the estimated settlement at each location and the calculated average tailings levels.

10.2 Water Treatment

The main water inventories that are relevant to closure are those associated with:

- Pond water: derived from rainfall that falls within catchments of the active mine site and requires active management.
- Process water: the most impacted water class onsite derived from water that has passed through, or encountered, the uranium extraction circuit. This water may also be sourced from rainfall from designated process water catchments.
- Brines: residue water from the treatment of process water through the brine concentrator or water treatment plants.

Closure of the Ranger mine requires a zero balance between the pond and process water inventory onsite, with continuation of pond water treatment at the existing water treatment plants and discharge of clean water to available wetland filters and LAAs until 2025. Brines produced from the pond water treatment process were initially recirculated to the process water inventory pending construction of the Pit 3 underfill and brine injection bores. ERA commenced injection of the brine into the underfill during 2016; however, operational issues associated with the Pit 3 underdrain bore caused brine injection activities to cease and recirculation of brines back to the process water was recommenced. Brine injection is expected to resume in the second half of 2018, with discharge back to the process water inventory if required.

ERA undertakes monitoring of total dissolved solids (TDS) concentration within the process water and predicts future concentrations through water balancing modelling using OPSIM modelling software. The modelling indicates TDS levels in process water over time remain well below 120 g/L. Chapter 3 (Section 3.2.9) presents further detail on current water management practices.

ERA is currently installing a new water treatment plant (brine squeezer), to further treat the pond water brine and create a release quality water and higher concentration of the brine stream, which will be directed to process water. Separate regulatory approval is required for
operation and discharge of clean water from the brine squeezer and is expected to be submitted to the MTC during the second half of 2018.

OPSIM modelling has been undertaken by ERA to estimate the volume of produced brine by the brine concentrator against the capacity of the Pit 3 underfill for brine disposal. The estimated volumes are provided in Table 10-4 of the MCP. Various other studies have been completed (including surface water modelling and BPT analysis) to predict contaminant concentrations of the release water and inform further assessment required to achieve ALARA in onsite water bodies.

Process and pond water inventory will be reduced through catchment management. As rehabilitation works progress, catchments will slowly be converted from process to pond and eventually release. The final landform surface will be constructed of the lowest uranium grade material (1s waste rock) and has had preliminary erosion and sediment controls engineered to ensure the lowest possible concentrations of contaminants and sediments in this release water.

The water treatment plants, brine concentrator and all associated infrastructure will be decommissioned and decontaminated in 2025 in preparation for offsite disposal.

To comply with the wishes of the traditional owners and cultural criteria, where practicable, ERA will not construct or leave additional water bodies on site post-closure. However, it is recognised that some sumps and/or water bodies may be required post-closure to capture any erosion of sediments from the final landform.

Section 10.2 of the MCP provides further details on the current catchment management and water management practices for the RPA, as well as the proposed strategy for mine closure and the supporting studies undertaken. The milestones for water treatment are also summarised in Table 10-3 of Section 10.2.

### 10.3 Pit 3 Closure

The approval for Pit 3 closure requires a standalone assessment, with the requirements to be submitted to the MTC by 31 March 2019. The following provides a summary of the Pit 3 rehabilitation and closure activities based on the closure studies that have been completed to date:

- **November 2012**: ceased mining of Pit 3 and preparation for pit closure commenced during December 2012:
  - 33.7 million tonnes of underfill (waste rock and low grade ore material) placed within the base of the pit to raise the pit floor approximately 165 m. The underfill was completed in August 2014.
  - Installation of the Pit 3 underfill to maximise tailings consolidation and minimise the final landform settlement, as well as provide a final disposal area for brines from the brine concentrator facility.
- **2014**: Construction of an engineered underdrain comprising:
• A 2 m waste rock layer to remove water expressed downwards during the consolidation process, and upward displacement of pond water from the underfill during brine injection.

• Installation of five brine injection wells directly into the underfill and associated pipework to enable safe storage of brines produced by the brine concentrator within the available void space within the underfill.

• **2015 - 2016:**
  
  • Transfer of tailings from the processing plant to Pit 3 commenced in 2015 and from the tailings dam to Pit 3 in 2016. Tailings deposition into Pit 3 is expected to conclude in 2020.
  
  • Commissioning of the brine injection system (Figure 36) in 2015 and full-scale operation in 2016. An operational issue with the underdrain bore was identified at the end of 2016, which caused the brine injection activities to cease. Further work on the underdrain bore is currently being undertaken and aims to enable commencement of brine injection into the Pit 3 underfill during the second half of 2018.

• **2020 - 2026:**

  • Following cessation of tailings deposition into Pit 3, prefabricated vertical drains (wicks) will be installed (similar to Pit 1), with an estimated completion date of 2022.
  
  • A geotextile layer will be installed to provide the required geotechnical strength and allow access for backfill. A pre-load layer of waste rock will be deposited on the underlying geotextile layer to activate the wicks, followed by backfill of the remainder of Pit 3 with waste rock from the remaining stockpiles.
  
  • The surface of the pit will be contoured to the final landform shape.
  
  • Revegetation is anticipated to commence in 2024.

ERA’s current progress towards the brine management milestones and Pit 3 closure milestones is presented in Chapter 10, Table 10-5 and Table 10-6 of the MCP.
10.3.1 Pit 3 Closure Objectives and Risks

Pit 3 has similar closure objectives and/or outcomes to Pit 1 (Section 10.1.1). The risks associated with the Pit 3 closure that were not covered in Pit 1 have been summarised in Section 10.3.1 of the MCP and are related to:

- **TB1-01**: Erosion and gully formation across the landform surface (Class I; low).
- **TA2-02**: Poor water quality from Pit 3 entering offsite water bodies (Class III; high).
- **TB1-03**: Greater consolidation settlement than predictions for Pit 3 (Class III, high).

Compared to Pit 1, the potential for exposure of tailings in Pit 3 due to erosion processes has been identified as a Class I (low) risk. The lower risk ranking is predominantly attributed to differences in pit geometry. The final depth of consolidated tailings is significantly greater than Pit 1, therefore tailings are less likely to be exposed (Table 8). In addition, landform evolution modelling competed by the Supervising Scientist shows tailings in Pit 3 to not be exposed for 10,000 years, refer Chapter 7, Section 7.5 of the MCP.

Table 8: Pit 3 versus Pit 1 consolidation

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Pit 1</th>
<th>Pit 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geometry</td>
<td><img src="image" alt="Diagram" /></td>
<td><img src="image" alt="Diagram" /></td>
</tr>
<tr>
<td>Tailings depth (maximum)</td>
<td>152 metres</td>
<td>80 metres</td>
</tr>
<tr>
<td>Tailings deposition width: depth ratio(a)</td>
<td>≈3.5</td>
<td>&gt;6</td>
</tr>
<tr>
<td>Prefabricated vertical drainage wick penetration(b)</td>
<td>≈12 to 25 percent</td>
<td>up to 48 percent</td>
</tr>
</tbody>
</table>
Waste rock backfill depth | ≈29 metres | ≈49 metres

(a) Ratios determined for minimum pit width at the end of deposition.
(b) Assumed 38 metre wick depth.

Various studies have been completed to assess these risks and develop mitigation strategies where required. Further information on these and the relevant chapters that outline the studies, is provided in Section 10.3.1 of the MCP.

### 10.3.2 Pit 3 Backfill and Closure Design

The Pit 3 closure strategy has been designed to meet the objectives and mitigate the identified environmental risks as described in Pit 1 and Pit 3 closure objectives and risks.

The mitigation measures being implemented to manage the potential environmental impacts will continue to be reviewed and refined for the final design and include all engineered controls. The key elements of the Pit 1 closure design (Section 10.1.1) also apply to Pit 3, particularly:

- The decanting of process water during tailings consolidation.
- Placement of low 2s material below the minimum simulated average water table elevation (approximately 14 mRL).

The combined tailings from the process plant and tailings dam will fill the Pit 3 void, reaching an elevation of -20 mRL by end of deposition in 2020. This level will reduce to -30 mRL at the end of bulk backfill after tailings consolidation has occurred.

A BPT assessment has been undertaken during 2016 to assess tailings treatment options. The assessment indicated use of unthickened tailings with prefabricated vertical drains (wicks) as the preferred option based on the Pit 1 tailings deposition and consolidation processes previously undertaken.

Tailings deposition at Pit 3 is currently carried out via a sub-aerial deposition technique, which involves discharge of tailings above the water level from discharge points at the pit crest that enable a sloping beach to form across the pit floor surface. Decant water that accumulates towards the lower end of the beach is extracted for water management purposes. This deposition method is undergoing assessment as to its long-term ability to mitigate risk TB1-03. An option is to convert to a sub-aqueous method and ERA expects to submit an application to the MTC during August 2018.

Section 10.3.2 of the MCP presents further information on the Pit 3 backfill and closure design.

### 10.4 Tailings Dam

The approval for the tailings dam closure requires a standalone assessment, scheduled to be submitted to the MTC by 1 December 2019. The following provides a summary of the tailings management closure activities, based on the closure studies that have been completed to date:
• 1979: Tailings dam was constructed and consists of a "turkeys nest" structure, which is designed to contain both tailings and process water.

• 2012: Six crest raises have been carried out since commissioning to enable containment of process water and tailings prior to Pit 3 undergoing preparations to receive tailings in 2015.

• 2014 – 2015: Dredging was identified as the best practicable technology for transfer of tailings during the ITWC PFS. Approximately 23 million cubic metres of tailings from the tailings dam is to be transferred to Pit 3 to meet closure objective L2:
  • Construction of the tailings dam dredge was completed in 2014 and commissioned along with the relevant dredging infrastructure in December 2015 (Figure 37).

• 2015: All production tailings material was directed to Pit 3 following 2015, through dredge operations. This progressively reduces the process water in the tailings dam as it is treated by the brine concentrator. Tailings transfer is estimated to be complete by the end of 2020.

The tailings deposition within Pit 3 will undergo consolidation as water is continuously expressed via upwards flow to the decant water to be recovered at the Pit 3 surface, as well as downwards flow and recovery at the underdrain layer (Figure 38). This water will be pumped via the process water tanks back to the tailings dam to allow for continued operation of the dredging infrastructure.

Further information on the tailings dam closure activities is provided in Section 10.4 of the MCP.

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Figure 37: Flow diagram of tailings transfer
10.4.1 Tailings Closure Objectives and Risks

The objectives and/or outcomes relevant to the tailings dam closure (outlined in Chapter 6) are similar to those specified for Pit 1 and Pit 3, and incorporate technical requirements, human health and ecosystem health and cultural land use requirements (traditional owners).

The environmental risks associated with closure, including the existing and proposed controls for all risks identified are detailed in Chapter 9 of the MCP, with a summary below:

The risks identified are related to the aquatic ecosystem (TA) risk category and include:

- **TA3-01**: Uncontrolled release of contaminated material into the onsite environment during tailings transfer to Pit 3 (Class III, high).
- **TA3-02**: Uncontrolled release of process water stored in tailings dam to the environment (Class III, high).
- **TA3-05**: Potential migration of contaminants from tailings dam plumes (Class III, high).

The tailings dam has been identified as an area of concern for surface water during the mining operational phase; however, solute migration from the original tailings dam sources are expected to greatly reduce post-mine closure, as the rate of migration decreases due to the substantial reduction in hydraulic gradient.

Various studies have been completed to assess the risks and develop mitigation strategies where required. Further information on these and the relevant chapters that outline the studies completed is provided in Section 10.4.1 of the MCP.

10.4.2 Tailings Dam Deconstruction and Closure Design

The tailings dam deconstruction strategy will be designed to meet the closure objectives and mitigate the identified environmental risks as described above. At this stage of the MCP, the design is yet to be completed.

The following works are anticipated as part of the final tailings dam deconstruction and closure design:
• Removal of all residual tailings material at the completion of dredging in 2020, to be transferred to Pit 3. This includes any potentially contaminated material at the base of the dam or along the walls.

• Decommissioning of the dredge and tailings transfer infrastructure following transfer of the tailings and contaminated material to Pit 3.

• Storage of process water within the tailings dam until 2024.

• Removal of the tailings dam wall, followed by re-contouring and revegetation of the site during 2025.

A separate application detailing all components of tailings dam deconstruction, including contaminated material management is scheduled to be submitted to the MTC by December 2019.

Section 10.4.2 of the MCP provides further details on the envisaged tailings dam deconstruction and closure design, as well as a summary of the milestones and progress for tailings management in Table 10-8.

10.5 Contaminated Sites Management

The decommissioning of contaminated sites other than Pit 1, Pit 3 and the tailings dam will require active management through to 2025, to ensure that the final outcome demonstrates as low as reasonably achievable (ALARA) principles on the RPA.

10.5.1 Contaminated Sites Closure Objectives and Risks

The risks identified are related to potential migration of contaminants from other legacy plumes and poor water quality from cumulative sources entering offsite water bodies. One threat (e.g. ineffective decommissioning of contaminated sites) has been identified as causing three potential risks that result in risk ratings ranging from Class I (low) to Class III (high).

Numerous studies have been completed to assess the contamination levels across the RPA and specific areas of potential concern, to assess the risk and develop mitigation strategies where required. The site conceptual model developed for Ranger mine (Chapter 7, Section 7.7) considers the information gained from these studies in relation to areas of interest / concern within the RPA to identify the COPC present, the predicted receptors and contaminant transport pathways post-closure.

The key findings relating to contamination in the processing plant, LAAs, Ranger 3 Deeps and final landform waste rock are summarised below:

• **Processing plant area**: Risk **TA3-06**: Potential migration of contaminants from the processing plant; Class II (moderate risk).

  Contaminated runoff and/or groundwater discharge is unlikely to become a concern for surface water at present or post-closure, due to the distance between the processing plant and Corridor Creek and Georgetown Billabong, as well as the low COPC concentrations observed in bores adjacent to Corridor Creek and Georgetown Billabong.
In addition, contaminated material from the processing plant footprint and surrounding areas will be recovered for placement in Pit 3.

- **LAAs:** Risk **TA3-07**: Potential migration of contaminants from LAAs and wetland filters; Class I (low risk).

  Radiation doses to members of the public are very low and are below the exemption levels published in the ARPANSA National Directory, except for sites Magela A and B.

  The LAAs are not considered to be areas of concern for groundwater or surface water post-closure for various reasons including (but not limited to): nearly 20 years of wet season flushing between when the LAAs were decommissioned and when the site will be closed; groundwater chemistry has improved in some LAAs since switching from the application of RP2 water to clean water; and transport of uranium and/or $^{226}$Ra on sediment in surface water runoff is possible, but will likely result in small quantities entering surface water bodies and will be diluted on entry.

- **Ranger 3 Deeps:**

  No potential concern at post-closure. Modelling of COPC migration from closure of the Ranger 3 Deeps mine indicates impacts to Magela Creek are negligible.

- **Final landform waste rock:** Risk **TA2-03** Poor water quality from cumulative sources enters offsite water bodies; Class III (high risk).

  Waste rock is a potential COPC for Pit 1, Pit 3, Ranger 3 Deeps, the tailings dam and the final landform. Landform waste rock will leach COPC, however concentrations for runoff are expected to be much lower than those for water infiltrating to groundwater through the waste rock. A preliminary system of controls has been developed to minimise erosion and sediment discharge from the final landform, hence minimising transportation of waste rock solutes to the offsite environment (Section 10.7.8).

Further information on these studies and the relevant chapters that outline the studies completed, is provided in Section 10.5.1 of the MCP.

### 10.5.2 Cumulative Impacts

The risks of cumulative impacts to offsite water bodies from COPC sources other than waste rock as discussed in Section 10.5.1 of the MCP is also a consideration for the Class III risk **TA2-03**. An example of another COPC sources identified within the RPA is asbestos, which will be removed by a qualified contractor and buried in Pit 3. In 2018 a contaminated sites assessment commenced. Remediation and/or infill revegetation works are scheduled to commence in 2019 (where required), with some areas such as the staged removal of infrastructure within the LAAs, to continue to 2025.

Section 10.5.2 of the MCP presents further details on the progress towards the identified milestones for this work.
10.6 Demolition and Decommissioning

ERA has divided the infrastructure within the RPA into demolition work packs to estimate the tonnage of infrastructure to be removed from each area or building. A decommissioning permit is required from Australian Safeguards and Non-Proliferation Office (ASNO) upon cessation of $\text{U}_3\text{O}_8$ production and prior to commencing demolition of some areas of the processing plant. In addition to the permit, a management plan will also be developed to comply with the current demolition and decommissioning strategy.

Further information on the demolition and decommissioning of the processing plant is outlined in Section 10.6 of the MCP.

10.6.1 Demolition Objectives and Risks

Section 10.6.1 of the MCP presents the objectives and/or outcomes relevant to the demolition of contaminated sites (outlined in Chapter 6). The objectives and/or outcomes identified are related to cultural land use of the site (traditional owners).

No risks were identified that are directly related to the proposed demolition activities, or where demolition activities are considered a cause. All demolition activities will be undertaken in compliance with current operational controls and critical risk management protocols.

Further information on the closure objectives and/or outcomes is provided in Section 10.6.1.

10.6.2 Demolition Methods

The following demolition methods are proposed for Ranger closure including the demolition of concrete and buried items:

- Disconnection of cables and pipes connecting services to structures.
- Demolition of structures using excavators, and where needed, use of cranes. Explosives may be required for structures which cannot be dismantled using these methods.
- Demolition of foundations, pavements (bitumen or concrete) and associated infrastructure including kerbs, gutters and gully pits by excavator and rock breaker.
- Large assemblies containing major voids, such as tanks, vessels and structural pre-assemblies, shall be disassembled and/or crushed to eliminate such voids.
- Transport of material to Pit 3 using ERA mine haul trucks, via a ramp on the southern face of the pit to transfer loads to the base of the pit.
- Backfill of excavations with compacted material, followed by site trimming and grading.

The following concrete and buried items will be demolished or removed:

- Concrete slabs (suspended and at ground level).
- Minor underground services (i.e. pipes 100 nominal bore or less and cables within 1 metre of the surface level).
- Buried items (i.e. concrete footings, pipes greater than 100 nominal bore and sumps within 3 m of the surface level).
- Underground tanks.
- Buried items greater than 3 m below the surface level (i.e. deep foundations) to be demolished to a depth of 1 m below the surface. Remaining voids to be filled with material from the 1P stockpile.

Further detail on the proposed demolition methods is provided in Section 10.6.2 of the MCP.

### 10.6.2.1 Processing Plant Closure

The following activities will be undertaken during closure of the processing plant:

- **2020**: Operation of the processing plant will cease.
- **2021**: Removal of processing plant infrastructure to be stockpiled for disposal in Pit 3. This will occur following cessation of tailings transfer from the plant to Pit 3.
- **2024**: Final landform contouring and revegetation.

The existing water management structures and controls surrounding the processing plant will remain until the infrastructure is removed, to manage potential contamination associated with the dismantled processing plant during decommissioning and remediation works.

Section 10.6.2.1 presents further detail on the processing plant closure and the progress towards the closure milestones (Table 10-10 of the MCP).

### 10.6.2.2 Water Storage

The retention ponds onsite hold surface water runoff that has come into contact with mineralised materials including low grade ore stockpiles and is managed according to quality. Retention Pond 6 (RP6) was constructed in 2012 to provide 1 gigalitre of additional water storage and management capacity. The pond is double-lined with a high-density polyethylene liner and connects to the existing RP2 via a two-way pumping system.

RP6 will be decommissioned in 2024 and all components will be transferred to RP2. The RP2 and RP3 retention ponds will be decommissioned in 2025. Any contamination will be remediated at this time, and the landforms of RP6, RP2 and RP3 will undergo contouring and revegetation. RP1 will be retained temporarily post-closure for management of water quality runoff from the final landform.

The milestones for closure of the retention ponds are provided in Table 10-11 of the MCP. Further information on decommissioning of the water storage systems within the RPA is provided in Section 10.6.2.2.
10.7 Final Landform

The approval of the final landform requires a standalone assessment, with the construction requirements to be submitted to the MTC by 4 May 2018. The following provides a summary of the final landform closure activities based on the closure studies that have been completed to date.

10.7.1 Landform Closure Objectives and Risks

The objectives and/or outcomes relevant to the final landform (outlined in Chapter 6) incorporate technical requirements (erosion and sediment loads), human health and ecosystem health, and cultural land use (traditional owners). The closure strategy for final landform construction, outlined in this section, has been designed to meet these objectives and mitigate identified environmental risks, described in Chapter 9 and Appendix 9.1.

The landform risks that have not been previously addressed under Pit 1 and Pit 3 closure (Section 10.1 and Section 10.3) include:

- **TB1-05**: Landform does not meet the values (e.g. land uses) that are expected from the stakeholders (Class II; moderate risk).
- **TB1-06**: Excessive erosion impacts landform stability and revegetation success (Class III; high risk).
- **TB1-07**: Legacy erosion areas persist post 2026 (Class II; moderate risk).

ERA anticipates that ongoing stakeholder consultation combined with the extensive level of detail provided in this MCP and separate applications submitted to the MTC will ensure that the final landform meets the expectations of stakeholders (risk TB1-05).

Various studies have been undertaken to assess these risks and develop mitigation strategies where required. Further information on the studies and the relevant chapters of the MCP is provided in Section 10.7.1.

10.7.2 Final Landform Construction

Construction of the final landform will involve significant backfill into pits and the redistribution of appropriate materials to ensure closure requirements are met. The activities to be undertaken to construct the final landform have been grouped into the following four areas of the RPA based on the timing of their availability to be used for reclamation:

- Pit 1 area.
- Tailings dam.
- Processing plant.
- Pit 3 area (includes stockpile area).

Figure 39 presents the locations of the reclamation areas within the RPA.
Backfill and construction of the final landform will use grade 2 and grade 1 waste rock materials, with the surface layer (or landform cover) to consist entirely of grade 1 material. The landform cover will be installed to a minimum of 2 metres thickness to ensure sufficient attenuation of any gamma radiation. The use of grade 1 material for the cover will be confirmed using the stockpile grade block model and truck load gamma analysis via a discriminator. A materials balance has been calculated for all areas.

Further information of the final landform construction including a summary of the quantitative values for site reclamation is provided in Section 10.7.2 of the MCP.

10.7.2.1 Pit 1 Area

Bulk backfill of the Pit 1 area commenced in May 2017 using both grade 1 and low grade 2 waste rock materials from stockpiles. The backfilling process will occur in three stages:

- 2.0 million cubic metres of low grade 2 material will be placed into Pit 1 in concentric rings to accelerate consolidation.
• An additional 1.1 million cubic metres of the same material will be placed into Pit 1 and the consolidation process will be monitored.

• 3.2 million cubic metres of grade 1 material will be placed over the previous layers of grade 2 material to cover the entire pit surface.

Subsidence will be monitored during backfill to allow adjustment of the backfill program accordingly. The majority of the grade 1 material used to backfill Pit 1 will be sourced from the stockpile area adjacent to Pit 1, with any additional grade 1 material required sourced from other stockpiles located to the north of Pit 1 (Figure 40).

Figure 40: Pit 1 area and adjacent grade 1 stockpile

Section 10.7.3 of the MCP presents further information on the backfill process and stockpile locations for backfill of Pit 1.

10.7.2.2 Tailings Dam Area

ERA is currently assessing the best method for remediation of the tailings dam contaminated material; in-situ or removal and burial. If remediation works are required these will be completed prior to the commencement of material movement in 2024 (refer Section 10.7.4 of the MCP).
Approximately 1.8 million cubic metres (3.6 million tonnes) of waste rock material within 150 m of the tailings dam will be transferred to the final landform surface, followed by 5.4 million cubic metres (10.8 million tonnes) of wall material to the landform in the tailings dam area. A volume of 2.3 million cubic metres (4.6 million tonnes) of material on the north wall of the tailings dam will remain, to be moved by 2025.

The clay borrow pit at Retention Pond 5 (RP5) as well as (potentially) the Corridor Creek wetland filter to the south-east will be reclaimed during 2025. The location of the total tailings dam area (including the Corridor Creek wetland filter) to be rehabilitated is provided in Figure 41.

Figure 41: Tailings dam area

Section 10.7.4 of the MCP provides further information on the remediation process of the tailings dam contaminated material.
10.7.2.3 Processing Area

Backfill of the processing plant area will commence once decommissioning of the plant has occurred, and all demolition and disposal of the process plant infrastructure into Pit 3 has been finalised (approximately 2024). Grade 1 waste rock material will be used to backfill the processing plant area and will be sourced from the final stages of the stockpile area. The run-of-mine (ROM) pad will be reclaimed and made contiguous with the Pit 1 area during 2021. Figure 42 presents the total processing plant area including the ROM pad for rehabilitation.

![Processing plant area, including ROM pad](image)

10.7.2.4 Pit 3 Area

Bulk backfill of the Pit 3 area (includes stockpile area; Figure 43) will require the largest volume of material movement in the construction of the final landform, at approximately 30 million cubic metres (60 million tonnes). Bulk backfill is estimated to be undertaken over 22 months and will commence following completion of the tailings transfer to Pit 3, natural consolidation, wick placement and preloading (refer to Section 10.3.2 of the MCP).

It is envisaged that low grade 2 stockpile material will be used during the early stages of backfill, and grade 1 material will be used to raise the Pit 3 area to the final landform elevation (approximately 15 to 26 m). The final stage of the Pit 3 backfill and contouring is scheduled to be completed by 2025.
10.7.3 Landform Design and Bulk Backfill Techniques

The final landform will be constructed and contoured to meet the closure criteria for the landform theme as described in Chapter 6, Section 6.2. A number of studies have been completed in relation to the final landform design to establish the current Version 5, which incorporates erosion control and ecosystem establishment. Further information on these studies can be referred to in Chapter 7 (Section 7.5) of the MCP.

Backfill techniques have been designed to maximise the plant available water potential stored in the final landform waste rock, minimise the potential for erosion and sediment runoff and maximise ecosystem development. An analysis of the thicknesses and locations of backfill across the final landform was conducted, resulting in the following three main categories or areas of backfill technique (Figure 44):

- Category A: Represents the final landform areas that overlay the natural ground surface, excluding the pits and grade 1 stockpiles. Backfill levels will range from less than 1 to 3 m of fill for the majority of the area, with 8 to 10 m generally required within the central area. This may reach up to 13 m for some sections of the central area.
• Category B: represents the areas that overlay the existing stockpiled grade 1 material (landform cover) and tailings dam walls. These will not require further infilling, but will be cut and left as final landform surfaces. The depth of natural ground surface in these areas ranges from 1 to 12 m, and after backfill it will generally lie at 6 to 10 m above natural ground surface.

• Category C: represents the areas that lie within Pit 1 (40 ha) and Pit 3 (75 ha):
  - The Pit 1 initial grade 2 backfill layer will range from 1 to 7 m thickness, and the overlying grade 1 material will generally consist of a 10 m layer.
  - The Pit 3 initial grade 2 backfill layer will be placed at a thickness of 35 to 40 m. Subsequent layers (including decommissioned plant material) will be placed in 10 m lifts, with the final layer of grade 2 material placed at a surface elevation that grades from 6 to 14 mRL (8 m below the final land surface).

Figure 44: Categories of backfill techniques

Further information on the backfill techniques and studies undertaken is provided in Section 10.7.7 of the MCP.
10.7.3.1 Bulk Backfill Method

The overall bulk backfill approach for the final landform has been divided into five plan view sections (south to north) to explain the different methods of bulk backfilling that will be applied across the variable landform elevations (e.g. cut and/or fill).

Figure 45 presents a backfill contour map showing the contour depths of the final rehabilitated footprint, corresponding to the plan view backfill sections 1 to 5.

The following presents a summary of the bulk backfill methods for each of the plan view sections:

- Section 1 and 2, west to east plan view (Figure 46): for areas containing backfill greater than 5 m, tight paddock dumping (2 layer) will be implemented followed by smoothing of the surface by dozers and placement of additional layers:
  - The eastern portion of Section 1, across Pit 1, will require a specific bulk backfill methodology. Placement of the initial bulk backfill layers will be grade 2 materials, range between 6 to 7 m and will be undertaken based on instruction from tailings experts.

- Section 2 (Figure 47): the same bulk backfill approach will be applied across the tailings dam in the western portion of the sector. The same 2 layer paddock dumping method described for Section 1 will be applied for the central area of Section 2.
Section 3 (Figure 48): consists of minor cuts and fills towards the extremities of Section 3 and relatively large cut and fill processes towards the centre.

Section 4 (Figure 49): consists of minor fills towards the west, increasing to 5 m fills towards the centre and larger fills across Pit 3. Pit 3 will be covered or "capped" with grade 1 material.

Section 5 (Figure 50) bulk backfill is focussed on Pit 3. The final landform in this area is generally 8 m above the grade 2 material layer.

Section 10.7.7.1 of the MCP presents further detail on the bulk backfill methods described above.

Figure 46: Bulk backfill plan view, Sections 1 and 2

Figure 47: Bulk backfill plan view, Section 2
Figure 48: Bulk backfill plan view, Section 3

Figure 49: Bulk backfill plan view, Section 4

Figure 50: Bulk backfill plan view, Section 5
10.7.3.2 Erosion and Sediment Control

ERA engaged Water Solutions to develop a concept design for control of erosion and sediment discharge from the Ranger mine final landform. The designs were based on:

- The design flow rates determined in the landform flood study, refer Chapter 7, Section 7.5.2.
- Advice in a range of relevant guidelines
- The professional experience of the consultant, Water Solutions.

A system with four key components was developed, as follows, with various studies completed for each:

- **Component 1 – Surface Treatment:** Measures on the hillslopes to reduce erosion and sediment discharge.
  - ERA has developed a revegetation strategy for the RPA (refer Section 10.8.3 of the MCP). Revegetation is a critical action for reducing erosion from the site as the roots help bind the soil together, the canopy intercepts direct rainfall to the soil surface and the leaf matter and woody debris that falls from the vegetation will help protect the ground surface in the long term. Other specific construction methods have also been identified, such as ripping 0.5 m along the contour at 4 m intervals; applying a concave slope approach to the final landform terrain; and use of a “Rotree” cultivator (or similar) to cultivate holes for the tubestock.

- **Component 2 – Drainage Channel Treatment:** Measures along the more defined drainage lines to reduce erosion and sediment discharge:
  - Design criteria for the Ranger final landform drainage channels were developed based on the landform flood study (Chapter 7, Section 7.5.2 of the MCP) and used to develop long and short-term scenarios.
  - As discussed in Chapter 7, Section 7.5.2 of the MCP, the short-term case is expected to cover conditions in the first decade or two after construction of the final landform. If a large event occurs immediately after construction (when no vegetation is present and the landform material has undergone little consolidation), some erosion would be expected, and this will be addressed through the site monitoring and maintenance program.
  - A preliminary drainage channel assessment was undertaken and demonstrates that peak velocities for long term (LT) events are comfortably under the target velocities in the nominated design criteria (1.0 – 1.5 m/s and 2.0 – 2.5 m/s, respectively). However, landform evolution modelling undertaken by the Supervising Scientist (Chapter 7, Section 7.5.1) indicates that there is tendency for deep gullies to form, particularly in the upper catchment areas.
  - Following the studies above, a series of recessed rock checks have been designed to help maintain a wide drainage path and limit the likelihood of deep gullies forming on the landscape, particularly while the vegetation is getting
established. Figure 51 presents the key elements of this design. Key design features of the rock checks have been defined and include, but are not limited to:

- 1 m x 1 m deep, buried into the profile of the minor drainage channels.
- Follow the shape of the drainage channel.
- A minimum rock size d50 of ~200 mm, etc.

Once the vegetation gets well established, both in the drainage channel and on the edges of the drainage channel, the vegetation should largely take over in providing appropriate erosion resistance for the drainage channels.

Component 3 – Edge Sediment Basins: The design of sediment basins around the edge of the final landform to capture sediment discharging from the landform. The following design criteria were developed for the Ranger final landform sediment basins:
• Design Operation Flow – The event likely to be exceeded once a year on average (1EY) during the establishment phase of the site. This event is used for the sizing of the settling pond area in the sediment basin.

• Design Capture Efficiency – 90% capture efficiency for particles 0.125 mm (very fine sand) and above. The design capture efficiency is also used for the sizing of the settling pond area in the sediment basin.

• Design Overtopping Flow – The event which has a 10% chance of being exceeded in any one year during the establishment phase of the site. Used for the structural design of the rock weir wall for the sediment basin.

The sediment basins are temporary in nature. At this stage it is unknown how long the stabilisation and monitoring phase will take, but based on the trial landform vegetation plots it appears it will be at least 10 years for the vegetation to become fully mature. Regular monitoring and maintenance will be required throughout this phase. The rock weir sediment basins will be decommissioned after the site is considered to be stable.

Further information on the key details of the sediment basin design are presented in Section 10.7.8 of the MCP, and summarised below:

• An indicative sketch of the key elements of the leaky rock weir sediment basin design is provided in Figure 52.

• The edge sediment basins will be located on local drainage lines at the edge of the final landform terrain Figure 53.

• The rock weir sediment basins will be decommissioned after the site is considered to be stable.
Figure 52: Key elements of the concept sediment basin hydraulic design (source: Water Solutions)
Component 4 – Second Layer Sediment Basins: Where the terrain permits, a second sediment basin has been positioned further downstream from the final landform, providing a second layer of protection to limit sediment discharge from the site:

- Includes two second layer sediment basins on the Coonjimba and Corridor Creek sub-catchments, sited on the location of former constructed waterbodies and designed using a similar approach to the edge sediment basins.

Further information on the studies undertaken for erosion and sediment control designs, and the design specifications are provided in Section 10.7.8 in the MCP.

10.8 Revegetation

The approval of the final landform requires a standalone assessment, with the components of the landform revegetation to be submitted to the MTC in 2018. The following provides a summary of the current revegetation plan based on studies that have been completed to date (refer Chapter 7, Section 7.6 of the MCP).
Approximately 950 ha of land requires rehabilitation and revegetation as part of the Ranger mine closure. This includes 759 ha of waste rock covered area. Assessments of radiation risk and chemical contamination risk will determine whether the LAAs (approximately 200 ha) will need remediation before revegetation.

The revegetation works consist of three broad components:

- Site preparation (includes preparation of the ground surface, i.e. surface ripping and cultivation):
  - A layer of growth medium made up of either: a) entirely waste rock; b) waste rock over natural ground (ripped if compacted); or c) entirely natural soil, will be required to achieve successful revegetation. The latter two options where natural soils occur as part of the media, are assumed to have sufficient plant available water to support sustainable revegetation.
  - As outlined in Section 10.4.2 of the MCP, ERA is currently undertaking studies to determine the best method for remediation of the tailings dam contaminated material, prior to revegetation of the reshaped area.
- Revegetation includes the establishment (planting seedlings supplemented by direct seeding) and management of plants on disturbed sites where the natural recruitment of vegetation is unlikely to satisfy closure criteria.
- Maintenance and monitoring (discussed in Chapter 11, Section 11.5).

Further information on the revegetation works described above is outlined in Section 10.8 of the MCP.

10.8.1 Revegetation Closure Objectives and Risks

This section presents the objectives and/or outcomes relevant to the final landform revegetation (outlined in Chapter 6), which are related to technical requirements for revegetation and cultural land use requirements (traditional owners).

The closure strategy for revegetation has been designed to meet these objectives and mitigate identified environmental risks, described in Chapter 9 and Appendix 9.1 and summarised below.

The landform revegetation risks are drawn from the risk breakdown structure in Chapter 9, terrestrial ecosystem (TB), and include:

- **TB2-01**: Consolidated tailings level impacts revegetation success in Pit 3 (Class I; low risk).
- **TB2-02**: Consolidated tailings level impacts revegetation success in Pit 1 (Class I; low risk).
- **TB2-03**: Insufficient volume or quality of viable seed stock available for whole of site revegetation (Class II; moderate risk).
• **TB2-04**: Low plant propagation success in the nursery (Class III; high risk). TB2-04 is also a potential cause for risk TB2-06; the controls associated with this risk are discussed in Chapter 9, Section 9.4.5.

• **TB2-05**: Low plant survival rates in the field during establishment and vegetation decline at mature stage (Class III; high risk).

• **TB2-06**: Inability to plant out landform within timeframe (Class III; high risk).

Various studies have been completed to assess the risks and develop mitigation strategies where required, including:

- Consideration of plant selection and distribution across the final landform, informed by topographic and predicated edaphic conditions.

- Seed harvesting using a local indigenous workforce.

- A revegetation strategy informed by the trial landform studies and revegetation trials, enhanced by expert local indigenous seed collection and propagation knowledge.

- Implementation of a multifaceted backfill and landform construction approach, to enhance water availability, the accumulation of organic material and nutrient cycling.

Mitigations to manage the estimated environmental impacts are subject to continual refinement and include all engineered controls. Further information on these and the relevant chapters of the MCP that outline the studies completed is provided in Section 10.8.1.

### 10.8.2 Site Preparation

To capture resources (e.g. water, fine sediments, seeds, litters/organic matters, nutrients, etc) close to plants; to create micro habitats for seed germination and ground dwelling fauna; and to reduce erosion and facilitate water infiltration to deeper rooting zone, the finished waste rock final landform surface will be ripped along the contour.

#### 10.8.2.1 Surface Ripping and Cultivation

Rip lines will be installed to increase the water residence time on the landform surface and increase the amount of water infiltrating below the surface and into the rooting zone. The rip line spacing (4 m apart x approximately 0.5 m deep) has been informed by the flood study undertaken for the RPA and is necessary to allow safe operation of the excavator and vehicles used to facilitate planting, as well as meeting the cultural criterion (C3) of constructing a traversable final landform.

Tubestock will be planted between the rip lines, at sites pre-cultivated by a “Rotree” cultivator (or similar) attached to an excavator. Cultivated holes for planting seedlings will be distributed such that the resulting vegetation will look ‘natural’ (e.g. Figure 54). It is expected that on the final landform the ‘flat’ surface area between rip lines will be about double that on the trial landform (e.g. approximately 2 m apart).
Service tracks approximately 200 m apart will be established on the final landform to facilitate activities, such as planting, irrigation, fire and weed management, and post planting monitoring.

Figure 54: View of the tree distribution and also the flat ground space among trees at Jabiluka revegetation site, Feb 2016. (Note that the surface at Ranger will be rougher due to waste rock substrate.)

### 10.8.2.2 Revegetation Strategy and Implementation

Revegetation of the final landform will be based on ERA’s revegetation strategy. The strategy has been developed based on over 30 years of revegetation, studies of the analogue vegetation and the findings from the trial landform.

Site revegetation plans will be prepared for each revegetation area and will include:

- Information on the revegetation activities (implementation and schedule of implementation over 5 years).
- Maps and field layout plans.
- Monitoring and reporting requirements.
- On-ground activities required for identification of planting boundaries, planting configuration and location of species, monitoring plots and service tracks.

Ongoing monitoring of the trial landform revegetation will continue to inform the final approach to revegetation of the RPA.
10.8.2.3 Species Selection and Plant Distribution

For revegetation of the final landform, the initial planting density will be about 1,000 plants (trees and shrubs) per ha, with provision for a further 200 plants per ha, for infill planting depending on the survival results, 6 – 12 months after initial planting. The aim is to achieve a long-term density and composition that is similar to the woodland of the surrounding area, and to establish a functional and sustainable vegetated landform.

ERA has undertaken a number of analogue vegetation and trial landform studies (Chapter 7, Sections 7.3 and 7.6). The selection and distribution of vegetation (e.g. species, composition and density) across the final landform is based on these studies and will be established according to the micro-ecology of the site – i.e. site topography (crest, mid slope, low slope and toe of the landform, drainage channel, and riparian zone) and properties of the underlying substrate. Furthermore, cultural aspects will be taken into account for the distribution and location of species across the landform.

Section 10.8.3.1 of the MCP presents further details on the vegetation selection and distribution for the final landform area, including the general design and list of potential understorey species (e.g. grasses and legumes) identified based on the studies undertaken.

10.8.2.4 Provision of Seeds and Seedlings

ERA has been working extensively with Kakadu Native Plants Pty Ltd, a locally owned and run indigenous supplier, to provide seedlings for much of the revegetation projects that have occurred both at Ranger and Jabiluka over the past 15 years. Seed collection of agreed local native species provided in the species list in Table 7.27, in Chapter 7, Section 7.6.3 will be acquired from Kakadu Native Plants Pty Ltd.

Further information on the proposed methodology for raising the tubestock is provided in Section 10.8.3.2 of the MCP.

10.8.2.5 Tree and Shrub Planting, and Establishment of Understorey

To ensure planting sites are prepared to a condition which will achieve high plant survival rates and rapid early growth, the following will be undertaken:

- Planting holes will be cultivated mechanically.
- All sites will be free of weeds at the time of planting; pre-planting residual herbicide may be used, and a weed-control buffer zone (approximately 200 m) around the revegetation site will be maintained.
- Handling and planting of seedlings and the application of fertiliser will follow the standard operating procedure.
- Weed control will be undertaken by the application of knockdown, selective and residual herbicides in accordance with the standard operating procedure.
- Tubestock planted on waste rock will be watered by irrigation (e.g. stadium impact sprinklers); tubestock planted in LAAs will be watered using watering cart.
Watering of tubestock will be undertaken at a frequency and for a duration that minimises soil moisture deficit for newly planted seedlings. Upon establishment of the overstorey and mid-storey, seed will be directly sown onto the final landform to facilitate the development of the understorey. There is opportunity for introducing low fuel, low vigour native ground cover species, especially legumes, as soon as possible.

Further information on the revegetation strategy for the RPA is provided in Section 10.8 and Appendix 10.2 of the MCP.

10.9 Contingencies

A number of contingency options are available for the Ranger mine closure, the majority of which have been discussed in Chapter 8 as part of the best practical technology assessment. In addition to these contingency options, ERA is committed to completing rehabilitation and the achievement of the environmental requirements. Currently, the closure schedule indicates that this can be completed by the closure date of January 2026. If this changes, the contingency will be to apply to allow rehabilitation activities to continue past this date.

10.9.1 Water Treatment

The volume of process water that will require treatment prior to the end of closure is directly dependent on rainfall. Therefore, if rainfall received during consecutive wet seasons is higher than predicted, additional water treatment capacity may be required to meet the final closure date of January 2026.

In the case of a very large late wet season, ERA may not be able to treat all the process water prior to the final closure date. In this case, an application would be submitted to the MTC under the current Ranger Authorisation, requesting that water treatment infrastructure, including any ponds, be allowed to remain on site for a period to enable for completion of this treatment. Current contingencies for additional process water treatment include expansions to the current brine concentrator and recommissioning and expanding the current high-density sludge plant.

Further information on the water treatment to be undertaken prior to closure and contingencies associated with these activities is provided in Section 10.9.1 of the MCP.

10.9.2 Tailings Transfer

As discussed in Section 10.9.2 of the MCP, the current dredge is not performing as expected and a dredging improvement plan has been activated. This includes the assessment of an option for a second dredge. ERA has recently implemented a study into this that will be completed during 2018. The outcomes of this study will be included in the next update of the MCP.

10.9.3 Brine Injection

The concentrated brine that is produced from the brine concentrator is intended to be injected into the Pit 3 underfill through 5 injection wells, installed directly within the underfill. The current
contingency plan, should upscaling or failure of the injections wells occur, involves installation of directionally drilled wells from the Pit 3 edge into the underfill. ERA have installed a pilot drill hole during the ITWC prefeasibility study to assess this option.

As part of the best practical technology assessment, a number of alternative brine disposal options were also reviewed and assessed, in the case that the current brine injection to Pit 3 underfill ceases to be a viable option. The assessment indicated one potential alternative disposal option; conversion of the brine solution into a solid by crystallisation, calcination, precipitation or cementation and then co-disposal with the Pit 3 tailings or backfill. Should one of these alternatives be required further assessment would be undertaken, followed by application for approval from the MTC.

Further information on the brine injection assessment and potential options is detailed in Section 10.9.3 of the MCP.

10.9.4 Tubestock Production

ERA has two contingency options to mitigate potential issues associated with tubestock production:

- Option 1: reinstate the Ranger nursery, situated on the site of the current exploration yard, north of Jabiru East LAA to ensure tubestock production capacity of between 500,000 and 700,000 stems per annum.

- Option 2: ERA to engage Greening Australia to grow tubestock from seeds provided by ERA, should the need arise. Under this option, Greening Australia would be required to supply tubestock in accordance with the intended production procedures (e.g. soilless substrate, mycorrhiza inoculation, fertilising, etc).
11. CLOSURE MONITORING

Chapter 11 provides a preliminary indication of the breadth of proposed closure monitoring programs to track the progress of the site against the closure criteria during the stabilisation and monitoring phase, post January 2026.

Closure monitoring for the RPA is discussed under the same themes as the closure criteria: landform; radiation; water and sediment; flora and fauna; cultural; and soil, and builds upon the extensive monitoring regimes already implemented at Ranger. The monitoring plan within the MCP is likely to be revised based on findings of studies and new information being available.

The closure monitoring and stabilisation phase will commence post-decommissioning, after January 2026. The monitoring program will continue for a minimum of 25 years or until it can be demonstrated that the site has met the required closure objectives and relinquishment of the RPA is achieved.

During this phase of work, it is expected that there will be some subsidence and erosion as the landform settles and the revegetation becomes self-sustaining. ERA has made allowances for remedial work that may be required during this time, which includes, but is not limited to:

- Minor earthworks.
- Infill planting.
- Weed control.
- Fire management.
- Application of fertiliser.
- Pest control.
- Water management.

11.1 Landform Monitoring

The focus of the closure monitoring program will be on the surface of the landform and run-off of surface material to onsite sediment basin traps that will direct water to offsite waterways. The proposed monitoring incorporates surveys, visual inspection, photographs, and surface water turbidity monitoring.

11.2 Water and Sediment Monitoring

There is in excess of 30 years of surface water and sediment monitoring data that underpins the proposed stabilisation phase surface water and sediment monitoring program. Existing monitoring locations will be utilised during this phase; however, an additional location is proposed downstream from the Magela and Gulungul creek confluence.

It is proposed that should surface water quality monitoring results be trending to meet closure objectives, a review of the surface water monitoring program will be undertaken, with the aim of reducing some monitoring requirements over time.

The proposed stabilisation monitoring program details are summaries in Table 9.

Table 9: Parameters and locations for surface water monitoring to assess compliance with closure criteria for each outcome focus
<table>
<thead>
<tr>
<th>Location</th>
<th>Parameter (grouped by outcome with most restrictive criteria)</th>
<th>Outcome/environmental value</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Magela Creek downstream of the Gulungul confluence and GCLB</td>
<td>Turbidity, Mg, U, Mn, NH$_3$-N, NO$_2$, NO$_3$, Total-P, Total-N</td>
<td>Ecosystem protection outside the RPA</td>
<td>Continuous monitoring for EC (Mg) and turbidity. Event based grab sampling. Scheduled grab sampling for other parameters. Initially monthly during the wet season with frequency reduced over time based on performance.</td>
</tr>
<tr>
<td></td>
<td>Mn, SO$_4^{2-}$ Visual clarity and surface films</td>
<td>Diet and recreation*</td>
<td>Scheduled grab sampling, initially monthly during the wet season with frequency reduced over time based on performance.</td>
</tr>
<tr>
<td>Gulungul Billabong</td>
<td>U in sediment</td>
<td>Ecosystem protection outside the RPA</td>
<td>Accumulation in sediments limited by U in water criteria. Sample at end of decommissioning to demonstrate achievement.</td>
</tr>
<tr>
<td>MG009, GCLB, MCUS, GCC</td>
<td>Turbidity Mg, U, Mn, NH$_3$-N, NO$_2$, NO$_3$,</td>
<td>Ecosystem protection within the RPA</td>
<td>Continuous monitoring for EC (Mg) and turbidity. Event based grab sampling. Scheduled grab sampling for other parameters. Initially weekly with frequency reduced over time based on performance.</td>
</tr>
<tr>
<td>Upstream sites</td>
<td>Continuous EC and turbidity will be measured at the upstream creek sites. Data for other parameters from upstream are not relevant to assessing if criteria are met. EC and turbidity data will provide information on natural seasonal fluctuations.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* NB: All drinking water and recreation parameters have less restrictive criteria than for ecosystem protection.

11.3 Groundwater Monitoring

The primary objective of the closure groundwater monitoring program will be to confirm that measured time series changes to water quality are consistent with the hydrogeological model predictions and that the regional groundwater environment remains protected. The groundwater monitoring program will monitor changes in groundwater level and solute concentrations.

There are four sub-catchments; Gulungul, Coonjimba, Djalkmarra and Corridor Creek, that are included in the groundwater monitoring program, these will be progressively refined during decommissioning. The sub-catchments will comprise new and/or existing monitoring bores.
The proposed monitoring will comprise monthly measurements of standing water level and quarterly sampling and chemical analysis of, for example, pH, EC, Ca, Cl, HCO$_3^-$, K, Mg, Mn, Na, SO$_4^{2-}$, and U.

The final groundwater monitoring program will be expanded with continued stakeholder engagement and advice from INTERA.

### 11.4 Radiation Monitoring

The radiation monitoring program for the landform targets the three identified pathways of:

- Inhalation of Long Lived Alpha Activity and of radon progeny.
- Ingestion of radioactive material in (or with) food or water.
- External irradiation from gamma rays (and beta particles).

A final airborne radiometric survey will be undertaken at completion of decommissioning activities.

Airborne particles will be monitored annually, at the end of the dry period, for five years, post landform construction, as lower soil moisture increases Rn exhalation rates and higher dust concentrations.

Grab samples of potentially contaminated waters (Magela Creek both downstream and upstream of the confluence of Magela and Gulungul creeks) will be taken monthly, initially, reducing to annually once low levels have been confirmed.

### 11.5 Flora and Fauna Monitoring

The monitoring program will comprise vegetation plots and fauna trapping transects to address terrestrial flora and fauna. The monitoring program to be implemented would be developed to capture relevant information as the revegetation progresses.

Proposed survey frequency of flora and fauna across the final landform is:

- Year 1: three, six and 12 months.
- Years 2-5: annually.
- Post 5 years: one-off surveys every five years.

Feral animal monitoring and management will continue for years 1 to 5, however after this period it is proposed that feral animal management will follow the same practices as implemented in Kakadu National Park.

Weed monitoring will be informed by the current operational weed survey and mapping practices with a particular emphasis on the first 1 – 5 years, while the revegetation is establishing.
11.6 Cultural Monitoring

Cultural monitoring on the RPA will be determined by the success of rehabilitation. This could be achieved by using a set of cultural health indices, such as the examples described in Chapter 6 of the MCP. Cultural criteria for closure monitoring will need to be conducted at a representative number of sites that collectively provide a cross section of the range of site types where rehabilitation has been carried out. An assessment of cultural criteria will need to be conducted at each of the chosen sites on an annual basis. However, the mechanism by which the cultural monitoring will occur is still under consideration by traditional owners.

11.7 Soils Monitoring

Ranger's contaminated site register and identified sites where contamination could occur from mine-related activities will be used to guide the locations for soil contamination investigations and subsequent monitoring. The degree of remediation required for each potentially contaminated site will be based on soil concentrations at these locations compared to local background concentrations or the published investigation levels (i.e. Health Investigation Level (HIL) and/or Environment Investigation Levels (EIL)).

Further work on the proposed framework to develop soil contamination management options across the RPA will be undertaken during the feasibility study in 2017-18.

11.8 Trigger Action Response Plan (TARP)

ERA have developed a preliminary TARP, which will be updated based on the agreement of the closure criteria and findings of ongoing studies.
12. MANAGEMENT OF INFORMATION AND DATA

Chapter 12 provides a description of management strategies, including systems and processes for the retention of mine records relevant to mine closure.

ERA is committed to obtaining quality information and maintaining a robust data management system to ensure successful management of rehabilitation, closure and post closure activities. ERA have identified the potential uses for monitoring data that will be collected, they form 3 key components:

- Validation of models.
- Validation of construction standards.
- Progressive rehabilitation.

ERA maintains accreditation to ISO 14001:2004 and AS4801 health, safety and environmental management systems and records are managed according to a range of polices, standards and work instructions that ensure that data is secure, maintained and accurate. For perpetuity, information is not kept on personal computers but in approved, managed data systems. There is a clear line of responsibility for data collection and management for each package of information and/or data.